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Teaching Sustainable Development Goals in Science Education

Edited by
Kerstin Kremer and Deidre Bauer

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About the Editors

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Preface to "Teaching Sustainable Development Goals in Science Education"

At the core of the Agenda 2030 are 17 Sustainable Development Goals (SDGs). The aim of the SDGs is to secure a sustainable, peaceful, prosperous and equitable life on Earth for everyone now and in the future. To achieve the SDGs, education for sustainable development (ESD) aims to develop competencies that empower individuals to reflect on their own actions, taking into account their current and future social, cultural, economic and environmental impacts, from a local and a global perspective. Therefore, ESD must define new knowledge, skills, values and attitudes and evaluate effective ways towards a new pedagogy.

Science education faces the challenge of the SDGs and ESD in different ways: (1) it plays a dominant role in equipping students with an adequate understanding of the complexity and the causes of global challenges such as climate change, water scarcity, energy transition or biodiversity loss; (2) it seeks to find new ways to integrate scientific knowledge and skills into real-world situations and elucidate ways to connect knowledge to sustainability-relevant values and attitudes; (3) it has to overcome disciplinary boundaries to understanding a problem comprehensively and, at the same time, provide discipline-specific knowledge and skills to solve the problem.

This Special Issue focuses on empirical educational research and theoretical considerations that address transformational competences in science education in the context of the SDGs. It is designed to present new pedagogical approaches that aim to empower learners and teachers to contribute to a sustainable future and to evaluate their effectiveness in science education. Papers can focus on, e.g., new curricula or textbooks, teacher education, classroom and informal learning, whole-institution approaches, action-oriented and transformative learning approaches in science education.

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Article

Quantitative Modelling and Perspective Taking: Two Competencies of Decision Making for Sustainable Development

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Abstract: Land use change, natural resource use and climate change are challenging Sustainable Development issues (SDGs 13–15). Fostering the competencies to deal with such issues is one core task for current educational endeavors. Among these competencies, decision-making competencies are central. In detail, we investigate how learners evaluate alternative decision-making options to improve existing competence models. We exemplify our competence modelling approach using the designation of a Marine Protected Area. The cross-sectional sample consists of secondary school students and student teachers (N = 760). Partial Credit modelling shows that *quantitative modelling* of decision-making options is a different competence dimension than *perspective taking* if contextualized for Sustainable Development. In *quantitative modelling*, mathematical modelling is used to evaluate and reflect on decision-making options. *Perspective taking* covers the ability to consider different normative perspectives on Sustainable Development issues. Both dimensions show plausible (latent) correlations with related constructs within the nomological net, i.e., with qualitative arguing, economic literacy, mathematical competencies, reading competencies and analytical problem solving. Furthermore, person-abilities increase with level of education for both dimensions. The identified competence dimensions *quantitative modelling* and *perspective taking* were successfully modelled and shown to be distinct; the resulting measuring instrument is reliable and valid.

Keywords: Sustainable Development; socioscientific issues; reasoning; decision making; economic evaluation; perspective taking; modelling; competence; measure

1. Introduction

Land use change, natural resource use and climate change are Sustainable Development issues (SDGs 13–15; see Section 1.1) [1] for which a suitable selection of policy measures is of paramount importance. Decision making on real-world policy measures frequently relies on quantitative data on the effects of the implementation of alternative policy options: If sufficiently valid and accurate data are available, modern decision theory makes extensive use of quantitative data [2].

This crucial quantitative aspect is inadequately reflected within Education for Sustainable Development (ESD) to date. Typically, ESD interventions focus on qualitative problem descriptions.

Even if problems such as climate change are quantified, potential solutions are mostly discussed using *qualitative* pro and contra arguments [3,4]. Consequently, learners are not adequately equipped with the competencies to deal with complex decision-making issues for which quantitative data can be provided [5]. For instance, it will often be essential to quantitatively compare the magnitudes of ecological, social and economic advantages as well as disadvantages of policy options restricting the use of land or other environmental resources. In particular, this is relevant if advantages and disadvantages are born by different stakeholder groups. In addition to environmental values and justice, the efficient allocation of natural resources is at stake [6]. Purely *qualitative* argumentation is insufficient here [5].

The relative neglect of *quantitative* argumentation on complex decision-making challenges is not limited to ESD. Common approaches to *socioscientific issues* (SSIs) [7] and *socioscientific reasoning* [8] display similar blind spots (see Section 1.2). The main exception is economics education/financial education, in which learners are encouraged to analyze decision making through the lens of detailed analyses of trade-offs, costs and benefits [9], and frequently need to calculate numerical solutions to problems [10]. Unfortunately, economics and financial education rarely address Sustainable Development issues [6]. Recent research exceptions relate to learner conceptions on economic policy instruments or on market solutions to environmental problems [11,12]. Further, student concepts on the relation of nature and economic development have been addressed [13]. Decision making for Sustainable Development faces factual complexities and ethical uncertainties [14]. The respective learner competencies have, to our knowledge, not been investigated. Thus, a substantial research gap of high political, educational as well as academic importance exists:

> *Which competencies do learners bring to the quantitative evaluation and reflection of potential real-world decision-making options on Sustainable Development issues?*

After identifying potentially relevant competence components [15,16], a first attempt was made to psychometrically model and measure a respective competence dimension. We called this preliminary dimension *evaluating and reflecting solutions quantitatively and economically* (*ERSQE*) [5]. This preliminary study was restricted by sample size and sample composition, and did not test if *ERSQE* was truly a one-dimensional construct. Thus, there is some evidence that the research gap can be closed using competence modelling. Much more solid evidence will be presented in this contribution that overcomes the major shortcomings of Böhm et al. (2016) [5]. Specifically, we test the dimensionality of *ERSQE* using a larger, independent and more balanced sample of secondary school students and student teachers. Most measures of psychometric fit as well as educational considerations suggest two independent *ERSQE* dimensions: *quantitative modelling* and *perspective taking*.

1.1. Sustainable Development Issues as Socioscientific Issues

Land use change, natural resource use, and climate change are typical Sustainable Development issues. They form a particular subset of SSIs [17]. Sustainable Development issues share relevant features of SSIs: being complex real-world issues, located at the science–society interface and often being contentious (see Figure 1). Their contentious nature stems from uncertainty in the facts used to argue specific issues (fragile evidence), and from uncertainty in the norms and values used to transform facts to societal decision making and action (normative uncertainty).

A highly relevant subset of Sustainable Development issues directly relates to *Sustainable Development Goals*, agreed upon internationally to guide socio-environmental development at the global scale (SDGs) [1]. Here, normative uncertainty is often particularly challenging. In this study, we focus on these normatively challenging Sustainable Development issues. To illustrate features of the Sustainable Development issues, we refer to a resource use issue and the SDG *life below water*. Thereby, we use *Marine Protected Areas*—a policy instrument to facilitate the sustainable management of fishery resources [18]—as a specific example throughout the following explanations.

- Sustainable Development issues are factually complex. This results in factual uncertainty in assessment and judgment [16]. When establishing a Marine Protected Area, the data are often incomplete. That is because of uncertainty regarding fish stock sizes, ecosystem interactions of different populations or changing biotic as well as abiotic factors. Therefore, and also as for SSIs, scientific evidence may be fragile, requiring ongoing inquiry [8,19,20].
- Sustainable Development issues are at the interface of science and multiple societal considerations [21]. Designating a Marine Protected Area implies a broader range of societal concerns by communicating effects from the individual level (e.g., individual opportunity costs of local fisherman due to fishing restrictions) up to a global level, i.e., welfare gain in terms of food production and climate regulation. To analyze causes and effects of current ecosystem exploitation patterns, and to devise potential options require knowledge from the natural sciences (marine biology), engineering/applied sciences (fishing and aquaculture technology) and the social and economic sciences (resource economics [11], institutional economics, rural sociology).
- Sustainable Development issues are normatively controversial. Any specific Marine Protected Area is likely to differentially affect concerned coastal stakeholders: Traditional fishing folk at tropical shores may favor a ban on mangrove conversion to shrimp farms but may oppose restrictions on coastal fisheries. In contrast, stakeholders involved in shrimp aquaculture are likely to oppose a ban on mangrove conversion and be indifferent concerning fishing restrictions. Other examples include conflicts between tourism, biodiversity conservation and the fishing industry. This setting results in multidimensional socioeconomic, cultural and political conflicts. Solutions that please all stakeholders are difficult. Thus, implementing a Marine Protected Area is often normatively controversial [18].
- Sustainable Development issues are goal- and decision-oriented. The designation of a Marine Protected Area implies several decisions about the location, the size and restrictions (cf. Appendixes A.1 and A.2).

Some Sustainable Development issues and certain SSIs have a crucial quantitative component. The real-world discourse on many Sustainable Development issues focuses on quantitative information, e.g., on the cost-effectiveness of a particular intervention, regulation and policy measure. One example is a designation of a Marine Protected Area (see Appendixes A.1 and A.2).

1.2. Socioscientific Reasoning and Decision Making for Sustainable Development

In this Section 1.2, we explain how the present research relates to the international debate on socioscientific reasoning and previous work on decision making for Sustainable Development. Romine and colleagues define socioscientific reasoning as '... *thinking practices that individuals use as they make sense of, consider solutions for, and work to resolve complex SSI* ...' [7] (p. 276). They used the socioscientific reasoning framework [8] to develop an instrument for quantitative assessment [7]. The framework for socioscientific reasoning covers a '*four-pronged*' structure: (i) recognizing the inherent complexity of SSIs, (ii) examining issues from multiple perspectives, (iii) examining potentially biased information with a skeptical attitude, and (iv) considering that SSIs are subject to ongoing inquiry [7] (pp. 274, 277) (Figure 1). Due to the nature of SSIs, the development of instruments to assess learning outcomes in line with competence modelling is lagging [22]. Romine et al. (2017) published an instrument on socioscientific reasoning for adaptive online testing with multiple choice questions [7]. However, multiple-choice testing can be an obstacle for higher-order thinking [23], is doubtful for assessing critical-thinking skills [24] and can lead to false indication regarding the learners' knowledge and understanding [25].

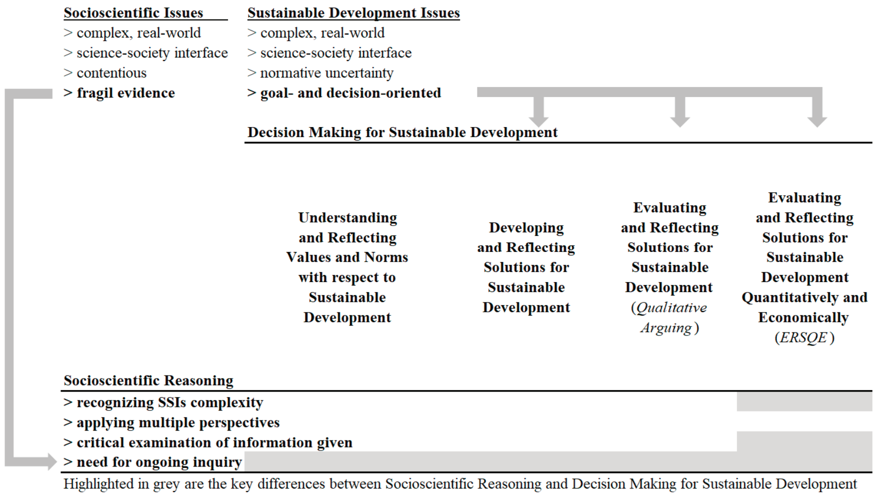

Figure 1. Socioscientific Issues (SSIs), Sustainable Development Issues, and Socioscientific Reasoning compared to Decision Making for Sustainable Development.

The competence model for decision making for Sustainable Development [16] (Figure 1) includes (i) understanding and reflecting values and norms with respect to Sustainable Development, (ii) developing and reflecting solutions for Sustainable Development, (iii) evaluating and reflecting solutions for Sustainable Development [4]—in the following labeled in short '*qualitative arguing*', and (iv) evaluating and reflecting solutions for Sustainable Development quantitatively and economically (*ERSQE*) [5].

Qualitative arguing focuses on the use of different decision-making strategies by highlighting the process of using the pro and contra arguments of different possible solutions and weighing arguments [4]. The competence was successfully modelled as one dimension [4,26].

ERSQE focuses more on the quantification with tools and procedures from social, economic and engineering sciences with a more formal, quantitative evaluation of decision-making problems. Preliminary modelling (N = 268) with the Rasch Partial Credit Model [27] resulted in hints for a one-dimensional (1D) competence scale [5]. This study used an open-answering format. Nevertheless, this study is limited by (i) a small sample size, (ii) an unbalanced sample composition (n = 161 9th/10th graders, n = 71 11th graders and n = 36 student teachers), (iii) a lack of dimensionality testing by multidimensional modelling, (iv) a lack of testing for *differential item functioning* [28], and (v) a lack of validating the investigated construct with related constructs within a nomological net [29].

In general, the socioscientific reasoning and the decision making for Sustainable Development approaches are closely related in treating factual complexity, in examining or reflecting the information given and in considering multiple perspectives. Both differ in their focus: Socioscientific reasoning highlights the need for ongoing investigations and decision making for Sustainable Development underlines a more goal- and decision-oriented approach in the face of factual and normative uncertainty. The approach focuses more strongly on structured decision making either in qualitative or quantitative terms.

1.3. Research Questions

This study aims at modelling and measuring *evaluating and reflecting solutions quantitatively and economically* (*ERSQE*). The present main study represents the final step in competence modelling of the preliminary competence dimension *ERSQE* that resulted from a pilot study [5]. Thus, the present study belongs to the developing of the modelling of *ERSQE*. At the same time, the present study questions the 1D modelling from the pilot study. Doing so, both developing a model and testing an existing model is the purpose of the present study.

The pilot study [5] is restricted by sample size, sample composition and exclusively 1D modelling. Thus, the present study aims at testing the dimensionality of *ERSQE* for secondary school students and student teachers by an independent sample to the previous study with larger sample size and more balanced sample composition.

As current practice in competence modelling with heterogeneous sample composition, there is a need to check whether the test items function in the same way, e.g., for different levels of education [30].

Thus, the first set of research questions (RQ 1.1–RQ 1.3) concerns the modelling, dimensionality and measuring of *ERSQE*:

RQ 1.1 In which way can *ERSQE* adequately be modelled and measured?
RQ 1.2 Which is/are the resulting dimension(s)?
RQ 1.3 In which way can we use the items of the resulting dimension(s) for different levels of education?

One typical validation approach in competence modelling reflects that competencies can be learnt [31]. For example, it is a validation hint if competence increases with the level of formal education. We showed this for the *qualitative arguing* dimension for decision making for Sustainable Development [4,26]. Another typical validation approach concerns correlations with related constructs [32]. Up to now, validations with related constructs represent a research need in examining *ERSQE* related dimension(s). One related construct is *qualitative arguing* [4] within the decision making for Sustainable Development approach (Figure 1). Other constructs include economic literacy, mathematical competencies, reading competencies and analytical problem solving.

Thus, the second set of research questions (RQ 2.1–2.3) serves validation purposes:

RQ 2.1 In which way does/do competence/ies according to the resulting dimension(s) increase with the level of education?
RQ 2.2 In which way does/do the resulting dimension(s) differ from *qualitative arguing*?
RQ 2.3 In which way does/do the resulting dimension(s) differ from related constructs such as economic literacy, mathematical competencies, reading competencies and analytical problem solving?

2. Method and Approach

2.1. Measurement Instrument: Composition and Administration

For operationalizing the research questions, the approach for developing the measurement instrument published in Bögeholz et al. (2014) [16] was simplified, specified and further developed (Figure 2). The specification includes, e.g., links to selected SDGs.

The approach reflects the quantitative-economic evaluation of real-world decision making for Sustainable Development. We did that by (i) designing tasks, e.g., for resource use (i.e., decision for designating a Marine Protected Area) of relevance for SDG *life below water*, (ii) reflecting Sustainable Development-related norms, e.g., retinity and (iii) considering economics concepts, mathematical modelling and decision making as well as perspective taking (Figure 2). This integrative, interdisciplinary conceptualization is in line with the *Next Generation Science Standards* [33] (p. XV). These standards integrate *disciplinary core ideas* with *cross-cutting concepts* and *scientific practices.*

The measurement instrument consists of three tasks which take up three SDGs, i.e., SDGs 15 *life on land*, 14 *life below water* and 13 *climate action* [1]. The tasks address three Sustainable Development issues (Figure 2): land use change, marine resource use and climate change. Each task provides a particular set of requirements in order to cover a broad spectrum of challenges calling for integrative quantitative evaluation by considering different perspectives.

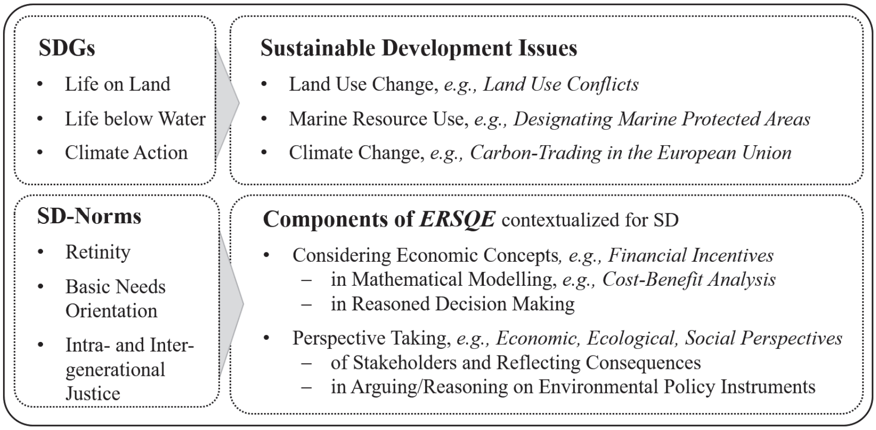

Figure 2. Measuring *Evaluating and Reflecting Solutions Quantitatively and Economically* (*ERSQE*) [5,16]. SD = Sustainable Development; SDGs = Sustainable Development Goals [1]).

Regarding the land use change task, we presented a land use conflict of an Ecuadorian family. The study participants have to take the perspective of the family and decide how to use the land in the case of different incentives (e.g., protecting as much natural forest as possible). They also have to reflect on the consequences of land use decisions. For each of the three presented land use options, we gave data on the income ($) per ha, and the tons of released carbon dioxides per ha. Later, the policy instrument *Reducing Emissions from Deforestation and Degradation* (REDD) is introduced as a potential solution for deforestation and degradation resulting from land use changes [16].

Regarding the marine resource use task (Appendixes A.1 and A.2), we presented a proposal of designating a Marine Protected Area. Thereby, the impact on different stakeholders of a local town in Great Britain has to be evaluated. We asked the participants to analyze different stakeholder interests qualitatively (e.g., item 11, Appendixes A.1, A.2 and C.2) and quantitatively (item 10; Appendixes A.1, A.2 and C.1). Items address an individual (items 8 and 9) and a public welfare level (items 10 and 11). For this task, the structural resemblance to the *Next Generation Science Standards* [33] is the following: the standards combine the disciplinary core idea *biodiversity and humans* by integrating the scientific practice of *using mathematics and computational thinking* [33] (p. 114). Within the marine resource use task, participants conduct a cost-benefit analysis addressing biodiversity aspects and impacts on different sectors of human activity (Appendixes A.1, A.2 and C.1).

Further, the *Next Generation Science Standards* point out that '... *empirical evidence is required to [...] make claims about specific causes and effects* ... ' [33] (p. 114). Within the marine resource use task, we gave the empirical evidence through quantitative data in terms of costs and benefits resulting from the designation of a Marine Protected Area (Appendix A.2).

Regarding the climate change task, participants work on the policy instrument *European Union Emission Trading System*. The material details three options for a paper factory and a steel mill to balance their annual carbon budgets—including quantitative cost data. The learners have to reflect on the *allocative efficiency* of the three options using multi-step mathematical modelling. Further, they are confronted with *market failure*: The price of EU carbon emission certificates does not reflect the full social costs of carbon emissions. Learners are asked to evaluate what happens if the EU reduces the supply of emission certificates.

In sum, the three tasks require different kinds of mathematical modelling, quantification in combination with economics concepts (e.g., decision making and cost-benefit analysis to maximize public welfare) and perspective taking. We kept the needed level of mathematical competencies low to avoid measuring mathematical competencies. In the case of challenging concepts or policy instruments (e.g., ecosystem services; Appendix A.2), we used brief explanations and graphic representations to facilitate an understanding.

Regarding perspective taking (Figure 2), we contextualized it for Sustainable Development. The latter includes the concurrent consideration of the ecological, economic and social dimensions of Sustainable Development, action consequences at family, local and global levels, by reflecting on basic needs orientation and justice aspects.

The measurement instrument consists of an information booklet (Appendixes A.1 and A.2) with the three tasks and an answering booklet. Within the answering booklet, participants work on open-ended questions or reflect on the given solutions (Appendixes A.1 and A.2). Mostly, questions were ordered by increasing answering difficulty within each task. The instrument took 90 min of testing time. Positional effects were avoided at the task level by systematically varying the position of the task [34]. This results in six different booklet versions.

2.2. The Scoring of Empirical Data

Two coders analyzed the written answers to the questions using a scoring rubric for 16 polytomous items. Thereby, five items on mathematical modelling of real-world environmental problems or solutions, three items on reasoned decision making and eight items on perspective taking considering norms of Sustainable Development were coded (Appendixes B.1 and B.2). The scoring rubric differentiates according to the sophistication of the given answers (Appendixes D.1 and D.2). The latter implies the number of mentioned valid arguments, the degree of understanding, the degree of plausible and correct use of economics concepts, and mathematical modellings for decision making (for detailed information, see Appendixes C.1 and C.2; for an overview, see Appendixes D.1 and D.2). Both coders had already worked on the development of the scoring rubric in the previous study [5]. Discussions occurred in the case of disagreement. Either one coder convinced the other with arguments or an agreement on the final score was reached between both coders. The inter-rater reliability for the 16 items was very good (κ_{ERSQE} = 0.99; SD = 0.01).

2.3. Sample

The cross-sectional study was conducted from winter 2015 to summer 2016 with 760 participants (Table 1). Among them were 584 pupils from seven German secondary schools from a western federal state and a new eastern federal state of Germany. In addition to that, we tested 176 student teachers (bachelor and master programs) of six universities from four federal states of Germany. The student teachers were specializing in at least one of the following subjects: biology, politics, geography, economics or mathematics. Table 1 depicts the detailed sample description for modelling of *ERSQE* and two validation subsamples (V-Study I, V-Study II; see Section 2.5 *Correlation and Group Comparisons in Validation Studies*).

Table 1. Sample composition regarding competence modelling study (N = 760) and validation studies with subsamples (V-Study I: n = 191; V-Study II: n = 71; n. sp. = not specified; SD = standard deviation).

	Sample Composition	*n*	% (of Study)	Gender Female	Gender Male	n. sp.	Age [SD]
Competence Modelling	9th/10th Graders	368	48.4	171	186	11	15.23 [0.80]
	11th/12th Graders	216	28.4	127	89	-	17.15 [0.76]
	Student Teachers	176	23.2	117	58	1	22.49 [2.77]
V-Study I	9th/10th Graders	109	57.1	49	59	1	15.01 [0.78]
	11th/12th Graders	42	22.0	27	15	-	16.86 [0.65]
	Student Teachers	40	20.9	29	11	-	22.95 [1.95]
V-Study II	9th/10th Graders	71	100.0	46	24	1	15.03 [0.82]

The survey was conducted in regular classes and during replacement lessons. All respondents participated voluntarily. We rewarded student teachers by incentives (€15 each) for attendance.

Seven hundred sixty test persons answered the questions thoughtfully. We treated any other missing answers as unworked in order to avoid model errors [35].

2.4. Procedure in Competence Modelling

Regarding RQ 1.1, the competence modelling was conducted with the Partial Credit Model [27] using Acer ConQuest version 4.14.2 [36]. Item parameters, model fit, reliability of the instrument and differential item functioning were analyzed and evaluated. For item analyses, we used the weighted (infit) mean-square fit statistics (*wMNSQ*) and the corresponding *T*-values. Item fit is considered as good, if the *wMNSQ* value is between 0.8 and 1.2 [37,38] and if the corresponding *T*-value is between −2.0 and 2.0 [38]. For item discrimination, we used the threshold of 0.25 according to PISA 2006 [39]. Following Wetzel and Carstensen (2014), the Partial Credit Model ' ... *does not assume ordered threshold parameters and,* [...] *the order of the response categories is preserved even when reversed thresholds occur* ... ' [40] (p. 773). Thus, categories were not collapsed necessarily due to reversed thresholds. However, categories had to be collapsed due to the restricted number of responses.

To determine the resulting dimensions concerning RQ 1.2, relative model fit was analyzed using the two information criteria: Akaike's information criterion (AIC) [41] and Bayesian information criterion (BIC) [42]. Further, the chi-squared difference test (χ^2-test) was applied. As for reliability information, the expected *a posteriori*/plausible values reliability (EAP/PV) was analyzed. EAP/PV is comparable to Cronbach's alpha from classical test theory [38].

To examine if the items are appropriate for different levels of education regarding RQ 1.3, we applied differential item functioning analyses for identifying biased items in the assessment [30]. We followed Pohl and Carstensen (2012) who defined ' ... *absolute differences, [...] between 0.6 and 1 [as] noteworthy for further investigation, [...] between 0.4 and 0.6 as considerable but not sincerely, and differences smaller than 0.4 as not considerable [differential item functioning]* ... ' [43] (p. 12). We compared the groups regarding the educational levels (9th/10th graders versus 11th/12th graders, as well as all school students versus student teachers).

2.5. Correlation and Group Comparisons in Validation Studies

Concerning the open question of a competence increase with levels of education posed in RQ 2.1, we conducted a one-way ANOVA using IBM's SPSS (version 26). Doing so, we assessed the effects of level of education on the average person-abilities (weighted likelihood estimate, WLE) [44]. WLEs were z-standardized, and we used the value of ±3.29 to cut off the top and bottom 0.1% of the distribution. We applied three categories of educational levels: 9th/10th graders, 11th/12th graders and student teachers.

For validation purposes of the resulting dimension(s) out of *ERSQE* modelling, already established test instruments of related constructs or excerpts of these instruments were administered to a subsample of the participants in a first validation study (n = 191; Table 1). In this validation study with only one subsample, we deleted item 12 from modelling due to low discrimination.

For answering RQ 2.2 that focuses on validating the resulting dimension(s) from *ERSQE* modelling with *qualitative arguing*, we used the established instrument of our working group on *qualitative arguing* [4]. 1D modelling of *qualitative arguing* (n = 191) resulted in 13 (eight polytomous, five dichotomous) out of 14 items (ten polytomous, four dichotomous). For the instrument of *qualitative arguing*, we applied reasonable, less restricted thresholds for the *wMNSQ* of 0.7 to 1.3 [37] to keep a better representation of the construct measured. Here, we investigate how the dimension(s) resulting from our modelling differ from *qualitative arguing* within the competence model of decision making for Sustainable Development.

RQ 2.3 aims at validating the resulting dimension(s) from modelling with related constructs such as economic literacy, mathematical competencies, reading competencies and analytical problem solving. We applied a 12-item excerpt of the German adaptation (Wirtschaftskundlicher Bildungs-Test) [45] of the test of economic literacy [46] and an excerpt of a German mathematics test for the ninth grade

(*DEMAT 9*) [47]. The mathematics test reviews *ERSQE*-relevant competencies in linear equations as well as data-based graphs and tables. The excerpts of the test of economic literacy and mathematics competencies were also Rasch modelled in order to analyze latent correlations by multidimensional modelling with resulting dimension(s) from *ERSQE* modelling. The 1D modelling resulted in 11 of 12 items for the test of economic literacy and 14 out of 16 for the mathematics test; we deleted items with low discrimination. In order to control for divergent validity of the from assessment resulting *ERSQE* dimension(s) against reading competencies, we assessed for reading speed and reading comprehension as well (*LGVT 6-12*) [48]. We administered the four above mentioned validation instruments (or excerpts)—including mathematical competencies, *qualitative arguing*, test of economic literacy and reading competencies—after the three decision-making tasks on land use change, marine resource use and climate change. These supplementary assessments took 90 min.

In a second validation study ($n = 71$; Table 1) six selected PISA items [49], measuring analytical problem solving, were administered after the three decision-making tasks. We only investigated 9th/10th graders as they are in the PISA age. Assessing analytical problem solving took 30 min.

For all validation instruments used, measuring *qualitative arguing*, economic literacy, mathematics competencies and analytical problem solving, the inter-rater reliability was very good ($\kappa_{\text{qualitative arguing}} = 0.97$, SD = 0.02; $\kappa_{\text{economic literacy}} = 1$, SD = 0.00; $\kappa_{\text{mathematics competencies}} = 0.99$, SD = 0.00; $\kappa_{\text{analytical problem solving}} = 0.99$, SD = 0.04).

3. Results

3.1. First Set of Research Questions—Dimensionality, Measurement, and Differential Item Functioning

In Sections 3.1.1–3.1.3, we address the first set of research questions. We respond to RQ 1.1 (adequate modelling and measuring) in Section 3.1.1, to RQ 1.2 (resulting dimensions from modelling) in Sections 3.1.1 and 3.1.2, and to RQ 1.3 (appropriateness of items for different educational levels) in Section 3.1.3.

3.1.1. Modelling and Dimensionality

After some refinements, such as removing two items compared to the preliminary study [5], psychometric modelling resulted in 16 polytomous items ($N = 760$; Appendixes B.1 and B.2). The analysis of the fit parameters indicates that all items fit the requirements made explicit in Section 2.4 *Procedure in Competence Modelling*. *ERSQE* again, can be satisfactorily modelled one-dimensionally (1D; EAP/PV reliability: 0.73, item separation reliability: 0.99, variance: 0.33). In addition to that, two-dimensional (2D) modelling gives further hints: comparing a 1D and 2D modelling, the *wMNSQ* values of the 16 items are slightly better for the 2D model (closer to 1; data not shown). Regarding dimensionality, the final deviance, as well as the AIC and BIC, indicate a better fit of the 2D model compared to the 1D model (Table 2). The χ^2-test confirmed the better fit of the 2D model ($p < 0.001$).

Table 2. Fit statistics for the one- and two-dimensional models (1D, 2D) regarding *Evaluating and Reflecting Solutions Quantitatively and Economically* ($N = 760$; ***: $p < 0.001$).

Models	Parameters	Deviance	AIC	BIC	ΔDeviance (*df*)
1D	40	20515	20595	20781	-
2D	42	20367	20451	20646	148 *** (2)

Items regarding mathematical modelling of real-world environmental problem solutions and reasoned decision making form one dimension *evaluating and reflecting solutions—quantitative modelling* (in short, *quantitative modelling*; eight items; Appendixes B.1 and D.1). Items regarding *perspective taking considering the norms of Sustainable Development* (in short, *perspective taking*; eight items; Appendixes B.2

and D.2) form the second dimension. The latent correlation between *quantitative modelling* and *perspective taking* in 2D modelling is 0.69 (N = 760).

3.1.2. Quantitative Modelling and Perspective Taking: Test Quality and Wright Map

The two dimensions, i.e., *quantitative modelling* and *perspective taking*, exhibit satisfactory values for the different characteristics of test quality (Table 3). For *quantitative modelling*, EAP/PV reliability and the variance are noticeable exceptions. For both dimensions, item reliability is very good. The average person-abilities are similar because we '... *set the mean of the latent ability distribution to zero*' [36] (p. 24). The average item-difficulty lies higher for *quantitative modelling*, whereby the standard deviation for *perspective taking* is twice as much as for *quantitative modelling*. All items are within the acceptable boundaries regarding the item fit and discrimination.

Table 3. Test quality characteristics of the two dimensions *Quantitative Modelling* (eight items) and *Perspective Taking* (eight items) (N = 760; SE = standard error; *wMNSQ = weighted (infit) mean-square)*.

	Quantitative Modelling	*Perspective Taking*
Variance (SE)	0.26 (0.03)	0.71 (0.07)
EAP/PV Reliability	0.53	0.70
Item Reliability	0.97	0.99
Average Person-Ability (SE)	0.00 (0.03)	0.00 (0.04)
Average Item-Difficulty (SE)	0.35 (0.13)	0.08 (0.26)
Item-Difficulty from min. to max. value	−0.17 to 0.68	−1.00 to 1.33
Item Fit *wMNSQ* from min. to max. value	0.96 to 1.06	0.93 to 1.17
Discrimination from min. to max. value	0.37 to 0.64	0.48 to 0.66

The Wright map for *quantitative modelling* (Figure 3) shows a good fit between the item-difficulty and the person-abilities within a range of −1 to 1 logits. It is the same for the *perspective taking* Wright map between −1.5 to 1.5 logits. For both dimensions, only a few item steps deliver similar information, e.g., 10.1 and 2.1 for *quantitative modelling* as well as 11.1 and 3.1 for *perspective taking* (Figure 3) [37].

The content structure of *quantitative modelling*, as well as the ordering of the item steps, is exemplarily described for two items. First, we explain item 10 on resource use and designating a Marine Protected Area. It requires multi-step mathematical modelling (Appendix C.1). Item step 10.1 represents the step from Score 0 to Score 1. For Score 1, a person had to apply the economics concepts of *public welfare* as well as *cost/benefit* correctly (at least implicitly). The corresponding multi-step mathematical modelling is incompletely documented, but the right result presented. To achieve Score 2, in addition to Score 1, the mathematical results had to be transferred back to the given Sustainable Development issue (e.g., a recommendation for designating the Marine Protected Area). For Score 3, in addition to Score 2, the mathematical modelling has to be correct and completely documented. Also, the economics concepts have to be correctly applied (at least implicitly).

Second, item 1 on land use change requires one-step mathematical modelling (Appendix D.1). It displays nearly the same structure as item 10. Here, the economics concept *profit maximization* and the one-step mathematical modelling with very manageable data given are easier. Consequently, the item steps for this item are all below those of item 10 (Figure 3). In average the whole item 1 is easier than the item 10 (see item-difficulties in Appendix B.1: −0.17 and 0.60).

Regarding *quantitative modelling*, not all areas of the Wright map are equally well-covered. Partly difficult item steps and low-difficulty item steps that are performed with a 50% probability are lacking (needed for equal distribution between 1 and 2 logits and −2 and −1 logits). Three item steps are located at the very upper end (5.2, 13.2 and 16.2) and one item step at the very lower end (5.1). The land use item 5 focuses on an environmental economics instrument for preserving the rainforest and involves the economics concept of *financial incentives*. The items 13 and 16 on the climate change issue address the principle function of the EU Emission Trading System. In addition, item 13 integrates the economics concepts *cost-efficiency* and *market failure*, whereas item 16 integrates the concepts *supply/demand* and *externalities* (Appendix B.1). For achieving full credit in the items 5, 13 and 16, the test persons need to process demanding information.

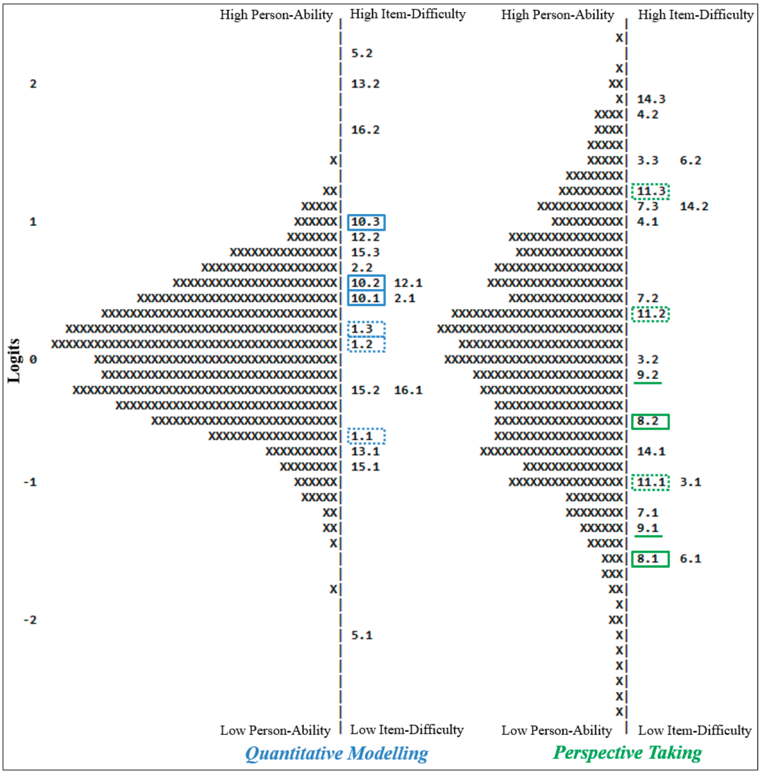

Figure 3. Wright maps of *N* = 760 regarding *Quantitative Modelling* and *Perspective Taking* (each 'X' represents 1.8 test persons in each dimension; the numbers indicate the thresholds of different item steps of trichotomous items, e.g., item 5 with item steps 5.1 and 5.2 and quadrotomous items, e.g., item 14 with item steps 14.1, 14.2 and 14.3). The three thresholds of items 1 and 10 from *Quantitative Modelling* and the two thresholds of items 8 and 9 as well as the three thresholds of item 11 from *Perspective Taking* are marked. The item markings help to locate the thresholds on the logit scales that are discussed in the text.

In summary, the Wright map for *quantitative modelling* seems to differentiate the complexity of (i) the economics concept(s) at hand (difficulty-generating appears the number of economics concepts), (ii) the required mathematical modelling steps and (iii) the environmental policy instrument, which has to be reasoned. Thereby, economic and mathematical aspects must be understood separately as well as interconnected. The latter seems to be the most challenging facet of *quantitative modelling* (cf. Score 3 for item 10 in Appendix C.1 or Appendixes B.1 and D.1).

Concerning *perspective taking*, we describe the content structure, as well as the ordering of the item steps, regarding marine resource use item 11. The item contains reasoning of the environmental policy instrument designation of a Marine Protected Area. To achieve Score 1, the test person had to take two Sustainable Development-specific perspectives out of three (ecological, economic and social). For the two perspectives, the point of view had to be substantiated by one valid argument for each perspective (Appendix C.2). To reach Score 2, one had to take all three Sustainable Development-specific perspectives with one valid argument for each perspective. For gaining Score 3, in addition to Score 2, more than one valid argument for at least two perspectives is required. Item steps for items with two perspectives (item 9) and item steps for items with one specific stakeholder perspective (item 8) can be found in lower areas of the logit scale for *perspective taking* than items which require more perspectives (e.g., item 11; Figure 3).

Perspective taking includes the cognitive processes of positioning, arguing and reasoning/reflecting. Positioning refers to tasks in which the learners have to take predefined perspectives that are very close to real-life (items 8 and 9, Appendix A.1). Arguing includes applying arguments for and against an environmental policy instrument (REDD for item 7, Appendix D.2). Reasoning/reflecting includes understanding the principle functioning of an environmental policy instrument in combination with Sustainable Development-relevant norms (see item 11 above, Appendixes C.2 and D.2). Items regarding positioning (items 8, 9 and 6) are easier compared to items regarding arguing (item 7) and especially compared to items regarding reflecting/reasoning (items 3, 11, 14, and 4; see item-difficulties in Appendix B.2).

Regarding *perspective taking*, there are no considerable gaps between the placed item steps in the Wright Map (Figure 3). Nevertheless, two item steps are located at the upper end of the scale (see 4.2, 14.3; Figure 3). Climate change item 14 focuses on a proposal regarding a more effective functioning of the EU Emission Trading System. One can answer this item correctly by understanding the economics concept of *allocative efficiency*. Land use change item 4 focuses on the trade-off between a good living and its resulting negative externalities.

In summary, item-difficulties depend on the number and type of sustainability-relevant perspectives. Besides, it includes an increase in elaboration regarding the required cognitive processes of positioning, arguing and reasoning/reflecting (Appendix B.2).

3.1.3. Differential Item Functioning

According to Pohl and Carstensen (2012) [43], no proper differential item functioning occurred between lower and upper secondary school students and between all secondary school students and student teachers for *quantitative modelling* and *perspective taking*.

A comparison of the 9th/10th graders with 11th/12th graders revealed only one considerable differential item functioning for *quantitative modelling* in favor of the 11th/12th graders (item 10, Δ_δ 0.40) [43]. Not one of the items for *perspective taking* had considerable differential item functioning (max. Δ_δ 0.37). The 9th/10th graders scored 0.23 (SE = 0.03) logits lower than 11th/12th graders in all items of *quantitative modelling* and 0.43 (SE = 0.03) logits lower in all items of *perspective taking*.

Comparing the secondary school students (9th/10th and 11th/12th graders) with the student teachers, each dimension displays one considerable differential item functioning: *quantitative modelling* item 12 (Δ_δ 0.45) favors the secondary school students, and *perspective taking* item 9 (Δ_δ 0.45) favors the student teachers. All in all, secondary students scored 0.46 (SE = 0.03) logits lower than student teachers for *quantitative modelling* and 0.78 (SE = 0.03) logits lower for *perspective taking*.

3.2. Second Set of Research Questions—Validation

In Sections 3.2.1–3.2.3, we address the second set of research questions. We respond to RQ 2.1 (increase in competencies with level of education) in Section 3.2.1, to RQ 2.2 (distinction of *quantitative modelling* and *perspective taking* from *qualitative arguing*) in Section 3.2.2, and to RQ 2.3 (differentiation of *quantitative modelling* and *perspective taking* from related constructs) in Section 3.2.3.

3.2.1. Competence Increase in Quantitative Modelling and Perspective Taking with Level of Education

Data were normally distributed for the two groups 11th/12th graders and student teachers for *perspective taking* (Shapiro–Wilk test, $p > 0.05$), but not for 9th/10th graders for *perspective taking* and all groups regarding *quantitative modelling* (Shapiro–Wilk test, $p < 0.05$). Visual inspection of the histograms revealed no extreme outliers for both dimensions. Levene tests showed that homogeneity of variances could be assumed (p-values > 0.05). The average WLE person-abilities differed for the three educational levels regarding *quantitative modelling* with medium effect size ($F(2, 748) = 46.07$, $p < 0.01$, $\eta^2 = 0.11$) and for *perspective taking* with great effect size ($F(2, 750) = 101.86$, $p < 0.001$, $\eta^2 = 0.21$).

Figure 4 shows the frequency of the person-abilities regarding the three educational levels for both dimensions in detail. Dashed vertical lines mark the average person-abilities for the three educational levels. Arrows indicate the level of education at hand. Average person-abilities increased with level of education for both dimensions (Figure 4). The increase in competencies is visibly more significant for *perspective taking* than for *quantitative modelling*.

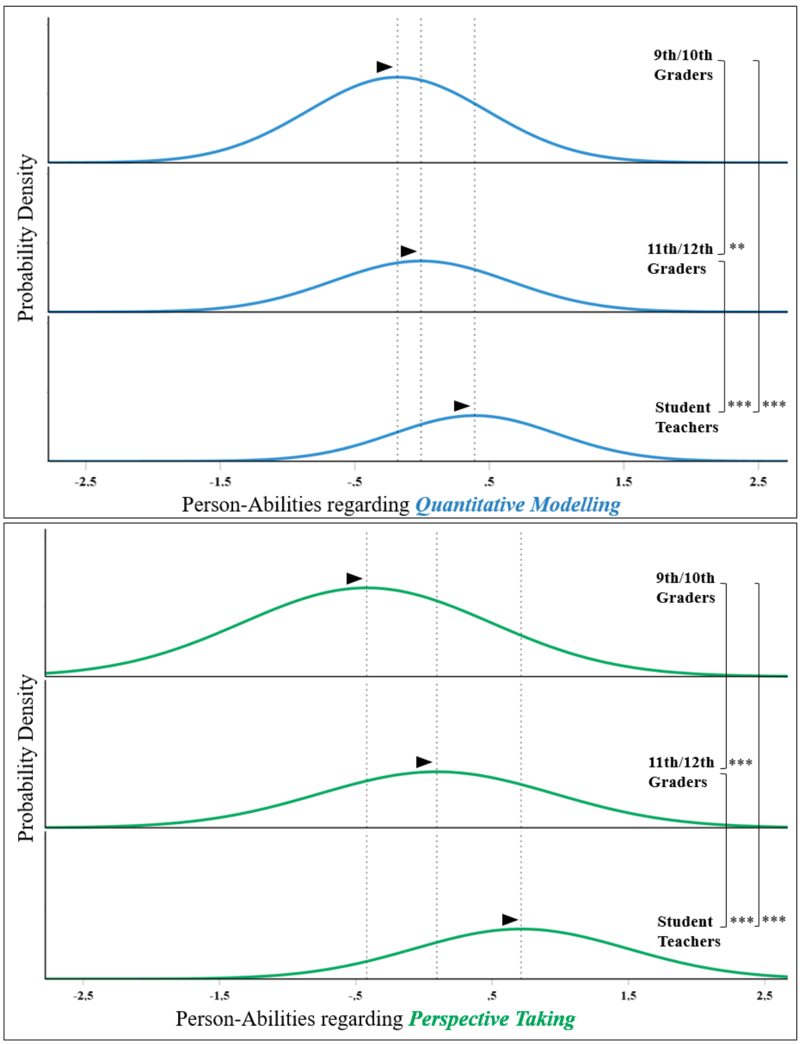

Figure 4. Person-abilities from one-dimensional modelling regarding *Quantitative Modelling* (above: 362 9th/10th graders, 213 11th/12th graders, 176 student teachers) and *Perspective Taking* (below: 362 9th/10th graders, 216 11/12th graders, 175 student teachers). Remark: triangles mark the average person-ability for each level of education; *** $p < 0.001$, ** $p < 0.01$.

3.2.2. Quantitative Modelling and Perspective Taking with Qualitative Arguing

To find out whether *quantitative modelling* and *perspective taking* differ from *qualitative arguing*, 2D models for *quantitative modelling* and *qualitative arguing* as well as for *perspective taking* and *qualitative arguing* were each compared to correspondent 1D models (Table 4). 1D modelling included seven out of eight *quantitative modelling* items and all eight *perspective taking* items. The final deviance, as well as the AIC and BIC information criteria, support both 2D model solutions (Table 4).

Table 4. Fit statistics for the one- and two-dimensional models (1D, 2D): *Quantitative Modelling* in combination with *Qualitative Arguing* as well as *Perspective Taking* in combination with *Qualitative Arguing* ($n = 191$; ***; $p < 0.001$).

***Qualitative Arguing* combined with**	**Models**	**Parameter**	**Deviance**	**AIC**	**BIC**	**Δ Deviance (df)**
Quantitative Modelling	1D 2D	40 42	6359 6299	6439 6383	6570 6519	- 60 *** (2)
Perspective Taking	1D 2D	45 47	6983 6927	7073 7021	7219 7174	- 56 *** (2)

The χ^2-test confirms the latter (p-values < 0.001). In addition to that, the corresponding latent correlation of the 2D modelling between *quantitative modelling* and *qualitative arguing* is 0.46 and between *perspective taking* and *qualitative arguing* 0.67 ($n = 191$).

A 3D modelling of the three dimensions of the competence model for decision making for Sustainable Development revealed similar latent correlations (see Figure 5).

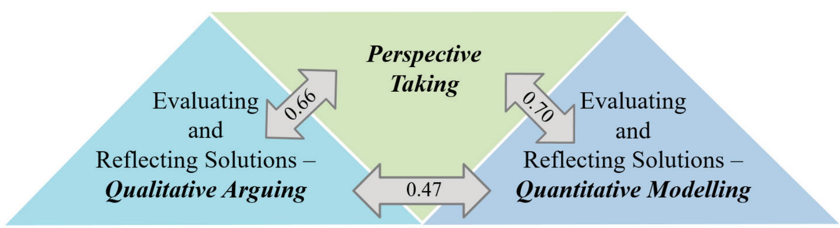

Figure 5. Three-dimensional modelling and latent correlations between *Quantitative Modelling*, *Perspective Taking* and *Qualitative Arguing*—dimensions of the competence model of Decision Making for Sustainable Development ($n = 191$).

3.2.3. Quantitative Modelling and Perspective Taking and Further Related Constructs

Correlation analyses with related constructs serve to locate *quantitative modelling* and *perspective taking* within the nomological net. The 4D modellings reveal latent correlations of *quantitative modelling* with related constructs, i.e., economic literacy, mathematical competencies and *qualitative arguing* of the competence model of decision making for Sustainable Development (Table 5). The same applies for *perspective taking* (Table 6).

Table 5. Latent correlations from four-dimensional modelling of *Quantitative Modelling* with constructs of validation study I ($n = 191$).

	Quantitative Modelling	***Qualitative Arguing***	**Economic Literacy**
Qualitative Arguing	0.47		
Economic Literacy	0.81	0.42	
Mathematical Competencies	0.60	0.41	0.52

Table 6. Latent correlations from four-dimensional modelling of *Perspective Taking* with constructs of validation study I (n = 191).

	Perspective Taking	*Qualitative Arguing*	Economic Literacy
Qualitative Arguing	0.66		
Economic Literacy	0.72	0.43	
Mathematical Competencies	0.32	0.41	0.51

Quantitative modelling correlates in 4D modelling (Table 5) highest (0.81) with economic literacy, followed by mathematical competencies (0.60). The latent correlation with *qualitative arguing* is the lowest (0.47; cf. 0.46 in 2D modelling, see above, and 0.47 in 3D modelling, see Figure 5 above). Further, *quantitative modelling* displays higher latent correlations with economic literacy and with mathematical competencies than *qualitative arguing* (Table 5).

Regarding *perspective taking* (Table 6), the latent correlation again is the highest with economic literacy (0.72), followed by *qualitative arguing* (0.66). Mathematical competencies are weakest related to *perspective taking* (0.32). Comparing the latent correlations of *perspective taking* and *qualitative arguing* with economic literacy, it is roughly 0.30 higher for *perspective taking*. For mathematical competencies, it is approximately 0.10 lower for *perspective taking* than for *qualitative arguing*.

Very low differences (0.01 deviation) of latent correlations between related constructs (displayed in the second and third column in Tables 5 and 6) result from rounding errors and from the two different underlying 4D models. The 191 test persons are identical in both 4D models.

Quantitative modelling and *perspective taking* differently correlate with performance in different school subjects (measured via grades; see Table 7). Correlations with intermediate effect sizes (0.30–0.50) are given for *quantitative modelling* in politics/economics for lower secondary students as well as for upper secondary students in mathematics and biology. For *perspective taking*, there are only low correlations—except one moderate correlation with the grade in German for lower secondary education.

Table 7. Correlations between average person-ability (WLE) and grades from relevant subjects (Spearman's Rho; *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$).

	Quantitative Modelling				*Perspective Taking*			
Educational Levels	**9th/10th**		**11th/12th**		**9th/10th**		**11th/12th**	
Subjects	***r***	***N***	***r***	***n***	***r***	***n***	***r***	***n***
Mathematics	0.23 ***	361	0.31 ***	209	0.11 *	361	0.19 **	212
Politics/Economics	0.34 ***	348	0.25 **	173	0.28 ***	347	0.28 ***	176
Biology	0.24 ***	356	0.34 ***	197	0.29 ***	354	0.25 ***	200
Geography	0.25 ***	347	0.23 **	146	0.25 ***	347	0.24 **	147
German	0.20 ***	361	0.14 *	209	0.30 ***	361	0.23 **	212

Correlation analyses relating WLE person-abilities in *quantitative modelling* and *perspective taking* to analytical problem solving revealed no significant correlations (Spearman's Rho).

Concerning partial correlation (controlled for age) of *quantitative modelling* and *perspective taking* with reading speed and reading comprehension, only *perspective taking* correlates significantly with reading comprehension ($r = 0.16$, $p < 0.05$).

4. Discussion

4.1. First Set of Research Questions—Dimensionality, Measurement, and Differential Item Functioning

In Sections 4.1.1–4.1.4, we discuss results concerning the first set of research questions. We address results regarding RQ 1.1 (2D modelling and measuring of *ERSQE*) and regarding RQ 1.2 (resulting dimensions: *quantitative modelling* and *perspective taking*) in Sections 4.1.1–4.1.3. We argue results regarding RQ 1.3 (appropriateness of items for different educational levels) in Section 4.1.4.

4.1.1. Dimensionality

ERSQE can be modelled one-dimensionally with the Partial Credit Model, de novo. However, a 2D model better fits the empirical data. The two dimensions are: *evaluating and reflecting solutions—quantitative modelling* (in short, *quantitative modelling*), and *perspective taking contextualized for Sustainable Development* (in short, *perspective taking*).

4.1.2. Quantitative Modelling

The 1D model of *quantitative modelling* shows satisfactory statistics regarding item reliability, item fit and discrimination. The EAP/PV reliability is restricted but still meets the critical value of 0.50 (specified for Cronbach's alpha, see [7,50]). Nonetheless, this coincides with a limited number of eight polytomous items [51]. Thus, selection or deletion of items was not an option for optimization. Further, workable test lengths are necessary for designing sophisticated competence tests, which can make achieving high reliability difficult [52].

Further, low reliability can occur with significant content coverage of the construct to be measured [51]. *Quantitative modelling* covers a broad spectrum of contents that can contribute to restricted reliability and low variance. Nevertheless, the measure provides trustworthy information because it resulted from a systematic, iterative and gradual development [5,16] according to Wilson (2005) [53].

The low variance originates from the distribution of the person-abilities (between ca. −1.5 and ca. 1.2; Figure 3). Some item steps have higher difficulty (located at approximately 2 logits) and one item less difficulty (located at ca. −2 logits). Achieving full credit for the items 5, 13 and 16 is very difficult. This phenomenon is explainable by the requirements for solving interdisciplinary Sustainable Development tasks. The necessary integrated application of knowledge from different disciplines seems to be challenging. Further, an unfamiliarity with and a reluctance to perform quantitative environmental-economic analysis of environmental problems could contribute to the item-difficulty [5].

The economic setting provides somewhat unfamiliar contexts [54] for the participants. Furthermore, the economics concepts required for many real-world Sustainable Development issues may not be connected with the underlying rational behind them [55]. The latter can result in a lack of a well-developed schema within the learner's mind [56]. Hence, we think that the economics concepts constitute some kind of a content knowledge threshold. Thereby, the economics concepts prevent the learners from reaching a sophisticated level of *socioscientific reasoning* [57]. Additionally, it may be that the unfamiliarity and the knowledge thresholds, mutually reinforce each other. For instance, deficient decision making can result from a misunderstanding of basic science [54].

Findings from mathematics education can also contribute to explaining the difficulty-generating factors regarding *quantitative modelling*. There is empirical evidence that pupils have difficulties in applying a familiar formula in unfamiliar contexts [58]. Further, the interpretation of graphs in real-world situations is more difficult compared to spare contexts [59]. These findings may be transferred partly to economics, too. The result that the latent correlation between *quantitative modelling* and mathematical competencies is lower compared to the correlation between *quantitative modelling* and economic literacy is plausible: The solution for the Sustainable Development tasks require only a low level of mathematical competencies.

4.1.3. Perspective Taking

Perspective taking can be modelled one-dimensionally in a suitable manner. It generally exhibits satisfactory statistics regarding item reliability, item fit and discrimination as well as variance and EAP/PV reliability.

Being able to take different perspectives is of high relevance for Education for Sustainable Development: It can promote the engagement of learners with '*psychologically distant issues*' and contribute to '*motivate sustainable behaviour change*' [60] (p. 155). *Perspective taking* is in line with the dimension applying multiple perspectives of the *socioscientific reasoning* approach [8] and with research related to evaluating medical ethics issues [61]. The latter results from a qualitative study in which *perspective taking* is considered as an independent dimension. The research presented here psychometrically underpins the importance of *perspective taking* within Education for Sustainable Development.

The curricular relevance of *perspective taking* as a competence dimension is underlined in the most recent German national educational standards for biology [62], resolution of the conference of ministers of education and cultural affairs from 18 June 2020. For example, the standards demand that upper secondary school students be able to (i) look at issues from multiple perspectives, (ii) reflect short- and long-term consequences of their own and of societal decisions, (iii) reflect decision-making processes from personal, societal and ethical perspectives, and (vi) assess and evaluate the effects of biology applications in terms of Sustainable Development from ecological, economic, political and social perspectives [62] (pp. 17, 18). The most recent German national educational standards for chemistry and physics from 2020 introduce similar provisions on perspective taking [63,64]. Likewise, the national German guidelines on global development education [65] describe perspective taking as a central competence.

In sum, we improve the competence model on decision making for Sustainable Development by identifying two distinct dimensions: *quantitative modelling* and *perspective taking*. The latter is an innovative contribution of this paper.

4.1.4. Differential Item Functioning

Quantitative modelling and *perspective taking* can be measured among different groups of secondary school students and student teachers. Considering all analyses conducted, only items 9, 10 and 12 partly exhibited considerable differential item functioning. In *perspective taking* item 9, we ask learners to take two potential conflicting perspectives of a specific stakeholder (Appendixes B.2 and D.2). The fact that the item is easier for the student teachers is consistent with the increase in *perspective taking* competence in adolescence [66]. Regarding item 10 of *quantitative modelling*, the participants had to conduct a cost-benefit analysis. The curricula address corresponding knowledge in grade 10 [67,68]. Therefore, it is plausible that item 10 was easier for 11th/12th graders than for the 9th/10th graders. *Quantitative modelling* item 12 requires identifying an error in mathematical modelling. The task was easier for the school students than for the student teachers. We explain this by the kind of task with which school students are more familiar with than the student teachers without mathematics as a teaching subject.

In sum, items with differential item functioning are limited, and thereby, differential item functioning is not '*sincerely considerable*' [43] (p. 12), but plausibly explainable.

4.2. Second Set of Research Questions—Validation Studies

In Sections 4.2.1–4.2.3, we discuss results concerning the second set of research questions. First, we address results regarding RQ 2.1 (competence increase in *quantitative modelling* and in *perspective taking* with level of education) in Section 4.2.1. Second, we focus results regarding RQ 2.2 (distinction from *quantitative modelling* and *perspective taking* from *qualitative arguing*) in Section 4.1.2. Third, we argue results regarding RQ 2.3 (differentiation from related constructs) in Section 4.2.3.

4.2.1. Competence Increase in Quantitative Modelling and Perspective Taking with Level of Education

The findings that average person-abilities regarding *quantitative modelling* and *perspective taking* increase with level of education (Figure 4) is consistent with the character of competencies, which can be learnt [31]. The phenomenon of developing *perspective taking* during adolescence was determined ' *. . . as a result of cognitive development . . .* ' [66] (p. 881). We explain the more substantial increase in *perspective taking* than of *quantitative modelling* (Figure 4) via the following: In nearly every school subject *perspective taking* is fostered at some point of time or even continuously. Relevant components of *quantitative modelling* are prone to fewer subjects and opportunities to practice.

4.2.2. Quantitative Modelling and Perspective Taking: Two distinct Dimensions to Qualitative Arguing

Figure 5 depicts three competence dimensions of the competence model on decision making for Sustainable Development. We explicitly contextualize each dimension for Sustainable Development. Latent correlations of 3D modelling show that *quantitative modelling* and *perspective taking* are relatively distinct from *qualitative arguing* (0.47 and 0.66). For comparison, PISA reports higher latent correlations within a range of r = 0.77 and 0.89 between reading competencies, mathematical competencies, and scientific as well as cross-disciplinary problem solving [49].

As expected, the latent correlations between *quantitative modelling* and *qualitative arguing* are lower (0.47 in 3D modelling in Figure 5 and in 4D modelling Table 5) than for both with *perspective taking* (*quantitative modelling*: 0.70 in Figure 5; *qualitative arguing*: 0.66 in 3D modelling in Figure 5 and 4D modelling in Table 6). The given correlations appear plausible against the background, that general cognitive abilities cannot be separated entirely from context-specific competencies [31].

In the following the resulting latent correlations of the 3D modelling of the investigated three competence dimensions of the competence model on decision making for Sustainable Development (Figure 5) are explained. The latent correlation between *quantitative modelling* and *qualitative arguing* is plausible because both share the same rational when it comes to reflecting on the advantages (benefits) and disadvantages (costs) of a particular option. Fundamental for both dimensions is the question whether the advantages of the option outweigh its drawbacks. Within *quantitative modelling*, learners work on this question quantitatively in the form of cost-benefit analysis. In contrast, within *qualitative arguing*, learners engage qualitatively by the weighing of pro- and contra arguments. For *quantitative modelling*, the best option in solving the task can be identified (if enough data are available), whereas, for *qualitative arguing*, the result is more depending on values. At the same time, *qualitative arguing* focuses more on the arguments and the quality of argumentation within the process of decision making instead of the resulting decision itself.

The latent correlation between *qualitative arguing* and *perspective taking* can partly be explained by structural similarity. For example, the qualitative weighing of the advantages and disadvantages of different options (*qualitative arguing*) is similar to considering different positions, arguments and consequences of Sustainable Development-relevant *perspective taking*.

Two reasons can explain the highest correlation between *quantitative modelling* and *perspective taking*. Firstly, in both dimensions, the economic points of view have to be considered. Secondly, we measured both dimensions in a combined measurement of *quantitative modelling* and *perspective taking* within the three Sustainable Development tasks of the questionnaire addressing land use change, marine resource use and climate change.

4.2.3. Quantitative Modelling, Perspective Taking and further Related Constructs

The finding that the latent correlations between *quantitative modelling* and related constructs resulting from 4D modelling (Table 5) are highest between *quantitative modelling* and economic literacy, followed by mathematical competencies, is plausible. *Quantitative modelling* in our questionnaire tasks requires applying economics concepts, mathematical modelling and formalization (Appendixes B.1 and D.1). Even for *perspective taking*, the latent correlations are highest for economic literacy (Table 6), followed by *qualitative arguing*. The economic contextualization of both dimensions can explain the highest correlation of economic literacy with *quantitative modelling* and *perspective taking*. The more moderate (weaker) correlations of *quantitative modelling* (and *perspective taking*) with mathematical competencies can be explained by the low level of (and the not requested) mathematical competencies required to solve the questionnaire tasks.

The correlation patterns regarding *quantitative modelling* and *perspective taking* with grades from relevant subjects are in line with the contents of school curricula. We discuss the correlations of minimum intermediate effect sizes (Table 7) in the following. The 9th/10th graders *quantitative modelling* competence correlates with the subject politics/economics. *Quantitative modelling* requires relevant economics content knowledge regarding the corresponding curriculum. For example, in grade 10 topics such as the strained relationship between economy and ecology as well as the economics concepts such as *efficiency* (weighing costs and benefits), *market failure* or *supply and demand* are addressed in the school curricula of the two German states [67,68].

Concerning the 11th/12th graders, correlations of intermediate effect size from *quantitative modelling* can be found with the subject mathematics and the subject Again, these correlations can arise because general cognitive abilities cannot be separated entirely from context-specific competencies [31].

Regarding *perspective taking* competence, the only correlation of intermediate effect size occurs for the correlation with the grade in German for 9th/10th graders. The moderate correlation is plausible regarding the curricula for the German language, requiring argumentation [69,70].

Regarding correlations between *quantitative modelling* and *perspective taking* with analytical problem solving, no mentionable correlations occurred. The lack of mentionable correlations can be explained by the contextualization for Sustainable Development, and the specific problem situations addressed as well as the missing structural similarity of the tasks.

The missing correlation between *quantitative modelling* and analytical problem solving underpins the independency of an integrative quantitative evaluation from general problem solving. The complex and abstract context in which a problem is embedded affects learner strategies [71,72]. In addition to that, these strategies cannot be considered as identical across domains [73].

Regarding the control check, only *perspective taking* (not *quantitative modelling*) correlates with small effect size with reading comprehension. Thus, the impact is restricted.

4.3. Limitations

The measurement of *quantitative modelling* and *perspective taking* is also prone to some barriers. Kahn and Zeidler (2016) specify '... *resistances to anomalous data in order to protect prior beliefs* ... ' [74] (p. 264). Such resistance especially applies in emotionally charged contexts. Resistance to anomalous data, in terms of points of view or arguments contrary to the students' core beliefs [72,74], is likely within *quantitative modelling* and *perspective taking*, because Sustainable Development raises questions of justice or injustice, which can lead to emotions. Second, examining environmental problems through an economic lens was somewhat unfamiliar to most of our respondents or caused reluctance and eventually even aversions. Aversions were already reported within the context of economic life in Germany [75]. This phenomenon also occurred in our empirical data. For example, the participants of our study had to take a specific stakeholder perspective with strong economic interests. A corresponding student response was: '*I will not take this position*' (17 years old female student). Therefore, the lacking willingness could prevent students from analyzing the land use, marine resource use or climate change issues quantitatively and economically.

This is also plausible regarding the 2014 published overview of corresponding phenomena regarding decision making in SSIs of Jho et al. [72]. SSIs that are possibly contradictory to learner beliefs, interests or values could lead learners to pay more attention to their own value judgments [72] (p. 1146). Further, the authors gave evidence in the same publication for possible influencing factors on decision making, especially regarding complex SSIs. Decision making in SSIs requires multiple types of knowledge and further considerations. They argue that this could lead to neglect scientific knowledge compared to other factors such as personal experiences and values as well as trust in scientific information (for details, see [72]).

Another limitation concerns the sample composition. It includes (i) a positive selection bias for the subsample of student teachers due to financial incentives, (ii) not all subsamples were equally sized, e.g., due to 12th graders who were in their final exams, and (iii) there are more female student teachers than male student teachers; this is in line with the situation in the teacher study programs in Germany, though.

5. Conclusions

This research on competence modelling deepens the insights on the structure of the competence model on decision making for Sustainable Development. Further, we provide instruments to realiably and validly measure *quantitative modelling* and *perspective taking* if contextualized for Sustainable Development. Thus, the work presented contributes to the desiderata of standardized assessments [76] that are in line with competence modelling [22]. Concerning *perspective taking*, a conceptually important and curricula-relevant competence dimension of Education for Sustainable Development could be empirically modelled. The results are promising for future educational work as *perspective taking* is considered as vital for promoting engagement in SSIs [8,77–79].

The developed instrument can analyze starting points for teaching and learning. The instrument provides information on learning outcomes, specifically, for land use issues, resource use issues and climate change issues. Thus, crucial issues of Sustainable Development and several SDGs are addressed. Furthermore, our modelled competence dimensions are contextualized for actual political decision making.

Thus, educational efforts in teaching and assessing competencies should explicitly focus on learning environments that fulfill the interdisciplinary requirements to cope with real-world tasks such as designating Marine Protected Areas (Appendixes A.1 and A.2). The latter includes dealing with factual complexity and uncertainty as well as with normatively controversial issues characterized by normative uncertainty. Doing so, using available scientific knowledge and data is essential. Thereby, ecological, economic, political and social facets need to be considered in analyzing causes and effects of land use issues, resource use issues and climate change issues in devising potential solutions.

The present work enriches Education for Sustainable Development for the SDGs *life on land*, *life below water* and *climate action* [1,80]. The innovations provided with this study are the modelling and measuring of *quantitative modelling* and *perspective taking* for coping with the complex real-world tasks of Sustainable Development. All of these tasks include the systematic integration of economic, social and environmental aspects in decision making. This study improves existing competence models. Alongside a small set of similar studies, this paper demonstrates that these tasks can successfully be addressed by empirical educational research. Such research is the main step toward evidence-based teaching in Education for Sustainable Development.

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Appendix A

Appendix A.1. Information Booklet for the Resource Use Issue—Marine Resource Use Task—Part I

Oceans and shores are important for human nutrition as well as leisure and recreation. Oceans play a significant role regarding climate regulation as they absorb and store CO_2. Further, in economic terms, oceans are of great importance for human well-being. All in all, the state of the oceans affects human well-being.

Information I for the designation of a Marine Protected Area in Great Britain

The British government plans to designate a Marine Protected Area. Communications were sent to all parties and communities concerned in order to inform citizens and economic sectors about three proposals for the designation of a Marine Protected Area (Tables A1–A3).

Table A1. Three proposals for the designation of a Marine Protected Area.

Features	Marine Protected Area 1	Marine Protected Area 2	Marine Protected Area 3
Area [ha]	125,700	156,000	147,300
Percentage of Endangered Species and Habitats [%]	20	60	60
Special Features of the Marine Protected Area	None	Fish breeding grounds and fish nursery	Does not include coastal regions

Whitstable is a traditional port city popular among tourists. Whitstable will be directly affected by the designation of a Marine Protected Area. The city and its people will bear part of the economic losses, but at the same time benefit from the Marine Protected Area as well. Therefore, many interested citizens and representatives of different sectors appear at the city council meeting. Among them is Graig Hering. He is the owner of the largest and oldest fish factory in Whitstable. Also present, is Jeanette Bristlecomp. She is an hotelier and also director of the nature conservation group *Birds of Whitstable*. At the city council meeting, Graig Hering and Jeanette Bristlecomp bring forward arguments regarding their personal point of views relevant for the impacts of a designation of a Marine Protected Area.

Now work on the Questions 1 and 2 in your Answering Booklet!

Excerpt of the corresponding Answering Booklet:

Question 1: Imagine you are Graig Hering. Justify your point of view regarding the designation of a Marine Protected Area close to your town! [→ Item 8]

Question 2: Imagine you are Jeanette Bristlecomp. Justify your point of view regarding the designation of a Marine Protected Area close to your town! [→ Item 9]

Appendix A.2. Information Booklet for the Resource Use Issue—Marine Resource Use Task—Part II

Despite the intensive use, oceans and their natural resources are poorly protected. This results in the overfishing of many fish stocks.

Information II for the designation of a Marine Protected Area in Great Britain

Due to the designation of a Marine Protected Area, no interventions may take place in the protected area. As a result, some individual economic sectors will suffer losses (costs, Table A2).

Table A2. Costs for individual economic sectors over the next 20 years.

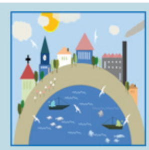
Economic Sectors	Marine Protected Area 1	Marine Protected Area 2	Marine Protected Area 3
Fisheries [€]	208 million	227 million	346 million
Oil and Gas Companies [€]	535 million	811 million	799 million
Telecommunications and Energy Companies [€]	24 million	57 million	43 million

The disuse of the area, protected under a Marine Protected Area, favors *ecosystem services*[1] generated by the ocean, such as the food production and climate regulation. The equivalent of these benefits is presented in monetary terms (see Table A3).

Table A3. Benefits to the public in the next 20 years.

Ecosystem Services	Marine Protected Area 1	Marine Protected Area 2	Marine Protected Area 3
Food Production and Climate Regulation [€]	8000 million	18,000 million	14,000 million
Tourism, Research, Leisure and Recreation [€]	2000 million	2500 million	2800 million

Margaret Fields is the mayor of Whitstable. She wants to achieve a sustainable solution for the benefit of the entire city. To find a sustainable solution, she rationally analyzes the situation according to the data available within *Information I and II for the designation of a Marine Protected Area in Great Britain*. Afterwards, she presents her decision to the local community at the city council meeting.



Now work on the Questions 3 and 4 in your Answering Booklet!

[1] ***Ecosystem services*** *are services provided by nature that can be used by humans to ensure their well-being (e.g., trees produce oxygen and bind CO_2).*

Excerpt of the corresponding Answering Booklet:

Question 3: Imagine you are Margaret Fields. Explain to the local community which potential Marine Protected Area you would recommend in terms of public welfare for the entire city. Justify your decision mathematically! [→ Item 10]

Question 4: To what extent does the designation of a Marine Protected Area constitute a sustainable solution in terms of public welfare for the entire city? Justify your point of view through social, economic and economical aspects! [→ Item 11]

Appendix B

Appendix B.1. Overview of all Items for Quantitative Modelling:

- ● Content,
- ➢ *Economics Concept(s)*,
- - Sustainable Development issues [Environmental Policy Instrument], and
- σ Item-Difficulty

		Items regarding *Quantitative Modelling*	σ
1	● ➢ -	**One-Step Mathematical Modelling** with very Manageable Data *Profit Maximization* Land Use Change Issue	−0.17
15	● ➢ -	**Reasoned Decision Making** regarding the Environmental Policy Instrument *Supply/Demand* and *Incentives* Climate Change Issue [European Union Emission Trading System]	−0.11
5	● ➢ -	**One-Step Mathematical Modelling** with very Manageable Data *Financial Incentives* Land Use Change Issue [Reducing Emissions from Deforestation and Forest Degradation]	0.07
2	● ➢ -	**Multi-Step Mathematical Modelling** with Manageable Data; Additional Constraint *Minimum Principle* Land Use Change Issue	0.46
13	● ➢ -	**Reasoned Decision Making** regarding the Environmental Policy Instrument *Cost-Efficiency* and *Market Failure* Climate Change Issue [European Union Emission Trading System]	0.60
10	● ➢ -	**Multi-Step Mathematical Modelling** with Manageable Data (Cost-Benefit Analysis) *Public Welfare* and *Cost/Benefit* Marine Resource Use Issue [Marine Protected Area]	0.60
12	● ➢ -	**Reflection** of a Given Multi-Step Mathematical Modelling with Manageable Data; Determination of an Error in one Modelling Step (without any Economics Concept to consider) Climate Change Issue [European Union Emission Trading System]	0.67
16	● ➢ -	**Reasoned Decision Making** regarding the Environmental Policy Instrument *Supply/Demand (Pricing)* and *Externalities* Climate Change Issue [European Union Emission Trading System]	0.68

Appendix B.2. Overview of all Items for Perspective Taking:

● Content,
▲ *Sustainable Development-relevant Norms* or *Perspectives* respectively,
- Sustainable Development issues [Environmental Policy Instrument], and
σ Item-Difficulty

		Items regarding *Perspective Taking*	σ
8	●	**Positioning** on the Environmental Policy Instrument	−1.00
	▲	*Specific Stakeholder* with *Economic Interests*	
	-	Marine Resource Use Issue [Marine Protected Area]	
9	●	**Positioning** on the Environmental Policy Instrument	−0.74
	▲	*Specific Stakeholder* with conflicting *Economic* and *Ecological Interests*	
	-	Marine Resource Use Issue [Marine Protected Area]	
6	●	**Positioning** on the Environmental Policy Instrument	−0.06
	▲	*Basic Needs* and *Inter-/Intragenerational Justice*	
	-	Land Use Change Issue [Reducing Emissions from Deforestation and Forest Degradation]	
7	●	**Arguing** for or against the Environmental Policy Instrument	0.10
	▲	*From Local to Global* (Family/Community, Society and Humanity)	
	-	Land Use Change Issue [Reducing Emissions from Deforestation and Forest Degradation]	
3	●	**Reflecting** Consequences of conflicting Interests in StakeholderLand Use Decisions	0.11
	▲	Equal Consideration of the *Social, Ecological and Economic Dimension* on a *Specific Stakeholder*-Level (Family)	
	-	Land Use Change Issue	
11	●	**Reasoning** of the Environmental Policy Instrument	0.22
	▲	*Equal Consideration of the Social, Ecological and Economic Dimension* on a *Global Level* (Humanity)	
	-	Marine Resource Use Issue [Marine Protected Area]	
14	●	**Reasoning** of the Environmental Policy Instrument	0.71
	▲	Equal Consideration of the *Social, Ecological and Economic Dimension* on a *Global Level* (Humanity)	
	-	Climate Change Issue [European Union Emission Trading System]	
4	●	**Reflecting** Consequences of conflicting Interests in Stakeholder Land Use Decisions	1.33
	▲	*Global Level* (Humanity)	
	-	Land Use Change Issue	

Appendix C

Appendix C.1 Scoring of Item 10—Quantitative Modelling

Item 10 Marine Resource Use Issue		
Question:	Imagine you are Margaret Fields [major of the town Whitstable]. Explain to the local community which potential Marine Protected Area you would recommend in terms of public welfare for the entire city. Justify your decision mathematically!	
Content:	Multi-Step Mathematical Modelling, Manageable Data	
Economics Concepts:	*Public Welfare* and *Cost/Benefit*	
	Scoring	**Responses**
0	• Concepts not or correctly applied (implicitly) • Mathematical Modelling incorrect or false, incompletely documented	***9th grade, female, 16 years old*** I would recommend Marine Protected Area 1 because it includes the smallest percentage of endangered species and there are not many restrictions for the fishery. In addition, the costs for individual economic sectors are lowest for Marine Protected Area 1. Also in regard of the use for the general public for the next 20 years the costs are rather small.
1	• Concepts at least correctly applied (implicitly) • Mathematical Modelling with correct result, incompletely documented	***9th grade, sex not specified, 15 years old*** Marine Protected Area 2 should be designated. - € 227 million € 18,000 million - € 811 million € 2500 million - € 57 million - € 1095 million € 20,500 million € 20,500 million - € 1095 million = € 19,405 million A benefit of € 19,405 million.
2	• [see Score 1] • Mathematical results transferred back to the Sustainable Development issue	***11th grade, male, 17 years old*** Benefits Marine Protected Area 1 € 9233 million Marine Protected Area 2 € 19,405 million Marine Protected Area 3 € 15,612 million → Marine Protected Area 2 generates the highest benefit while safeguarding the protected species in 60% of the area.
3	• [see Score 2] • Concepts correctly applied (at least implicitly) • Mathematical Modelling correct and completely documented	***11th grade, male, 17 years old*** **Marine Protected Area** **1** **2** **3** **Area/Surface** 125,700 ha 156,000 ha 147,300 ha **Costs [€]** −767 million −1095 million −1188 million **Benefits [€]** +10,000 million + 20,500 million + 16,800 million **Total [€]** +9233 million +19, 405*million* + 15,612 million **Per Hectare [€]** +0.0734 million + 0.1244 million + 0.1059 million In regard of the city's benefit, I would recommend Marine Protected Area 2, since it contains 60% endangered species which need to be protected on one hand, and contains fish spawning grounds and nurseries, and on the other hand, the city would benefit in the next 20 years from the benefit of up to € 19,405 million. At the same time, Marine Protected Area 2 is by far the biggest profit per hectare in the next 20 years, even though it occupies a large area of 156,000 ha, it comes with a great benefit.

Appendix C.2. Scoring of Item 11—Perspective Taking

Item 11 Marine Resource Use Issue		
Question:	To what extent does the designation of a Marine Protected Area constitute a sustainable solution in terms of public welfare for the entire city? Justify your point of view through social, economic and economical aspects!	
Content:	Reasoning of the Environmental Policy Instrument *Marine Protected Area*	
Remark:	*Taking three Sustainable Development-specific Perspectives: Ecological, Economic and Social*	
	Scoring	**Responses**
0	• Perspective taking missing, superficial or given for one point of view, substantiated by one valid argument	***9th grade, female, 15 years old*** It's a great way to protect fish species that are threatened with extinction. Even the natural space is preserved in a natural way.
1	• Perspective taking given for two points of view • Points of view substantiated by one valid argument	***9th grade, male, 15 years old*** Social: research for the general public Ecological: natural space for fish is preserved, regeneration of fish stocks and water quality Economic:
2	• Perspective taking given for three points of view • Points of view substantiated by one valid argument	***11th grade, female, 17 years old*** From an ecological point of view, the non-use promotes ecosystem services and thus also food production. From a social point of view, the expansion of nature reserves promotes the recreational factor of tourists. Even economically (see Table A3), the implementation of a Marine Protected Area has only advantages, as you can see the expenses cover the revenues and you get high profits.
3	• [See Score 2] • At least two points of view substantiated by more than one valid argument	***10th grade, female, 16 years old*** I think that a Marine Protected Area is a good solution. Everyone has advantages and disadvantages. Socially: There is more food, tourism, research, leisure and recreation. Ecologically: It would protect the environment and also their living beings more and in a sustainable manner. Economically: The fishery would suffer as they have less revenue in the first few years until the fish stocks have recovered. Employees have to be dismissed and there would be financial losses. Nevertheless, in the end, every aspect, socially, ecologically and economically, has something of it. I think it's a good solution, because at some point we have to start with sustainable thinking. Our children also want to eat fish.

Appendix D

Appendix D.1. Scoring Rubric for the Items of Quantitative Modelling

	Item 1	Item 5	Item 2	Item 10	Item 13	Item 15	Item 16	Item 12
Sustainable Development issue	Land Use Change			Marine Resource Use	Climate Change			
Content	**One-Step Mathematical Modelling**, very Manageable Data		**Multi-Step Mathematical Modelling**, Manageable Data, Additional Constraint (secured livelihood)	**Multi-Step Mathematical Modelling**, Manageable Data	**Reasoned Decision Making** regarding the Environmental Policy Instrument *European Union Emission Trading System*			**Reflection** of given Multi-Step Mathematical Modelling with Manageable Data; Determination of an Error in one Modelling Step
Immanent Economics Concept(s)	*Profit Maximization*	*Financial Incentives*	*Minimum Principle*	*Public Welfare* *Cost* and *Benefit*	*Cost-Efficiency* *Market Failure*	*Supply/Demand* *Financial Incentives*	*Supply/Demand* (Pricing) *Externalities*	(without any Economics Concept to consider)
Score 0	Concept(s) not or correctly applied (implicitly); Mathematical Modelling incorrect or false, incompletely documented				Both Concepts missing or incorrect			Valid Reasoning of Mathematical Modelling might be given but Error within Mathematical Modelling not mentioned
Score 1	Concept(s) at least correctly applied (implicitly); Mathematical Modelling with correct Result, incompletely documented		Approximate Calculation		One Concept correctly applied (implicitly)	[See Score 0] Plus: a viable and sophisticated Criticism regarding *European Union Emission Trading System*	One Concept correctly applied (implicitly) Quantification partly applied	Error mentioned but not precisely determined and valid Reasoning of Mathematical Modelling given or: Error precisely determined but valid Reasoning of Mathematical Modelling missing
Score 2	[See Score 1] Plus: Mathematical Results transferred back to Sustainable Development issue		Mathematical Modelling completely documented		Both Concepts correctly applied (implicitly)	[See Score 1] Plus: One Concept correctly applied (implicitly)	Both Concepts correctly applied (implicitly) Quantification completely applied	Error precisely determined and valid Reasoning of the Mathematical Modelling given
Score 3	[See Score 2] Plus: Mathematical Modelling correctly and completely documented	No Score 3 available	No Score 3 available	[See Score 2] Plus: Concepts correctly applied (at least implicitly); Mathematical Modelling correctly and completely documented	No Score 3 available	[See Score 2] Plus: Both Concepts correctly applied (implicitly)	No Score 3 available	No Score 3 available

Appendix D.2. Scoring Rubric for the Items of Perspective Taking

	Item 3	Item 11	Item 14	Item 4	Item 6	Item 7	Item 8	Item 9
Sustainable Development issue	Land Use Change	Marine Resource Use	Climate Change	Land Use Change			Marine Resource Use	
Content	**Reflecting** the Consequences of Conflicting Interests in Stakeholder Land Use Decisions	**Reasoning** of the Environmental Policy Instrument *Marine Protected Area*	**Reasoning** of the Environmental Policy Instrument *European Union Emission Trading System*	**Reflecting** the Consequences of Conflicting Interests in Stakeholder Land Use Decisions	**Positioning** with respect to the Environmental Policy Instrument *Reducing Emissions from Deforestation and Forest Degradation*	**Arguing** for or against the Environmental Policy Instrument *Reducing Emissions from Deforestation and Forest Degradation*	**Positioning** with respect to the Environmental Policy Instrument *Marine Protected Area*	
Perspective taking	Taking three Sustainable Development-specific Perspectives: *Ecological*, *Economic* and *Social*			Taking the Sustainable Development-relevant Perspective: *Global Impact*	Taking the Sustainable Development-specific Perspectives: *Basic Needs*, *Inter-* and *Intragenerational Justice*	Taking three Sustainable Development-specific Perspectives: *From Local to Global Levels*	Taking a Sustainable Development-specific Stakeholder Perspective	
Remark	Perspective taking on a concrete Stakeholder-Level (Family)	Perspective taking on a general Level regarding the Benefits and/or Costs for the Humanity			Perspective taking on a general Level regarding the Sustainable Development-relevant Principles and Objectives	Taking of different Perspectives: *Family/Community*, *Society* and *Humanity*	Perspective taking of a Stakeholder: *Economic interests*	Perspective taking of a Stakeholder with Conflicting Interests: *Economic* vs. *Ecological*
Score 0	Perspective taking missing, superficial or Perspective taking given and Point of View substantiated by … … one valid Argument for one Perspective			… one valid Argument (implicitly)	… one valid Argument	… one valid Argument for one Perspective	… one valid Argument for the specific Stakeholder Perspective	
Score 1	Perspective taking given and Point of View substantiated by … … one valid Argument for each of two Perspectives			… two valid Arguments (at least implicitly)	… two valid Arguments	… one valid Argument for each of two Perspectives	… two valid Arguments for the specific Stakeholder Perspective	
Score 2	Perspective taking given and Point of View substantiated by … … one valid Argument for each of three Perspectives			… at least two valid Arguments (at least implicitly)	[See Score 1] Plus: a viable and sophisticated Criticism regarding *Reducing Emissions from Deforestation and Forest Degradation*	… one valid Argument for each of three Perspectives	… at least three valid Arguments for the specific Stakeholder Perspective	
Score 3	[See Score 2] Plus: more than one valid Argument for at least two Perspectives			No Score 3 available	No Score 3 available	[See Score 2] Plus: each Perspective specified	No Score 3 available	No Score 3 available

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sustainability

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Article

Understanding of Sustainability and Education for Sustainable Development among Pre-Service Biology Teachers

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Abstract: Sustainable development (SD) is one of the global and central aims of today's politics. As stated in Agenda 21, education must play an essential role in achieving a sustainable society. The present research is focused on Slovenian and Austrian biology teacher students' understanding of SD and education for sustainable development (ESD). The research was carried out at the University of Ljubljana and the University of Vienna. Altogether, 60 Slovenian and 60 Austrian pre-service biology teachers participated in the questionnaire-based study. Pre-service biology teachers answered a set of Likert-type and open survey questions. Less than half of the pre-service biology teachers from Slovenia and Austria had a good understanding of the environmental aspects of SD, but they lack understanding of the interconnections between the environmental, economic and social dimensions related to SD. They describe and connect ESD with environmental education and environmental awareness. Students from both countries know some pedagogical principles of ESD, such as active learning and transformative education. Analysis with the sustainable development goals (SDGs) in focus showed that only some of them were mentioned by the teacher students. The results of the research contribute to the evaluation and development of curriculum for middle and high school biology teachers.

Keywords: attitudes; knowledge; 17 SDGs; pre-service biology teachers; sustainable development; teacher education

1. Introduction

One of the most important goals of humanity in the 21st century is to construct a sustainable society. Education is one of the keys for achieving sustainability and also one of the targets for a sustainable society [1]. The term sustainable development (SD) was first mentioned by Carlowitz [2] in the book, *Silvicultura oeconomica* (1713), and was described as a principle in the field of forestry. Nowadays, Brundtland's definition of SD as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [3] (p. 43) has become well known. This concept has received the most attention since the United Nations Conference on Environment and Development, held in Rio de Janeiro in 1992. The key document of the Rio agreement is called Agenda 21 [4] and is a major action plan for SD in the 21st century [5]. The core concept of strong sustainability is that the benefits of nature are irreplaceable and that the entire economy is reliant on society, which in turn is entirely dependent on the environment. This emphasizes the interdependencies between our society, our economy and the natural environment [6,7]. Human survival is directly tied to our relationship with the natural environment; therefore, it is essential to establish a sustainable lifestyle that depends on a balance between individuals' consumption and the capacity of the natural environment for renewal [8]. Some researchers perceive ecological systems as a known fixed boundary inside of which all human social systems must exist and economic systems as existing within the boundaries of social systems [9].

Education for sustainable development (ESD) is one of the main aims of the national as well as international educational policies [10]. ESD was first mentioned by Chapter 36 of Agenda 21, where four main aims of the work of ESD were described: improve basic education, reorient existing education to address SD and develop public understanding, awareness and training [4]. For (future) teachers it is essential to raise awareness about SD and ESD [11]. Nowadays, SD is the theoretical basis and an increasingly important norm for human development worldwide [1]. Science education, including and as a part of it biology education, plays an important role for SD and ESD, as van Eijck and Roth [12] have pointed out. SD in education is a framework for orientation, for selecting topics and for developing educational settings [13].

The United Nations Decade for ESD (2005–2014) was followed by the Global Action Plan (GAP) on ESD, designed to provide core learning content and approaches for the post-2015 ESD agenda. Seventeen sustainable development goals (SDGs) are the core elements of Agenda 2030. SDG 4 is focused on quality education: "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all" [14]. ESD is an approach to education, which includes an integrative and holistic view, linking knowledge and action. Kopnina [15] has criticized weak models of sustainability, as, for example, quoted above. On this basis, she also suggests new concepts of ESD, which are more ecocentric. It should be an education for environmental issues, including social and ecological sustainability, as opposed to an anthropocentric view with the economic aspects as a starting point and environmental aspects as resource issues for the economy or an affected domain due to economic activities. Selby [16] argues that the current de-natured nature of ESD makes it unlikely that the student will become motivated to care and act for nature. According to the author, nature is only accorded instrumental and utilitarian value in ESD.

Education for Sustainable Development in Teacher Education

We can find many models of how to include ESD in general teaching and biology education. All these models comprise a multi-level process. Models include societal issues (at local, regional, global levels) and inter- and multidisciplinary approaches as well as changes in pedagogy. ESD teaching and learning is a combination of different views and taking on different perspectives, frequently dealing with socially relevant topics, biology in combination with chemistry and/or physics and the three pillars of sustainability: social, economic and ecological. The aim of teaching follows a skill-orientated paradigm [17] or, more recently, a competencies-driven discussion [18]. Topics in the context of a sustainable future include biodiversity, climate change, the sustainable use of natural resources (e.g., soil, water, energy, ...), health, cultural heritage, multiculturalism and global welfare [10]. One example of an ESD case study in research literature is the work on a local watershed by Eijck and Roth [12]. These authors studied the complexity of human–nature interactions, but at the same time, they made in-depth physical, chemical and biological observations to link everything together and start thinking about solutions for prevalent problems at hand. Another exemplary work is about the return of the wolf as a case for ESD in Germany and looks at how the topic is valued by pre-service teachers for implementing in schools [19].

One of the main critical issues for teachers is to discuss with students the effects of students' behavior and sustainable practice in the local environment. Other important goals are to learn negotiation, problem-solving and decision-making skills through discussions about ecological, social, economic and ethical principles concerning local and global responsibility in their own lives. Through memorable, experiential and active processes, students learn to discuss their values and to critically select and evaluate sources of information [20]. It is essential to present biology as action-oriented science education, where students are engaged in socio-political actions and start making a change [21].

Torkar [22] reports that Slovene in-service biology teachers under-emphasize the importance of students' interactive participation in environmental actions. They have encouraged them to analyze and discuss problems rather than to empower them to take proactive roles, which would provide them with the necessary experiences to actively participate in societal change. Participation of youth is a central feature in the development of citizenship and youth development [23].

Understanding SD and ESD are nowadays one of the critical competencies for future teachers worldwide [7,24–27]. National strategies for ESD have been developed in the formal education systems of Austria and Slovenia [28–30]. ESD is increasingly achieving an interdisciplinary role in the curricula from kindergarten to the university level. SD goals are integrated into biology and other biology-related subjects at the lower and upper secondary school level in Slovenia and Austria.

From the curricula for biology in Slovenian lower secondary school (8th and 9th grade), SD is directly mentioned in the 9th grade in the context of biology and society and human impact on the environment [31]. Sustainability is also mentioned as one of the key goals in science subjects in the 6th and 7th grade of the lower secondary school [32]. In the Austrian curricula for biology and environmental education that we investigated, SD is mentioned in all of the four grades of lower secondary school in the context of humans and health, animals and plants, and ecology and environment [33]. In upper secondary school, SD is mentioned in the context of ecology and environment in 10th and 11th grade [34]. These above-mentioned concepts in biology education and ESD as well as the curricular demands require well-prepared, competent biology teachers. As far as we know, no previous research has investigated the understanding of sustainability and ESD among student teachers of biology in Slovenia and Austria. Slovenian researchers have already studied the SD understanding of preschool teachers [35] and among future primary school teachers [36]. Future primary school teachers (a little more than 40%) connect the term SD with the conservation of nature and other goods for future generations (Bruntland's definition of SD), and the most frequent description of ESD (27% of students) is teaching and informing pupils about environmental pollution or the importance of a clean environment. Torkar [37] studied students' views on the acceptability of their teachers' value-related statements about sustainability and climate change and results show that students expect their teachers to promote the concepts of SD.

International network ENSI (Environment and School Initiatives: www.ensi.org) has supported educational developments, environmental understanding, active approaches to teaching and learning in the fields of EE and ESD [38]. Austrian researchers report on the desired competences for ESD in teacher education [26], which were developed in a European cooperation project. There is an established school and university college network for promoting ESD in the formal education system in Austria (www.oekolog.at). Heinrich [39] looked at selected students' perspectives on SD in Austria within Ökolog and discovered that the school system produces tensions with daily and non-sustainable routines on the one hand and imperatives about sustainable behavior on the other. Rauch and Pfaffenwimmer [40] studied this network for innovation in ESD in the school system, and Ucsnik [41] did so from a political perspective. In international studies, we found more studies among student teachers and their understanding of sustainability and ESD. Summers et al. [42] analyzed subject matter knowledge of science teacher trainees regarding SD in the field of geography. Burmeister and Eilks [7] described the understanding of sustainability and ESD among German student teachers and trainee teachers of chemistry. The results show that student teachers and trainee teachers of chemistry show positive attitudes towards ESD in chemistry education but lack clear theory supported concepts about SD and ESD. The Ceulemans and Eilks article [43] about experienced Flemish chemistry teachers and their knowledge regarding sustainability was based on the same questionnaire. They report that experienced Flemish chemistry teachers have limited knowledge about SD and ESD, with the main sources of knowledge mentioned being the media or other personal information channels and which did not include school initiatives or further education programs. Palmberg et al. [44] researched teaching methods in biology education and sustainability education used to promote sustainability. The results indicate that the most commonly mentioned teaching methods were those in which students worked in groups and participated actively in learning processes. Maurer and Bogner [45] researched freshmen perception of environmental education and ESD. Results show that family, school (especially teachers), outreach and media are the most important sources of knowledge about EE and ESD.

Therefore, different studies recognized positive attitudes towards concepts of SD and ESD, but also the lack of theoretical knowledge and interconnections between different aspects of sustainability. A new political document, global action plan (GAP) [1], has also influenced ESD greatly in the past three years. Introduction of SDGs as a commonly shared political document also affects ESD. One way of dealing with this new situation was proposed by Kioupi and Voulvoulis [46], taking the sub-points of the SDGs as desired endpoints of developments and the different steps in education, which are necessary for making substantial progress. The three-pillar model of sustainability was pushed to the background in the discussion, maybe because it was too coarse for everyday politics. As a different approach, the 17 SDGs with many more sub-indicators take a different approach insofar as they are very concrete ways to reach each of the aims. Therefore, a great fragmentation of the overall topic of sustainability took place. For our study, we followed the critique of Kopnina [15], which states that there are anthropocentric and ecocentric motives in SD, and we therefore take these two positions as underlying thinking structures into consideration for our study.

2. Research Problem

The study aimed to identify knowledge and understanding about SD and ESD among Slovenian and Austrian pre-service biology teachers and compare the results between the two countries. We think a comparative view on two cohorts of biology teacher students in neighboring countries with different study programs can help to understand commonalities and differences in their knowledge and understanding. The research also focused on pre-service biology teachers' willingness to implement ESD in their future teaching. Moreover, the open answers were analyzed to look for the 17 SDGs and how they are being covered by the examples given.

3. Materials and Methods

The research was based on descriptive and causal non-experimental research methods. In this research, qualitative and quantitative methods were used, with quantifying methods in analysis being used to extract the essence of the qualitative answers. A questionnaire was used to collect data. Finally, a comparative approach helped us to elaborate conclusions.

3.1. Sample and Settings

Pre-service biology teachers from the University of Ljubljana and the University of Vienna participated in the research. The first sample was 60 students from the University of Ljubljana, Faculty of Education, Department of Biology, Chemistry and Home Economics. The second sample was 60 pre-service biology teachers from the University of Vienna, Centre for Teacher Education.

The study was conducted in May and June 2018. Students completed the anonymous paper-and-pencil questionnaire in 15 to 20 min. Firstly, the instructions and the general goals of the research were presented to the students. The sample was non-randomly chosen. From the University of Ljubljana, more than 80% of future biology teachers from the 3rd and 4th year of bachelor study and from the 1st year of a master's course were reached. At the University of Vienna, Centre for Teacher Education, the same number of future biology teachers represented less than 40% of future biology teaches from the 3rd and 4th year of a bachelor course and the expiring diploma course (this was the study program as it existed before the Bologna architecture of bachelor and master graduation was implemented in the academic year 2014/15).

Student teachers from Slovenia and Austria had different second subjects of study. Slovene students at the University of Ljubljana studying the two-subject teacher education program can select home economics or chemistry as the second subject. In the sample, 52% of students chose home economics and 48% chemistry. At the University of Vienna, the study program for biology teachers is called

Biology and Environmental Education. Students can choose it in combination with one of 27 other subjects. The combinations were with geography (15%), psychology and philosophy (15%), German language (13%), home economics (10%), Spanish language (8%), English language (7%), math (7%), sport (7%), chemistry (5%), French language (5%) and other subjects (8%).

3.2. Instrument

The questionnaire developed by Burmeister and Eilks [7] was used. The questionnaire was originally developed in the German language and for chemistry teachers. It was slightly modified (one question was added: "Write 15 words you associate with the term sustainability") in order to serve for pre-service biology teachers; moreover, it was translated into Slovenian. The questionnaire included open questions and closed questions with Likert-scale response options (four levels of agreement). In the first part of the questionnaire, pre-service teachers answered questions about socio-demographic information, study program and their level of education. In the second part, students answered four open questions. In the first question, students wrote 15 words they associated with the term "sustainability". In the next two questions, students had to describe and define SD and ESD. The last question in this set was about the appropriate school subject in which students could best deal with ESD. The third part of the questionnaire focused on more modern concepts of sustainability: where did participants hear about the most recent concepts (in universities, in the media, etc.) and where did participants hear about ESD.

3.3. Data Analysis

All data, as well as the written answers from the paper-pencil questionnaires, were digitized and translated from the Slovenian and German languages to English. First, the closed questions were analyzed using the statistical program IBM® SPSS® Statistics version 24 Data obtained from the questionnaire were processed on the level of descriptive and inferential interfering statistics, using the following statistical methods: *t*-test for Independent Samples and a chi-square test were used to compare the differences between Slovenian and Austrian students' knowledge and attitudes. The level of significance is 0.05; the corresponding confidence level is 95%. Secondly, open questions were coded. Coding is the interpretive process by which data are broken down analytically [47]. Deductive and inductive coding methods were used. The categories were taken from the Burmester and Eilks' study [7] and derived from SDGs literature [1] and finally from the material itself. Some categorizations were later redefined and added, based on data material and the theoretical framework. For other open questions, categorizations were created based on the data materials and literature review [15,18,48]. Therefore, we coarsely grouped the SDGs into those two categories, anthropomorphic and ecocentric, for the analysis. We are aware that this is only a rough categorization, because the mainly anthropocentric SDG 6 "clean water and sanitation", which was classified as anthropocentric, includes 6.6 "protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes", a clearly ecocentric goal. An example in reverse would be SDG 14, which was classified as ecocentric, but includes, for example, 14.4 according to which sustainable production of seafood is the indicator. Data (associations/words/sentences) with the same meaning were coded together. In our research, data that appeared less than three times per question were not coded. This represented 2% of all the answers. The frequency of the codes in each category was calculated as a percentage of the whole cohort in our study.

4. Results

The following chapters report the current situation on the matter among pre-service biology teachers in Slovenia and Austria. Results are divided into three main sections: SD and SDGs, sources of knowledge about SD and ESD. We compare the results of Slovenian and Austrian students in order to contribute to further development of teacher education programs.

4.1. Sustainable Development (SD) and SDGs

Data obtained from students' answers (n = 1104) to the word "sustainability" were coded into the categories presented in Figure 1. Students strongly linked the term sustainability to environmental aspects and rarely to economic and social aspects of the concept. They also emphasized the time issue in relation to sustainability, meaning mainly long-term thinking, the importance of education for sustainability or simply reproduced the Brundtland's definition of SD. Some responses are more frequently mentioned in one of the two cohorts (Appendix A, Table A1). The Slovenian students mentioned green chemistry, the European Union, home economics and students' competences. Meanwhile, the Austrian students gave answers such as ecological footprint, vegan and vegetarian lifestyle, environmentally friendly, environmental organizations, wildlife conservation, rainforest protection, local products, seasonal products, agriculture and genetically modified organisms, global thinking and First World vs. Third World countries. Differences in associations between the two cohorts could be associated with the curricula, the second subject of study, content knowledge or the differing influences of the mass media in each country.

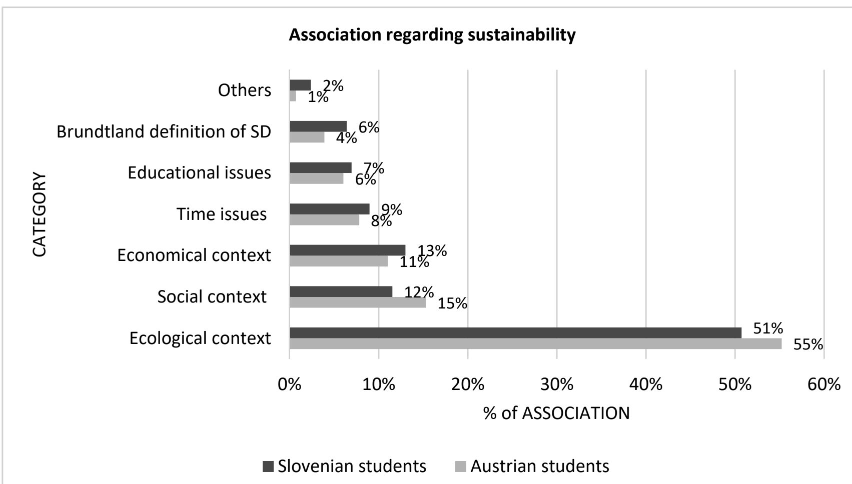

Figure 1. Slovenian (SI) and Austrian (A) students' associations (n = 1104) with the term "sustainability" in main categories.

In Table 1, only the most frequent associations are presented (<15 mentions) and classified according to Figure 2. A few associations (future, sustainable development,) are not classified because of generality. Maybe due to the study group (all are future biology teachers), the ecocentric considerations also have some representation in the analyzed data (Table 1).

Table 1. Categorization of students' answers.

Category	Students' Answers
Egocentrism	-
Anthropocentrism	consumption, ecolabels, education, energy conservation, future generations, health, pollution, renewable energy sources, recycling, values, waste management
In between ecocentrism and anthropocentrism	ecological footprint, environmental conservation, extinction of species, nature conservation, organic production, time, water conservation
Ecocentrism	biology, environment, nature

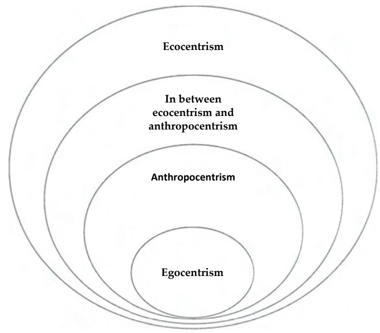

Figure 2. Categorization of students' answers.

Purely egocentric positions could not be found, but anthropocentrism was dominant. In this conception, the demands of people are a central motive and natural factors are only used as resources for human benefit regardless of their value or scarcity. In the transition towards ecocentrism, human needs are still arguments for acting but with more care about nature or natural resources. Finally, ecocentrism was also found, where nature and natural resources are protected for themselves, without a secondary function or effects for human benefits as justification.

Classification of students' associations with the term sustainability was made in order to illustrate which SDGs predominate in their understanding of the subject matter (Figure 3). These findings imply that students' perception of sustainability has not yet reached the full shift to being actively committed to the wellbeing of everyone, including the yet unborn, regardless of gender, economic status, race, religion, age, place of residence, species, etc. as well as the ecocentric positions. The concepts show mainly human-related thinking, with anthropocentric or transitional thinking (compare to results above).

Figure 3. Categorization of students' answers based on the OECD model [49].

4.2. Education for Sustainable Development (ESD)

Students were asked to explain how they would define/describe ESD. Figure 4 shows that students had an abstract understanding of ESD, linking it to environmental education and describing pedagogical approaches (students' answers are in Appendix A, Table A2).

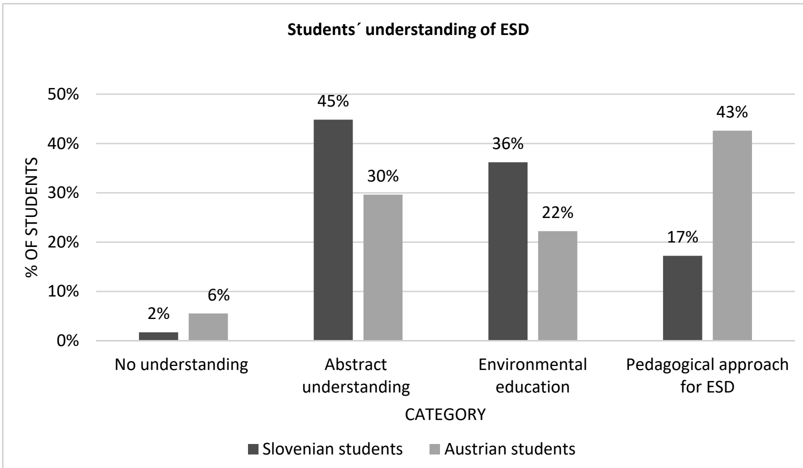

Figure 4. Slovenian and Austrian students' understanding of education for sustainable development (ESD).

Abstract understanding means that students mentioned few ideas about education in relation to sustainability, and those they did were very general and vague. Exemplary answers were, "Teaching about ESD, following the trends in education" or "To bring the so-called concepts closer to everyone, especially in school." Most of the Slovenian students had an abstract understanding. Second, most of the students from Slovenia defined ESD as environmental education. Meanwhile, most students from Austria defined it as a pedagogical approach for teaching about SD. Environmental education was described as learning about environmental protection and creating environmental awareness. Exemplary answers were, "Activating awareness and making people aware of problems that affect the future of our environment" or "Paying attention to environmental impact that is bad for the environment! Everyone can do something! Ecological Footprints Create awareness!" The pedagogical approach was defined as teaching methods that were recommended by ESD (e.g., lifelong learning, working with students' values and competencies, learning by case studies, etc.). Exemplary answers were, "Sustainable thinking exists on a holistic level and must include the environment in which the students live. Therefore, sustainability issues need to be communicated to students on a holistic level."

Students were asked which school subjects might be best for promoting ESD in school. We divided subjects into four main categories: natural science subjects (biology, chemistry and physics), interdisciplinary subjects (geography and home economics), humanities subjects (languages, philosophy and psychology, history) and others (sport, math).

Figure 5 shows that the participants acknowledged the significant role of natural science subjects. 60% of Slovenian students and 42% of Austrian students preferred natural science subjects. Biology was the most frequently mentioned subject in both cohorts. In the Slovenian cohort, the second most mentioned category was interdisciplinary subjects; in first place was home economics and in second place, geography. In the Austrian cohorts, the second most mentioned subjects were the humanities subjects, such as languages and psychology. Austrian students more often preferred humanities subjects compared to the Slovenian ones. This may be connected with their study choice (i.e., more than 70% of Austrian students had chosen an interdisciplinary subject or humanities subject as their second subject area). The majority of the participating students mentioned their second study subject as also appropriate for promoting ESD. Given that the second subject choices of the participating students were very diverse, it can be argued that ESD can be meaningfully implemented in very different school subjects and subject areas.

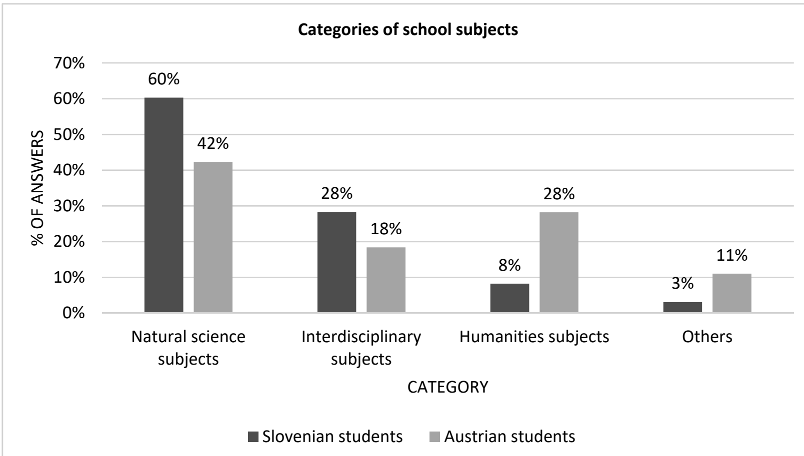

Figure 5. Categories of school subjects.

In Figure 6, it is shown that students from Slovenia and Austria significantly differ regarding implementation of ESD in upper secondary school (t = 2.450, df = 118, p = 0.016). In this regard, more Slovenian students (M = 3.70, SD = 0.619) want to implement ESD in upper secondary school than Austrian students (M = 3.25, SD = 0.895). No statistically significant difference was recorded between Slovenian and Austrian students' attitudes to implementing ESD in lower secondary school (t = 1.233, df = 118, p = 0.220) and their own class (t = 0.875, df = 118, p = 0.383). Students in both cohorts showed high levels of support for the importance of ESD in society in general as well as in biology education.

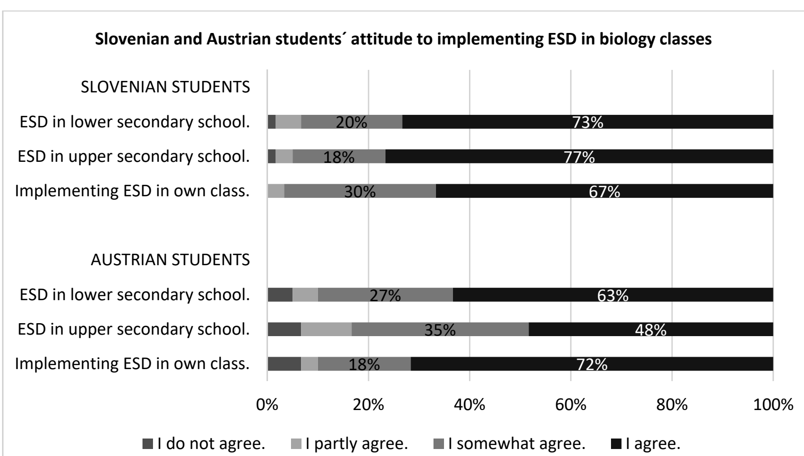

Figure 6. Slovenian and Austrian students' attitude to implementing ESD in biology classes.

4.3. Sources of Knowledge about ESD

Students were asked what their main source of knowledge regarding the three pillars of sustainability was: Brundtland's definition of sustainability or education for SD. Their responses reflected the influence of their biology study, second subject of study, educational study (general didactics, educational psychology, etc.) and other sources external to the university (such as mass media, social media, personal channels). Students' reflection on their sources of knowledge showed differences between Slovenian and Austrian students' answers (Figures 7 and 8). A Pearson Chi Square test was conducted to determine the significance of differences between Slovenian and Austrian students' sources of knowledge. More than half of the students from both cohorts heard about the three pillars of sustainability in their biology courses. A statistically significant difference between the cohorts from biology was found regarding their recall of Brundtland's definition ($\chi^2 = 10.096$, $df = 2$, $p = 0.006$) and ESD ($\chi^2 = 59.200$, $df = 2$, $p < 0.001$). Approximately 40% of Slovenian students and 60% of Austrian students remembered Brundtland's definition from their biology studies.

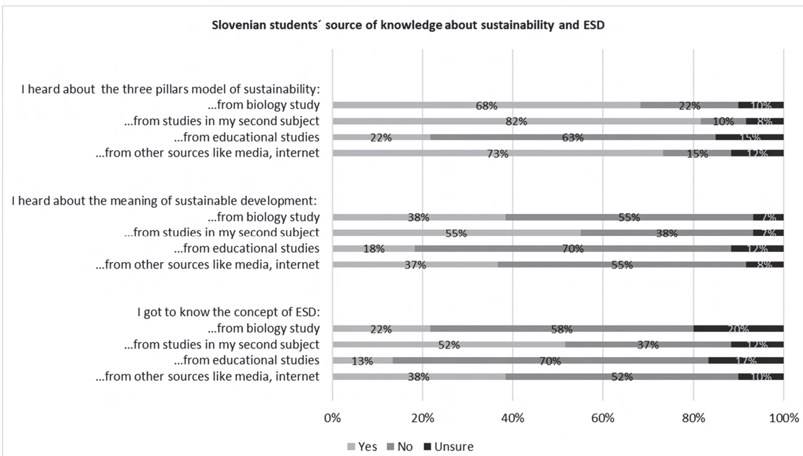

Figure 7. Slovenian students' source of knowledge about sustainability and ESD.

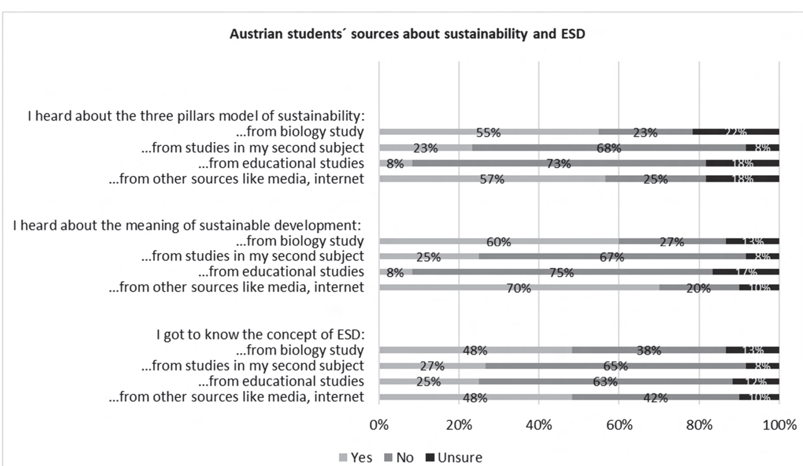

Figure 8. Austrian students' source of knowledge about sustainability and ESD.

In both cohorts, students have courses where they learn about sustainability. For example, pre-service biology and home economics teachers at the University of Ljubljana attend the compulsory subjects "Consumer Education" and "Population and Environment". They can also attend elective courses such as "Environment and SD". Austrian students can select among 27 subject areas; more than 70% of those are social science subjects. Some of them, such as geography, include many courses about sustainability issues; one of them is on the human use of natural resources and human-environment interactions. Pre-service biology teachers at the University of Vienna attend the compulsory subject "Cross-sectional Topics in Teaching Biology", one of the topics of which is "Education for Sustainable Development". Austrian students mentioned the biology subject as a main source of knowledge about ESD, while the second subject was emphasized more in the Slovene cohort. Other sources, such as mass media, have been found to be an influential channel of information for students.

5. Discussion and Conclusions

This study tried foremost to sketch the actual situation on the knowledge about SD and ESD of two biology teacher student cohorts in Slovenia and Austria. Through comparison and discussion of these results, ideas and recommendations for further improvement of teacher education for sustainable development were developed.

The majority of pre-service biology teachers in Slovenia and Austria similarly perceived SD in connection with ideas taken from the Brundtland's concept of SD, i.e., all three aspects of sustainability and/or inter-generational equitability. Overall, environmental aspects dominate within their perception and there is much less awareness of the complexity of sustainability issues and even less of social and intergenerational equity. Moreover, in grouping the associations about the SDGs in a continuum from egocentric towards ecocentric, we found that most of the thinking about sustainability is done from an anthropocentric position, which is in line with a critique of the concept addressed by Selby [16] stating that the perception of nature and the natural world are limited and decidedly anthropocentric in tone. This is not problematic per se but has to be reflected to enable changing perspectives, which is an important issue in ESD.

The findings are consistent with findings by Hagevik et al. [50] where they report that primary school science teachers have a lack of understanding of the interrelations between different approaches to sustainability. Summers et al. [42] reported quite similar results in their research among English student teachers of science and geography, and Uitto and Saloranta [51] found similar issues in understanding of sustainability dimensions among Finnish lower secondary school teachers. They report that science teachers, especially biology and geography teachers, considered the ecological aspect of sustainability more than the economic or social ones. This applies to the inclusion of other topics into sustainability discourses in addition to environmental issues.

A very important result of the present research, which should be further investigated and elaborated, is the impact of the second study area on pre-service biology teachers' understanding of SD and ESD. The second subject of study varies a great deal between Slovenian and Austrian students, and this may contribute to the differences in the conception of sustainability. Slovenian students can study biology with either home economics or chemistry. Most of the Austrian students combine biology studies with one of the social science subjects. The significant difference in teaching in upper secondary school (Austrian students mentioned this to a lesser degree) might have its basis in the second subject as well as in the curricula and the prescribed topics. Home economics and chemistry could be much more clearly linked to sustainability issues than the broad range of subjects in Austria. Nonetheless, Austrian students reported, like the Slovenian students, that biology studies are their first source of knowledge. From this result, much more inclusion of SD in all subjects of teacher education is needed.

When comparing our results to Burmeister and Eilks' study [7], it must be also pointed out that Slovene and Austrian students were more able to clearly outline the aims and pedagogy of ESD. In line with Ceulemans and Eilks' study [43], most of the answers occurred in the categories of abstract understanding and environmental education. This could be a consequence of the UNESCO decade; the previous studies were conducted during, while this study was carried out after that decade. Therefore, it is possible that they describe ESD as an approach to education, which includes an integrative and holistic view linking knowledge and action. There are no major differences between Slovenian and Austrian pre-service biology teachers. They mostly describe ESD as environmental education and environmental awareness. Only a few students possessed clear, theory-based concepts about SD and ESD. Pre-service biology teachers report learning about the concepts of SD and ESD from courses in biology studies, the second study subject, and from the mass media. For pre-service biology teachers in Slovenia, the second subject of study (chemistry or home economics) was a more important source of information about SD and ESD than for their colleagues from Austria. Pre-service biology teachers from Austria heard more about these concepts in the mass media.

Interestingly, the students mentioned educational studies only to a small degree. Since pedagogy is a central pillar in the studies of all student teachers of all subjects, we claim that ESD within educational studies should be strengthened in both countries. This presents the possibility that SD and ESD are not tied to a subject's logical structure and would make it a more cross-sectional topic in teacher education. ESD can be meaningfully implemented in very different school subjects. An interdisciplinary approach in the development of the curriculum of two-subject teachers would be advantageous because SD and ESD are cross-curricular topics that should be addressed in the natural sciences, social sciences and humanities alike. ESD teacher training must be improved and enriched; all sciences and disciplines should contribute with different perspectives to learning about and for SDGs.

Furthermore, greater emphasis should be given to research on the perception and practice of SD and ESD among teachers before and during service. These results can serve in the planning of longitudinal research that focuses on changes in students' SD and ESD understanding from the first to the last semester at university. This will provide a better insight into the impact of higher education programs on students' understanding of SD and ESD.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Slovenian (SI) and Austrian (A) students' associations about the term sustainability.

NO	Category	Number of Answers (*f SI* [1]/*A* [2]/*T* [3]) (*f % SI/A/T*)	Answers Included in the Category and Their Frequency *(f SI/A/T)*
1	**Ecological context**	*(f 277/311/588)* *(f % 51/55/53)*	*More than 30 mentions per associations* recycling (37/38/75), environmental conservation (34/35/69), environment (35/29/64), nature (16/24/40), nature conservation (21/15/37), renewable energy sources (22/12/34). *30–15 mentions per associations* waste management (15/7/22), pollution (12/8/20), ecolabel (3/12/15), ecological footprint (0/15/15), water conservation (9/6/15). *15–10 mentions per associations* biology (2/12/14), extinction of species (6/8/14), energy conservation (5/8/13), ecology (5/6/11), biodiversity (6/4/10), global warming (2/8/10). *10–5 mentions per associations* animals (7/2/9), fossil energy (5/4/9), plastic pollution (2/7/9), reuse (5/4/9), environmental problems (3/5/8), public transport (5/3/8), vegan and vegetarian (0/8/8), water pollution (3/5/8), ecological awareness (5/2/7), climate changing (2/5/7), plants (5/2/7), food self-sufficiency (2/4/6), Earth (5/1/6). *5–3 mentions per associations* CO_2 emissions (2/3/5), environmentally friendly (0/4/4), environmental organizations (0/4/4), green chemistry (4/0/4), rainforest protection (0/4/4), wildlife conservation (0/4/4).

Table A1. *Cont.*

NO	Category	Number of Answers (*f SI* [1]*/A* [2]*/T* [3]) (*f % SI/A/T*)	Answers Included in the Category and Their Frequency (*f SI/A/T*)
2	**Economical context**	(*f 63/86/149*) (*f % 12/15/13*)	*30–15 mentions per associations* consumption (9/8/17). *15–10 mentions per associations* organic production (7/8/15), economy (5/8/13), saving (8/3/11). *10–5 mentions per associations* local products (0/9/9), money (8/1/9), transport (4/5/9), seasonal products (0/8/8), organic products (5/2/7), energy consumption (4/3/7), globalization (2/5/7), corruption (1/5/6), Fair trade (2/4/6), industry (5/1/6), technology (2/4/6). *5–3 mentions per associations* agriculture (0/5/5), traffic (1/3/4), GMOs (0/4/4).
3	**Social context**	(*f 67/60/127*) (*f % 13/11/12*)	*More than 30 mentions per associations* future generations (17/18/35). *30–15 mentions per associations* health (10/7/17), values (6/11/16). *10–5 mentions per associations* society (3/4/7), human (4/2/6), politics (2/4/6), quality of life (6/0/6), European Union (2/3/5), responsibility (3/2/5), global thinking (0/5/5). *5–3 mentions per associations* convention (4/0/4), care (3/1/4), awareness (3/1/4), adaptability (4/0/4), first world vs. third world (0/3/3).
4	**Time issues**	(*f 49/44/93*) (*f % 9/8/8*)	*More than 30 mentions per associations* future (20/26/46). *30–15 mentions per associations* time (7/13/20). *15–10 mentions per associations* duration (7/5/12), long-lasting (11/0/11). *5–3 mentions per associations* time limited (4/0/4).
5	**Education issues**	(*f 38/34/72*) (*f % 7/6/7*)	*30–15 mentions per associations* education (15/9/24). *15–10 mentions per associations* education for sustainable development (3/8/11). *10–5 mentions per associations* science (2/7/9), knowledge (3/4/7), learning (2/4/6), teaching (3/2/5). *5–3 mentions per associations* chemistry (4/0/4), home economics (3/0/3), competences (3/0/3).
6	**Bruntland's definition of SD**	(*f 35/22/57*) (*f % 6/4/5*)	*30–15 mentions per associations* development that meets the needs of the present and future generations (paraphrasing Bruntland's definition) (17/12/29), sustainable development (18/10/28).
7	**Others**	(*f 13/4/17*) (*f % 2/1/2*)	*5–3 mentions per associations* balance (4/1/5), information (4/0/4), goal (1/3/4), solution (4/0/4).
	No answer	(*f 2/0/2*) (*f % 3/0/3*)	(2/0)
	Total answers	(*f 542/561/1104*) (*f % 49/51/100*)	

[1] Slovenian students. [2] Austrian students. [3] All together.

Table A2. Students' understanding of ESD.

NO	Category	Number of Answers (*f SI/A/T*) (*f % SI/A/T*)	Typical Answers
1	No understanding	(*f 1/3/4*) (*f % 2/6/4*)	"I do not know." "This term does not mean anything to me."
2	Abstract understanding	(*f 26/16/41*) (*f % 45/30/37*)	"Teaching about sustainability" "Build the awareness about sustainability" "The role of school is to educate for the future." "Lessons, so that students can also deal with the concept of sustainability." "To bring the so-called concepts closer to everyone, especially in school." "To pass on sustainable development in schools - as a task for teachers." "Teaching about ESD, following the trends in education." "Is the education and teaching towards sustainability" "Education creates an awareness of the necessity and feasibility of sustainability"

Table A2. *Cont.*

NO	Category	Number of Answers (*f SI/A/T*) (*f % SI/A/T*)	Typical Answers
3	Environmental education	(*f* 21/12/33) (*f % 36/22/30*)	"Environmental education for now and future generation." "Education of specialists for ecological research areas." "To make pupils aware that their behavior has a significant impact on the environment and to show them ways to behave sustainably." "Activating awareness and making people aware of problems that affect the future of our environment." "To show learners the sustainable use of resources, to motivate them to avoid garbage, e.g., to buy 'second hand' goods, to replace plastic bags with paper or fabric bags, etc. Making the consequences of 'waste' visible." "Paying attention to environmental influences that are bad for the environment! Everyone can do something! Ecological Footprint — Create awareness!" "To motivate students to treat the environment in an environmentally friendly and resource-conserving way." "To make students aware that we have only one planet Earth and that we need to use the given resources in the best possible way." "Newly developed technologies/inventions with protection of the environment in mind."
4	Pedagogical approach for ESD	(10/23/33) (*f % 17/43/30*)	"Lifelong learning" "Social and political development/education, rethinking and alternative actions." "Learning by case studies" "Offer seminars, workshops and in-depth discussions on the topic." "To teach students values and competences so that they can also become part of sustainable development." "Sustainable thinking lives on a holistic level and must include the world in which the students live. Therefore, sustainability issues need to be communicated to students on a holistic level." "To demonstrate cross-disciplinary awareness raising and options for action." "To raise awareness and knowledge among students at school, but also among the population through certain public events, in order to enable sustainable development and the help of people." "To educate students/children/people critically, to become critical citizens, to question everything. e.g., Is Amazon good? No. Many do not know what is behind it." "Education that enables learners to develop competences that are preserved throughout their lives, thus opening up opportunities in many areas of life." "To make future generations and/or adults aware of sustainability within the framework of further training and to show them the possibility of becoming active themselves."
	No answer	(*f 2/6/8*) (*f % 3/10/13*)	

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Article

Science Education for Sustainability: Strengthening Children's Science Engagement through Climate Change Learning and Action

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Abstract: Scientists and sustainability scholars continue to make urgent calls for rapid societal transformation to sustainability. Science education is a key venue for this transformation. In this manuscript, we argue that by positioning children as critical actors for sustainability in science education contexts, they may begin to reimagine what science means to them and to society. This multi-site, mixed-methods study examined how children's climate change learning and action influenced their science engagement along cognitive, affective, and behavioral dimensions. For fifteen weeks, ten- to twelve-year-olds participated in an after-school program that combined on-site interactive educational activities (e.g., greenhouse gas tag) with off-site digital photography (i.e., photovoice process), and culminated in youth-led climate action in family and community settings. Participants were 55 children (M = 11.1 years), the majority from groups underrepresented in science (52.7% girls; 43.6% youth of color; 61.8% low-income). Combined survey and focus group analyses showed that, after the program, science became more relevant to children's lives, and their attitudes towards science (i.e., in school, careers, and in society) improved significantly. Children explained that understanding the scientific and social dimensions of climate change expanded their views of science: Who does it, how, and why—that it is more than scientists inside laboratories. Perhaps most notably, the urgency of climate change solutions made science more interesting and important to children, and many reported greater confidence, participation, and achievement in school science. The vast majority of the children (88.5%) reported that the program helped them to like science more, and following the program, more than half (52.7%) aspired to a STEM career. Lastly, more than a third (37%) reported improved grades in school science, which many attributed to their program participation. Towards strengthening children's science engagement, the importance of climate change learning and action—particularly place-based, participatory, and action-focused pedagogies—are discussed.

Keywords: children; climate change education; participatory action research; photovoice; science attitudes; sustainability

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1. Introduction

Promoting children's science engagement is often framed as a means to address the world's most pressing problems over the decades to come [1]. For example, by shoring up children's science interest and achievement today, young people may go on to become leaders and agents of change in addressing the major scientific and technological challenges of tomorrow [2,3]. From a sustainability perspective, however, this is a problematic starting point. Current global crises—including climate change and biodiversity loss—demand rapid societal transformation towards social and ecological sustainability beginning now, not in the abstract future when today's children have reached adulthood [4]. Indeed, climate change is already wreaking havoc on a global scale in the form of more frequent and more intense extreme weather events and causing unprecedented environmental, societal, and economic disruption [5]. Reimagining the very purpose of science education—beyond honing the "potential" of young people to take decisive action in the future—has become a necessity.

Promoting children's science engagement is also commonly framed in the language of global dominance. A persistent narrative is that, by feeding the STEM "pipeline" today, the U.S. may remain competitive in the global marketplace of the future by remaining a leader in technology and innovation [6,7] This narrative is clear in federal STEM education reports and initiatives, which have for decades emphasized the connection between intensifying STEM education and regaining or maintaining the U.S. position on the frontiers of discovery [8–11]. Again, from a sustainability perspective, this worldview is misaligned with the kinds of societal transformation that are required to avert catastrophic ecological and societal consequences. Specifically, the modes of transformation required to adequately address sustainability challenges are those that force us to rethink, reinvent, and restructure our institutions (e.g., global economies, the scientific enterprise) in ways that shift away from the non-sustainable modes of interaction (e.g., competition, consumerism, individualism) that have delivered us into the present moment [12]. The prevailing neoliberal ideology of limitless growth and perpetual global competition has locked us onto the current crisis-bound trajectory [13,14]. Rethinking the very purpose of the STEM pipeline—beyond the language of global competition—is required for course correction.

In sum, there is a need for rapid societal transformation to sustainability in ways that substantively involve children and young people in climate change learning and action as well as a need to redefine science not as a "competitive edge" to safeguard against the threat of future subordination, but as a collaborative process to envision and enact sustainable futures today. Moreover, given the overwhelming nature of sustainability challenges, there is a need to encourage children's informed actions on sustainability topics in ways that promote their sustained interest and engagement. What if, rather than attempting to shore up children's science engagement today to ensure their status as capable actors in the future, we positioned children as critical actors for sustainability today as a means to simultaneously strengthen and reimagine children's science engagement for the well-being of people and planet?

This article is the third in a series of manuscripts exploring what constitutes, and how to facilitate, children's constructive climate change engagement through the lens of *Science, Camera, Action!*, an afterschool program that combined educational activities with digital photography to facilitate children's individual and collaborative climate change action [15,16]. The present article examines how children's agentic experiences in the program influenced their thoughts (i.e., perceptions of), feelings (i.e., attitudes toward), and behaviors (i.e., engagement) related to science as a school subject, potential career, and societal force. Findings suggest that children's climate change engagement can be a vehicle not only for supporting children's science interest, but for opening up pathways to a sustainable future by positioning children as agents of change today.

2. Literature Review

Today's most urgent challenges are increasingly those that call upon broad sectors of society to understand and practice sustainability. Sustainability is defined as "meeting the needs of the present without compromising the ability of future generations to meet their needs" [17], and is commonly acknowledged to have environmental, social, and economic dimensions. High-stakes sustainability challenges (e.g., climate change and biodiversity loss) are understood to be the consequence of decisions and actions by humans. The conclusion that human activity has had such a massive impact on the global environment has prompted scientists to refer to our current geological age as the Anthropocene—*anthropo* meaning "human" and -*cene* referring to a geological period [18]. To avert catastrophic ecological and societal consequences, what is needed now are broad shifts in how societies operate and how people live their everyday lives to reduce future threats to people and planet. In the sections that follow, we review the current state of sustainability science education in the U.S., and make the case that what is needed now are empowering and transformative pedagogies that encourage children's sustained interest and participation in sustainability action. Doing so, we argue, could redefine the very purpose of science education while strengthening children's science engagement as they reinterpret what science means to them and to society.

2.1. Science Education for a Sustainable Future

Science education must play a pivotal role in promoting sustainability, in particular through facilitating climate change learning and action. To date, however, climate change education is not a national priority in the U.S., and many science teachers report feeling unsupported in teaching about climate change in the classroom [8]. For example, many teachers feel under-prepared due to a lack of training on the subject, and there is no national policy mandate requiring that they include climate change topics in their curriculum [8,19]. Consequently, most teachers spend a limited amount of time teaching about climate change, if at all, and students sometimes receive "mixed messages" about the topic that do not align with accepted science [8,20]. Even still, demanding that teachers teach according to the scientific evidence may not be enough. Research critiquing the "information deficit" approach to climate change communication has shown that merely learning facts about a problem does not necessarily lead to action [21]. Moreover, young learners can feel overwhelmed by the issue, causing them to disengage [22]. What is needed, rather, are agency- and action-focused engagement strategies that empower learners to feel capable of addressing the issue in meaningful ways, particularly by working together in local settings [15,16,23].

Within and beyond the U.S., sustainability education has been criticized for being 'depoliticised' [24,25]. The Next Generation Science Standards (NGSS), which shape P-12 science education and teacher education in the U.S., position the environment as entirely separate from living organisms, humans in particular [26]. Further, sustainability challenges are often framed as having physical properties and primarily technological solutions, which overlooks their complex human elements (e.g., cultural, social, and political) [26–29]. In the U.S. classroom, for example, the siloed, discipline-based approach to teaching climate change as science tends to ignore the social dimensions of climate change, and the political dimension is likely to be omitted [30]. Further, the individualism that drives—and is perpetuated by—the competitive orientation of STEM education has been linked to a renunciation of pro-environmental thought and behavior, and the rejection of human behavior as a contributor to environmental problems [28]. Consequently, sustainability learning from the formal classroom is focused on individualistic learning of scientific facts rarely paired with opportunities for action, especially collaborative action within local communities.

Positioning young people as capable actors today could promote their science engagement and redefine the role of science in society—for promoting the stability of ecosystems that support human life on this planet. To accomplish this, we must rethink the nature of science education as well as the purpose of the "STEM pipeline". Students need opportunities to see how the science they learn matters to their lives and that of other living beings, to spread their knowledge across their networks of families and friends, and to transform the world around them as they engage collaboratively to translate their knowledge into action.

2.2. Sustainability Science Education for Children's Sociopolitical Inclusion

Explanations for the depoliticization of sustainability education can be found at multiple levels. Beyond the institutional level (e.g., policy, school), discussed earlier, a less apparent reason is the broader cultural issue of children's exclusion from the socio-political domain. Put differently, children are viewed not as "human beings", but rather as "human becomings" whose political participation and engagement is not yet considered an age-appropriate behavior [31]. Dominant constructions of childhood, including *children as innocent* and *children as becoming*, regard early life as fundamentally a period of preparation and socialization leading toward the full citizenship of adulthood [32].

Such images of young people in primarily Western societies, including the U.S., render adult-youth relations as inherently paternalistic, whereby young people are often neither consulted as competent citizens nor invited as capable actors with rights to participate in civil society [33]. Politics is an "adult-only" domain, and children are asked to learn and observe from society's margins [34]. This state of affairs inevitably leaves young people without a voice in important matters that impact their lives. More generally, the disjuncture between science and society has given rise to critical dialogue about promoting public engagement through "scientific citizenship" [35] and redefining the meaning of "science literacy" [36,37].

Given children's general lack of engagement with critical societal issues in the classroom, researchers have argued that the formal education system has failed to empower young people as citizens [38,39]. Relative to other societal issues, this accusation is especially severe in the context of sustainability education, given that today's children are the "future generations" whose health and well-being will be increasingly harmed as the stability of social and ecological systems continues to unravel [40]. Towards building sustainable futures in collaboration with youth—and towards developing empowering pedagogies in the process—inviting young people to learn about the scientific and social dimensions of sustainability is critical, as is encouraging their action [4,41].

2.3. Sustainability Science Education for Collaborative Action

To date, most classroom-based climate change learning is not paired with an action component of any kind [30]. When opportunities for action are incorporated into environmental programming, within and beyond the classroom, a key criticism is their emphasis on individual rather than collective action. Underscoring individualized behavior change implicitly frames sustainability challenges as a matter of personal responsibility rather than large-scale structural change, or the kinds of change that require communication, coordination, and collaboration [28,42]. This trend is rooted in neoliberal ideology, as the implied message is that sustainability challenges can be overcome through aggregated, freely taken individual actions (e.g., consumer choices) that need not involve coordinated efforts or policy-level decisions that may prompt state interference in the marketplace. A key distinction here is between individual actions taken *within* existing systems (i.e., behavior change) versus collaborative actions taken to *transform* existing systems (e.g., via collective action).

Of great significance for sustainability learning is that such a micro-level framing misrepresents the macro-level (i.e., policy, infrastructure) changes that must occur in order to adequately address sustainability challenges, thus hindering learners' ability to imagine alternative futures and the kinds of decisions and actions necessary to realize them. As noted by Hayward,

> … the psychological lens inadvertently narrows our vision of citizenship, reducing the potential of political agency to the aggregation of personal value choices, aspirations and psycho-social interactions with the natural world, obscuring the political potential of citizens collaborating and reasoning together to create alternative pathways and forms of public life. [42] (pp. 7–8)

In a sustainability education context, then, "fight(ing) post-political representations of the present" is a first step towards building a sustainable future [43] (p. 148).

To be transformative for learners, pedagogies must move beyond *instrumental* (i.e., prescriptive) modes and towards *emancipatory* engagement, as the former "stifles creativity, homogenises thinking, narrows choices and limits autonomous thinking and degrees of self-determination" [44] (p. 180). For example, engaging young people using participatory approaches—in which they are treated as decision-makers and collaborators throughout the process of learning and action—can cultivate a sense of agency that combats climate change anxiety and withdrawal [15,16,41]. Moreover, engaging young people in collaborative approaches to education and action have the potential to promote pro-environmental thoughts and behaviors that may lead to a more interdependent (rather than independent) ways of thinking and solving problems [28]. Positioning young people as radical visionaries and capable actors for sustainable transformation demands that educators cultivate their critical awareness and invite them to envision preferable futures, dialogue about and develop their own plans for action, and then act on them collaboratively within communities [15,16,45–48].

2.4. Science Engagement for Societal Transformation

Societal transformation to sustainability requires widespread shifts in modes of thinking, being, and interacting in the world as a way of preventing the worst effects of environmental degradation. Science education is critical to this transition. Not only do students need deep knowledge and understanding of disciplinary concepts and processes, they also must have extensive scientific literacy to use disciplinary knowledge to make evidence-based decisions that simultaneously consider environment, social, and economic dimensions. In the U.S., children and youth are most likely to learn about today's most urgent sustainability challenges, including climate change, in the science classroom. It is therefore imperative not only to support learners' fact-based understanding of sustainability challenges, but to cultivate their sustained interest and participation in addressing these challenges through empowering and transformative pedagogies that position children as critical actors for a sustainable future.

Transformative sustainability learning theory holds that profound changes in learners' thinking and action can result from pedagogical modes that encompass cognitive, affective, and behavioral engagement [49]. By cultivating critical awareness and collaborative action, sustainability science education can lead to increased pro-environmental knowledge, more positive attitudes, and greater behavioral engagement. What if, beyond transforming learners' perspectives on sustainability, such modes had the capacity to transform learners' perspectives on science? For example, could transformative sustainability pedagogies also influence science learning, attitudes, and behavioral engagement? Doing so could begin to reframe what science means to children and their understanding of the role of science in society. Using mixed-methods data collected through a collaborative, multi-site research study, the present research examines how children's climate change learning and action influenced their science interest and engagement. An earlier manuscript in this series [16] examined children's knowledge gains through the program, and showed that after the program, children knew more about climate change than they did before, and—on average—more than the average U.S. teenager or adult. The present research moves beyond climate change learning to examine how the program impacted children's cognitive, affective, and behavioral science engagement.

3. Program Description, Community Partner, Research Context

The present study was carried out in partnership with three Boys and Girls Club (BGC) units in the Mountain West Region of the U.S. The BGC is one of the longest-standing and largest community-based youth development organizations in the U.S., founded in 1860 and currently serving over 4 million youth annually across 4600 clubs in urban and rural areas, in public housing communities, and on Native lands [50]. As a non-profit organization funded by government grants as well as corporate donations and private philanthropy, the BGC offers out-of-school youth services year-round, with annual membership fees as low as five U.S. dollars [51]. As an approximation of members' socio-economic status, 61% of BGC youth receive free or reduced-price school lunches, for which eligibility is based on federal poverty guidelines. To achieve their mission to enable young people to "reach their full potential as productive, caring, responsible citizens", BGC provides positive and safe places to learn, be with friends, and develop relationships with caring adults. The BGC offers "unstructured, drop-in, recreational" activities [52] (p. 52) as well as structured programming aligned with its five focal areas: character/leadership, education/career, health/life skills, the arts, and sports/fitness/recreation [51].

Science, Camera, Action! (SCA) was an after-school program that aligned with BGC structured education-oriented programming by pairing climate change science education with photovoice methodology. Throughout the program, participants engaged with topics of global climate change (e.g., ecosystems; the greenhouse effect) and sustainable solutions (e.g., energy use; teamwork and leadership) as well as digital photography (i.e., photovoice), while being encouraged and assisted as they developed and implemented action plans in their families and communities. The present research aligned with regional BGC efforts to integrate "STEAM" programming into their clubs. STEAM is science, technology, engineering, and mathematics (STEM) combined with the arts.

Designed and implemented by the first author, SCA took place for one hour weekly over a period of 15 weeks in 2016 (January to May). Program content and activities were shaped by the 'Head, Hands, and Heart' model for sustainability education, which underscores the transformative potential of simultaneous cognitive, behavioral, and affective engagement [49]. Using these dimensions, key program components are described below.

3.1. Science: Cognitive Engagement

SCA's educational program content consisted of six activities integrating the scientific and social dimensions of climate change by demonstrating the relationships between Earth's changing climate, the functioning of local ecosystems, and the actions of individuals and communities. In the framework of 'Head, Hands, and Heart,' SCA's *Science* component encouraged children to think critically and systematically ("Head") about the problem of climate change (e.g., causes and consequences) and its many solutions through human action. Hands-on activities also introduced children to relevant STEM fields (e.g., ecology, climatology) and communicated how various STEM careers affect communities and improve lives.

3.2. Camera: Affective Enablement

Digital cameras were distributed at the conclusion of each of the six educational activities (one per week), and children were prompted to photograph images conveying their views of and connections with the week's topic. Three subsequent photovoice sessions, scheduled at regular intervals across the 15-week program, allowed children to reflect on what they learned and the connections represented in the images, to narrate their photos, and to discuss the connections between their own and others' photographs and experiences. The final photovoice session involved identifying common themes discussed during photovoice sessions and translating themes into action plans [15]. In this way, the photovoice methodology bridged educational activities with children's action projects [53].

Photovoice is typically employed as a participatory action research method but has also been adopted as an equity- and empowerment-oriented pedagogical technique [54]. When used as a pedagogical technique, photovoice has the potential to support learners to make personal connections to disciplinary content (e.g., [55]), to recognize the value of their subjective experiences, and empower them to conceptualize "new and reflective ways to perceive their own world and the science around them, as well as the potential to generate change in their own community" [56] (p. 340). Regardless of its application, photovoice is a powerful tool that promotes critical and reflexive group dialogue. Participants use photographs as representations of important issues to reflect on community strengths and concerns and collaborate to engage in action to advance social change [57]. In the framework of 'Head, Hands, and Heart,' the photovoice method encouraged participants to experience connection ("Heart") to their surroundings through deeper awareness of the interconnected nature of ecological systems and their own place in them. Moreover, photovoice was intended to facilitate children's ability to make connections between their own lives and SCA's science content, which served both to make seemingly distant and abstract science concepts feel more personally relevant and concrete.

3.3. Action: Behavioral Enactment

Youth-led action projects included: (1) *Family action plans*, crafted by each child in response to personalized carbon footprint feedback, emphasizing behavior change toward sustainability; and (2) *Community action projects*, planned and implemented by each group of children, towards advancing sustainability through community advocacy and action. In the framework of 'Head, Hands, and Heart', these family action plans and community action projects each enabled children to deeply and actively engage with the learned climate change concepts ("Hands") through everyday practices and innovative projects.

For each of the three community action projects, there are outcomes that continue to be felt nearly four years later. Children in a small politically conservative agricultural community prepared a speech that described climate change and some of its global and local impacts. This speech, presented to 60 officials and community members at a city council meeting, included an appeal for permission to begin a tree planting campaign. Not only were they given approval, when trees were planted in a local park, they were accompanied by a plaque commemorating the children's environmental stewardship [15]. Children attending at another site created an education- and action-oriented website designed to raise awareness about climate change and inspire action within their community and beyond. At a gallery event to launch the website, a selection of children's photographs—matted and mounted with titles and short narrative descriptions—were put on display to convey participants' personal connections to climate change topics. Children served as docents to over 100 visitors, discussing the meaning of photographs and directing them to the newly unveiled website to learn more. At the third SCA site, children revitalized an abandoned and overgrown garden on the BCG property. After preparing the garden site (e.g., weeding, turning the soil, spreading compost), children planted more than 100 fruit and vegetable plants. At harvest time, not only did BCG member families and the community have access to fresh local produce, the older children used the produce in educational healthy-eating activities for younger BCG members. In planning for the future, SCA participants created a BCG garden club for all ages to ensure the ongoing maintenance and use of the restored garden space [15]. Inspired by the SCA garden, at least four additional at-home gardens were established that summer by participants' families.

4. The Present Study

This mixed-methods study used surveys and focus groups to explore the impact of SCA on children's science engagement. Learner engagement is a multidimensional construct comprised of interrelated cognitive, affective, and behavioral dimensions [58,59]. For the purposes of this study, "science engagement" encompassed children's perceptions, attitudes, and behaviors related to science. Children's *perceptions* of science included how they thought about science (and scientists) before and after the program as well as their general regard for science. Children's *attitudes* towards science included the extent to which they viewed science as interesting, appealing, and important in school, career, and societal contexts. Conceptually, children's perceptions and attitudes differ in the sense that perceptions encompass mostly knowledge and beliefs, whereas attitudes entail evaluative judgments and feelings. Finally, the behavioral dimension of science engagement was explored through children's narratives of school-based science participation and achievement. The present study was guided by three research questions:

1. How did SCA influence children's perceptions of science?
2. How did children's attitudes towards science change following SCA?
3. How did children describe the influence of SCA on their behavioral engagement with science?

5. Methods

5.1. Participants

Participants were 55 children (52.7% girls; $n = 29$), ages 10 to 12 ($M = 11.1$), who attended one of the three partnering BGC units. For socio-demographic characteristics by research site, see Table 1. Participants were recruited during BGC site visits, through flyers, and via letters to parents. Participation in both SCA and this study were voluntary, and parental consent and youth assent were obtained for all participants. This study was approved by the university's institutional review board.

Table 1. Socio-demographic characteristics by research site.

		Town		City		Suburb		Total	
		(*n* = 9)		(*n* = 19)		(*n* = 27)		(*n* = 55)	
Characteristic		**Total**	**%**	**Total**	**%**	**Total**	**%**	**Total**	**%**
Gender	Girls	7	77.78	12	63.16	10	37.04	29	52.73
	Boys	2	22.22	7	36.84	17	62.96	26	47.27
Age	10	4	44.44	6	31.58	13	48.15	23	41.82
	11	1	11.11	3	15.79	7	25.93	11	20.00
	12	3	33.33	7	36.84	6	22.22	16	29.09
	13	1	11.11	3	15.79	1	3.70	5	9.09
Average Age		11.11 years		11.37 years		10.81 years		11.05 years	
School Grade	4	2	22.22	4	21.05	12	44.44	18	32.73
	5	2	22.22	7	36.84	6	22.22	15	27.27
	6	5	55.56	4	21.05	8	29.63	17	30.91
	7	0	0.00	4	21.05	1	3.70	5	9.09
Race/Ethnicity	White	3	33.33	9	47.37	19	70.37	31	56.36
	Hispanic/Latino	3	33.33	6	31.58	5	18.52	14	25.45
	Multiple Ethnicities	3	33.33	4	21.05	1	3.70	8	14.55
	Other	0	0.00	0	0.00	2	7.41	2	3.64
Free/Reduced Price Lunch		4	44.44	17	89.47	13	48.15	34	61.82
Single Parent Household		3	33.33	10	52.63	11	40.74	24	43.64

5.2. Data Sources and Analysis Procedures

To explore the impact of the program on children's science engagement, pre- and post-program surveys included scales measuring children's attitudes towards school science, attitudes towards the societal implications of science, and attitudes towards careers in science [60], as well as one prompt that asked children to report their most recent overall grade in science class. In the post-survey, children were asked to respond, yes or no, to whether SCA helped them to "like science more", and to write about why. Also in the post-survey, one open-ended item explored children's career aspirations.

Post-program focus groups were conducted to further explore this study's research questions, as well as to clarify and expand on survey findings [61,62]. Specifically, a portion of the focus group guide examined children's thoughts and feelings about science before and after their program participation. In total, 11 focus groups were conducted, averaging four to five children each and lasting an average of 38 min. Focus groups were audio-recorded, transcribed verbatim, edited for accuracy, and then entered into NVivo 10 software [63] for analysis following the process and rules of thematic analysis [64].

6. Results

Findings are organized into three sections aligning with this study's research questions. The first section explores the cognitive dimension of children's science engagement by examining children's perceptions of science (i.e., thoughts, beliefs) before and after the program, including how and why SCA helped them to like science more. The second section explores the primarily affective dimension of children's science engagement by examining differences in their attitudes towards science. Lastly, the third section examines the behavioral dimension of children's science engagement by assessing differences in children's school science achievement as well as their self-reported classroom behavior and career choices. Each section begins with quantitative survey results, followed by focus group findings, which serve to clarify and expand the survey results.

6.1. Children's Perceptions of Science

This study's first research question aimed to explore children's general *perceptions of science*, or "the way[s] in which [science] is regarded, understood, or interpreted" by children [65]. Perceptions of science encompassed general thoughts and beliefs about what science entails, who needs science and why, and the relevance of science to their own lives.

6.1.1. Survey Results

Recognizing that children's general perceptions of science may have influenced whether or not they participated in the program, one open-ended survey item asked children about their motivations for joining SCA. The most common response category was SCA's digital photography component (n = 23, 41.8%), followed closely by participants' fondness for science (n = 21; 38.2%). Other reasons for joining SCA included children's: Belief that SCA would be fun or interesting (n = 15; 27.3%), love for nature (n = 5; 9.1%), eagerness to learn (n = 5; 9.1%), interest in action (n = 3; 5.6%), and desire to be around friends (n = 3; 5.6%).

After the program, children were asked "Did *Science, Camera, Action!* help you to like science more?" and were then prompted to provide an open-ended explanation of their response. Separate thematic analyses [64] were conducted for "Yes" and "No" groups. Most children (n = 46; 88.5%) indicated that SCA did, in fact, have a positive impact on how they regard science. Among the remaining participants (n = 6; 11.5%), several described their love of science as a motivator for joining SCA. Consistent with pre-survey findings, these children perceived SCA to be a venue for engaging in science programming aligned with their existing interests. Of the children who reported that SCA helped them to like science more, most said it was because: (1) SCA was fun and they learned science could be fun; (2) they learned new things in SCA; and (3) they gained a better understanding of the applicability of science to real-world problems. A summary of thematic analyses of children's explanations, along with representative quotations, is provided in Table 2.

6.1.2. Focus Group Findings

Focus group discussions explored children's perceptions of science before and after the program. Before SCA, children's knowledge about, and images of, science and scientists ranged widely. While some valued science as important to know and relevant to their lives, others expressed less familiarity with science. Miguel described his limited exposure to science at school, and Theo reported not knowing a lot about science, while Gabe viewed it as extremely important to society.

> I don't do science at school.
>
> —Miguel (12)

> I don't know much about science.
>
> —Theo (10)

> Overall, I think science is a big help to the human race, and without it, we'd not be where we are now.
>
> —Gabe (12)

A few children explained that SCA expanded their perspectives on science, particularly which types of problems are dealt with by science and how scientists do their work. Some began with simplified impressions of science. To Theo, science was about "making rockets fly". Without having a class in school dedicated explicitly to science, Miguel perceived science to be "all about experiments". Olivia and Nora had similar impressions, sharing that before participating in SCA, they understood science to take place "indoors", such as in laboratories, and focus on "inside" things rather than the environment.

> I thought that science was just like an indoors thing … Like science experiments and stuff? I didn't know it had anything to do with the outdoors or anything … We don't need to mix stuff together to make science.
>
> —Olivia (12)

> I thought it was like … I didn't know that science was like outside things. I thought that was social studies. Social studies and science are two different things. It confused me at the beginning of the program, but I kind of get it now.
>
> —Nora (12)

By including nature in their concept of science, both Olivia and Nora gained more expansive views of what science entails. Olivia remarked that, "Science is actually all around the world". Nora said, "Science opened my mind … Science is a bigger topic than [I thought]". In the following exchange, three additional participants, all girls, agree that anyone can do science, and that science is much more than "chemicals and labs".

Riley (10): At first, I just thought *scientists* could do science and you had to be a scientist or grow up to be one. But now I know that you don't have to be a scientist, you can be anyone [and do science].
Aubrey (11): Like Riley said, it doesn't matter if someone is a scientist or not because, at the beginning, I thought, like Riley, "You have to be a scientist to know what you're doing". But I learned that if you have enough experience, you don't have to be a scientist … You can do all this stuff.
Charlotte (10): When I hear the word "science", I think of like chemicals and like labs, but then we're going through this program and it's not just chemicals and labs. It's the Earth and it can be—
Riley: Anything!
Charlotte: —It could be plants, the sky. It could be … *That* can be science.
Riley: Climate change … Inventions. It's so magical.

For some, science was interesting because scientific innovation was understood to have a significant impact on people's lives, including the need for science in addressing climate change.

> I think science makes Earth cool because, with science, people can change a lot of things, like how we do this or how we do that.
>
> —James (11)

> [SCA] changed how I felt because now I know that science is all around us and we can do science stuff to help the environment and to help the Earth be healthy and for us to be able to live without any of this bad stuff. Also, that sometimes science can do bad things to the Earth, but if you do more science then it will help fix it, too.
>
> —Olivia (12)

Eleven-year-old Grace explained that SCA enhanced her views of the importance of science. As she put it, "I used to think that science wasn't that important and now I know it's really important and that we can help". Not everyone's views of science changed. For example, 10-year-old Ben said he "[didn't] really think of science differently" because, as he put it, "scientific studies … can be about anything really".

Table 2. Thematic analysis of *Science, Camera, Action!* (SCA)'s impact on participants' perceptions of science.

Thematic Categories & Representative Quotations †	n ‡ (%)
The program helped me to like science more because . . .	**46 (88.46)**
SCA was fun and I learned that science can be fun. "Because I now know science can be FUN!"—Ali, 12 "Because we did fun activities." —Riley, 10	11 (21.15)
I learned new things in SCA. "I learned things I never knew!"—George, 11 "Because I had learned more about my subjects in school."—Lexi, 11	10 (19.23)
SCA helped me understand the applicability of science. "Yes, because science can help the world."—Gabe, 12 "Yes, because I like helping other people, and science helps people."—Maria, 10	9 (17.31)
It gave me ideas for action-taking to benefit the environment. "[SCA] helped me learn what I could do to help."—Tim, 11 "Because we can save our ecosystem."—Henry, 10	6 (11.54)
SCA made science more interesting. "Because I slept through class in school. Now I don"t."—Nora, 12 "[SCA] helped me like science more because I know there is a point to it."—Noah, 10	4 (7.69)
It built on my existing enjoyment of science. "It allowed me to do a lot of science."—Owen, 12 "Because it made me enjoy the science even more than I did."—Bill, 13	4 (7.69)
It helped me to understand science as a career. "Because it taught about science. Now I kind of want to be a scientist."—Carlos, 10 "Because it helps to know what to do if you become a scientist."—Olivia, 12	2 (3.85)
The program did not help me to like science more because . . .	**6 (11.54)**
I already liked science. "I liked science already too much to add to."—Abigail, 12 "SCA is great, but my love for science is too strong already."—Scarlett, 12	4 (7.69)
The program could be improved. "It didn"t really have interesting activities."—Ben, 10	1 (1.92)
I just don"t like science. "Not really. I still hate science!!"—Kelly, 12	1 (1.92)

Note: n = 52; † Categories appear in order of descending prevalence. Participant responses could be categorized into more than one response type; Bold headings indicate whether perception change occurred; Italics indicate thematic category, followed by direct quotes. ‡ n (%) = number of participant responses corresponding with each thematic category, followed by the percentage of full sample coverage.

6.2. Children's Attitudes Towards Science

This study's second research question explored how the program influenced children's attitudes towards science. Attitudes are simultaneously cognitive and affective in nature and refer to a "general evaluation of an object, person, group, issue, or concept on a dimension ranging from negative to positive" [66]. Attitudes are "feelings" towards the attitude object that are grounded in perceptions (see previous section) and lead to behavior (see next section).

6.2.1. Survey Results

A combined 15 items on the pre-post questionnaire asked children about their attitudes towards school science, science careers, and the societal implications of science. On all constructs, responses ranged from 1 ("Strongly Disagree") to 5 ("Strongly Agree"), with higher scores indicating more positive attitudes.

Attitudes Towards School Science

The "Attitudes Towards School Science" (ATSS) scale [60] consists of seven items (α_{pre} = 0.88; α_{post} = 0.82). Children's school science attitudes were very positive overall, though they were more positive following program participation (*M* = 4.41, *SD* = 0.54), compared to before (*M* = 4.25, *SD* = 0.70). A paired-samples *t*-test was conducted to assess changes in ATSS following program participation. Results of the *t*-test revealed that the mean increase of 0.16 in children's ATSS, 95% CI [0.02, 0.30], was statistically significant, t(52) = 2.22, *p* = 0.031, *d* = 0.30 (see Table 3).

Table 3. Summary of paired-samples *t*-tests for science attitudes and grades.

Variable	Pre	Post					95% CI		Cohen's
	M (SD)	*M (SD)*	*MD*	*t*	*df*	*p*	*LL*	*UL*	*d*
Attitudes Towards School Science	4.25 (0.70)	4.41 (0.54)	+0.16	2.22	52	0.031 *	0.01	0.30	0.30
Attitudes Towards Careers in Science	3.73 (0.78)	4.02 (0.71)	+0.29	2.96	51	0.005 **	0.09	0.49	0.41
Attitudes Towards Societal Implications of Science	4.12 (0.70)	4.33 (0.56)	+0.20	2.13	53	0.038 *	0.01	0.40	0.29
Science Grades	7.20 (2.48)	8.02 (2.10)	+0.81	2.19	53	0.033 *	0.07	1.56	0.30

Note: * $p < 0.05$; ** $p < 0.01$.

Attitudes Towards Science Careers

Five items assessed children's "Attitudes Towards Careers in Science" [60]. Internal consistency correlations were acceptable to good (α_{pre} = 0.73; α_{post} = 0.60). Children's attitudes towards science careers were more favorable after the program (*M* = 4.02, *SD* = 0.71), compared to before (*M* = 3.73, *SD* = 0.78). A paired-samples *t*-test was conducted to assess differences in children's attitudes towards science careers prior to and following their participation in the program. The mean increase of 0.29 in children's attitudes towards science careers, 95% CI [0.09, 0.49], was statistically significant, t(51) = 2.96, *p* = 0.005, *d* = 0.41. Differences in children's science attitudes by research site are summarized in Table 4.

Table 4. Summary of descriptive statistics for children's science engagement.

Variable (Number of Items)	Town (*n* = 9)			City (*n* = 19)			Suburb (*n* = 27)		
	Pre-Survey *M (SD)*	Post-Survey *M (SD)*	*MD*	Pre-Survey *M (SD)*	Post-Survey *M (SD)*	*MD*	Pre-Survey *M (SD)*	Post-Survey *M (SD)*	*MD*
Attitudes Towards School Science (7) [a]	4.08 (0.76)	4.40 (0.40)	+0.32	4.21 (0.72)	4.29 (0.80)	+0.08	4.29 (0.79)	4.43 (0.53)	+0.14
Attitudes Towards Societal Implications of Science (3) [a]	4.33 (0.76)	4.30 (0.72)	−0.04	4.11 (0.75)	4.37 (0.59)	+0.26	4.01 (0.69)	4.33 (0.51)	+0.32
Attitudes Towards Careers in Science (5) [a]	3.87 (0.85)	4.00 (0.81)	+0.13	3.47 (0.86)	3.74 (0.71)	+0.26	3.85 (0.68)	4.12 (0.84)	+0.27
Science Grades (1) [b]	3.56 (0.53)	3.78 (0.44)	+0.22	2.89 (1.24)	3.50 (0.71)	+0.61	3.30 (0.72)	3.63 (0.74)	+0.33
Science Career Aspirations (1, post only) [c]		66.67 (*n* = 6)			42.11 (*n* = 8)			55.56 (*n* = 15)	.

Note: [a] Response range: 1–5, where higher scores indicate more positive attitudes; [b] Response range: 0–4, where scores are coded as grade point averages (0 = F; 4 = A); [c] Response range: 0–100% of participants within each group aspiring to a science career.

Attitudes Towards Societal Implications of Science

Three items assessed children's "Attitudes Towards Societal Implications of Science" [60]. Internal consistency correlations were high (α_{pre} = 0.79; α_{post} = 0.81. Children's attitudes in this domain were very positive overall, though they were more positive following program participation (*M* = 4.33, *SD* = 0.56), compared to before (*M* = 4.12, *SD* = 0.70). A paired-samples *t*-test was conducted to assess pre- and post-program differences in children's attitudes towards the societal implications of science. The mean increase of 0.21 in children's attitudes towards the societal implications of science, 95% CI [0.01, 0.40], was statistically significant, t(53) = 2.13, *p* = 0.038, *d* = 0.29.

6.2.2. Focus Group Findings

A portion of the focus group guide explored children's generalized attitudes towards science. When asked about their feelings towards science, several children said they viewed science favorably prior to their participation in SCA. For example, 10-year-old Noah said he "always liked" science, while 13-year-old Matthew said he "already liked science". More commonly, children reported that SCA enhanced their interest in, and enjoyment of science. As 10-year-old Lexi put it, "I kind of did not like science before. I do like it now". Girls and boys across ethnicities, age groups, and research sites explained that SCA either deepened their appreciation or changed their attitudes in favor of science. This came about through their enjoyment of SCA activities, viewing science as more accessible, interesting, or valuable.

> I didn't really like science until I actually started to learn more about [it in] the program.
>
> —Bryan (10)

> What I feel about science now is I like it more than I did before.
>
> —Michael (11)

> I enjoy science a lot now. It's one of my favorite subjects now actually.
>
> —Sydney (12)

> I mean, I liked science but I didn't like science *too* much. I didn't think it was very interesting. I can tell you this much, I like my Geo classes a lot more!
>
> —Ali (12)

Some children suggested that SCA captured their interest and held their attention more than school science sometimes did.

> At my school, if there's a topic that we're talking about that doesn't interest me ... science is not actually fun for me. But [SCA] made me care a lot about global warming.
>
> —Athena (10)

> I've been learning about [climate change] in class, but I wasn't paying attention much ... So now I really know what it means and ... how it is.
>
> —Luke (11)

When asked to explain whether his views on science had changed overall, Luke added, "Well, I thought that science was kind of boring and you didn't really have to do it. But when I came here and I knew that it was about climate change and how the world is, I thought of it differently". Climate change made science relevant. Grace expressed a similar view, saying, "I didn't really like [science] before, and I wasn't interested in it. But now I know that you really need to know about it and you can't just ignore the changes happening in the world". For Arie, science went from "not really that interesting" to absolutely essential. As she explained, "Before [SCA], I had thought of [science] as just something to do and something that's not really that interesting. But now ... I'd rather do science now than pretty much anything else".

6.3. Children's Behavioral Engagement with Science

This study's final research question explored how SCA influenced children's science-relevant behaviors. Children's perceptions of, and attitudes towards, science can lead to changes in behavior and behavioral intentions [67]. In this study, children's behavioral engagement with science before and after the program was assessed in the survey and focus group by asking children about their academic performance in school science and their career goals.

6.3.1. Survey Results

To assess the behavioral dimension of children's science engagement, children were also to report their most recent letter grade in science class before the program (i.e., from the fall term) and after the program (i.e., from the spring term). The pre-survey was administered in January, closely following winter break, and the post-survey was administered in May, closely following the end of the school year. In the post-survey, children were also asked about their career aspirations.

Science Grades

For exploratory purposes, children's grades in science class, measured before and after the program, were treated as a proxy measure of children's behavioral science engagement. On the pre-survey, most children reported receiving A's (n = 24, 44.4%) and Bs (n = 22, 40.7%) in science class the previous fall. In the post-survey, 70.4% (n = 38) reported receiving an A grade in science class in the spring term, while 22.2% (n = 12) reported receiving a B. Of the 54 children who completed these items, 20 (37.0%) received improved science grades after the program compared to before, seven (13.0%) received a lower grade, and 27 (50.0%) received the same grade. Scores ranging from 0 (F) to 10 (A+) were subjected to a dependent samples t-test to determine pre- and post-program differences. Results of the t-test revealed that children's science grades improved from the fall term (M = 7.20, SD = 2.48) to the spring term (M = 8.02, SD = 2.10), a statistically significant mean increase of 0.82, 95% CI [0.07, 1.56], t(53) = 2.19, p = 0.033, d = 0.30.

Career Choice

In the post-survey, one open-ended item asked children about their career aspirations. The 55 responses were categorized into major career fields. More than half (52.73%) aspired to a STEM career (see Figure 1). These included careers in physical science (e.g., physicist), earth science (e.g., geologist), space science (e.g., astronomer), and life science (e.g., biologist) careers, as well as applied science careers in engineering, computer science, and medicine.

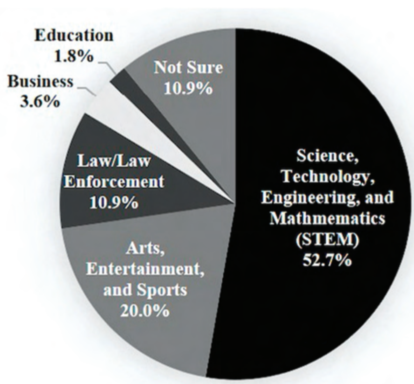

Figure 1. Children's career aspirations by major career category.

6.3.2. Focus Group Results

During focus groups, several children reported that their participation in SCA had a positive impact on their achievement in school science. For some, doing better in school was attributed to their enjoyment of SCA. Ten-year-old Lexi said, "I liked ... learning all this stuff and plus I'm ahead in my class". Others attributed their improved school science performance to an enhanced interest in science, which they gained through SCA.

> [After SCA], I enjoy science *so* much more. Before, I thought science was just one of those things we had to learn and so I wasn't really interested. I did what I had to do to get a good grade. Before I started *Science, Camera, Action!*, I started falling behind in science, but after I started the program it helped me catch up [in school].
>
> —Sydney (12)

A number of children reported that SCA content mapped onto current school science topics. As Scarlett, age 12, explained, "[SCA] helped me out in class because we're kind of learning about the same things at the same times and so I could put more input into my science class because I knew more from here". Children across the age spectrum identified connections between SCA and school science, which made them feel knowledgeable and better able to learn new things in the classroom.

> It helped me learn what we're actually doing in school.
>
> —Daniel (10)

> In science, sometimes I don't know the answers, and now I know a lot more answers about carbon dioxide and that stuff.
>
> —Jack (11)

> With all that ... I've learned here, I feel like it's kind of helped me with my learning ... Because the time that I'm here ... I had time to really understand what I need to in science or social studies.
>
> —Wayne (12)

Several children described feeling more confident in science, which made them more likely to actively participate in science class. As Wayne continued, "I feel like it was easier for me to open up [and say] what I learned [here] at my school and stuff". When asked whether SCA influenced her self-confidence, 10-year-old Peyton said, "When we read books [in science class], they would ask us questions on the side of the books. And I was usually the one that would be most confident to raise my hand and tell them what I know about". After participating in SCA, Scarlett and Arie also felt more confident communicating about science.

> Every year ... we do the school science fair. SCA gave me more ideas for the science fair and gave me more confidence in myself so I could present it to everyone.
>
> —Arie (10)

> I learned how to better communicate what I meant ... because, when we were learning about [climate change] in school, I didn't know to say certain terms. Or how to [choose] my words so that it made sense or got my point clear. I felt like this program really helped me realize how to tell better on what I learned and what I know. How to put that into real life.
>
> —Scarlett (12)

A couple of children explained that their increased interest and confidence in science, gained through SCA, helped them to feel better on school science tests and standardized tests.

> Well, I wasn't really into science [before the program]. But after I got more into science, it actually made me feel better on my tests when I had to take tests.
>
> —Bryan (10)

> I thought [the program] did help because ... we had TCAP [the Transitional Colorado Assessment Program test], and doing this program actually helped me feel more confident on one of the tests. Some people were like, "I don't want to take the test because I don't know a lot about science". But I was ... excited because I know about it.
>
> —Peyton (10)

Others reported getting better grades in science. For Cristy, it was a matter of paying more attention in science class. Jimmy thought joining SCA may help boost his science grades. After the program, he said his science performance had improved a full letter grade.

> Cristy (11): I pay attention to class now. I'm getting an A.
>
> Ali (12): I'm getting a B.
>
> Jimmy (10): Before the program, I would usually get C-pluses or C-minuses and now I'm getting either B-pluses or A-minuses.

7. Discussion

The present study explored whether and how SCA—an after-school program focused on climate change learning and action—impacted children's science engagement along cognitive, affective, and behavioral dimensions. SCA combined hands-on climate change educational activities with digital photography (i.e., photovoice methodology) to simultaneously explore and expand children's role as change agents for sustainability in both family and community contexts. Prior to SCA, children's survey-based attitudes towards science were, on average, generally positive. For more than a third of participants, joining SCA was at least partially due to their fondness for science. However, not everyone favored science prior to the program. Although few articulated an explicit dislike for science during focus groups, many discussed their previous indifference or narrow definitions of science. Some children described inattention and poor performance in school science, while others said they completed class requirements satisfactorily, but with little enthusiasm. Following SCA, children's perceptions of science had expanded beyond indoor laboratory-based science to include the outdoors and their everyday environments. Through SCA, science became relevant to their lives, and their attitudes towards science (i.e., in school, careers, and in society) improved significantly. In short, climate change made science interesting and important. The vast majority of the children reported that SCA helped them to like science more, and following the program, more than half aspired to a STEM career. In sum, climate change learning and action became an avenue towards children's increased science engagement.

7.1. Strengthening Children's Science Engagement through Climate Change Learning and Real-World Action

One reason for SCA's positive impact on children's science engagement—even among those who already liked science—could be that the program's content and format diverged from traditional school science in important ways. In particular, SCA emphasized the connections between science and everyday life through place-based, participatory, and action-focused programming. In formal classroom settings, science topics can often be perceived as disconnected from real-world issues [68]. Learning about socio-scientific issues such as climate change, however, can crystallize the connection between what children are learning in the science classroom and their own everyday lived realities [39]. After teaching about atmospheric processes (i.e., the greenhouse effect), SCA brought climate change "down to Earth" through activities focused on people, plants, and animals. Further, SCA brought science content into children's everyday environments through place-based content focused on local ecosystem impacts. A previous article in this series showed that not only did children demonstrate significant knowledge gains through their participation in SCA, they also felt motivated to act on this knowledge and doing so strengthened children's sense of agency to make a difference on climate change [16]. School-based science curriculum is not often associated with action-taking on learned concepts, particularly in U.S. science classrooms [67,68]. An exclusive focus on the cognitive dimensions of science learning without connecting science topics to students' civic engagement, "isolates scientific knowledge and practices from individuals' lived experiences and the immediacy of community life" [69] (pp. 287–288). These researchers have advanced the concept of educated action in science, which "requires both knowing and doing . . . the capacity to leverage scientific knowledge and practices to inform actions(s) taken" (p. 287). Beyond SCA's place-based content, it was likely this pairing of knowing with doing that strengthened children's science engagement. They understood how climate change—and thereby science—was important and relevant to their own everyday lives and behaviors.

Implementing programming like SCA in the formal science classroom, however, is impeded by a number of factors. Some students in this study shared that they did not have school science. While many elementary-aged students receive the recommended 30 min per day [70], infrequent classroom science instruction is not uncommon. This is particularly true in schools not meeting benchmarks on high stakes tests, where instructional time has been shifted away from science in favor of literacy and mathematics [71–73]. Further, science teachers who want to implement projects or link learning to action may face an uphill battle. Teachers face demands to teach in certain ways, to cover certain topics, and—implicitly or explicitly—are discouraged from slowing down to dive deeply into topics or do open-ended projects. Indeed, "implementing project-based science curriculum is challenging in the context of standardized tests, 45-min class periods, large class sizes, and the emphasis on individual grades" [74] (p. 455).

The SCA program—having taken place outside the formal classroom—undoubtedly benefited from increased flexibility on these dimensions, which have been associated with successful science learning outcomes in informal contexts [75–77]. At present, school science policies and practices emphasize the role of education in preparing "future citizens", rather than creating opportunities for children's educated action now. This focus on preparation (e.g., via testing) is a barrier to children's full science engagement. While informal learning spaces that can offer children empowering and constructive ways to learn about climate change are paramount [15], informal and after-school programming alone is not the answer. To adequately address sustainability challenges and to make engaged science the norm, there is a need for larger-scale policy change focused on school reform recognizing children's capacities to be change agents in their communities. Such policies would support teachers in evidence-based instruction and real-world action, making science relevant to the lived realities of learners and their families. Deliberately inviting young people to think about and act on critical societal and global issues—beyond advancing children's sociopolitical inclusion—is a first step towards repositioning science education at the heart of necessary societal transformation to sustainability.

7.2. Promoting Diversity in Science through Climate Change Learning and Collaborative Action

Findings of the present study suggest that, through their participation in SCA, children came to view science as more interesting, accessible, and important. For many, this was due to an expanded view of the scope of science inquiry, who can be a scientist, and how science connects to their lives. Perspectives shifted beyond stereotypical views of scientists in the laboratory or building rockets to scientists whose work takes place in the outdoors and deals with environmental aspects of everyday life. After SCA, some children saw science all around them. This enlarged view of science made it fascinating, and its role in understanding and addressing climate change made it valuable. Although connections between science attitudes and attitudes towards climate change are under-studied, they have been shown to have weak but positive correlations [60]. In this study, knowing about climate change made science important, a finding that resonates with previous studies documenting the expanded significance of science topics when implications are considered beyond the confines of the classroom [39,78]. Viewing science as more approachable and appealing translated into youths' increased confidence and performance in school science. They reported being more engaged. For some children, greater self-confidence and enthusiasm made active participation in science class less effortful, and science tests less daunting. A few participants attributed better grades in science to their participation in SCA, while surveys showed significantly improved science grades by participants overall. Most children left the program aspiring to a science career of some kind, representing a variety of subfields.

These findings are encouraging given the socio-demographic composition of children in SCA, many of whom were from groups underrepresented in science. SCA's participants were mostly girls (52%), nearly half youth of color (44%), and a majority were from low-income households (61%). Issues of equity, access, identity, and confidence still impede the science engagement of underrepresented groups such as girls, racial and ethnic minorities, and economically disadvantaged students [79–81]. From early adolescence, girls express less interest in math and science careers compared to boys [82], with gender differences in STEM self-confidence beginning to emerge in middle school [83]. This makes upper elementary and early middle school, the age of SCA participants, a critical stage for girls' science interest and confidence. Youth of color, despite showing increased interest in science at earlier educational stages, continue to be underrepresented in higher education and careers [84]. Finally, low-income youth often have less access to science enrichment opportunities and after-school activities, and are more likely to attend schools with insufficient resources to support science learning [80,85]. To date, most research on diversifying the sciences looks at marginalized groups based on single identities (e.g., girls or youth of color). It is worth noting that many SCA participants had multiple marginalized identities (e.g., low-income girls of color) and face a combination of barriers to their interest and pursuit of science higher education and careers [86]. In this context, climate change learning and action became an avenue through which to markedly strengthen their overall science engagement.

It is possible that a critical element supporting children's science engagement, in this study, was its collaborative action component. Research on goal congruity in STEM education contends that students' educational and career choices are affected by how much they perceive a career path to align (or dis-align) with their life goals [87]. For example, to the extent that STEM careers are viewed as fulfilling communal goals—of working alongside or helping other people—they are more appealing to girls and many first-generation college students whose socialization emphasizes a communal orientation [87,88]. Similarly, altruistic goals are associated with STEM career interest by underrepresented minority students [85]. Similarly in SCA, children's recognition that science was relevant to their everyday lives supported their overall engagement in the program, and their full-cycle participation provided opportunities for individual and collaborative climate change action, which further emphasized the connections between science learning and addressing real-world challenges. In particular, SCA's collaborative action component was framed in terms of community service and action, which may have contributed to the shift in children's perceptions about the importance of science in society.

To date, when climate change education is paired with an action component, most often it is focused on individual behavior change rather than collaborative sustainability action [42]. In action-focused climate change programming, offering children opportunities to engage in collaborative community-focused action is important because—compared to promoting individual behavior change, which is often framed in terms of personal responsibility—it more accurately frames climate change as a complex, global issue requiring collective, coordinated action region by region. As this study suggests, collaborative action may also play a critical role in helping children from groups underrepresented in science to reimagine science as fitting with their other-oriented goals (i.e., to be communal, altruistic). Through climate change learning and informed action, children were able to see how science permeates every aspect of their daily experience, and many were able to view themselves as future scientists. Inviting children to participate as co-researchers and collaborators in making sense of and acting on sustainability challenges is an additional step towards their full sociopolitical inclusion. Importantly, through SCA, climate change became a portal through which children were able to rethink who can do science, how, and why.

7.3. Transforming Science Education through Climate Change Learning and Action

So far, we have discussed the transformative potential of action-focused climate change programming in terms of its capacity to deepen students' engagement with science. Resonating with previous research [39,68], this study's results show that when children perceive science as relevant to their lives and connected to social change action, its value and attraction grow. As mentioned, this may be especially appealing to children from backgrounds underrepresented in science, an effect which itself could transform the discipline [85,87]. Beyond transforming children's views of science, on a much broader level, action-focused climate change learning has the potential to transform science education in terms of its role in society. Rather than focusing on the STEM "pipeline" and children's "potential" futures, science education could be a societal force for positive social change and building cultures of sustainability today. Doing so would mean making visible the inherent interconnectedness across disciplinary 'subjects' in addressing sustainability challenges and emphasizing children's participatory action in addressing sustainability challenges in local settings.

Sustainability has long been a key site of disciplinary re-integration [12]. Findings of the present study suggest that action-oriented climate change learning can help learners draw linkages across fields framed in the classroom as disparate or disconnected, helping them to better understand and act on sustainability challenges in meaningful ways. Despite having been enculturated into the world of disciplinary silos in the form of school subjects, through SCA, children made connections between, for example, science and social studies through the lens of climate change. Advocates and scholars of scientific literacy have argued for years that traditional disciplinary boundaries are not only arbitrary, but also impede deep understanding of complex socioscientific issues like those related to sustainability [36,37,89]. That SCA participants were seeing the socio-ecological complexity of climate change and the interconnectedness between the sciences and other fields was a key strength of the program [23,24]. Adequately addressing sustainability challenges will require the participation of diverse fields, and appreciating these connections is critical [90,91]. Towards positioning children as agents of change, action-oriented climate change learning can prompt children's awareness of the inseparability of school subjects when focusing on complex environmental problems.

Finally, by taking action on learned concepts, children were reframing the meaning of science education for themselves as well as their families and communities. The SCA program allowed children to engage with science on their own terms through voluntary participation, digital photography, and youth-designed action projects. Importantly, children designed and implemented their own community-focused sustainability projects. Following the program, children reported that they had fun during SCA activities, which made science enjoyable and approachable, rather than boring or intimidating. According to Riemer and colleagues [92], the most successful non-formal youth-based environmental engagement programs tend to provide youth the opportunity to "define the context of their participation" and "act as co-creators or partners" in projects that bring about meaningful change to the youth as individuals or to the communities to which they belong (p. 570).

To their families and communities who were impacted by children's projects, SCA represented a "science program" that had a tangible impact beyond children's learning. By working to address sustainability challenges in locally meaningful ways, SCA became an example of *educated action in science* [69]; children's science knowledge opened up the possibility for their informed action. Rather than framing science education as a pathway to a "competitive edge" grounded in neoliberal logic, this approach to learning positions science education at the center of a broader, more inclusive and collaborative process of cultural transformation to sustainability—one that opens up the possibility of supporting human life and the health of ecosystems amidst unprecedented environmental degradation [5].

8. Limitations

Findings of the present study should be viewed within the context of its limitations. First, this study's non-experimental research design calls into question whether the effects attributed to SCA were, in actuality, due to the influence of the program. A strength of this study's mixed-methods design, however, was that qualitative analyses of focus group discussions clarified the diverse ways that children's perceptual, attitude, and behavior change were directly tied to program content.

Another limitation is this study's small sample size, which precludes robust analyses of effects by sub-group (e.g., demographic characteristics). A further limitation is that, because children self-selected into the program, most already held positive attitudes towards science. As stated previously, children's enjoyment of science was a main reason for enrolling in the program. Children's voluntary participation was a strength of the program, and future research might explore whether children with less positive views of science show similar gains in science engagement. Relatedly, children's preexisting positive views of science may be a reason for their high science grades both before and after the program. As with all findings in this non-experimental study, it is not possible to say with confidence that changes over time are attributable to children's program participation. In future similar studies, data that could otherwise be obtained from primary sources (e.g., report cards) should be sought. Further, more comprehensive documentation of the content of children's school-based learning should be both acquired and accounted for in analyses.

9. Conclusions

As climate change continues to destabilize ecosystems, economies, and societies around the globe, climate scientists and sustainability scholars have continued to make urgent calls, as they have for decades, for rapid societal transformation to sustainability. In this paper, we argue that science education is a key venue for this transformation. Specifically, science education could address the need to substantively involve children and young people in climate change learning and action towards redefining science not as a pathway towards endless competition and domination, but as a collaborative process to envision and enact sustainable futures today. Reimagining science, we argue, begins with forms of engagement that allow children to think about science—and science education—in new ways. The present research explored participatory and action-focused pedagogies that, by positioning children as critical actors for sustainability, simultaneously sought to strengthen and reimagine children's science engagement for the well-being of people and planet.

Findings of the present study suggest that climate change learning and action can support children's engagement with science by emphasizing its real-world significance and by connecting learning with collaborative, community-based action. Making such practices accessible to students in the formal science classroom, we have argued, would require broad shifts in school science policy and practices. Doing so, however, would be worth the effort as the stakes could not be higher [5]. Climate change is increasingly referred to in terms of "crisis" and "chaos". Whereas "crisis" means a *turning point*, the point after which things get better or worse, "chaos" refers to an *opening* or empty space. Some have argued that our position on the precipice of irreversible changes to the climate system is a window of opportunity for transformative change—the kind that promotes the flourishing of human societies and ecosystems. A science education that rises to today's challenges by opening up space for children to be critical actors for sustainability in their communities could be decisive in creating the future that is to be.

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Land-Use and Health Issues in Malagasy Primary Education—A Delphi Study

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Abstract: Education for Sustainable Development (ESD) plays a key role in Sustainable Development. In low-income countries like Madagascar, this key role is particularly relevant to primary education. However, the curricula lack a comprehensive ESD approach that incorporates regional issues. In Madagascar, sustainable land-use practices (Sustainable Development Goals 12, 15) and health prevention (SDGs 2, 3, 6) are educational challenges. Procedural knowledge allows problem-solving regarding unsustainable developments. We adapted and further developed a measure of ESD-relevant procedural knowledge. Considering curricula, sustainability standards, research, and a two-round Delphi study ($n = 34$ experts), we identified regionally relevant land-use practices and health-protective behavior. After the experts rated the effectiveness and possibility of implementation of courses of actions, we calculated an index of what to teach under given Malagasy (regional) conditions. Combined with qualitative expert comments, the study offers insights into expert views on land-use and health topics: For example, when teaching ESD in Northeast Madagascar, sustainable management of cultivation and soil is suitable, particularly when linked to vanilla production. Health-protective behavior is ultimately more difficult to implement in rural than in urban areas. These results are important for further curricula development, for ESD during primary education, and because they give insights into the topics teacher education should address.

Keywords: Sustainable Development Goals; Education for Sustainable Development; primary education; Madagascar; land use; health behavior; Delphi study; procedural knowledge

1. Introduction

Madagascar aims to achieve the Sustainable Development Goals (SDGs; [1]) by 2030. For this purpose, the implementation of SDG 4: Quality Education plays a key role [2]. It contributes to all SDGs by listing “one of the most ambitious, interesting and challenging targets” [3] (p. 25): to “promote sustainable development [...] through Education for Sustainable Development and sustainable lifestyles” [1]. The implementation of SDG 4 is a challenge worldwide, especially for developing countries like Madagascar, where investments in Quality Education are low [4]. Madagascar is one of the poorest countries worldwide; approximately 77.6% of the population lives below the poverty line [4]. Madagascar faces multiple challenges related to Sustainable Development (SD). Environmental issues such as unsustainable land use (e.g., slash-and-burn practices [5] and forest degradation [6]) threaten Madagascar’s unique biodiversity [7,8]. Furthermore, health issues like malaria and diseases that are partially caused by critical hygienic conditions (e.g., cholera, typhus, and diarrheal diseases) are extant threats, particularly for children [9–11].

The simultaneous promotion of biodiversity conservation, sustainable land use, and sustaining of Malagasy livelihoods [12]—addressed in the SDGs—makes Education for Sustainable Development

(ESD) highly relevant. According to the SDGs, all Malagasy children should have access to primary education until 2030 [1]. Thus, formal education plays a crucial role in ESD.

The Malagasy education system faces many obstacles, including high proportions of underqualified teachers and a lack of materials and resources (cf. [13,14]). The information about the "gross intake rate to last primary grade" in Madagascar differs depending on the source: it is claimed to be around 40% [15,16] or 60–70% [14,17]. According to the latest source available, referring to data from 2016, only 68% of children enter the last grade of primary and only 37% enter the last grade of lower secondary education throughout Madagascar [17]. On average, Malagasy female pupils attend 5.8 years and male pupils 6.4 years of primary education [4]. Therefore, in Madagascar, the implementation of ESD is particularly important for primary education.

The concept of SD is perceived differently under conditions of extreme poverty [18]. Hence, ESD approaches in developing countries, such as Madagascar, must be connected to local realities (cf. [18]). While the semi-arid Southwest is extremely poor [19], the socioeconomic situation in Northeastern (NE) Madagascar, the SAVA region, has improved due to vanilla production and trade in recent years [20]. This appears to be an important factor in the health-, biodiversity- and agriculture-related education challenges connected to the SDGs (i.e., SDGs 2, 3, 6, 12, and 15). To improve local schooling and to increase the relevance of education to students, an adaption of Malagasy curricula "based on (the) region and local source of income" [13] (p. 233) has been suggested.

However, the current national school curricula in Madagascar hardly reflect regional requirements for a sensible arrangement of ESD [21]. Further hurdles to meaningful and effective instruction are the widespread shortcomings in teacher qualifications [21,22].

In the present study, we aim to identify regionally specific means for teaching ESD that allow for promotion of the SDGs, exemplified for the SAVA region. As the learning objectives in the current primary school curricula already show predominant links to SDGs 2, 3, 6, 12, and 15 [23], we focus on land-use and health issues that might be addressed in ESD. Furthermore, the approach takes into account sustainability standards that are present in Madagascar, research, and a two-round Delphi study with national and regional experts through which different perspectives with regional and educational relevance are brought together. The gained knowledge can be a starting point for future educational developments and educational programs in Madagascar.

1.1. Primary Education in Madagascar and ESD for Promoting SDGs

1.1.1. Conditions of Malagasy Primary Education

Since the colonial era, the Malagasy formal education system has mainly been based on the French system: it is divided into three years of preschooling (*maternelle*), five years of compulsory primary education (*école primaire*), four years of lower secondary education (*collège*), and three years of higher secondary education (*lycée*) [14]. Each stage has to be completed with a final exam in order to continue to the next stage [14]. Since the year 2000, the primary school enrolment rate in Madagascar has developed remarkably [14]. However, strong population growth increasingly challenges the Malagasy education system. The statistics of UNDP [4] indicate that only 15% of primary school teachers in Madagascar are trained to teach—compared to a mean of 80% in Sub-Saharan Africa; many teachers in Madagascar are underqualified [13]. Hurdles in Malagasy primary education appear particularly in rural areas (cf. [13,24]). In the SAVA region, this phenomenon leads to lower completion rates of the primary school final exam (CEPE) in rural schools (21.4%) than in urban schools (66.7%) [25].

Since 2000, Madagascar has emphasized the development of its educational sector, e.g., by designing and implementing ambitious education sector plans [14]. However, political changes led to postponement of the intended educational reforms [14,26]. The latest strategic document published by the government, the *Plan Sectoriel de l'Éducation* [27], aims to provide inclusive access to quality education for all. It includes substantial reforms, such as implementing nine years of compulsory fundamental education, more regionally adapted school curricula, and improved teacher training. Although the *Plan Sectoriel de l'Éducation* does not explicitly refer to the SDGs, its targets are in line with SDG 4: Quality Education (cf. [27]). However, the results of the latest presidential election led to indefinite suspension of the plan.

1.1.2. SDGs and Malagasy Primary Education

The Malagasy school curriculum contains general and specific learning objectives for each subject [28]. These are complemented by suggested teaching contents, activities, methods and materials, and evaluations.

A previous study by Niens et al. [23] identified starting points for further development of the current curricula with respect to ESD. As the SDGs describe the major challenges of SD with international relevance [29], the qualitative analysis focuses on the existing links between the learning objectives of the curricula and the SDGs. Most of the learning objectives address SDG 3: Good health and well-being. The second most important focus is on SDG 15: Life on land. The shares of learning objectives related to SDG 2: Zero hunger, 6: Clean water and sanitation, 11: Sustainable cities and communities, and 12: Responsible consumption and production are similar and follow SDG 15 [23]. Despite the presence of these SDG-relevant topics, the curricula do not address ESD as a comprehensive approach [21]. The references to SDGs 12 and 15 correspond to the tradition of environmental education in Madagascar that has been strongly promoted by NGOs [22]. However, their approaches are not adapted to local or regional situations [22]. Furthermore, many teachers have difficulties connecting the teaching content to regional examples (cf. [21,30]). For example, teachers in the Alaotra region in NE Madagascar perceived charcoal and fire as major environmental threats but had problems identifying a regional invasive fish species as an environmental problem [21]. Despite curricula revision for primary schools in 2015 [28], regional adaption hardly exists up to now.

The strong presence of SDGs 2, 3, and 6 in Malagasy curricula corresponds to the crucial role of primary education in the improvement of health in Madagascar [11]. This is especially true in rural areas, where medical health care is often not available [31]. To improve health and to fight malnutrition, the Malagasy state provides medical visits and promotes dental health, deworming, good hygiene and sanitation behaviors, and, sometimes, school canteens for public schools [11]. As a spillover effect, these activities positively affect school attendance by Malagasy children [14].

1.2. Topics Relevant to Promote Primary Education for SDGs in the SAVA Region

Because of their presence in the primary school curricula and their relevance for the SAVA region, land-use (e.g., SDGs 12 and 15) and health issues (e.g., SDGs 2, 3, and 6) are focused on in the following.

1.2.1. Land-Use Issues in the SAVA Region

Madagascar is one of the hottest biodiversity hotspots on Earth [7,8]. NE Madagascar is home to the highest share of remaining forest cover in the country and belongs to one of its most biodiverse regions [6,32]. However, outside of the two national parks in the SAVA region, remaining forests have declined in size in the past decades [33]. A key challenge for SD, especially in developing countries, is maintaining forests while simultaneously improving livelihood through enhanced food production [34]. Coping with this challenge requires sustainable land use [35,36]. In the SAVA region, the most common land-use options are vanilla and rice production [20]. Vanilla vines are cultivated in agroforestry systems that include tutor trees and shade trees [37]. Agroforestry has the potential to combine high agricultural yield with biodiversity conservation (cf. [38,39]), and it can thereby contribute to several SDGs (e.g., SDGs 12 and 15) [40]. Intensified monocultures such as rice paddies, on the other hand, can lead to a decreased biodiversity of cultivated land [41,42]. Biodiversity can be improved by the management of cultivation and soil (cf. [38]). Certification schemes with sustainability standards can foster the adoption of sustainable land-use strategies [34,43].

1.2.2. Health Issues in Madagascar

Diseases like malaria, cholera, and typhus are present threats in Madagascar. Also, bad hygienic conditions promote infectious diseases like diarrheal and respiratory illnesses [9–11]. Moreover, many water sources contain contaminants like pathogenic bacteria [44]. Exposure to air pollution, insufficient waste management, pesticides, and dangerous traffic constitute further health risks [11]. Likewise, undernutrition and malnutrition are widespread problems [11].

Causes of the unsatisfying health situation in Madagascar are manifold, though limited access to infrastructure and resources plays an important role across the country. Access to soap or improved sanitation [45], bed nets for protection from mosquitos [46], alternative biomass for cooking [47], and foods for balanced nutrition [48] are all limited. Access to health care and health-related resources such as point-of-care technology or trained personnel is especially weak in rural areas [31,49]. Furthermore, health is negatively affected by prevalent open defecation [45]. In the SAVA region, toilets and latrines are rare; when extant, they are generally shared and often do not conform to hygiene standards [20]. Moreover, insufficient food and body hygiene [10,45] and insufficient protection against sexually transmitted diseases are problematic [11].

1.2.3. Educational Needs Regarding Land-Use and Health Issues

To cope with land-use and health issues in Madagascar, it is important to empower the population through education (cf. [50]). In this realm, ESD benefits from the inclusion of local and regional realities (cf. [18]). Up to now, formal education on sustainable land-use practices seems to be rare (cf. [51]). As vanilla is of unique environmental, economic, and social importance for the SAVA region [20], Blanco et al. [52] suggest to address vanilla-related topics in regional education. However, which specific topics and means regarding sustainable land use in the SAVA region should be introduced into schools, remains an open question.

Coping with health issues in the SAVA region requires health-conscious behavior (cf. [53]), including health-related knowledge. In Madagascar, primary schools play an important role in health care by providing medical treatment and health training [11]. Furthermore, health-related learning objectives dominate primary school curricula [23]. As rural and urban areas have different schooling conditions [13,24,25] and different access to health-related infrastructure and sanitation [31,49,52], careful adaptation of teaching approaches to individual school settings might provide adequate education on health-conscious behaviors.

In sum, a further definition of what to teach for regionally relevant promotion of sustainable land use and health-conscious behavior in the SAVA region is needed.

1.3. Knowledge for ESD Teaching

There are several models for explaining environmental behavior and health behavior (e.g., [54–57]). In these models, knowledge plays a crucial role. The same can be said for ESD: it aims to equip learners "with the knowledge and competencies they need" [29] (p. 8) to promote SD.

The literature provides various knowledge classifications. Most of them differentiate between declarative/conceptual knowledge ("know that") and procedural/action/strategic knowledge ("know-how") (i.e., [58–61]).

Focusing on problem-solving, de Jong and Ferguson-Hessler [59] developed a knowledge model. It includes situational knowledge as knowledge about typical situations that appear in the problem-specific domain [59]. Facts, concepts, and principles appearing in this domain are part of conceptual knowledge. Procedural knowledge comprises specific actions that can change the state of the problem. Strategic knowledge depicts the problem-solving process [59]. It is often assumed that conceptual knowledge (knowledge about facts) is a prerequisite for generating procedural knowledge [58,62].

Koch et al. refer to procedural knowledge as "the cognitive skill of identifying and judging potential solutions ('strategies')" [63] (p. 1447) to SD-related problems. ESD explicitly requires action-oriented problem-solving [29]; thus, procedural knowledge is of particular importance.

Procedural knowledge, according to de Jong and Ferguson-Hessler [59], turns out to be a crucial knowledge type for ESD [63,64]. Koch et al. [63] and Richter-Beuschel et al. [64] asked Indonesian and German experts about the effectiveness of solution strategies ("courses of action", (cf. [65])) for SD aspects linked to resource use and land use. These issues often require the consideration of multiple, sometimes conflicting, perspectives, and thus often lack a definitive solution. Coping with such issues requires respective knowledge [57,63,66]. The studies of Koch et al. [63] and Richter-Beuschel et al. [64] focus on courses of action for coping with complex real-world SD issues in higher education. To the best of our knowledge, there are no studies addressing the procedural knowledge that is necessary to effectively teach in ESD in primary education.

1.4. Research Questions

Promotion of procedural knowledge regarding SD issues is a promising avenue of ESD. However, the identification of regionally relevant SD teaching issues can further benefit from expert knowledge on the effectiveness of certain courses of action.

The current curricula in Madagascar already address contents linked to SDGs 2, 3, 6, 12, and 15 [23]. These are suitable starting points for SDG-related education. Therefore, the present study focuses on defining topics connected to land-use and health issues and on charting corresponding courses of action for the promotion of procedural knowledge related to SDGs 2, 3, 6, 12 and 15 in NE Madagascar. Once regionally relevant courses of action for topics related to land-use and health issues are defined, the knowledge helps to design of culturally sensitive regional ESD curricula. For identification of ESD-relevant contents (e.g., for courses of action) Delphi studies are suitable procedures [63,64,67]. A small pre-study that included five primary school teachers in the SAVA region and utilized an instrument based on Koch et al. [63] and Richter-Beuschel et al. [64], including regionally adapted courses of action, revealed a need for further adaptation of the questionnaire. In addition to the effectiveness ratings of the courses of action, the corresponding possibility of implementation in the local setting provided significant information. These measurements led to the following main research questions (RQ1 and RQ2), and to three sub-research questions for each:

RQ1: *What land-use-related procedural knowledge is worth teaching in NE Malagasy primary schools for regionally adapted teaching of the SDGs?*

1.1 How effective and implementable are the land-use-related courses of action compiled for primary education?
1.2 How do these courses of action differ in their effectiveness and the possibility of implementation?
1.3 Which of these courses of action are worth teaching under the given conditions in NE Madagascar in order to promote biodiversity conservation and agronomic productivity?

RQ2: *What health-related procedural knowledge is worth teaching in NE Malagasy primary schools for regionally adapted teaching of the SDGs?*

2.1 How effective and implementable are the health-related courses of action compiled for primary education?
2.2 How do these courses of action differ in their effectiveness and the possibility of implementation?
2.3 Which of these courses of action are worth teaching under the given conditions in NE Madagascar in order to promote good health and well-being?

2. Method and Approach

To design an instrument for measuring procedural knowledge relevant for primary education, we focused on curricular, regional, and SDG-relevant land-use and health issues (i.e., contexts). We furthermore decided upon relevant topics that would allow operationalization in both contexts (Figure 1). For teaching the land-use issue, sustainable management of cultivation and soil are relevant topics [48,51,68]. As vanilla is the predominant cash crop in the SAVA region [20], we differentiated between vanilla and other cultivation (including rice). Regarding the health context, we chose topics related to clean water, hygiene, diet, and prevention of illnesses.

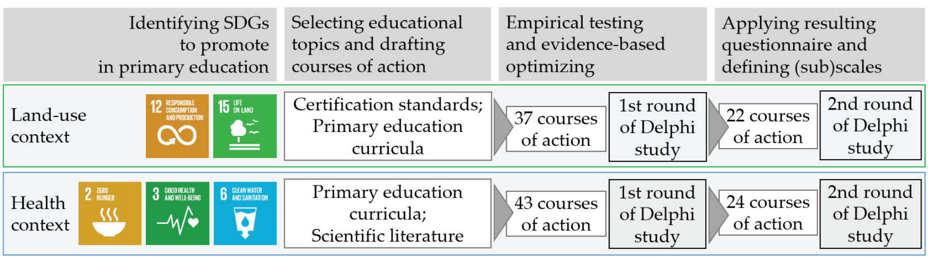


Figure 1. Developing and conducting the Delphi study on procedural knowledge for promoting Sustainable Development Goals (SDGs) in primary education.

As performed by Koch et al. [63] and Richter-Beuschel et al. [64], we operationalized procedural knowledge through judgement of courses of action. According to the selected topics, we developed courses of action relevant to ESD and promotion of the SDGs. In doing so, we drafted courses of action and then conducted a two-round Delphi study. The first round served to test the courses of action and to explore further needs to cover the relevant land-use and health issues of the SAVA region. In the second round, we used an optimized and timely feasible version of the questionnaire (Figure 1). The second round served to determine the effectiveness and possibility of implementation of the courses of action regarding land-use and health issues.

2.1. Drafting Courses of Action for Topics Relevant for Teaching Land-Use and Health Issues

We designed courses of action that were related to predominant ESD-relevant learning objectives in primary school curricula [23]. The drafted courses of action had particular relevance for the SAVA region. Thus, we focused on SDGs 12: Responsible consumption and production, and 15: Life on land in the land-use context, and on SDGs 2: Zero hunger, 3: Good health and well-being, and 6: Clean water and sanitation for the health context.

The courses of action in the land-use context derived from all 29 vanilla certification standards present in Madagascar in 2018, which were listed on the online Sustainability Standards Map by the International Trade Centre [69]. Most of these standards are also associated with rice production in Madagascar (cf. [69]). Based on these standards and on the learning objectives in Malagasy primary education curricula, we formulated sets of courses of action that incorporated the regionally and educationally relevant management of vanilla and other cultivations, as well as soil management.

For the health context, courses of action were based on health-related learning objectives present in primary education [23] and were refined using health recommendations by international development organizations and further literature [10,45–47]. In the SAVA region, nutrition and body hygiene, serious illnesses, and health risks are relevant health issues [11]. We compiled corresponding sets of courses of action.

2.2. First Round of Delphi Study and Further Development of the Questionnaire

In the first round of the Delphi study, the experts rated the (i) effectiveness and the (ii) possibility of implementation in rural life of the presented courses of action, as well as the (iii) certainty of their given answers. Completion of the paper-pencil questionnaire took place during personal interview meetings. Each meeting consisted of one expert, a local translator, the doctoral student, and/or the principal investigator. Each expert got a handout with information about the project and the data processing. The interview started only after the expert's informed consent. In the following 45 to 90 min, the expert provided personal data and filled out the questionnaire with a subsequent discussion of relevant aspects for further questionnaire development. This included suggestions for improvements of the courses of action. The experts' oral comments were noted during the survey. Each participant could choose between a French and a Malagasy version of the questionnaire. To ensure the translation quality of the French questionnaire into the local dialect, we used back-translation into French [70]. We discussed the deviations between the original French version and the back-translation and adapted the Malagasy version until we reached a satisfying translation.

According to the quantitative data and the qualitative feedback of the first Delphi round, we revised the questionnaire composition, including the courses of action. Based on the expert comments, we clarified the wording of the courses of action as well as added further ones or deleted if inappropriate. Furthermore, we adapted the questionnaire structure for the health context according to the expert feedback: in the first round, the possibility of implementation only referred to rural settings. The experts suggested to likewise include urban settings for the implementation ratings. The experts understandably did not suggest corresponding adaptions for the land-use context.

To create a timely feasible survey, we reduced the first round's 80 courses of action for both contexts to 46 courses of action in the second round. The quantitative results from the first round helped us to identify courses of action that were in principle implementable as common land-use practices or as everyday life practices. We further enriched the courses of action by regionally relevant examples in a one-week workshop with an interdisciplinary team of seven local assistants. The team consisted of seven graduates from biological, geographical, and economic disciplines and two language students. To standardize data collection, we only used the Malagasy version of the questionnaire in the second Delphi round. We put special emphasis on the translation process: the whole assistant team, including the doctoral student, made a side-by-side comparison of the French and the translated versions and adapted the Malagasy version as necessary [71].

The translation of the French items into English for the publication was done by the doctoral student, back-translated by a student assistant, and adapted as necessary [70].

2.3. Second Round of Delphi Study and Applied Instrument for Rating Courses of Action

For the second Delphi round, we first provided feedback on the results of the first round to all participants. We provided medians and percentage distributions of the ratings compiled graphically, as done by Richter-Beuschel et al. [64]. Subsequently, we gave the optimized questionnaire.

The second Delphi round was conducted with a tablet via the open-source KoBo Collect App [72], using XLS programming. All data collection took place in personal meetings (45–120 min) with a local trained assistant that were occasionally attended by the doctoral student. Oral explanations and feedback from the experts were noted by the local assistant.

Each course of action of the final instrument of the second Delphi round was rated regarding its effectiveness in one or two field/s of action: health—good health and well-being; land use—biodiversity conservation and agronomic productivity. The literal translation of "biodiversity" into Malagasy is a very technical term that is not common in local language usage. Therefore, we decided to translate "biodiversity" as "tontolo iainana", the common word for "environment", literally meaning "everything alive that surrounds me". In addition to the effectiveness ratings, each course of action was rated concerning one or two implementation setting/s: land use—rural life; health—rural and urban life. This resulted in three items per course of action with a four-point Likert scale (see Table 1).

Table 1. Concept for expert ratings of procedural knowledge on land-use and health issues relevant for primary education (L: course of action regarding land use; H: course of action regarding health).

Land-Use Context	Field of Action								Implementation Settings				Self-Evaluation			
Rating for the SAVA region regarding …	… conservation (and sustainable use) of the biodiversity				… agronomic productivity				… possibility of implementation in rural life				How certain are you about your ratings?			
L.1 Letting the vegetation on non-cultivated plots develop naturally (e.g., land on steep slopes, abandoned land).	Ineffective	Little effective	Effective	Very effective	Ineffective	Little effective	Effective	Very effective	Impossible to implement	Difficult to implement	Possible to implement	Easy to implement	Very uncertain	Partly certain	Certain	Very certain
	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
…	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
Health Context	**Field of Action**				**Implementation Settings**								**Self-Evaluation**			
Rating for the SAVA region regarding …	… good health and well-being				… possibility of implementation in rural life				… possibility of implementation in urban life				How certain are you about your ratings?			
H.1 Washing hands with clean water and soap (e.g., before eating, after using the latrine).	Ineffective	Little effective	Effective	Very effective	Impossible to implement	Difficult to implement	Possible to implement	Easy to implement	Impossible to implement	Difficult to implement	Possible to implement	Easy to implement	Very uncertain	Partly certain	Certain	Very certain
	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□
…	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□

The evaluation of possibility of implementation is a common prerequisite for planning pro-environmental and health-conscious courses of action (cf. [57,73]). For implementation ratings (Table 1), we asked the participants to consider practices that existed in the local population and thereby referred to extant routines, beliefs, and resources. This extended the measuring approach used in Koch et al. [63] and Richter-Beuschel et al. [64].

In general, the reliability of the results of Delphi studies benefits from the inclusion of information related to the subjective certainty of given ratings [74]. Thus, we asked the experts to evaluate their certainty for each course of action (see Table 1).

2.4. Administration of Questionnaire and Complementary Data Collection

During data collection, we first asked for personal data. Apart from age and sex, the experts provided information about their professional and voluntary activities and their experience regarding land-use and/or health issues. To assess the participants' expertise in the contexts under study, we asked them to rate their knowledge regarding selected domains of land-use and health issues (Appendix A). The experts could indicate their knowledge on a five-point Likert scale (0: *not satisfying*, 1: *satisfying*, 2: *good*, 3: *very good*, 4: *excellent*).

2.5. Sample Composition

For Delphi studies, small sample sizes of 10–18 experts are recommended [75,76]. Accordingly, the study sample consisted of 19 land-use and 20 health experts in the first Delphi round and 15 land-use and 14 health experts in the second (Appendix B). In the literature, little consensus exists regarding the definition of an "expert" within Delphi studies [74,77]. Strict definitions of an expert risk reduction of the potential sample size, especially when the study only focuses on a small region [77]. We refer to experts as representatives of a relevant working area and/or as a person in a dominant hierarchical position [77]. The working areas or institutions covered included those related to land-use and health issues and related education in the SAVA region.

To include multiple perspectives relevant for ESD or SDG promotion, we included representatives from regional ministries (n = 9), NGOs (n = 7), secondary and tertiary education (n = 7), (rural) practitioners with long-lasting expertise in health and land-use issues (n = 5), rural school directors (n = 3), and local authorities in rural areas (n = 3) in the two-round Delphi study. Because of time restrictions of the field study on-site, the selection of experts was based on convenience sampling. For the ministry group, we invited representatives from all regional ministries that had offices in the regional capital and whose working areas were related to land-use and health issues. The participants from remote rural areas were chosen from villages in three out of the four districts in the region that were already in contact with the joint project Diversity Turn in Land Use Science [20]. The experts from NGOs, secondary and tertiary education, and practitioners were mainly chosen from already-established contacts from a former project stage who corresponded to our expert definition. Further expert selection was based on recommendations by study participants. Apart from these occasional recommendations (n = 8 out of n = 25 experts in the 2nd Delphi round), the participation was completely anonymous. All participants were Malagasy, most of them living in the SAVA region. The majority of the experts participated in both Delphi rounds. The local authorities and school directors of three remote rural villages (4–8 h drive from the nearest paved roads) contributed to the first round. That helped to create a locally relevant questionnaire that includes deep rural perspectives. For the second round, those participants had to be excluded due to infrastructural restrictions. All experts got a small gift for participation.

For getting an impression of the second Delphi round: The age span of experts in the land-use context (n = 15; two females, 10 males, three not stated) was between 29 and 70 years (mean: 48.67; standard deviation: 12.91). The experts in the health context (n = 14; two females, 12 males) were 26 to 70 years of age (45.07; 14.47). In general, the experts who participated in the land-use context had a higher mean self-rated level of knowledge regarding context-specific domains (mean = 1.38 to mean = 2.31; *n* (2nd Delphi round) = 13) than did the experts who participated in the health context (mean = 1.50 to mean = 1.86; *n* (2nd Delphi round) = 12) (Appendix B).

2.6. Data Analysis

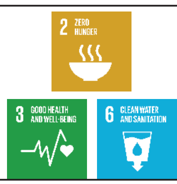
To answer the research questions, we used the data from the second Delphi round and applied IBM SPSS Statistics 25. Identifying courses of action for teaching land-use and health issues in primary education in the SAVA region followed four steps.

First, using Cronbach's alpha, we tested if the identified courses of action built reliable scales (one scale per field of action, one scale per implementation setting) for the land-use and the health contexts. We likewise tested if the courses of action built reliable subscales related to the selected topics (Tables 2 and 3). Second, we analyzed the effectiveness ratings, which give information on what can, in general, be effective with respect to the investigated fields of action (general effectiveness). Third, we shed light on regional and local situations (implementation). This allowed us to consider any severe hurdles to the implementation of courses of action in rural (and urban) settings.

Table 2. Underlying scheme for analysis in the land-use context.

	Fields of Action		Implementation Setting
Context	Scale	Scale	Scale
Topic	Subscale	Subscale	Subscale
Topic	Subscale	Subscale	Subscale
Topic	Subscale	Subscale	Subscale

Table 3. Underlying scheme for analysis in the health context.



	Field of Action	Implementation Settings	
Context	Scale	Scale	Scale
Topic	Subscale	Subscale	Subscale
Topic	Subscale	Subscale	Subscale
Topic	Subscale	Subscale	Subscale
Topic	Subscale	Subscale	Subscale

Fourth, we multiplied the rated general effectiveness by the rated possibility of implementation for each course of action to gain information on the effectiveness under the given conditions in the SAVA region (index for "what to teach under given condition")—abridged as "adjusted effectiveness." This can serve as a base for the creation of regionally sensitive teaching approaches under the given, current situation. It is a common procedure to multiply two relevant factors in order to evaluate the likelihood of performance of a specific (e.g., pro-environmental or health-conscious) course of action (cf. [56]).

For the comparison of scales and subscales, we used paired *t*-tests or repeated measures ANOVA (rmANOVA) with post hoc Bonferroni correction.

The experts' self-evaluation (certainty ratings) per course of action (Table 1) was very high for the land-use (3.87; 0.22) and the health contexts (3.89; 0.22), indicating a ceiling effect (1: *very uncertain*, 2: *partly certain*, 3: *certain*, 4: *very certain*). Thus, we did not further use this data to weigh effectiveness or implementation ratings, as it is common for Delphi studies [75].

The qualitative comments of the experts in the second Delphi round revealed that their effectiveness ratings regarding "conservation and sustainable use of biodiversity" only referred to "biodiversity conservation" (Table 1). Thus, we only refer to "biodiversity conservation" in the results. If not stated otherwise, the selected comments in the results section represent aspects that were mentioned by a minimum of five of the fifteen land-use or five of the fourteen health experts. Each comment is followed by the individual code we associated with the experts for pseudonymization.

3. Results

3.1. Land-Use-Related Procedural Knowledge for Primary Education

First, we present scales and subscales for the land-use context and give insights into descriptive statistics (sub-research question 1.1; see Section 3.1.1). Second, we report inferential data analysis regarding "general effectiveness", "possibility of implementation", and "adjusted effectiveness" on the scale and subscale levels (sub-research question 1.2; see Section 3.1.2). Third, we shed light on the "adjusted effectiveness" on course of action level for each topic. In doing so, we deepen the average quantitative ratings regarding the impact of courses of action on biodiversity conservation and agronomic productivity through use of qualitative expert comments (sub-research question 1.3; see Section 3.1.3). As a specific feature of the land-use context, we always distinguish between effectiveness for biodiversity conservation and for agronomic productivity.

3.1.1. Land-Use-Related Scales and Subscales

The data analysis revealed three scales in the land-use context (Tables 2 and 4). The Cronbach's alpha values of the scales "effectiveness for biodiversity conservation" (bc), "effectiveness for agronomic productivity" (ap), and "implementation in rural life" are between 0.77 and 0.87 (Table 4). Furthermore, we identified three topics: management of vanilla cultivations, management of cultivations other than vanilla, and soil management. Each topic included three reliable subscales (0.51–0.81), resulting in nine subscales for the land-use context (Table 4).

Table 4. Reliability of the scales and subscales of the land-use context, 2nd round of Delphi study (n = 15).

	Fields of Action		**Implementation Setting**
Land-Use Context in Color: Topics (*n* of Courses of Action)	**Effectiveness for Biodiversity Conservation**	**Effectiveness for Agronomic Productivity**	**Implementation in Rural Life**
Land-use scale: Management of cultivation and soil (20)	0.871	0.833	0.772
Management of vanilla cultivations (6)	0.575	0.703	0.781
Management of cultivations other than vanilla (5)	0.757	0.658	0.507
Soil management (9)	0.808	0.612	0.594

On the scale level, the management of cultivation and soil is rated more than *effective* ("general effectiveness") for biodiversity conservation (mean: 3.63; standard deviation: 0.28; range: 3.10–3.95) and agronomic productivity (3.46; 0.27; 2.95–3.80). The coding 3 signifies *effective* and 4, *very effective*. The management of cultivation and soil lies between 3: *possible* and 4: *easy to implement* (3.47; 0.23; 2.95–3.80).

The "adjusted effectiveness"—effectiveness under given conditions—of management of cultivation and soil is higher than 12 for both fields of action (bc: 12.62; 1.27; ap: 12.15; 1.38). The value 12 corresponds to, e.g., *effective* combined with *easy to implement* or to *very effective* combined with *possible to implement*. The ranges are located above 10 for both fields of action (bc: 10.75–14.65; ap: 10.20–14.25). The value 10 is derived from an answer, e.g., above *effective* and *possible to implement*.

The high ratings of "general effectiveness" (bc mean range: 3.58–3.67; ap mean range: 3.40–3.53) and "possibility of implementation" (3.34–3.64) are consistent throughout all nine subscales (Table 4; for detailed data see grey lines for subscales in Appendix C). This likewise applies to the "adjusted effectiveness" (bc mean range: 12.62–13.07; ap mean range: 11.89–12.72).

In sum, the land-use context includes courses of action that are, on the scale and subscale levels, effective for biodiversity conservation (bc) and agronomic productivity (ap) and implementable in rural life. This results in high calculated effectiveness under given conditions in the SAVA region.

3.1.2. Effectiveness for Biodiversity Conservation and Agronomic Productivity and Possibility of Implementation—Analysis on Scale and Subscale Levels

Comparing the effectiveness ratings on scale level, a paired *t*-test reveals that management of cultivation and soil is more *effective* for biodiversity conservation than for agronomic productivity (general effectiveness: t (14) = 2.93, p = 0.011; adjusted effectiveness: t (14) = 2.57, p = 0.022).

Figure 2 demonstrates that these differences likewise appear on the subscale level, are significant for soil management (p = 0.024), and show a tendency for both subscales regarding management of cultivations ($p < 0.1$). The paired *t*-tests between the "adjusted effectiveness" values for biodiversity conservation and those for agronomic productivity display a similar pattern regarding *t*- and *p*-values (same order as in Figure 2): t (14) = 1.71, p = 0.109; t (14) = 1.77, p = 0.099; t (14) = 1.98, p = 0.068.

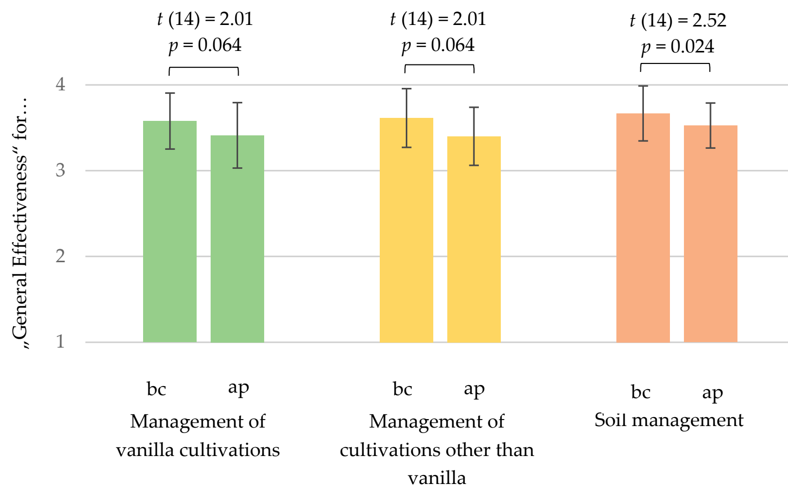


Figure 2. Mean and standard deviation of the subscales of "general effectiveness for biodiversity conservation" (bc) and "general effectiveness for agronomic productivity" (ap) regarding the three land-use topics (1: *ineffective*, 2: *little effective*, 3: *effective*, 4: *very effective*; n(2nd Delphi round) = 15).

Comparing the three subscales of "implementation in rural life", the rmANOVA with Greenhouse-Geisser correction reveals statistically significant differences (F(1.4, 19.6) = 4.83, p = 0.030, partial η^2 = 0.26). The post hoc Bonferroni test shows the following: The sustainable management of vanilla cultivations shows overall the highest "possibility of implementation" (data not shown). Compared to this, sustainable soil management is significantly more *difficult to implement* (p = 0.012, 0.30, 95%–CI [0.06, 0.54]).

3.1.3. Effectiveness and Possibility of Implementation of Land-Use-Related Courses of Action

Figure 3 displays the means of five variables for each course of action. The experts rated three items per course of action:

- "general effectiveness for biodiversity conservation",
- "general effectiveness for agronomic productivity", and
- "possibility of implementation in rural life."

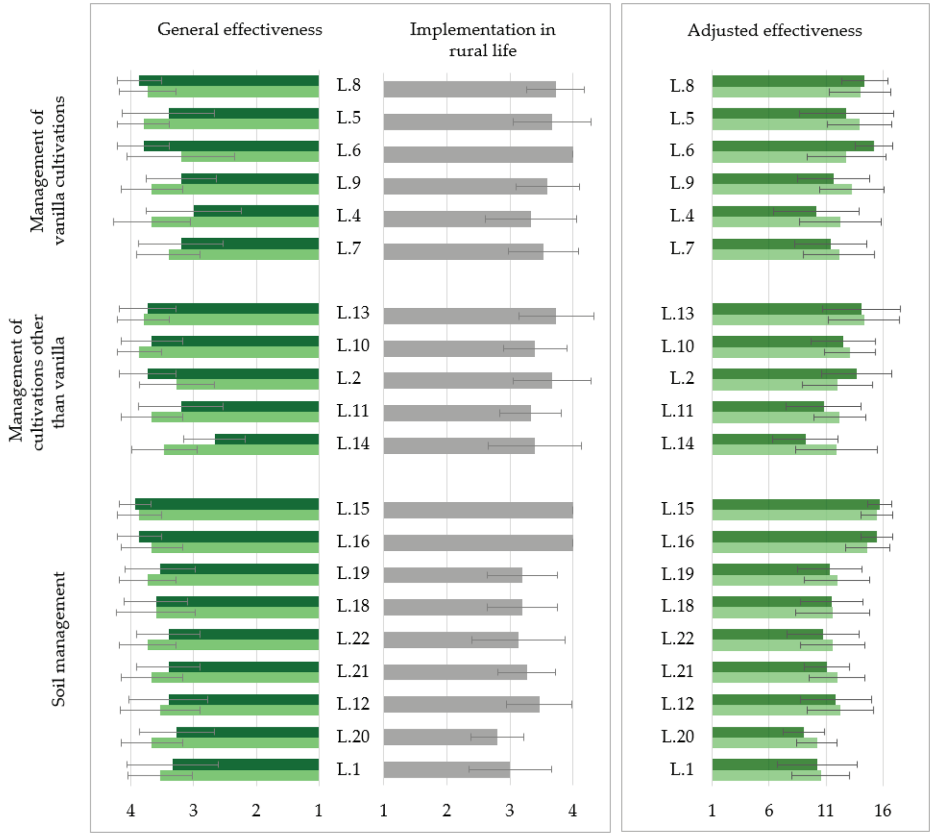


Figure 3. Mean and standard deviations of land-use items regarding "general effectiveness" (1: *ineffective*, 2: *little effective*, 3: *effective*, 4: *very effective*); "possibility of implementation in rural life" (1: *impossible to implement*, 2: *difficult to* . . . , 3: *possible to* . . . , 4: *easy to* . . .); and calculated "adjusted effectiveness" ("general effectiveness" x "possibility of implementation in rural life"); *n* (2nd Delphi round) = 15. Fields of action are differentiated by color: dark green (agronomic productivity); light green (biodiversity conservation).

The additional two variables are the calculated

- "adjusted effectiveness for biodiversity conservation" and
- "adjusted effectiveness for agronomic productivity."

In the following, we deepened the average expert ratings with qualitative expert comments. An overview of the quantitative data on the level of courses of action (descriptive and inferential) is documented in Appendices C and E. If not otherwise stated, all of the following results from the quantitative data concern the adjusted effectiveness values.

Regarding management of vanilla cultivations, all items possess a mean of minimum 3 on average (3: *effective* and 3: *possible to implement*). Thus, the "adjusted effectiveness" is remarkable: a value exceeding 9 for all courses of action.

The qualitative data particularly support the L.5 and L.6 courses of action. For example, L.5—*Having diverse endemic shade trees* (bc: 13.93; ap: 12.80; t (14) = 2.16, p = 0.048) *"[. . .] does not pose any problem if the chosen and planted species in the vanilla plantation respond to the needs of the vanilla plant"*

(V_02). L.6—*Regulating shade trees* (bc: 12.80; ap: 15.20; t (14) = −2.55, p = 0.023) is even considered to be "*[...] mandatory. It belongs to the requirement of the vanilla for its productivity*" (M_03).

In contrast, some courses of action show lower "adjusted effectiveness." For example, L.4—*Having a diversity of tutor trees* (bc: 12.27; ap: 10.13; t (14) = 3.81, p = 0.002) is more effective for biodiversity conservation than for agronomic productivity because it *"[...] could cause more expenses and more work. The best is to find one single species that is the most favorable for the soil to be cultivated*" (M_05).

According to the experts, some further courses of action require technical knowledge for adequate implementation. For example, L.7—*Burning of contaminated vanilla lianas* (bc: 12.13; ap: 11.40; p > 0.05) is practiced by "*most of the farmers [...] but to avoid the persistence of the illness, it is necessary to make a call to technicians*" (V_04). Three experts had a similar opinion regarding L.9—*Cultivation of other crops on vanilla plantations* (bc: 13.27; ap: 11.67; t (14) = 2.91, p = 0.011): e.g., "*it is very effective for the environment and also for the production. However this needs technical supervision because every plant has its own needs*" (O_06).

With respect to management of cultivations other than vanilla, all three items per course of action reach mean values higher than 3 with the exception of item L.14—*Fruit trees on hill rice cultures* regarding agronomic productivity (bc: 11.93; ap: 9.20; t (14) = 3.98, p = 0.001). On the one hand, the experts emphasized that the farmers generally do not cut fruit trees and mentioned their clear benefits as they "*constitute sources of income and also respond to their own need of fruits*" (M_04). However, fruit trees in the middle of a rice cultivation reduce the area available for rice. This reduction negatively impacts the agronomic productivity of the rice field (explanation through personal communication with the assistant team).

L.13—*Cultivation in small house gardens* shows the highest "adjusted effectiveness" values (bc: 14.33; ap: 14.13; p > 0.05) (Figure 3). The experts explained that such gardens can reduce pressures on biodiversity, improve household income, and help provide a healthy diet. Regarding L.10—*Planting paddy rice plants of good quality* (13.13; 12.53; t (14) = 1.87, p = 0.082) and L.11—*Sowing hill rice seeds of good quality* (12.20; 10.80; t (14) = 2.43, p = 0.029), the experts clearly differentiated between the two land-use types. Hill rice was negatively associated with the slash-and-burn technique that "*offers generally a poor production. Even if one uses a good seed, the harvest will always be limited. The most effective would be to abandon the habit of using fire*" (O_08).

Surprisingly, choosing good quality seeds for hill rice has significantly lower "adjusted effectiveness" for agronomic productivity than for biodiversity conservation (t (14) = 2.43, p = 0.029). Regarding paddy rice, however, one expert explained that the ministry "*currently [encourages] the farmers to use improved seeds to face the problems related to the current climate change*" (M_04).

Concerning soil management, the high "adjusted effectiveness" values of L.15—*Having a herbaceous undergrowth* (bc: 15.47; ap: 15.73; p > 0.05) and of L.16—*Using natural fertilizers in vanilla plantations* (14.67; 15.47; t (14) = −1.87, p = 0.082) are striking. These are the two vanilla-related courses of action within the topic and both are often described as obligatory for good vanilla production. Three experts stated that L.15 is practiced by most farmers, as they "*know very well the importance of herbaceous undergrowth*" (U_04).

The courses of action not related to vanilla production (L.1, 12, 18–22) have lower "possibilities of implementation" and a lower "adjusted effectiveness." Interestingly, the experts often mentioned wide-ranging challenges, such as land scarcity, as hindering factors for courses of action related to soil management. This accounts in particular for the results connected to L.1—*Natural vegetation development* (10.53; 10.20; p > 0.05), L.12—*Crop rotation* (12.27; 11.87; p > 0.05), L.19—*Fertilization of hill rice* (12.00; 11.33; t (14) = 1.85, p = 0.086) as an alternative for slash-and-burn practices, and L.20—*Recommended soil recovery* (10.20; 9.07; t (14) = 3.01, p = 0.009). The recovery of tired soil (L.20) "*is generally effective for biodiversity. However, given the current strong demographic growth, if we do not manage to propose other effective solutions to face the insufficiency of exploitable soils, this measure will not be respected*" (M_05). Furthermore, the experts mentioned the need for action by the Malagasy state, NGOs, or local communities to foster the implementation of soil-management-related courses of action. This accounts especially for L.22—*Sustainable cultivation at riversides* (11.60; 10.73; $p > 0.05$) and for L.21—*Monitoring the soil quality* (12.00; 11.07; t (14) = 1.83, $p = 0.089$). For example, for L.21, "*agronomic technicians [...] should ensure the supervision of the farmers so that they improve little by little their cultural system*" (M_04).

3.2. Health-Related Procedural Knowledge for Primary Education

With respect to the health context, we present the results in the same steps and in a similar way as for the land-use context. Thus, we answer the three sub-research questions of RQ 2 (2.1, 2.2, and 2.3) by the following three Section 3.2.1, Section 3.2.2, and Section 3.2.3. As a specific feature of the health context, we always distinguish between the possibility of implementation in rural and in urban life.

3.2.1. Health-Related Scales and Subscales

The data analysis revealed three scales in the health context (Tables 3 and 5). The Cronbach's alpha values of the scales are between 0.59 and 0.89 (Table 5). Furthermore, we identified four topics, with three reliable subscales each (0.51–0.87—except for one out of 12): consideration of clean water, sanitation and hygiene, consideration of food hygiene and healthy diet, prevention of (serious) illness and risk avoidance (Table 5). This resulted in 12 subscales for the health context.

Table 5. Reliability of scales and subscales of the health context, 2nd round of Delphi study (n = 14).

	Field of Action	**Implementation Settings**	
Health Context in Color: Topics (*n* of Courses of Action)	**Effectiveness for Good Health and Well-Being**	**Implementation in Rural Life**	**Implementation in Urban Life**
Health scale: Health prevention (21)	0.889	0.592	0.820
Consideration of clean water, sanitation and hygiene (8)	0.869	0.655	0.505
Consideration of food hygiene and healthy diet (4)	0.692	0.432	0.543
Prevention of (serious) illness (4)	0.640	0.628	0.715
Risk avoidance (5)	0.715	0.601	0.721

On the scale level, health prevention is rated more than 3: *effective* ("general effectiveness") regarding good health and well-being (mean: 3.65; standard deviation: 0.26; range: 3.05–4.00). The "possibility of implementation" of health prevention lies between 3: *possible* and 4: *easy to implement* for rural settings (rs) (mean: 3.31; standard deviation: 0.35; range: 2.25–3.62) and for urban settings (us) (3.69; 0.24; 2.95–3.95).

The averages of "adjusted effectiveness" show that the means are higher than 12 for both rural and urban settings (rs: 12.09, 1.69; us: 13.52, 1.51). The ranges are above 8 for both implementation settings (rs: 8.15–14.29; us: 10.76–15.81).

The high ratings are consistent across all 12 subscales in the health context. All subscales show mean values above 3 for "general effectiveness" (mean range: 3.47–3.71) or "possibility of implementation" (rs: 3.19–3.48; us: 3.59–3.79) (for detailed data see grey lines for subscales in Appendix D). Accordingly, the "adjusted effectiveness" also shows high values (rs: 11.80–12.59; us: 12.50–14.13).

In sum, the health-related context includes courses of action that are, on scale and subscale levels, effective for good health and well-being and are implementable in rural (rs) and urban settings (us). This results in high calculated effectiveness under given conditions in rural and urban settings in the SAVA region.

3.2.2. Effectiveness and Possibility of Implementation in Rural and Urban Life—Analysis on Scale and Subscale Levels

The paired *t*-test between the scales "implementation in rural life" and "implementation in urban life" reveals that health prevention is easier to implement in urban than in rural settings (t (13) = −7.80, $p < 0.001$; adjusted effectiveness: t (13) = −7.89, $p < 0.001$). The same pattern appears on the subscale level ($p < 0.001$) with an exception for the subscales regarding risk avoidance, which show a tendency ($p = 0.095$) (Figure 4).

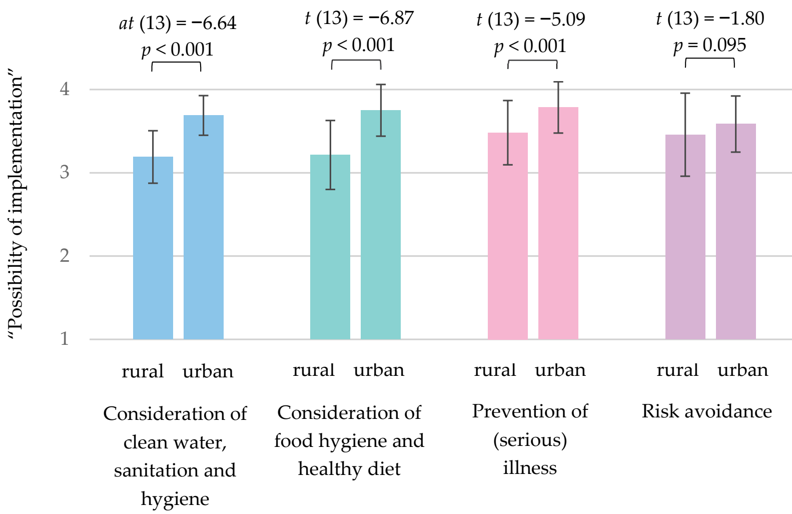


Figure 4. Mean and standard deviations of the subscales of "possibility of implementation in rural setting" and "possibility of implementation in urban setting" regarding the four health topics (1: *impossible to implement*, 2: *difficult to* . . . , 3: *possible to* . . . , 4: *easy to* . . . ; n (2nd Delphi round) = 14).

The paired *t*-tests between the "adjusted effectiveness" values for rural and urban settings show a similar pattern regarding *t*- and *p*-values (same order as in Figure 4): t (13) = −6.38, $p < 0.001$; t (13) = −7.45, $p < 0.001$; t (13) = −4.98, $p < 0.001$; t (13) = −1.66, $p = 0.121$.

Comparing the four subscales of "general effectiveness", the rmANOVA reveals significant differences between consideration of clean water, sanitation and hygiene, consideration of food hygiene and healthy diet, prevention of (serious) illness, and risk avoidance (F (3, 39) = 2.95, $p = 0.030$, partial $\eta^2 = 0.996$) (data not shown). The post hoc Bonferroni test indicates that only risk avoidance differs (it is less effective than consideration of clean water, sanitation, and hygiene) ($p = 0.044$, 0.23, 95%–CI [0.01, 0.46]).

3.2.3. Effectiveness and Possibility of Implementation of Health-Related Courses of Action

Figure 5 illustrates the means of five variables for each course of action. The experts rated three items per course of action:

- "general effectiveness for good health and well-being",
- "possibility of implementation in rural life", and
- "possibility of implementation in urban life."

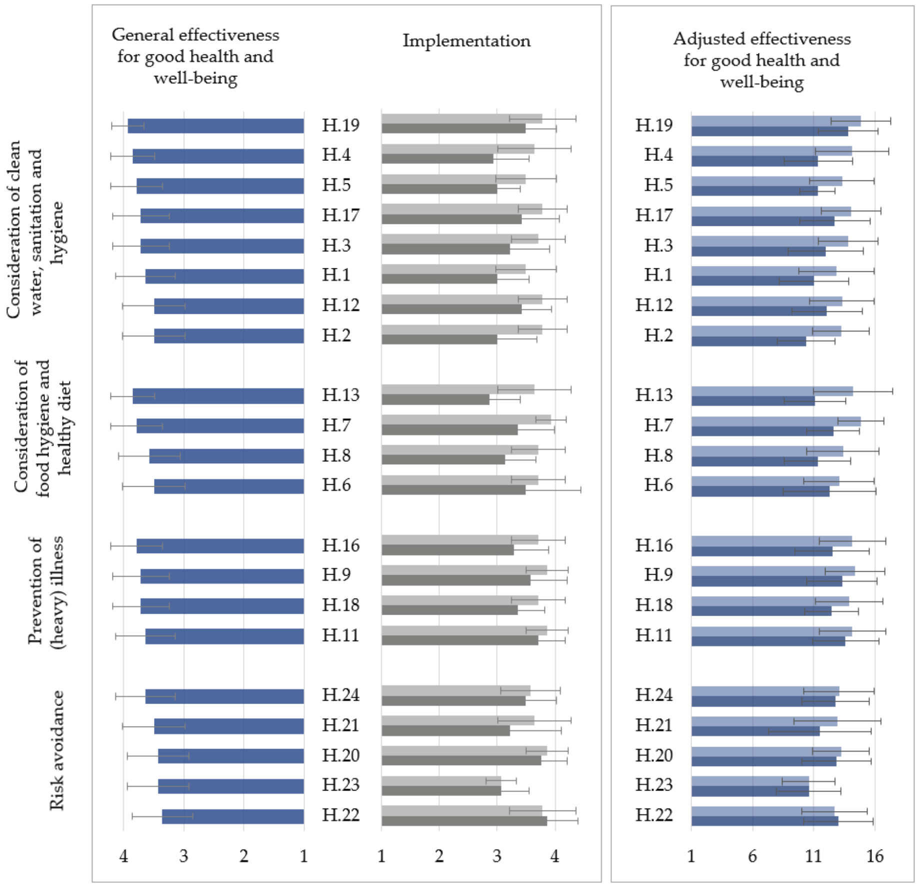


Figure 5. Mean and standard deviations of health items regarding "general effectiveness" (1: *ineffective*, 2: *little effective*, 3: *effective*, 4: *very effective*), "possibility of implementation in rural life" and "... in urban life" (1: *impossible to implement*, 2: *difficult to ...*, 3: *possible to ...*, 4: *easy to ...*) and calculated "adjusted effectiveness" ("general effectiveness" x "possibility of implementation"); *n* (2nd Delphi round) = 14. Implementation settings are differentiated by color: dark blue/grey (rural); light blue/grey (urban).

The additional two variables are the calculated

- "adjusted effectiveness for rural life" and
- "adjusted effectiveness for urban life."

An overview of the quantitative data on the level of courses of action (descriptive and inferential) is documented in Appendices D and F.

With respect to education for SDGs 2, 3, and 6, information on the "general effectiveness" as well as on "possibility of implementation" in specific settings of health-related courses of action is important. Thus, we provide such information in this section in addition to reporting the "adjusted effectiveness" values.

The courses of action in consideration of clean water, sanitation, and hygiene refer to very basic hygienic practices. H.4—*Preparation of drinking water* (adjusted effectiveness rs: 11.36; us: 14.14; t (13) = −4.30, p = 0.001) and H.5—*Hygienic water use* (11.29; 13.29; t (13) = −2.88, p = 0.013) show lower "adjusted effectiveness" in rural than in urban settings. They are particularly effective in terms of "general effectiveness" for good health and well-being but show implementation restrictions, especially with respect to rural life. Insufficient habits and misconceptions regarding clean water are prevalent, as "*most of the people consider transparent water to be clean*" (V_01).

H.1—*Handwashing* (11.00; 12.86; t (13) = −3.55, p = 0.004) and H.2—*Teeth brushing* (10.36; 13.21; t (13) = −3.90, p = 0.002) have a slightly more restricted "adjusted effectiveness" that is again more restricted for rural than for urban life. Compared with H.1 and H.2, H.17—*Teaching these habits in school* (12.71; 14.07; t (13) = −2.67, p = 0.019) has, on a descriptive level, higher "adjusted effectiveness" values. The experts explained that teaching children is important, but the sensitization of parents plays a crucial role, too. One expert pointed out that a sensitization campaign for teeth brushing (H.2) included free toothbrushes and toothpaste. The campaign was "*not successful because the parents are not motivated*" (S_01).

H.12—*The use of hands-free constructions for handwashing, e.g., tippy-taps*, is considered to be one of the less effective ("general effectiveness") courses of action in this topic. However, the "possibility of implementation" is relatively high, resulting in considerable "adjusted effectiveness" values (12.07; 13.29; t (13) = −2.65, p = 0.020). The experts emphasized the benefits of such constructions: "*it is very effective, very easy and not expensive. However this effectiveness always depends on the frequency of sensitization*" (V_01).

Regarding consideration of food hygiene and healthy diet, H.13—*Avoidance of malnutrition* is *very effective* ("general effectiveness") but not as *easy to implement*, especially in rural settings. Thus, the "adjusted effectiveness" is lower for rural than for urban settings (11.07; 14.21; t (13) = −5.08, p < 0.001). This result was supported by expert opinion: "*in remote rural areas, vegetables are very rare, beans very expensive, the people rarely consume meat. As a result, they content themselves with eating what they find in daily life*" (S_1). Also, three experts mentioned the effects of lack of knowledge (e.g., some people "*do not know how to prepare a balanced meal*" (M_01)).

In line with these results, H.7—*The preparation of healthy meals through washing and well-cooking* has a higher "adjusted effectiveness" for urban than for rural settings (12.57; 14.86; t (13) = −3.31, p = 0.006). This course of action is closely linked to the preparation of drinking water (H.4): "*everybody has the habit to clean the food before cooking it, but the only problem is that the access to drinking water is still weak*" (O_02).

Regarding prevention of (serious) illness, H.16—Consultation of a doctor is considered to have the highest "general effectiveness." However, "*the number of caring staff is far from being proportional to the population size. The medication is very expensive. As a result, those who do not have the financial means are obliged to treat themselves at a local* 'healer'"(O_04). This challenge is particularly strong in rural areas (12.50; 14.14; t (13) = −3.10, p = 0.008).

H.11—*The use of mosquito nets* is *easy to implement*, resulting in high "adjusted effectiveness" values for rural and urban life (13.57; 14.14; p > 0.05). The experts described it as common practice, but likewise mentioned prevalent alternative conceptions: "*some only use those [mosquito nets] that are not impregnated [treated with insecticide], because they fear respiratory diseases*"(U_02).

Concerning risk avoidance, most courses of action have approximately equal "adjusted effectiveness" in urban and rural life. An exception is H.21—*The safe use of pesticides*, which has higher values for urban settings (11.50; 12.93; t (13) = −2.22, p = 0.045) (see Appendix D). The experts mentioned the need for specific instruction to reduce the health risk regarding H.21: "*the sellers of pesticides should explain to their clients how to handle the products*" (O_03).

Likewise, the experts mentioned the need to better inform the population about H.23—*Respecting the security rules for driving* (10.57; 10.57; p > 0.05) as "*many drivers of motorbikes or cars do not master the traffic rules and drive with excessive speed*"(O_02). In both rural and urban settings, H.23 displays the lowest "implementation" ratings and the lowest "adjusted effectiveness" values of all risk avoidance courses of action. To foster the implementation of H.23, the experts called for increased controls: "*the responsible authorities should be strict and fair with the execution of penalties regarding the non-compliance of security and traffic rules*" (S_01).

4. Discussion

In this study, we identified regionally relevant topics and corresponding courses of action that can be incorporated into NE Malagasy primary education in order to promote SD-relevant procedural knowledge. The topics cover land-use issues (referring to SDGs 12 and 15) and health issues (referring to SDGs 2, 3, and 6). Expert ratings (second round of Delphi study) gave us information on

- the "general effectiveness" of courses of action with respect to land use and health—regardless of the possibility of implementation;
- the "possibility of implementation" of the courses of action in rural (and additionally, for the health context, urban) life in the SAVA region; and
- the calculated effectiveness under given conditions in the SAVA region, which can function as an index for "what to teach regarding ESD" under the given specific socioeconomic conditions (abridged as "adjusted effectiveness" value).

The "possibility of implementation" and hence the "adjusted effectiveness" of the courses of action can change over time depending on, among other factors, prosperity and support for primary education. The index, therefore, represents a "snapshot" of the conditions during the time of the study in 2018. Thus, the presented approach has two foci: (i) "general effectiveness", indicating the general, perhaps long-term (depending on improved socioeconomic conditions) relevance for regionally relevant ESD, and (ii) "adjusted effectiveness", indicating what to teach regarding ESD under the given specific socioeconomic conditions in 2018. From these results we can derive what to prioritize for regionally adapted ESD in primary education in the SAVA region, both now and in the future.

We discuss the issues of land use and health consecutively. For both, the focus first lies on the scale and subscale levels. Subsequently, we discuss the results on the level of courses of action.

4.1. Land-Use Topics for Teaching Procedural Knowledge to Promote SDGs 12 and 15 in the SAVA Region

The identified topics management of vanilla cultivations, management of cultivations other than vanilla, and soil management built reliable subscales of the three primary scales within the land-use context (biodiversity conservation, agronomic productivity, and possibility of implementation in rural life) (Table 4).

Higher ratings of "general effectiveness" for biodiversity conservation than for agronomic productivity on scale and subscale levels show that the experts clearly differentiated their ratings between the two fields of action. This is plausible in light of the sustainability standards considered for the development of the courses of action (Figure 1). The majority of these standards have an explicit focus on environmental aspects, including on the maintenance of soil, forests, and biodiversity, whereas management aspects, such as production efficiency, are only marginally included (cf. [69]).

The management of vanilla cultivations and the vanilla-related courses of action within soil management (L.15 and L.16) have a particularly high "possibility of implementation" (Figure 3). This indicates that agroforestry—combining high yields with biodiversity conservation [39,40]—is worth teaching in the SAVA region.

Moving on to the results on the courses of action level, the experts explained that courses of action such as having a diversity of endemic shade trees (L.5) or shade regulation (L.6) are common practice in vanilla cultivation in the SAVA region. For evaluation of the potential of shade tree diversity (L.5) for biodiversity conservation, the following has to be considered: most vanilla cultivations are either derived from former fallows or from forests. Fallow-derived cultivations have a low tree diversity, but their establishment increases biodiversity. Forest-derived cultivations have a high tree diversity, but their establishment decreases biodiversity [78]. This, again, is an issue to be considered in regionally adapted teaching.

Furthermore, the diversification of tutor trees (L.4) used in the cultivation of vanilla shows a high "adjusted effectiveness" for biodiversity conservation, but lower "adjusted effectiveness" for agronomic productivity. The experts emphasized the increased workload of this practice. Planting a diversity of tutor trees in agroforestry systems is part of the sustainability standards of vanilla certifiers [69]. These standards "typically consist of a core generic standard that may have difficulties doing justice to the highly variable conditions under which crops are produced across the tropics" [43] (p. 19).

The enhanced agronomic productivity of intensive use of land presented in management of cultivations other than vanilla (e.g., paddy rice monocultures) is generally accompanied by decreased biodiversity [41,42]. However, two courses of action have no significant differences in the "adjusted effectiveness" regarding biodiversity conservation and agronomic productivity: fertilization of paddy rice cultures (L.10) and cultivation of small gardens (L.13).

The experts clearly differentiated between paddy rice (L.10) and hill rice (L.11). Hill rice was negatively associated with slash-and-burn practices that contribute to biodiversity loss and decreased soil fertility in Madagascar [5,51]. Previous interventions to encourage farmers in NE Madagascar to replace self-provisioning hill rice production with cash crops like vanilla or coffee have not been successful (cf. [5]). This is most likely connected to the long tradition of slash-and-burn practices and self-provisioning [5]. The expert associations indicated that these complex factors should be taken into account when addressing unsustainable hill rice production in primary education.

Interestingly, the high "adjusted effectiveness" of cultivation in small house gardens (L.13) for biodiversity conservation and agronomic productivity was particularly supported by the qualitative comments. Currently, teaching gardening practices through school gardens is not common in primary schools in the SAVA region [25].

Soil management appears to be more difficult to sustainably implement than is the management of vanilla cultivations. The majority of experts mentioned land scarcity as a hindering factor in implementation of sustainable soil management, such as letting tired soil recover (L.20). This led to lower "adjusted effectiveness" values. Indeed, strong demographic growth is a major factor in the expansion of cropland in NE Madagascar [5]. Less available land forces poor rural households to practice unsustainable soil management (e.g., shorter fallow cycles) and prioritize short-term benefits over long-term biodiversity conservation [12,68]. This land scarcity, as mentioned in the expert comments, makes obvious that courses of action that are closely connected to sufficient land access would not fit the local realities in NE Madagascar.

The experts mentioned the need for technical supervision regarding three courses of action in the land-use context (L.7, L.9, and L.21). This response indicates that implementation requires specific knowledge far beyond primary education. Nevertheless, introducing such practices already at the primary level could be beneficial for sustainable land use (cf. [68]).

4.2. Health Topics for Teaching Procedural Knowledge to Promote SDGs 2, 3, and 6 in the SAVA Region

The identified topics consideration of clean water, sanitation, and hygiene, consideration of food hygiene and healthy diet, prevention of (serious) illness, and risk avoidance built reliable subscales of the three primary scales within the health context (good health and well-being, possibility of implementation in rural life and possibility of implementation in urban life) (Table 5).

On scale level, the experts gave, on average, remarkably high effectiveness ratings ("general effectiveness"). This is particularly the case for consideration of clean water, sanitation, and hygiene, for consideration of food hygiene and healthy diet, and for prevention of (serious) illness. In terms of health prevention, the courses of action are easier to implement in urban than in rural settings.

In Madagascar, the consideration of clean water, sanitation and hygiene is promoted by "Water, Sanitation and Hygiene" (WASH) initiatives that are, inter alia, active in primary schools (cf. [45]). Yet, differences between rural and urban WASH habits are still prevalent [49,52]. Most of the primary schools in the SAVA region lack direct access to water [25], which is an important hindering factor for practicing handwashing (H.1) and teeth-brushing (H.2) in school. Thus, both courses of action plausibly show a restricted "adjusted effectiveness", especially in rural areas. Here, the use of tippy-taps (H.12) with higher "implementation" ratings in rural settings can be an option for enhancing water access for handwashing, etc., in primary schools (cf. [79]). As the experts mentioned, households habits can be a hindering factor for regular hygiene practices, so teaching these practices in school (H.17) is highly relevant (cf. [80]).

Surprisingly, the experts rated the use of latrines (H.19) as *easy to implement* in rural and urban areas, resulting in a remarkable high "adjusted effectiveness" for both implementation settings (Figure 5). However, the low number of latrines and toilets in Malagasy households restricts the use of latrines, particularly in rural areas [20,49].

Concerning food hygiene and healthy diet, limited market access in rural areas makes a healthy diet highly dependent on the seasonal availability of fruits and vegetables (cf. [48]). In rural settings, many households suffer from dietary deficiencies during the annual hunger gap [48]. In contrast, food hygiene practices (i.e., cleaning the food and well-cooking—H.7) seem to be common in Madagascar even if urban households are more aware of the importance of clean food, compared to rural households [81]. These results suggest that differences in urban and rural settings should be taken into account when connecting teaching to local realities.

Regarding prevention of (serious) illness, existing infrastructure includes severe barriers, particularly in rural areas [31,49]. As a result, rural households, in comparison to urban households, seek professional health care less often (H.16) and more often choose self-medication or consultation with traditional healers [31,49]. In contrast, the use of bed nets to fight malaria (H.11) is common in urban and rural areas. Mass distribution campaigns of impregnated mosquito nets may be partially responsible for decreasing child mortality in Madagascar [46].

The experts rated courses of action related to risk avoidance as, tendentially, easier to implement in urban than in rural areas (Figure 5). Respecting the security rules when driving (H.23) shows the lowest "possibility of implementation" in both urban and rural areas. Traffic accidents are a severe problem in Madagascar [11]. As the *Plan Sectoriel de l'Éducation* was indefinitely suspended in 2019, introduction of road safety education into primary education as part of *Éducation civique* (cf. [23,82]) remains unclear. Similarly, the current primary school curricula do not include the importance of body protection during pesticide use (H.21) (cf. [28]). However, most of the untrained vendors of low-cost phytosanitary products are unable to appropriately inform their clients about environmental and health risks of pesticide use [83]. This causes "a serious threat to agro-ecological balance and health" [83] (p. 35).

4.3. Limitations

It was difficult to include an equal number of men and women in the study; women are underrepresented among the group that corresponds to our expert definition (see Section 2.5). Where possible, we explicitly invited women, but many refused participation due to lack of time. Instead, they mostly proposed male representatives. Therefore, a potential gender bias of the ratings has to be considered. As traditional gender roles and labor division are still prevalent in Madagascar [84,85], even among the more highly educated population [86], a biased perspective is possible (e.g., on daily household activities). This bias could potentially cause less reliable implementation ratings regarding courses of action related to household activities, such as food preparation.

Furthermore, the data show that experts in the health context had a lower self-estimation of knowledge than the experts in the land-use context (Appendix A).

As experts from remote rural areas had to be excluded in the second round due to infrastructural restrictions, the sample composition of the second round predominantly consists of experts from urban areas. Only three practitioners that participated in the second Delphi round come from rural areas. Thus, the expert ratings regarding "possibility of implementation in rural areas" could be biased. Nevertheless, both the first and second Delphi round included a rich sample composition that resulted in valuable information from multiple local perspectives (Appendix B).

Moreover, the answering format shows a limitation. Compared to the relative specificity of the effectiveness ratings, the implementation ratings are vaguer, as they refer to existing routines, beliefs, and resources. However, we were able to gain clarity through complementing the quantitative data with the qualitative expert comments.

5. Conclusions and Future Work

In this section, we give recommendations for land-use and health issues, draw conclusions, and provide an outlook on future work. In this study, we successfully elaborated a Delphi approach for the regionally sensitive identification of courses of action that are relevant for ESD in a development context, exemplified for the SAVA region. We identified topics to teach regarding land-use and health issues in the SAVA region. The corresponding courses of action are regionally effective and implementable and are generally worth teaching in regionally adapted primary education in ESD for SDGs.

In light of the gained knowledge of our study, regional ESD benefits from the following:

The higher general effectiveness of land-use topics regarding biodiversity conservation compared to agronomic productivity led to the necessity of additionally addressing further teaching content that focuses on agronomic productivity in ESD. Blanco et al. [52] suggested introducing into regional education vanilla-related teaching approaches unique to the SAVA region. Indeed, vanilla-related courses of action turned out to be particularly suitable for ESD in the SAVA region. However, the teaching has to be linked to the given situations (e.g., fallow- and forest-derived vanilla cultivation) in order to adequately address, for example, the value of shade tree diversity. With respect to management of cultivations other than vanilla, teaching gardening practices through school gardens (L.13) should be particularly promoted—especially as these practices also promote healthy diet in the health context. Even if some courses of action related to land use require specific knowledge for correct implementation (i.e., L.7, L.9 and L.21), it is worth addressing them at the primary level in order to highlight their relevance and meaningfulness for further learning in ESD (cf. [68]).

Based on the qualitative expert comments, courses of action regarding hill rice (L.10) and land scarcity (L.1, L.12, L.19, and L.20) ultimately did not completely fit the local realities. Regionally relevant teaching of such courses of action requires consideration of multiple factors that are linked to unsustainable hill rice production and land scarcity.

The striking differences between the "possibility of implementation" of health-related courses of action in rural and in urban settings highlight that health education requires an adaption to the rural or urban school setting. This applies particularly to the topics of clean water, sanitation and hygiene, food hygiene and healthy diet, and prevention of (serious) illness. The required adaption implies the consideration of, for example, existing water sources for teaching drinking water treatment, distance to health facilities for teaching medical treatment, and regional and seasonal availability of foods for teaching healthy diet. Furthermore, primary schools should explicitly target parents and "encourage more student-to-home messages" [45] (p. 26) in order to foster sustained health-conscious behavior.

Regarding risk avoidance, the safe use of pesticides (H.21) turned out to be particularly relevant for primary education, especially for rural areas. Road safety education (H.23) appears to be equally relevant for rural and urban settings. As both courses of action are currently not part of the primary school curricula, their integration should be considered for further developments.

In sum, the findings of this study highlight the importance of quantitative and qualitative information about current conditions on-site when one is designing regionally relevant school curricula with concrete links to local realities. The newly established index "adjusted effectiveness" explicitly considers the given socioeconomic conditions. The index is especially integral for understanding background information in low-income countries, for defining hurdles that must be overcome, and for figuring out what works. Such information makes the gained knowledge particularly relevant for regionally sensitive approaches (in our case, for the SAVA region).

As a result, the present study provides starting points for further developing primary school curricula in the SAVA region with respect to ESD, as intended in the *Plan Sectoriel de l'Éducation* [27]. Moreover, the gained knowledge can serve as a reference for NGOs that currently strongly contribute to environmental education in Madagascar [22] and to promotion of health in schools (e.g., [45]).

The successful implementation of a certain curriculum always depends on corresponding teacher knowledge. To design appropriate SD teacher trainings for land-use and health-related SDGs, it is necessary to gain information on teacher prerequisites for teaching procedural knowledge linked to specific SDGs. Therefore, the teacher's procedural knowledge has to be assessed, which we intend to do in future research. For this purpose, the results of the present Delphi study on expert effectiveness and implementation ratings, as displayed in Appendix C (land use) and Appendix D (health), can serve as a benchmark. This benchmark is suitable to use in the assessment of teacher procedural knowledge, as it is a highly important knowledge type for SD-related problem-solving. Following the procedure successfully applied by Richter-Beuschel and Bögeholz [87], our research provides a tool for making primary teacher procedural knowledge measurable in two crucial contexts of ESD. In doing so, the study provides a suitable standard with regional relevance (land use) and relevance for low-income countries (health context). Knowledge of corresponding teacher procedural knowledge and thus their prerequisites for further teacher education is integral to achieving the SDGs. In Madagascar, this applies particularly to primary education, as it is the highest level of formal education for most of the population. Our benchmark for measuring procedural knowledge on land-use and health issues allows for progress in evidence-based primary teacher ESD and for further education on the SDGs in the future.

In addition to allowing the assessment of primary teacher procedural knowledge on land-use and health issues in the future, the study argues mainly for the following benefits: (i) identifying suitable means to promote SDG-relevant procedural knowledge in primary education, and (ii) providing a procedure to define "what works", both in general and under given specific socioeconomic conditions. This study might thereby inspire future research into regionally adapted educational measures for promotion of the SDGs. Regarding the identified land-use and health issues, this study primarily accounts for Madagascar, specifically the Northeastern region of the country. However, with only a few adaptions, especially regarding the health issue, this procedure is applicable in other low-income countries far beyond the SAVA region of Madagascar.

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Appendix A. Expert Self-Rated Knowledge

Table A1. Self-rated knowledge by experts that participated in the second Delphi round in the land-use context (*n* (2nd Delphi round) = 13) and the health context (*n* (2nd Delphi round) = 12) (mean: M; standard deviation: SD; 0: *not satisfying*, 1: *satisfying*, 2: *good*, 3: *very good*, 4: *excellent*).

Land-Use Context			**Health Context**		
Domain of Self-Estimation	**M**	**SD**	**Domain of Self-Estimation**	**M**	**SD**
Sustainable development	2.31	1.18	Well-being	1.86	1.17
Education for Sustainable Development	2.23	1.17	Sustainable Development	1.71	0.99
Agricultural education	2.23	1.36	Health	1.57	1.28
Education for biodiversity conservation	2.08	1.19	Health education	1.57	1.22
Vanilla production	2.08	1.04	Clean Water	1.57	1.02
Paddy rice production	1.92	0.95	Sanitation	1.50	0.94
Biodiversity conservation	1.85	1.21	Education for Sustainable Development	1.50	0.94
Hill rice production	1.69	1.03			
Agronomic productivity of ecosystems	1.38	1.04			

Appendix B. Sample Composition

Table A2. Sample composition of the two rounds of the Delphi study (*n* (Both Delphi rounds) = 34) in land-use and health context.

Representatives from Working Areas/Institutions	**Land-Use Context** **n (Both Delphi Rounds) = 23;** **n (1st Delphi Round) = 19;** **n (2nd Delphi Round) = 15**	**Health Context** **n (Both Delphi Rounds) = 22;** **n (1st Delphi Round) = 20;** **n (2nd Delphi Round) = 14**
Local directorates of national ministries	Regional Directorate of Agriculture and Animal Husbandry (58), Regional Directorate of Environment, Forests and Tourism (29), Regional Directorate of Rural Development (48) [2]	Regional Directorate of the Population (35), Regional Directorate of National Education (Responsible for school health) (42), Regional Directorate of Water, Energy and Hydrocarbon (60) [1]
	Regional Directorate of National Education (42) [1], Regional Directorate of National Education (44) [2], Regional Directorate of Water, Energy and Hydrocarbon (53) [2]	
NGO/Association	CARE International (57), Duke Lemur Center (42), Graine de Vie (38)	Save the Children (31), Program MAHEFA Andapa (31), Program MAHEFA Sambava (50), VATIFA (35)
Secondary and tertiary education	Ph.D. Student in Ecology (33), Teacher of Technical School of Agriculture (45), Professor at Department of Sustainable Agriculture, University of Antananarivo (40) [1]	Professor at Medical Faculty, University of Diego (60), Teacher of Paramedical Institute (29), Teacher of Paramedical Institute (26)
	Teacher in leading position of CURSA University Andapa (58)	
Practitioners	Vanilla expert (n.a.) [2], Vanilla expert (68), Leader of local vanilla farmers' association (47)	Doctor in rural health center (62)
	Vanilla expert and influential person on community level (70)	
Rural school directors	Director in district of Andapa (43) [1], Director in district of Antalaha (43) [1], Director in northern district of Sambava (29)[1]	
Local authorities in rural areas	Deputy of village chief in district of Andapa (47) [1], Sector chief in district of Antalaha (40) [1], Village chief in northern district of Sambava (47) [1]	

Age indication at the time of study participation (May 2018—January 2019), [1] = only first round; [2] = only second round; n.a. = age not stated.

Appendix C. Expert Ratings Regarding Land-Use Issues—Benchmark

Table A3. Rated courses of action in the land-use context. Second Delphi round; each topic includes three subscales (i.e., one subscale per field of action/implementation setting); *n* (2nd Delphi round) = 15; mean: M; standard deviation: SD.

Topic	Course of Action	Fields of Action				Implementation Setting	
		Biodiversity Conservation		Agronomic Productivity		Rural Life	
		M	SD	M	SD	M	SD
Management of vanilla cultivations	L.4 Having a diversity of tutor trees (e.g., jatropha, gliricidia, coffee) on the vanilla plantations.	3.67	0.62	3.00	0.76	3.33	0.73
	L.5 Having a diversity of shade trees of Malagasy origin on the vanilla plantations (e.g., albizia, tsararavigny).	3.80	0.41	3.40	0.74	3.67	0.62
	L.6 Regulating the shade on the vanilla plantations (e.g., by trimming the trees and bushes).	3.20	0.86	3.80	0.41	4.00	0.00
	L.7 Uprooting the vanilla lianas that are contaminated in the plantations, burning them, and burying them.	3.40	0.51	3.20	0.68	3.53	0.52
	L.8 Selecting vanilla lianas of good quality for planting (e.g., healthy lianas that are resistant to disease and tolerant towards environmental influences).	3.73	0.46	3.87	0.35	3.73	0.46
	L.9 Having cultivated plants other than vanilla on the vanilla plantations (e.g., coffee, cacao).	3.67	0.49	3.20	0.56	3.60	0.51
	Subscales of management of vanilla cultivations	3.58	0.33	3.41	0.38	3.64	0.36
Management of cultivations other than vanilla	L.2 Not letting invasive plants grow in an uncontrolled manner (e.g., water hyacinth, *Lantana camara*).	3.27	0.60	3.73	0.46	3.67	0.46
	L.10 Planting paddy rice plants of the previous harvest that are of good quality (e.g., healthy plants that are resistant to diseases and tolerant towards environmental influences).	3.87	0.35	3.67	0.49	3.40	0.51
	L.11 Sowing seed of hill rice of the previous harvest that has a good quality (e.g., healthy seeds that are resistant to diseases and tolerant towards environmental influences).	3.67	0.49	3.20	0.68	3.33	0.49
	L.13 Cultivating fruits and vegetables in small gardens next to the house (e.g., oranges, litchis, tomatoes, eggplants).	3.80	0.41	3.73	0.46	3.73	0.59
	L.14 Leaving fruit trees on the hill rice cultures (e.g., mango, litchi).	3.47	0.52	2.67	0.49	3.40	0.74
	Subscales of management of cultivations other than vanilla	3.61	0.34	3.40	0.34	3.51	0.35
Soil management	L.1 Letting the vegetation on non-cultivated plots develop naturally (e.g., land on steep slopes, abandoned land).	3.53	0.52	3.33	0.73	3.00	0.66
	L.12 Alternating the hill rice with different cultures during the year (e.g., tomatoes, beans, cucumber).	3.53	0.64	3.40	0.63	3.47	0.52
	L.15 Having an herbaceous undergrowth on the vanilla plantations to fix the soil during the year (e.g., lawn, grass).	3.87	0.35	3.93	0.26	4.00	0.00
	L.16 Fertilizing the vanilla plantations with natural fertilizer (e.g., branches and leaves left from the cleaning).	3.67	0.49	3.87	0.35	4.00	0.00
	L.18 Fertilizing paddy rice cultures (e.g., with manure, compost).	3.60	0.63	3.60	0.51	3.20	0.56
	L.19 Fertilizing hill rice cultures (e.g., with residues from the previous harvest).	3.73	0.46	3.53	0.52	3.20	0.56
	L.20 Letting tired soil recover during a recommended period (e.g., the soil where slash-and-burn has been practiced).	3.67	0.48	3.27	0.59	2.80	0.41
	L.21 Monitoring the soil quality on hill rice cultures and adapting the cultures to the soil conditions (e.g., alternating the cultures during the year, doing companion planting).	3.67	0.49	3.40	0.51	3.27	0.46
	L.22 Having plants with big roots at riversides and river mouths to retain the soil (e.g., keeping trees and bushes, not cultivating sweet potatoes).	3.73	0.46	3.40	0.51	3.13	0.74
	Subscales of soil management	3.67	0.32	3.53	0.26	3.34	0.24

Appendix D. Expert Ratings Regarding Health Issues—Benchmark

Table A4. Rated courses of action in the health context. Second Delphi round; each topic includes three subscales (i.e., one subscale per field of action/implementation setting); n (2nd Delphi round) = 14; mean: M; standard deviation: SD.

Topic	Course of Action	Field of Action		Implementation Settings			
		Good Health and Well-Being		Rural Life		Urban Life	
		M	SD	M	SD	M	SD
Consideration of clean water, sanitation, and hygiene	H.1 Washing hands with clean water and soap (e.g., before eating, after using the latrine).	3.64	0.50	3.00	0.56	3.50	0.52
	H.2 Brushing the teeth regularly and in a recommended way (e.g., two times a day, with a toothbrush and toothpaste).	3.50	0.52	3.00	0.68	3.79	0.43
	H.3 Respect the hygiene rules for the genital organs (e.g., washing them regularly, wearing clean underwear, using clean sanitary towels during the menstruation).	3.71	0.47	3.21	0.70	3.71	0.47
	H.4 Prepare drinking water (e.g., treating with unexpired solutions like Sur'Eau, using filters, boiling water).	3.86	0.36	2.93	0.62	3.64	0.63
	H.5 Respect the hygiene rules concerning water use (e.g., retrieving treated water with a clean utensil, storing treated water in reservoirs with a solid cover).	3.79	0.43	3.00	0.39	3.50	0.52
	H.12 Having constructions for hands-free hand washing (e.g., a tap, a tippy-tap).	3.50	0.52	3.43	0.51	3.79	0.42
	H.17 Learning good techniques of daily hygiene in school (e.g., hand washing, tooth brushing).	3.71	0.47	3.43	0.65	3.79	0.43
	H.19 Using the latrine instead of open defecation and keeping it clean (e.g., rinsing with water, refilling and regularly changing the provided water, covering the hole).	3.93	0.27	3.50	0.52	3.79	0.58
	Subscales of consideration of clean water, sanitation and hygiene	3.71	0.32	3.19	0.32	3.69	0.24
Consideration of food hygiene and healthy diet	H.6 Storing food in safe places (e.g., protected from insects, rats, dust, heat, humidity).	3.50	0.52	3.50	0.94	3.71	0.47
	H.7 Preparing healthy meals (e.g., cleaning the food with clean water, cooking the food thoroughly).	3.79	0.43	3.36	0.63	3.93	0.27
	H.8 Preserving food that is still fresh (e.g., drying fish, salting meat, preparing jam from fruits).	3.57	0.51	3.14	0.54	3.71	0.47
	H.13 Avoiding malnutrition (e.g., eating regularly, eating balanced meals, eating fruits and vegetables with vitamins and minerals).	3.86	0.36	2.86	0.54	3.64	0.63
	Subscales of consideration of food hygiene and healthy diet	3.68	0.24	3.21	0.41	3.75	0.31
Prevention of (serious) illness	H.9 Avoiding to have nesting sites for mosquitos around the house (e.g., drying out puddles, draining standing water, covering standing water with soil).	3.71	0.47	3.57	0.65	3.86	0.36
	H.11 Sleeping under an impregnated mosquito net without holes (e.g., a new mosquito net given by the state). (n = 13; one missing value)	3.64	0.50	3.71	0.47	3.86	0.36
	H.16 In case of serious disease or heavy injury (e.g., measles, fever, a fracture), consulting a doctor, going to a health center or hospital, and following the given advice.	3.79	0.43	3.29	0.61	3.71	0.47
	H.18 Following the measures for good health promoted in the school or the health center (e.g., giving deworming to the pupils, seeking the vaccine).	3.71	0.47	3.36	0.50	3.71	0.50
	Subscales of prevention of (serious) illness	3.71	0.32	3.48	0.39	3.79	0.31
Risk avoidance	H.20 Avoiding exposure to polluted air (e.g., having sufficient ventilation in the kitchen, avoiding the exhaust gas of motor vehicles, avoiding dust).	3.43	0.51	3.77	0.44	3.86	0.36
	H.21 Protecting the body when handling pesticides and other dangerous substances (e.g., using gloves, wearing a working suit, glasses, masks, and shoes).	3.50	0.52	3.21	0.89	3.64	0.63
	H.22 As a pedestrian, paying attention to fast vehicles on the streets (e.g., motorbikes, cars, taxi-brousses).	3.36	0.50	3.86	0.54	3.79	0.58
	H.23 Respecting the security rules when driving a motorbike or a car (e.g., not driving too fast, wearing a helmet on a motorbike, attaching the seat belt if available, using a safe car).	3.43	0.50	3.07	0.48	3.07	0.27
	H.24 Collecting, piling up, and burying unusable waste (e.g., in a precise place outside of the village or city).	3.64	0.50	3.50	0.52	3.57	0.51
	Subscales of risk avoidance	3.47	0.35	3.46	0.50	3.59	0.34

Appendix E. Differences of Adjusted Effectiveness on Course of Action Level—Land-Use Context

Table A5. Paired *t*-test between adjusted effectiveness of the two fields of action in the land-use context. Second Delphi round; *n* (2nd Delphi round) = 15; test statistics: T, degrees of freedom: df.

Topic	Course of Action	Adjusted Effectiveness Biodiversity Conservation vs. Agronomic Productivity			Topic	Course of Action	Adjusted Effectiveness Biodiversity Conservation vs. Agronomic Productivity		
		T	df	*p*			T	df	*p*
Management of vanilla cultivations	L.4	3.81	14	0.002	Soil management	L.1	0.62	14	0.547
	L.5	2.16	14	0.048		L.12	0.63	14	0.536
	L.6	−2.55	14	0.023		L.15	−1.00	14	0.334
	L.7	1.49	14	0.159		L.16	−1.87	14	0.082
	L.8	−0.84	14	0.415		L.18	0.13	14	0.885
	L.9	2.91	14	0.011		L.19	1.85	14	0.086
Management of cultivations other than vanilla	L.2	−2.73	14	0.016		L.20	3.01	14	0.009
	L.10	1.87	14	0.082		L.21	1.83	14	0.089
	L.11	2.43	14	0.029		L.22	1.65	14	0.121
	L.13	1.00	14	0.334					
	L.14	3.98	14	0.001					

Appendix F. Differences of Adjusted Effectiveness on Course of Action Level—Health Context

Table A6. Paired *t*-test between adjusted effectiveness of the two implementation settings in the health context. Second Delphi round; *n* (2nd Delphi round) = 14; test statistics: T, degrees of freedom: df.

Topic	Course of Action	Adjusted Effectiveness Rural vs. Urban			Topic	Course of Action	Adjusted Effectiveness Rural vs. Urban		
		T	df	*p*			T	df	*p*
Clean water, sanitation, and hygiene	H.1	−3.55	13	0.004	Prevention of (serious) illness	H.9	−2.26	13	0.042
	H.2	−3.90	13	0.002		H.11	−1.47	13	0.165
	H.3	−2.77	13	0.016		H.16	−3.10	13	0.008
	H.4	−4.30	13	0.001		H.18	−2.69	13	0.019
	H.5	−2.88	13	0.013	Risk avoidance	H.20	−1.48	12	0.165
	H.12	−2.65	13	0.020		H.21	−2.22	13	0.045
	H.17	−2.67	13	0.019		H.22	1.00	13	0.336
	H.19	−1.69	13	0.114		H.23	0.00	13	1.000
Food hygiene and healthy diet	H.6	−1.28	13	0.222		H.24	−0.56	13	0.583
	H.7	−3.31	13	0.006					
	H.8	−3.47	13	0.004					
	H.13	−5.08	13	0.000					

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Students' Conceptions of Sustainable Nutrition

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Abstract: In Education for Sustainable Development, the topic of sustainable nutrition offers an excellent learning topic as it combines the five dimensions of health, environment, economy, society, and culture, unlike most topics with a regional-global scope. The identification of existing students' conceptions of this topic is important for the development of effective teaching and learning arrangements. This study aimed to understand students' conceptions of sustainable nutrition and the relevance that students attribute to the five dimensions. For this purpose, we conducted semi-structured individual interviews with 10th-grade students at secondary schools in Germany (n = 46; female = 47.8%; M_{Age} = 15.59, SD = 0.78). We found that the health dimension prevailed in students' conceptions of sustainable nutrition; however, the more dimensions the students considered, the less importance was attached to the health dimension. The ecological dimension, in turn, became more prominent as the students' conceptions became more elaborate. Many students neglected the social, economic, and especially the cultural dimensions. Furthermore, alternative conceptions of the terminology of sustainable nutrition, which did not correspond to the scientific concept, were identified. Students had difficulties linking the ecological, social, economic, and cultural dimensions to sustainable nutrition due to a predominant egocentric perspective on nutrition, which primarily entails focusing on one's own body.

Keywords: sustainable diet; pupils; preconceptions; understanding; qualitative interview study; Education for Sustainable Development

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1. Introduction

The current global food system is the largest greenhouse gas emitting sector in the world [1]. Furthermore, it is mainly responsible for biodiversity loss and the degradation of ecosystems [2,3] and is considered the largest sector-specific source of water pollution [4]. While 820 million people are currently suffering from hunger [5], the number of overweight people has almost tripled to over 1.9 billion since 1975 [6]. Similarly, the rising prevalence of diet-related diseases in industrialized countries is an expression of the inherent shortcomings of the current food and agricultural sector [7]. Without a transformation toward healthy diets from sustainable food systems, the international community will be unable to meet the Sustainable Development Goals (SDGs) set by the United Nations [8] and the Paris Climate Agreement [9,10].

Changes in individual nutritional behavior are an essential prerequisite for such a transformation; therefore, education that empowers learners in the context of nutrition "to take informed decisions and responsible actions for environmental integrity, economic viability, and a just society for present and future generations" is needed [11] (p. 7). In view of its importance for achieving the SDGs, our own diet and the processes related to our food system are perfectly suited to Education for Sustainable Development (ESD). As future consumers and decision makers, students can actively contribute to the sustainable development of the nutrition system, e.g., by shaping their individual nutritional habits in a sustainable way and exerting a positive influence on their personal and social environment. In this context, schools fulfill an important educational task, as appropriate education "empowers learners to take informed decisions and responsible actions for environmental integrity, economic viability, and a just society, for present and future generations, while respecting cultural diversity" [12] (p. 12).

Following a constructivist perspective, we understand students to be actively structuring their knowledge [13,14]. Based on their individual experiences, students already hold conceptions of teaching content before they are confronted with it in the classroom. We use the term "conceptions" to summarize cognitive constructs of different levels of complexity, such as associations, cognitions, and subjective theories [15]. Students construct new knowledge structures based on pre-existing conceptions [16]. They use already existing conceptions in order to explain new problems or phenomena (assimilation) and extend or adapt their conceptions when these are not adequate to explain new problems (accommodation) [14,16]. We base our research on this learning theory, because behaviorism only examines what is observable (interaction between environmental influences and behavior) and does not take into account the inner processes of information processing. Cognitivism, in turn, takes this inner process into account but fails to consider individual differences in the learning process and assumes that knowledge is passed on from one person to another and then exists as a representation of the environment in the individual [17,18]. This is contrasted with a constructivist view according to which learning represents an active, self-defined, and individual construction process that takes place in context-bound social situations and cannot be controlled from the outside but can be stimulated by a supportive learning environment with suitable learning options [14,19]. It forms the basis for research on students' conceptions in didactics of natural sciences.

A better understanding of students' conceptions helps teachers systematically address them in science teaching [20,21]; thus, the identification of students' existing conceptions is essential for the development of appropriate and effective teaching and learning arrangements on sustainable nutrition, and its consideration is critical for the students' learning success [20,21]. In our study, we were especially interested in students' naïve and alternative conceptions of sustainable nutrition. "Naïve conceptions" represent students' conceptions of sustainable nutrition before they receive information on this topic from us. "Alternative conceptions" represent students' conceptions that do not correspond to the scientific definition of a sustainable diet according to von Koerber et al. [22] (see also, Results, research question two (RQ2): What alternative conceptions do students hold about sustainable nutrition?).

To the best of the authors' knowledge, only a few studies on students' conceptions of sustainable nutrition have been published. Most of these studies relate to their general conceptions of nutrition or agriculture, but none were clearly based on a definition of sustainable nutrition; therefore, the primary aim of this study is to explore students' conceptions of sustainable nutrition in order to compare them with scientific conceptions and derive implications for teaching practice.

1.1. Definition of Sustainable Nutrition

There are various definitions of sustainable nutrition [4,10,22–24]. Internationally, reference is often made to the definition published by the Food and Agriculture Organization of the United Nations (FAO) [4] (p. 294), which defines sustainable diets as follows:

> "Sustainable diets are those diets with low environmental impacts which contribute to food and nutrition security and to healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources."

Our study is based on the concept of sustainable nutrition posited by von Koerber et al. [22], which is particularly prevalent in German-speaking countries and therefore suitable for use in German schools. This representation takes into account the five dimensions: (1) health, (2) environment, (3) economy, (4) society, and (5) culture. In addition, it contains seven recommendations for action in everyday life, which includes how people can feed themselves as sustainably as possible by incorporating (1) plant-based foods, (2) organic foods, (3) regional and seasonal products, (4) minimally processed foods, (5) Fair Trade products, (6) resource-saving housekeeping, and (7) an enjoyable eating culture.

There are many similarities between the two definitions of sustainable diets posited by the FAO [4] and von Koerber et al. [22], especially with regard to the different dimensions of sustainable nutrition. The concept of sustainable nutrition by von Koerber et al. [22] was used as a basis for data collection and evaluation in this study. The advantage of this definition lies in its clearer structure resulting from unambiguously defined dimensions and the concrete recommendations for implementing sustainable nutrition in everyday life. Conversely, the definition described by the FAO [4] is less accessible to students due to its complex structure. In addition, it does not give clear instructions on how to sustainably feed oneself in everyday life. Because a detailed description of sustainable nutrition according to Koerber et al. [22] is beyond the scope of this article, we recommend using the original literature to review the concept [22,25].

1.2. Sustainable Nutrition as a Teaching Topic in Education for Sustainable Development

Through the 2030 Agenda, the United Nations formulated 17 SDGs for shaping a sustainable future, which will guide political action until 2030 [8]. In the field of education, the SDGs aim to "ensure that all learners acquire the knowledge and skills needed to promote sustainable development" (Target 4.7 of SDG 4–Quality Education) [8]. The transition to sustainable nutrition is considered key for achieving many SDGs (e.g., SDG 2 "Zero Hunger" or SDG 12 "Responsible consumption and production") [26]. Due to its high relevance for achieving the SDGs, sustainable nutrition is perfectly suited for an ESD [11], and because this topic combines ecological, economic, social, and health aspects to a greater degree than most other topics with a regional-global scope, it was declared by the German Commission for UNESCO as the 2012 topic of the year of the UN Decade of Education for Sustainable Development [27].

In Germany, each of the 16 federal states has its own school curricula, but they are very similar. We only refer to the school curricula of the three school types (Hauptschule, Realschule, and Gymnasium; see *Data Collection and Sampling*) in Lower Saxony, where the study was conducted. German school curricula are competence-oriented, which is why there are few recommendations for concrete teaching topics, and teachers have a high level of freedom to choose adequate content. ESD is an integral part of school curricula and can be taught through varying content, which can be chosen at the teachers' discretion. Nevertheless, there are a few recommendations in the sifted school curricula for teaching nutritional topics and ESD.

Despite the topic of nutrition being perfectly suited for ESD, in Germany, school curricula for natural sciences only recommend it in combination with health aspects in the context of one's diet [28], or it is missing completely [29,30]. Conversely, ESD is associated with issues of environmental conservation or sustainable energy [28–30]. A similar trend can be observed in the most commonly used biology textbooks [31–35]. Both textbooks and school curricula indicate that, despite its potential, as indicated by Burlingame et al. and von Koerber et al. [4,22], the topic of nutrition is not yet perceived as a suitable topic for ESD in the German teaching practice.

1.3. Students' Conceptions of (Sustainable) Nutrition and Agriculture—Current State of Research

In recent studies, both high school students [36] and adult consumers [37] perceived nutrition mainly from a self-centered perspective and hardly noticed the environmental impact of their own nutrition. Consequently, they either did not recognize the influence of their own dietary behavior on the global food system or considered it to be very small [36,37]. Hamann [38], who examined primary school children's conceptions of agriculture in Germany, concluded that they had only diffuse and superficial ideas about the environmental impact of agriculture and took little account of ecological and economic aspects. A meta-study of 190 studies derived similar results, concluding that young people (aged 3–19 years) have very limited knowledge and understanding of agriculture and food production [39].

Regarding nutritional-physiological aspects, de Freitas Zompero et al. [40] found that Brazilian elementary and high school students lack coherent conceptions of nutrients and are unable to distinguish nutrients from food; however, a study on Australian high school students revealed they understand the importance of different macronutrients in the body but are unable to distinguish their functions [41]. Furthermore, Rasnake et al. [42] identified a tendency for young people to be dose insensitive (e.g., something harmful in large amounts should be avoided in small amounts) and categorical thinkers (e.g., foods are either good or bad). With respect to the relationship between body and nutrition, it has been shown that many young people are dissatisfied with their body, in the sense that they think they are overweight [43], and that female adolescents in particular adopt eating behaviors in which they forego certain foods or entire meals as a means of achieving their desired figure [44–46].

Concerning nutrition as a sustainability issue, Gralher [36] showed that high school students primarily focused on health aspects of nutrition and mostly ignored ecological, social, and economic aspects. The focus on health is also evident in the German population, where 89% of people believe that eating should be healthy [47], which some surveys found to be more important than taste [48]. In contrast, university students were found to have an ecological perception of sustainable nutrition [49,50]. The latter finding was also noted in numerous studies of other sustainability contexts in which the participants took account of ecological aspects but paid little attention to economic and social aspects [51–55]. Moreover, in general, high school students seem to have difficulties in taking into account more than two dimensions in sustainability contexts [56].

1.4. Aim of the Study and Research Questions

Based on the current state of research, the present study aimed to explore students' conceptions of sustainable nutrition. We were particularly interested in the extent to which their conceptions are consistent with the scientific conception of a sustainable diet according to von Koerber et al. [22]. In more detail, the following research questions were addressed:

RQ1: What relevance do the students attribute to the five dimensions of sustainable nutrition?
RQ2: What alternative conceptions do students hold about sustainable nutrition?

2. Materials and Methods

2.1. Data Collection and Sampling

To answer our research questions, we conducted semi-structured individual interviews with 46 10th-grade students from August 2017 to March 2018. The school system in Germany covers primary (grades 1–4) and secondary (grades 5–13) education. The lower secondary education (grades 5–10) follows a tripartite structure in which three different school types are included. The *Hauptschule* offers students a "basic general education," the *Realschule* offers a "more extensive general education," and the *Gymnasium* offers an "intensified general education" [57] (p. 121–122). The Hauptschule is completed after nine school years and can be extended by one year to achieve a better degree. The Realschule is completed after ten years, and the Gymnasium, after 13 years. In order to capture the diverse ideas of students from all three school types, we considered all three in our sample selection ($n_{Gymnasium}$ = 16, *female* = 8, M_{age} = 15.1, *SD* = 0.44; $n_{Realschule}$ = 15, *female* = 7, M_{age} = 15.6, *SD* = 0.63; $n_{Hauptschule}$ = 15, *female* = 6, M_{age} = 16.1, *SD* = 0.83; for detailed information on the respective subsamples and on individual participants, see Supplementary Material, Table S1). We decided to choose the 10th-grade because we assumed, based on a screening of the respective curricula, that students of all school types should already have received at least some ESD-relevant content in science education [28–30]. Since we conducted a qualitative study with a relatively small sample, it was at no time our intention to compare the students from the three school types.

For each school type, our sample comprised students from three or four different schools in northwest Germany in and around the city of Osnabrück. The acquisition of participants at the respective schools was conducted with the help of a supervising teacher, who was informed in advance by the first author regarding the contents and process of the study. The teacher gave a short introduction to the study and, if possible, selected two male and two female students from the volunteers. Apart from the gender ratio, they had no selection criteria. Accordingly, they selected the students who were the first to volunteer for participation. Since our goal was to explore naïve conceptions, the students were only informed that the study was about their conceptions of nutrition and not explicitly about sustainable nutrition. Due to deviations from the interview guide used during two of the interviews, the authors decided to exclude those two from the sample. Since the students who volunteered first were selected, it can be assumed that some of the participants had a particularly high interest in the topic of nutrition. This assumption is supported by the fact that six participants stated that they follow a vegetarian diet (13%; see Supplementary Material, Table S1), which is considerably higher than the proportion in the German population (4.3%; 18–79 years) [58].

Anonymity was guaranteed and participation was voluntary. Approval for the study was obtained in August 2017 from the responsible State Board of Education in Lower Saxony, Germany—Niedersächsische Landesschulbehörde (NLSchB), which is the body responsible for providing approvals for studies conducted in schools. The headmasters of the participating schools were informed beforehand about the study and provided written consent. In addition, the parents of the students were informed about the study by an information letter in which the voluntary participation and anonymity of the participants were explained. The possibility to contact us was given by the attached contact data. Both the parents and students gave their informed written consent for participation in the study. During the interviews, all participants could decline to participate and withdraw from the study at any time.

2.2. The Interview Procedure

Within the respective schools, individual interviews were conducted in a quiet room by one of three interviewers who were familiar with the subject matter and had received prior instructions in the interview procedure and interview management. All interviewers conducted two or three test interviews with students in the age group to become familiar with the interview procedure and content of the interview guide. The test interviews were not included in the final sample.

The interviews were conducted in German, and the statements were translated into English for the purpose of this paper. The duration of the interviews was between 40 and 113 min (M = 64.11 min; SD = 15.36 min). The large differences in interview duration were caused by the varying response behaviors of the students. Some students needed more time to formulate their thoughts, while others presented their thoughts in detail. The length of the interview does not have any bearing on the quality of the statements made.

Interviews were conducted with the help of a semi-structured interview guide that had previously been tested and adapted through pre-tests (the complete interview guide can be obtained from the first author upon request). The interview guide served as an orientation for the interviewers and was used to develop discussions while allowing participants to express their thoughts in a flexible way. Due to the limited space in this paper, we present the phases of the interview in a shortened form, considering all steps of the interview relevant to the research questions (see Table 1).

The interview guide was divided into four thematic phases: naïve conceptions of sustainable nutrition (Phase 1), the conceptions of the dimensions of (Phase 2) and recommendations for (Phase 3) sustainable nutrition, and the assumed connections between the dimensions and recommendations (Phase 4; see Table 1). For research question one (RQ1), only Phase 1 was considered. For research question two (RQ2), all interview phases were considered. The various interventions in the different phases aimed to create opportunities for talking and revealing alternative conceptions of sustainable nutrition. The statements that revealed alternative conceptions were determined in the course of the phases presented.

In the free association task used in Phase 1, we asked participants to note ten terms that they associated with a sustainable diet. They then explained why they wrote down these terms. Our analysis was based on the students' explanations regarding the terms and not on the terms themselves. The banana with the brand logo used in Phase 2 (see Table 1) represents the most famous brand for bananas in Germany. By the brand logo, we emphasized that it is neither a Fair Trade nor an organic product, whereby we wanted to encourage the students to talk about the different dimensions of sustainable nutrition.

Table 1. Excerpt from the interview guide with the questions that were used in the analysis. The original interviews were conducted in German.

Content and Questions	Materials Used in the Interview
Phase 1–Naïve conceptions of sustainable nutrition	
Students were given a list with the heading 'ten terms on sustainable nutrition' for entering ten terms (see right column). 1. What do you associate with sustainable nutrition? Please write down ten words on this sheet of paper that are coming to your mind. After the task, the students explained to the interviewer what they meant by each term, which was noted on the list. 2. Please try to describe in your own words what you understand by sustainable nutrition 3. Imagine giving a friend recommendations on how to eat more sustainably. Do you have any ideas what you could tell him/her?	**10 terms on sustainable nutrition** 1. Organic 2. Vegan 3. Genetic manipulation 4. Farm 5. Factory farming 6. Self-sufficiency 7. Vegetable garden 8. Home-baked 9. Whole grain spelt 10. Grain field (Data taken from GM9–Felix)
Phase 2–Dimensions of sustainable nutrition	
The students were given a schematic illustration of sustainable nutrition (see right column). 1. Can you explain to me what you understand by these five terms? In case they had any comprehension problems, the students were given a short explanation of the dimensions. 2. How would you relate these dimensions to sustainable nutrition? 3. Would you like to change something in the figure? The students were presented a banana with a clearly visible trademark sticker of a multinational company (Chiquita Brands International; see right column). 1. Do you have any ideas on how to relate this banana with the different dimensions of sustainable nutrition?	 Schematic illustration to illustrate the five dimensions of sustainable nutrition (modified from von Koerber et al. [22].  Banana used to relate the dimensions of sustainable nutrition to a concrete food item.

Table 1. *Cont.*

Content and Questions	Materials Used in the Interview
Phase 3–Recommendations for sustainable nutrition	
Students were presented with a list of the seven recommendations for implementing sustainable nutrition in everyday life (see right column). 1. Please explain what you think is meant by these recommendations. If the students misunderstood some recommendations, we gave them a short explanation.	 1. Preference of plant-based foods 2. Organic foods 3. Regional and seasonal products 4. Preference of minimally processed foods 5. Fair Trade products 6. Resource-saving housekeeping 7. Enjoyable eating culture Seven recommendations for sustainable nutrition (modified from von Koerber et al. [22].
Phase 4–Relationships between the dimensions and recommendations	
1. Could you try to link the recommendations with the terms in this figure? (see the excerpt of the table in the right column) The table listed the five dimensions in the top row and the seven recommendations in the left column.	 Excerpt of the table used in the interview to support the students connecting the recommendations with the dimensions of sustainable nutrition.

2.3. Data Processing and Analysis

The interviews were digitally recorded with an Olympus WS-550M Voice Recorder and transcribed according to the transcription rules set by Dresing and Pehl [59]. We analyzed the interviews using the Qualitative Data Analysis (QDA) software MAXQDA 2018 [60] based on the ideas of qualitative content analysis [61]. In order to answer the two research questions, we modified and adapted the analysis process. To answer RQ1, we classified the students' statements into five deductive categories; "health," "ecological," "economic," "social," and "cultural," according to the five dimensions of sustainable nutrition [22] (Figure 1). As these were deductive categories, they were defined before the interview material was analyzed. The definitions were documented in a coding guideline, which described in detail what kind of statements should be assigned to the respective categories. For better comprehensibility, anchor examples from the interview material were added at the beginning of the coding process for the respective categories. Based on the number of statements assigned to the different dimensions, we were able to determine how many students considered how many and which dimensions and to what extent in Phase 1 of the interview.

To capture the alternative conceptions in the context of RQ2, we retained the structure of our initial code system and extended it by inductive subcategories based on the participants' statements. Furthermore, we added one inductive category including subcategories (terminology of sustainable nutrition; Figure 1). Because the category system was inductive, we developed the coding guide during the analysis and continuously adapted it to newly coded statements. The final coding guide corresponds to Table 2 in the results for RQ2. In contrast to RQ1, in this research question, we considered the entire interview and only coded statements that did not correspond to the essential foundations of the scientific definition of a sustainable diet according to von Koerber et al. [22].

Some of the students' statements were coded into several categories if they applied to more than one category. This was the case for both research questions. For the coding procedure, two raters were used who were familiar with the topic. Each rated half of the interviews using the same coding guide and met several times to discuss the coding. To validate our analysis of RQ1, we conducted an inter-rater reliability test and used Brennan and Prediger's Kappa in MAXQDA to assess the level of agreement between the two raters [62,63]. Taking into account the expected number of coded segments in the interviews, the diversity of cases, and our available resources (people available who were willing and able to do a second round of coding), we chose to randomly select 15% of all statements for the calculation of Brennan and Prediger's Kappa [62]. The two raters each coded 15% of the interviews they had not coded before. The resulting Brennan and Prediger's Kappa revealed an "almost perfect" [64] (p. 165) agreement ($\kappa = 0.89$). Because the frequency distributions of the statements were not relevant for RQ2, and the categories were mainly inductive, the validity of our analysis on this research question was ensured by consensual validation. For this purpose, a consensus on the interpretations was reached among the researchers involved in the project as well as by argumentative validation with one layperson who was not involved in the project [65]. We conducted Chi-square tests with SPSS (IBM, version 26) to check for a random distribution of the statements to the different categories (health, ecological, social, economic, cultural) and for a random distribution of the categories to the subsamples (considering one, two, three, four, or five dimensions).

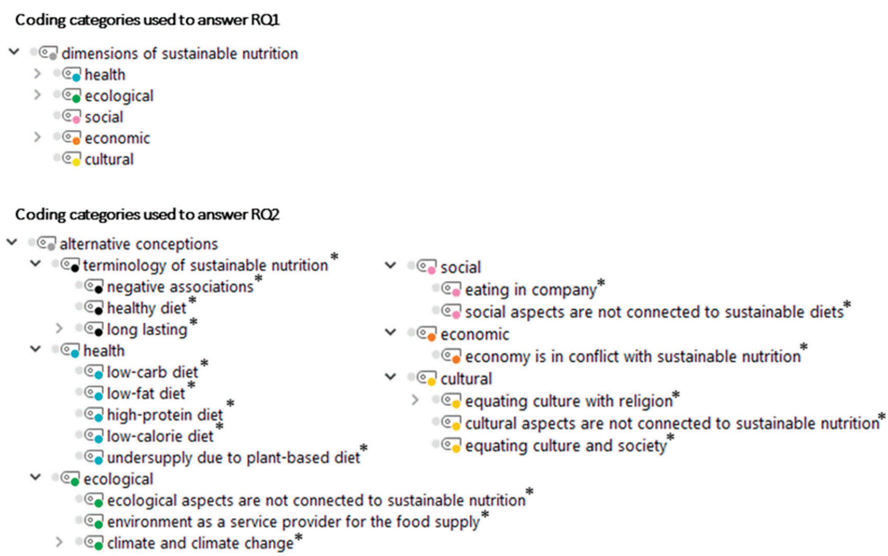

Figure 1. Overview of the coding categories used to analyze the interview material. Categories were further differentiated based on statements by the participants. * Inductive codes.

3. Results

3.1. RQ1: What Relevance Do the Students Attribute to the Different Dimensions of Sustainable Nutrition?

Based on the association task in interview Phase 1 (see Table 1), we assigned 159 statements to the health dimension, 77 to the ecological dimension, 37 to the social dimension, 23 to the economic dimension, and 7 to the cultural dimension (see Figure 2). A complete list of students' associations with sustainable nutrition can be found in the Supplementary Material (Tables S2–S6). With the help of a Chi-square test, we checked the probability that the distribution of the statements to the different categories could have occurred randomly [62]. We rejected the null hypothesis of a random distribution ($\chi^2 = 249.56$, $p < 0.001$; see Supplementary Material, Figure S1). The health dimension of sustainable nutrition, followed by the ecological dimension, had the highest relevance in the students' conceptions. The social and economic dimensions had relatively low relevance, while the cultural dimension was hardly considered.

Furthermore, we divided the sample into five different subsamples depending on how many dimensions the students considered in their conception of sustainable nutrition (see Figure 2). The health dimension dominated in almost all subsamples except the one that considered five dimensions. Especially in the subsample that considered only one dimension, the health dimension was the most frequently mentioned. Next, the ecological dimension was the second most mentioned and was present in all subsamples. Furthermore, the relevance of the ecological dimension increased with the number of dimensions considered. The social and economic dimensions were rare but present in all subsamples that considered two dimensions or more, whereas the cultural dimension was only mentioned by students who considered all five dimensions. For detailed information on how the conceptions of the subsamples are composed on an individual level, see Figure 3. In addition, using a Chi-square test, we checked the probability that the distribution of the different categories on the subsamples (considering one, two, three, four, or five dimensions) could have occurred randomly. We rejected the null hypothesis of a random distribution ($\chi^2 = 101.29$, $p < 0.001$; see Supplementary Material, Figure S2).

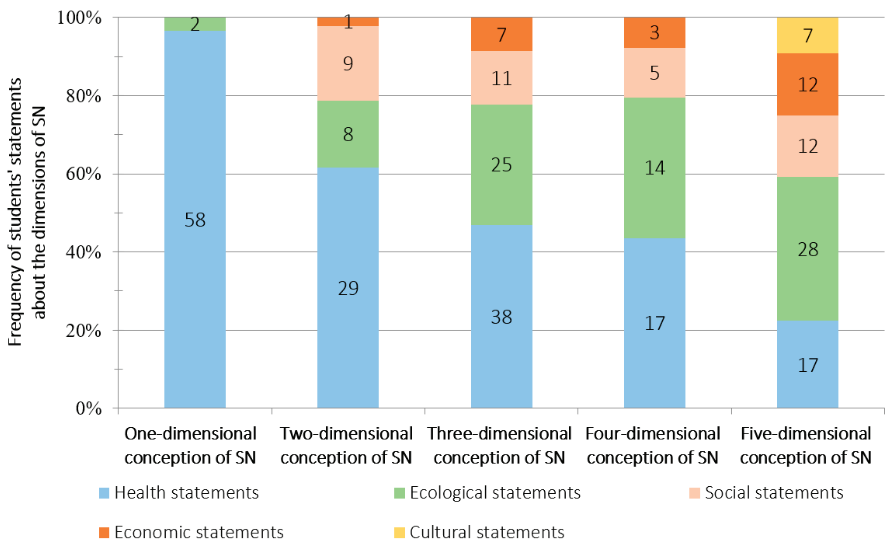

Figure 2. Frequency of (y-axis) and number of students' statements (in the bars) about sustainable nutrition, ranked according to whether they included one, two, three, four, or five dimensions in their conceptions. In total, the analysis included 303 coded statements from 46 students ($n_{\text{one dimensional conception}} = 21$; $n_{\text{two dimensional conception}} = 9$; $n_{\text{three dimensional conception}} = 9$; $n_{\text{four dimensional conception}} = 3$; $n_{\text{five dimensional conception}} = 4$). SN, sustainable nutrition.

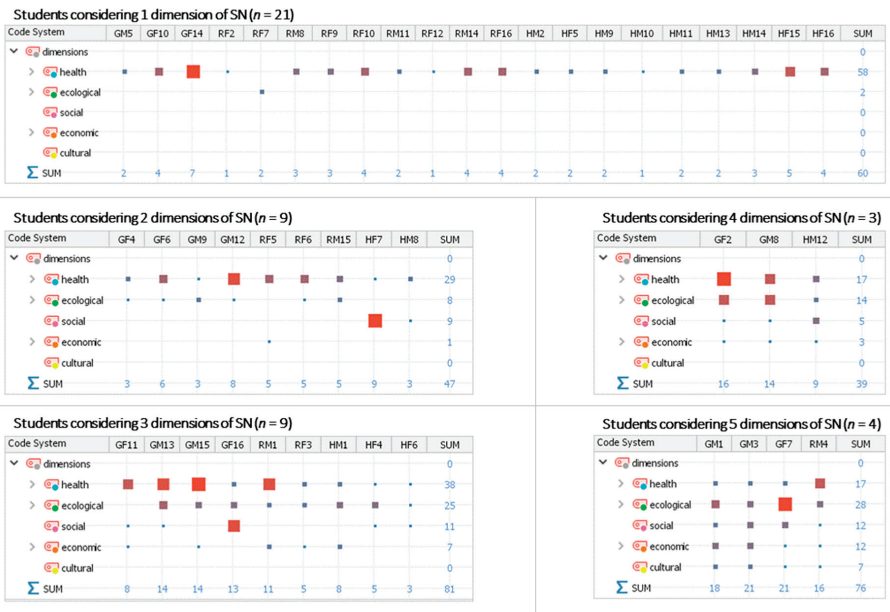

Figure 3. Students' conceptions of sustainable nutrition on an individual level, ranked according to whether they included one, two, three, four, or five dimensions in their conceptions. The size of the squares indicates the number of statements within a category; the larger the square, the higher the number of statements. SN, sustainable nutrition; G, Gymnasium; R, Realschule; H, Hauptschule; F, female; M, male.

3.2. RQ2: What Alternative Conceptions Do Students Hold about Sustainable Nutrition?

We structured students' alternative conceptions regarding the terminology of sustainable nutrition (Table 2) and the five dimensions of sustainable nutrition (Table 3).

Table 2. Students' alternative conceptions regarding the terminology of sustainable nutrition.

Conceptions	Definitions	Examples	Students Holding this Conception
Negative associations	Sustainable nutrition is understood as something negative.	GM12–Tim: "Sustainable" just sounds negative. So, in terms of nutrition, it might mean that it is simply not the ideal food.	GM12, RM8, RF9, RM11, RF12, RF16, HF5, HF6, HM10, HM11, HM13, HM14, HF16 (*13 students*)
Healthy diet	Sustainable nutrition is understood exclusively as a healthy diet.	RF2–Saskia: I imagine sustainable nutrition to mean eating things for a healthy body.	GF4, GM5, GM12, GF14, GM15, RM1, RF2, RF6, RF10, HF5, HM11, HF15, HF16 (*13 students*)
Lasting into the future	Sustainable nutrition is understood exclusively in the sense of long-lasting: long-lasting satiation, health or shelf life of foods.	RM8–Malte: Things you get full off longer or which are very nutritious, which have a lot of carbohydrates. RM14–Thomas: If you eat sustainably over a longer period of time, then you may also have a longer life expectancy and a good spirit. HM2–Jona: For me, milk would be sustainable because you can keep the milk in the refrigerator for two or three days.	GM1, GM5, GM8, GF11, GM12, GM13, GF14, GM15, RF7, RM8, RF10, RM14, HM2, HF4, HM8, HM14, HF15, HF16 (*19 students*)

G, Gymnasium; R, Realschule; H, Hauptschule; F, female; M, male.

Table 3. Students' alternative conceptions regarding the five dimensions of sustainable nutrition.

Conceptions	Definitions	Examples	Students Holding this Conception
Health dimension			
Low-carb diet	Sustainable nutrition is understood as a low-carb diet or implies the avoidance of products high in carbohydrates.	HM10—Burhan: In terms of carbohydrates, I would say that sustainable nutrition implies that you should try to buy as few carbohydrates as possible.	GF14, RF6, RM8, RF9, HM8, HM9, HM10, HF16 (*8 students*)
Low-fat diet	Sustainable nutrition is understood as a low-fat diet or implies the avoidance of fatty products.	HM9—Lutian: Sustainable nutrition might mean a diet "low in fat," not adding a lot of fat where it doesn't have to be.	GM1, GF4, GF6, GM12, GF14, RM1, RF6, RM8, RF9, RF10, RM11, RF16, HF5, HF6, HM8, HM9, HM10, HM11, HM14, HF15, HF16 (*21 students*)
High-protein diet	Sustainable nutrition is understood as a high-protein diet or implies preferring products high in protein.	RF9—Elif: When I think of sustainable nutrition, I think of a diet "high in protein," when a diet is based on many proteins.	GF14, RF6, RF9, RM11, HF6, HF8, HM14, HF16 (*8 students*)
Low-calorie diet	Sustainable nutrition is understood as a low-calorie diet or implies the avoidance of products high in calories.	HF5—Ela: For a sustainable diet, I would recommend buying fruits, vegetables, and potatoes, because they have relatively few calories […].	RF6, HF5, HM10, HF16 (*4 students*)
Undersupply due to a plant-based diet	An undersupply (especially of macronutrients) through a plant-based diet is feared since animal foods are considered to have a monopoly on certain nutrients.	GF10—Julia: Regarding the preference for plant-based foods, I wouldn't say that it would lead to sustainable nutrition. Well, it's clear to me that animals die for producing meat. But in some way, I need milk. Milk is also an important part of our diet. So, you need the calcium that is in it […] but I personally would not be a vegan, they do not use any animal food.	GF10, RF6, RF7, HM8, HM10, HF16 (*6 students*)

Table 3. *Cont.*

Conceptions	Definitions	Examples	Students Holding this Conception
Ecological dimension			
Ecological aspects are not connected to sustainable nutrition	No connection can be made between the environment and sustainable nutrition.	RF6—Caroline: I would leave out the environmental dimension, because for me, personally, it has very little to do with nutrition.	GM5, RF6, RF7, RF12, HF5, HM10, HM13 (*7 students*)
Environment as a service provider for the food supply	The relationship between sustainable nutrition and the environment is only understood in the sense that food comes from the environment.	HM10—Burhan: I can't imagine the connection between sustainable nutrition and the environment. Well, actually, I do, because vegetables are actually the environment. Well, it comes from the earth, the vegetables. And that's why I think that the environment plays a very important role in sustainable nutrition.	GF4, GM5, GF6, RF5, RF7, RM11, HF4, HF5, HM10, HM12, HF15 (*11 students*)
Climate and climate change	Statements about climate or climate change that show that the phenomenon of climate change has not been properly understood. Technically incorrect statements about the consequences of CO_2 emissions.	GM3—Lukas: CO_2 emissions are generally problematic for the environment. All this goes back into the cycle and then it becomes more and more difficult to cultivate food sustainably, if the whole soil is then contaminated, or the air, or the rain. Then the actual system will be damaged.	GM3, GM9, GF11, GM13, GM15, RF3, RM4, RF5, RF6, RF7, RM14, RM15, HM1, HF4, HF6, HF7, HM9, HM10, HM11, HM12, HM13, HM14, HF15, HF16 (*24 students*)
Social dimension			
Social aspects are not connected to sustainable nutrition	No connection can be made between society and sustainable nutrition.	GF16—Laura: In terms of the dimension society, I don't know exactly how this is related to sustainable nutrition.	GF2, GM5, GM12, GF14, GM15, GF16, RM11, HF5, HM9, HM10, HM14, HF15 (*12 students*)
Economic dimension			
Economy is in conflict with sustainable nutrition	The economic dimension is not considered compatible with the other dimensions of sustainable nutrition.	GM8—Noah: And the economy is for me rather the driving force against sustainable nutrition, because the economy in general has the urge to make a lot of money with little effort and regardless of the consequences and therefore I think that the economy really doesn't match well with sustainable nutrition.	GF4, GM5, GM8, RM1, RM4, RF6, RF7, RM15, HF6 (*9 students*)
Cultural dimension			
Equating culture with religion	Culture is being reduced to religion.	RF12—Leonie: When I link culture to sustainable nutrition, I would think about religion, for example that Muslims are not allowed to eat pork.	RF6, RF12, HF6, HF7, HM9, HM10, HM13 (*7 students*)
Cultural aspects are not connected to sustainable nutrition	No connection can be made between culture and sustainable nutrition.	RF5—Emilia: Regarding culture [...] I couldn't understand at all what this has to do with nutrition.	GM5, GF6, GF7, GM9, GM12, GF14, GM15, RF5, RF10, HM9, HM11, HM14, HF15 (*13 students*)
Equating culture with society	The cultural and social dimension cannot be separated.	GF4—Anna: In relation to culture or society 'preference for plant-based foods' refers to the fact that some people prefer to eat plant foods, for example, eating vegan or vegetarian.	GM1, GM3, GF4, GM5, GF6, GF7, GM8, GF11, GM12, GF14, GF16, RM1, RF3, RM4, RF7, RM8, RF9, RM14, HM1, HF4, HF6, HM8, HM14, HF15 (*24 students*)

G, Gymnasium; R, Realschule; H, Hauptschule; F, female; M, male.

4. Discussion

4.1. RQ1: What Relevance Do the Students Attribute to the Different Dimensions of Sustainable Nutrition?

The fact that many students—20 out of 46—solely considered the health dimension in their naïve conceptions can be explained by the great relevance attributed to the health aspect, which has already been demonstrated in other studies on students' and laypeople's conceptions of and attitudes toward nutrition issues [36,47,48]. The reason for this could be that, in German schools, a nutritional-physiological teaching approach is primarily used in biology lessons to help students become familiar with the topic of nutrition [28–35]. This could have led to an automated association of nutrition topics in the school context with the health aspect.

Our results suggest that the health dimension is particularly present in students' naïve conceptions. In the context of nutrition in adolescence, the health aspect, or rather the figure ideal, is of particular importance [44]. The enormous social pressure to optimize their bodies that young people are exposed to, which is often associated with eating behavior [44], may explain the focus of our sample on the health dimension. Moreover, the health dimension, in contrast to the other dimensions, has an immediate relation to the student's own body and thus affects their everyday life to a great extent. It seems easier for students to approach the topic of sustainable nutrition from an egocentric perspective rather than to adopt the perspective of other people (altruistic perspective) or the environment (biospheric perspective). We suggest that the link between nutrition and health aspects is the most intuitive one and therefore the easiest to create. This assumption is supported by the fact that the relevance of the health dimension decreases with an increasing number of the dimensions of sustainable nutrition considered by our participants. This means that the less elaborate the naïve conception of sustainable nutrition is in terms of the total number of dimensions considered, the more prominent the health dimension is.

Nevertheless, references to the ecological dimension frequently made by students should not be neglected. Although students' focus on ecological aspects has already been identified in other studies on sustainability topics [52,55], it was previously observed that it has no relevance in students' conceptions of nutrition in general [36]. Now, the results are completely different when the naïve conceptions of sustainable nutrition are investigated. The results of RQ1 showed that a total of 21 students considered both the health and ecological dimensions (see Figure 3, Students considering 2, 3, 4, or 5 dimensions).

The often co-occurring consideration of both dimensions can be explained by the specific question of "sustainable" nutrition, which did not take place in previous studies on nutrition (e.g., [36], as it combines the focus on ecological aspects in sustainability topics with the focus on health aspects in nutrition topics. However, the preference for the two dimensions cannot be attributed exclusively to the combination of the two topics. Health and the environment are generally two important topics for young people in Germany. For example, the 17th Shell Youth Study showed that 80% of over 2500 young people (aged 12–25 years) surveyed considered it important to live health-conscious lives and 66% to act with respect for the environment [66].

The ecological dimension was the second most coded, but unlike the health dimension, it became more prominent when two or more dimensions were considered. Studies conducted on student teachers in home economics classes showed that this sample group focused on the ecological dimension [50]. Since we assume that prospective home economics teachers have more elaborate conceptions of sustainable nutrition than many students, it confirms our assumption that consideration of the ecological dimension increases with increasing expertise.

The economic and social dimensions were rare in students' naïve conceptions but present in all subsamples that considered two dimensions or more, whereas the cultural dimension was only mentioned by students who considered all five dimensions (Figure 2). Although less pronounced, the presence of those dimensions (social, economic, cultural) in the students' conceptions is striking, as it is not commonplace in their conceptions of sustainability issues [56].

4.2. RQ2: What Alternative Conceptions Do Students Hold about Sustainable Nutrition?

4.2.1. Terminology of Sustainable Nutrition

We noticed that some students had problems with the terminology of sustainable nutrition. This is particularly evident in statements such as those of GM12—Tim (Table 2). In addition, particularly students with no prior experience with the term understood it as something negative; they associated it with a bad, unhealthy, or wrong diet. Their conceptions are therefore contrary to the scientific conceptions.

This contrasts with the results of a large-scale online survey of university students on the topics of "sustainable development" and "sustainability," in which no negative associations and only a positive understanding of the terms were found [67]; however, the study was conducted in an English-speaking country, and ours, in a German-speaking country. In our study, the negative evaluation of the term "sustainable nutrition" can be traced back to the German adjective "nachhaltig/sustainable," to which the students intuitively had negative associations. We assume as a possible cause of the negative connotation the similarity to other German words like "nachteilig/disadvantageous" or "nachlässig/careless," which are phonetically similar but semantically different [68,69]. In German, the prefix "nach" often gives words a negative meaning; therefore, the reason underlying the negative interpretation of sustainable nutrition could be an unconscious overgeneralization of this phenomenon.

In addition to the negative understanding of the term "sustainable nutrition", there were also positive understandings of it in the context of a healthy diet (Table 2; *Healthy diet*). This is likely due to the great relevance attributed to the health aspect and the predominant practice of teaching nutrition topics under the health aspect (explained in the discussion on RQ1). Although this alternative conception of a healthy diet does not entirely contradict the scientific conception of sustainable nutrition, it does not cover it completely and only illuminates a part of it.

Even more frequently, the students expressed the view that sustainable nutrition means *lasting into the future* (Table 2). This alternative conception suggests that there are parallels with the definition for sustainable development of the World Commission on Environment and Development (WCED) [70]: development that "meets the needs of the present without compromising the ability of future generations to meet their own needs." However, it is evident that the students' understanding of "anhaltend/long lasting" does not include future generations, which were considered by only 12 students (GF7, GM8, GF11, GM12, GM13, GM15, GF16, RM1, RM4, RM15, HM1, HF6) but often focuses on their own life span. Their conceptions regarding *lasting into the future* can be divided into long-lasting satiation, health, or the shelf life of foods (Table 2; *Lasting into the future*). The conception *lasting into the future* can also be traced back to the German adjective "nachhaltig/sustainable". The students seemed to interpret the prefix "nach/after" in the sense of continuation or extension [71].

Taken together, the large number of participants with alternative conceptions indicates that problems of understanding the term "sustainable nutrition" do not occur sporadically among students but are widespread; however, further quantitative studies are needed to verify the findings on the basis of larger samples.

4.2.2. Health Dimension

Regarding the health dimension, we found that students had strong beliefs about the recommended intake of macronutrients that contradict nutritional recommendations. The students frequently pointed out that only small amounts of carbohydrates and fats, but large amounts of protein, should be consumed (Table 3; *Low-carb diet*; *Low-fat diet*; *High-protein diet*); however, leading nutrition societies recommend covering approximately 50% of total energy intake with carbohydrates, 30% with fat, and only a small part with proteins (for normal body weight, 9% to 11%) [72]. We see the students' alternative conceptions of carbohydrate intake replicated in the actual nutritional behavior of the German population that fell below the recommended carbohydrate intake [73].

Our results regarding students' alternative conceptions of dietary fat intake are consistent with Rasnake, Laube, Lewis, and Linscheid [42], who identified a tendency for young people to be dose insensitive (e.g., something harmful in large amounts should be avoided in small amounts) and categorical thinkers (e.g., foods are either good or bad). Moreover, Heseker et al. [74] examined 238 textbooks of various subjects that included nutritional topics for general education schools in Germany and found that those textbooks gave lower fat intake recommendations than recommended by official nutrition societies [75]. Furthermore, the study found that textbooks do not mention the aspect of fat quality, especially in relation to vegetable fats. Considering that the fat intake of the German population is generally higher than recommended [75] and that the students' recommendations to consume only small amounts of fatty products comply with the dietary guidelines of various countries [76,77], the students' assessment is partly correct.

With regard to protein intake, it is evident that students' recommendations to consume large amounts of protein conflict with official recommendations of nutrition societies, which refer to a protein intake of 0.8 g/kg body weight (for normal body weight, 9% to 11% of total energy intake) [72]. However, it has been shown that even textbooks for general education schools erroneously give excessive protein intake recommendations [74]. Because textbooks are still the preferred teaching medium for teachers [78], we assume that their use in class may contribute to a fear of undersupply regarding protein intake.

We suspect that students' conceptions concerning macronutrients (carbohydrates, fats, and proteins) and the emphasis on low-calorie diets (Table 3; *Low-calorie diet*) can be attributed to the most popular weight loss diets (low-carb and low-fat diets) [79], which are designed for weight reduction rather than a balanced, long-term healthy diet. The reasons for this are traced to the slimness ideal supported by society and the media [80] alongside the associated social pressure that affects both sexes [44]. According to the data for Germany in the Health Behavior in School-aged Children (HBSC) Survey of the WHO, 53% of girls and 36% of boys at the age of 15 think they are too fat [43].

The importance of the desired body ideal in adolescents for the formation of conceptions of sustainable nutrition should therefore not be underestimated, as it is dietary behavior in particular that is one way to achieve a body ideal [45,46]. The results show that dietary recommendations for weight reduction are perceived by students as a healthy diet; therefore, the task of nutrition education must be to provide information about the actual conditions of the supply of energy-providing nutrients.

The alternative conception *undersupply due to a plant-based diet* (Table 3) is particularly relevant, as it affects all other dimensions of sustainable nutrition in a special way (e.g., greenhouse gas emissions due to livestock breeding (ecological), food shortage due to land usage for livestock breeding (social), higher input costs for the production of animal food products than for plant food products (economic), and high meat consumption has become normal over the last 60 years (cultural)) [22]. For some students, a plant-based diet is contrary to a healthy diet. We conclude from the students' statements that this evaluation is based on the assumption that animal food products are the only source of some macro- and micronutrients. Heseker et al. [74] found that 238 textbooks of various subjects, including nutritional topics, often overstated the negative consequences of a vegan diet and unjustifiably identified the consumption of animal products such as milk as the only way to prevent deficiency symptoms. Such misrepresentations in textbooks could be responsible for the students' alternative conceptions in this respect.

The students' fear of undersupply due to a plant-based diet seems unjustified as food societies in many countries are in favor of appropriately planned vegetarian diets, including vegan diets for all stages of the life cycle, even while recognizing the need to supplement certain nutrients [81,82].

Conversely, the German Nutrition Society does not recommend a vegan diet for certain groups of people (e.g., pregnant women, lactating women, infants, children, or adolescents), but assumes "that a plant-based diet (with or without low levels of meat) is associated [with] a reduced risk of nutrition-related diseases in comparison with the currently conventional German diet" [83] (p. 93).

4.2.3. Ecological Dimension

We found some students to have problems recognizing the environmental impact of food consumption and production. In some cases, students were entirely unable to deduce a connection between food and the environment, arguing that the ecological dimension should be omitted from the concept of sustainable nutrition because it "has very little to do with nutrition" (RF6–Caroline; Table 3; *Ecological aspects are not connected to sustainable nutrition*).

Apart from this complete negation of the ecological aspects of sustainable nutrition, other students only succeeded in establishing a unidirectional connection between the environment and sustainable nutrition by recognizing ecosystem services, such as the provision of food [84], but not taking into account the environmental impacts of dietary behavior or the intensive agriculture associated with it [1,10] (Table 3; *Environment as a service provider for the food supply*).

Moreover, several indications could be identified that point to a lack of understanding of the importance of greenhouse gases for climate change. This lack of understanding led to little or no recognition of the links between nutrition and ecological aspects, particularly climate change. For example, we observed that although the transportation of food was associated at a superficial level with environmental consequences such as "pollutants in the air" (RF3–Lara), no connection could be established directly with CO_2 emissions, the greenhouse effect, or climate change (RF3, HF4, HM11). In addition, some students identified CO_2 emissions as problematic but could not explain why or erroneously linked emissions to phenomena other than climate change, such as soil acidification and acid rain (GM3, GM15, RF6, RF7).

Our results complement the results of previous research on students' conceptions of climate change [85]. Previous studies found that climate change was attributed to more or less incorrect mechanisms, some of which did not involve greenhouse gases at all (for a summary of previously identified students' conceptions of the greenhouse effect, see [85]).

4.2.4. Social Dimension

A total of 12 students expressed that they could not connect the social dimension with sustainable nutrition (Table 3, *Social aspects are not connected to sustainable nutrition*). It is striking that all students who had this problem did not succeed in adopting the perspective of employees in the food sector, especially in developing countries, but only argued from an egocentric perspective as consumers. GM12–Tim, for example, spoke about the power of the consumer, noting that "society is already responsible for what is happening, for example, prices and so on," but did not manage to direct this perspective toward workers in the value chain of food products. It is thus evident that some students have shortcomings in their ability to take on the perspective of workers in the value chain of food products; however, the ability to change perspectives was defined as one key competency for sustainable development [86].

4.2.5. Economic Dimension

Regarding the economic dimension of sustainable nutrition, we found that some students perceived the economy as a kind of "driving force against sustainable nutrition" (GM8—Noah; Table 3; *Economy is in conflict with sustainable nutrition*). Such an alternative conception negates the possibility of achieving "sustainable development in its three dimensions—economic, social, and environmental—in a balanced and integrated manner" [8] (p. 3), as sought by the United Nations.

This alternative conception not only occurs from a macroeconomic perspective ("the economy"; GM8—Noah), but also at the level of the individual microeconomic situation of students and their families ("organic products are just more expensive and when they are more expensive, then you just buy them less often"; RM1—Tobias). Similar results were obtained by Krüger and Strüver [87], who found by conducting qualitative interviews with adult consumers that a part of the sample believed that the economy is opposed to healthy and sustainable food practices and that sustainable consumption is a privilege of the affluent population.

Such a conception carries the risk of feeling powerless in the face of the unsustainable practices of the food system and undermines the students' perceived effectiveness in their role as food consumers. Similarly, Gralher [36] found that students often did not know any ways of influencing the sustainable development of the food system; however, the seven recommendations of von Koerber et al. [22] show that there are many options that can be implemented at low costs that are even cheaper than the unsustainable alternative (e.g., preference for plant-based foods or resource-saving housekeeping).

4.2.6. Cultural Dimension

Although we considered different definitions of culture in our evaluation, we primarily followed the Cambridge Dictionary's social science definition of culture, which describes it as follows: The way of life of a particular people, especially as shown in their ordinary behavior and habits, their attitudes toward each other, and their moral and religious beliefs [88]. A total of seven students were unable to see the connection between the cultural dimension and sustainable nutrition (Table 3; *Cultural aspects are not connected to sustainable diets*). All seven students showed a very narrow understanding of culture, which probably explains this barrier. For example, some students reduced culture to "paintings of former times" (RF10—Hannah) or to "what once was, what remains of that time" (HM11—Daniel), and thus to the past preserved by traditional constructs. Also, a reduction in cultural festivals such as "Oktoberfest" or "Carnival" (HM14—Nicolas) led to difficulties in combining cultural aspects with sustainable nutrition. Even if it was recognized that the term culture also refers to current trends, these could not always be transferred to the field of nutrition but were exclusively related to the fashion sector (RF5—Emilia: "Trends are actually more about clothing than about nutrition"). A possible explanation for this could be that, in the short life span of adolescents (M_{Age} = 15.59, SD = 0.78), the slow changes in the food sector are difficult to experience. In contrast, changes in the fashion sector happen very quickly and are easier for adolescents to identify. Nevertheless, it is surprising that, despite the presence of a huge variety of ethnic restaurants from different countries in Germany, culture was not associated with nutrition by some students. Such a concept carries the risk that culturally determined eating habits that are contrary to sustainable nutrition (e.g., high meat consumption or its association with masculinity) will not be questioned.

Furthermore, a total of seven students considered the cultural dimension to be exclusively reduced to religion (Table 3; *Equating culture with religion*) and frequently referred their statements to the Islamic religion. With approximately 4.5 million Muslims in Germany, Islam is the third largest religion in Germany. It is therefore not surprising that, for some students, the rules of halal, especially the abstention from pork, are representative of religion-specific nutritional habits. Nevertheless, according to the Federal Statistical Office of Germany [89], 58% of the German population belongs to Christian religions. We therefore assume that Christian eating habits and the prevalent renunciation of food restrictions are considered normal and have therefore not been addressed by the students.

Furthermore, it was difficult for the students to separate the social and cultural dimension (Table 3, *Equating culture and society*). The students also criticized the distinct dimensions of sustainable nutrition posited by von Koerber et al. [22] and suggested they should be considered together. Von Koerber et al. only poorly justified the extension of the dimensions of sustainable nutrition by the cultural dimension by factoring "the respective cultural background [that] influences food habits" [22] (p. 35) and do not present it in a clear-cut way in relation to the social dimension. In older literature regarding the concept, cultural aspects were summarized within the social dimension [25]. The definition of culture is inextricably linked to social groups of people, which is why the cultural and social dimensions overlap greatly in content. We suspect that students were therefore unable to conceptually separate the dimensions from one another.

5. Conclusions and Educational Implications for Teaching

Before explaining the comprehensive conclusions and educational implications of this research for teaching, it is important to not ignore possible limitations regarding the results. First of all, due to the selection of participants by the teachers, we cannot exclude the possibility that some of the participants had a particularly high interest in the topic of nutrition, even though the students were only told that the interview was about nutrition (not sustainable nutrition). Furthermore, we recognize that education based policies have limited impact on the modification of nutritional habits. For example, despite well-developed educational concepts, they have not been able to prevent the increase in obesity worldwide [6]. Other factors, such as the socioeconomic status of parents, have a major influence on the nutritional behavior of young people [90]. However, in samples with nearly the same socioeconomic status, nutritional interventions in schools showed an effect on the nutritional behavior of students [91].

Considering these limitations, the following conclusions and educational implications can be drawn from the results described in this article. In the context of RQ1, we identified a self-centered perspective of many students on the topic of sustainable nutrition, with a frequent focus on the health dimension. For this reason, we suggest that it should be clarified, especially for students without much previous experience on the topic or at the beginning of a teaching unit, that sustainable nutrition and nutrition in general are not exclusively health-related topics. By promoting systems thinking, the connections between sustainable nutrition and the ecological, social, and economic dimensions should be highlighted. Although we advocate strongly for the promotion of a multidimensional perspective, we emphasize that the health and ecological dimensions should not be neglected, given their importance for sustainable nutrition, even though these were already present in the students' conceptions. The health dimension in particular can be used as a starting point to make sustainable nutrition more easily accessible for students without much previous experience.

5.1. Terminology of Sustainable Nutrition

Since the negative interpretations of the terminology (Table 2; *Negative associations*) are contrary to the positive meaning of sustainable nutrition in the sense of sustainable development, interventions must be taken in the classroom in the direction of scientifically accurate conceptions of sustainable nutrition. For example, cognitive conflicts could be used to trigger conceptual change [16,92]. For this purpose, impulses such as the use of the term "sustainable" in a known context (e.g., sustainable energy) would be useful. In class, media reports, advertisements, or product descriptions could be used as materials. This includes products advertised as sustainable, which seem to have a potential for cognitive conflicts due to the inherent contradictions to the students' conceptions.

In contrast to the *negative associations* mentioned above, the origin of the other alternative conceptions (Table 2; *Healthy diet, Lasting into the future*) already contains correct elements of the scientific conception that could be useful for the learning process. To achieve a modification toward scientific conceptions, the promotion of a wider understanding of the term is critical; perspectives restricted to the context of food or one's own body must be broadened. Since the term "sustainable" is subject to inflationary use in everyday life and the media in a wide variety of situations, teaching practice should promote the development of a differentiated understanding of the term.

5.2. Health Dimension

Due to the numerous alternative conceptions regarding the recommended intake of macronutrients contradicting official nutritional recommendations, we advocate for resources outlining the recommendations of nutrition societies, such as the Nutrition Circle of the German Nutrition Society [76], which shows dietary guidelines, or the Eat Well guide for the United Kingdom [93], because they demonstrate in everyday practice that each individual nutrient performs vital functions in the organism. Knowledge about actual macronutrient requirements can eliminate uncertainties regarding dietary behavior in everyday life. Because we identified fear of an *undersupply due to a plant-based diet* (Table 3), we propose the use of alternative dietary recommendations for vegetarians and vegans, such as vegetarian food pyramids, to alleviate this fear and enable students to adopt a healthy plant-based diet. Resources describing the positions of nutrition societies on vegetarian and vegan diets could also help to dispel those fears; however, attention should be drawn to the necessity of supplementing certain nutrients as well as regular medical observations.

5.3. Ecological Dimension

As we found some students to have difficulties recognizing the environmental impact of food consumption (Table 3; *Ecological aspects are not connected to sustainable nutrition*) and to understand the *environment as a service provider for the food supply* (Table 3), sustainable nutrition education should aim to illustrate the environmental impact of the food system and individual nutritional behavior. To prevent students' resignation, however, positive examples for the implementation of sustainable nutrition from an ecological perspective should also be provided. The recommendations of von Koerber et al. [22] are excellently suited for this purpose. To encourage the students' perceived effectiveness, the reduction of one's ecological footprint through a sustainable diet (e.g., preference for plant-based foods) compared to a meat-based diet could be illustrated. Ideas for comparing different meat alternatives in biology and geography classes according to selected sustainability criteria can be found in Fiebelkorn and Kuckuck [94].

Although other students considered the connection between sustainable nutrition and the ecological dimension, we found that students considered certain behaviors, especially the emission of CO_2, to be harmful to the environment but did not link them to the greenhouse effect; therefore, the relationship between CO_2 emissions and the greenhouse effect should be known by all students in order to correctly evaluate the positive effects of sustainable nutrition. Niebert and Gropengießer [85] provide a detailed overview of different methods to illustrate the relationship between CO_2 emissions and the greenhouse effect.

5.4. Social Dimension

Regarding the social dimension, we found that it bears little relevance in students' conceptions of sustainable nutrition. Moreover, we identified a frequently occurring egocentric perspective and shortcomings in students' abilities to adopt the perspective of other people in situations that are dissimilar to their own (e.g., workers in the value chain of food products); thus, teaching should aim to encourage students to change perspectives. This can be done both through direct contact with actors in agribusiness (e.g., farmers or food traders) and by using media that portray the food situations in other countries. In this way, a global perspective can be developed and a better understanding of people in countries with food poverty may be promoted. Furthermore, to better understand the interests and needs of different groups, group discussions with defined roles can be useful. The use of reports presenting problematic working conditions or child labor in the food industry could also be an effective means of stimulating a change in perspective. Here too, however, great care should be taken not to emotionally overwhelm the students and to avoid resignation. Instead, options for action for consumers to improve working conditions (e.g., regional and seasonal products and Fair Trade products) [22] should be highlighted; however, it is important to emphasize the freedom of the consumer and to also address students' perceived barriers that may make it difficult for them to consume socially sustainable products (e.g., low income of parents or limited control over food purchases in the family).

5.5. Economic Dimension

Education for sustainable nutrition should aim to teach students that the central idea of sustainable development is the promotion of the different dimensions "in a balanced and integrated manner" [8] (p. 3). Because the economic dimension had little relevance in the students' conceptions (results on RQ1; Figure 2), the importance of this dimension and its compatibility with sustainable nutrition should also be emphasized in biology classrooms. Examples could include the large number of jobs in the food sector as well as the creation of new jobs in new food areas, such as vegan and vegetarian products, or the support of regional agricultural businesses.

We found that some students perceived the economic dimension at the macro and micro levels as an antagonist of sustainable nutrition (Table 3; *Economy is in conflict with sustainable nutrition*); therefore, it is important to give students examples of economic actors in the food sector who, for example, manage their companies in a sustainable way, e.g., by marketing organic food, saving on packaging, and standing for fair working conditions, all within profitable business models. In this way, students can recognize that there is not necessarily a contradiction between economically strong companies and sustainable food. Students' perceived effectiveness can be fostered by discussing in class what opportunities consumers have to support sustainable companies (e.g., every purchase decision supports a particular company).

Because, at the microeconomic level, students often cited the higher costs of sustainable nutrition as a barrier to consuming sustainable products, we recommend providing concrete examples of sustainable nutrition that can be implemented at low costs (e.g., preference for plant-based foods, resource-saving housekeeping, regional and seasonal products; preference for minimally processed foods) [22].

5.6. Cultural Dimension

Because some students could not make a connection between culture and sustainable food, which could lead to adopting culturally determined unsustainable eating habits without questioning, we suggest a critical examination of students' own eating habits and their cultural determinants as well as helping them to become more familiar with the eating habits of other cultures (e.g., consumption of insects—entomophagy) [95]. In addition, an evaluation of different nutritional styles according to sustainability criteria [94] could strengthen cultural sensitivity and ultimately lead to increased acceptance of "foreign" eating habits. To reduce any fears of new foods, or so-called "food neophobia," it may also help to look at the origin and history of popular foods or dishes such as bananas, pizza, or döner kebab. In Germany, for example, the Federal Ministry of Food and Agriculture offers materials for time travel through nutrition, which can be used for teaching arrangements [96]. Students will quickly notice that many culturally accepted foods were considered novel until some time ago, and that supposedly novel foods (e.g., insects in Germany) already have a history in their own country [95].

Furthermore, it was difficult for the students to separate the social and cultural dimensions. Despite the predominant consideration of the three sustainability dimensions (ecological, economic, social) in the past, the cultural dimension is currently also taken into account in the context of ESD [11]. In our opinion, this dimension is of particular importance in many areas, but especially in the field of nutrition, and should also be considered in teaching practice. Nevertheless, our results show that a separate consideration of the cultural and social dimensions leads to numerous confusions for students and is difficult to understand. For this reason, and because the two dimensions overlap greatly in content, we agree with the students' suggestion to combine the two dimensions and support the consideration of cultural aspects under the social dimension.

5.7. General Conclusions

In conclusion, it can be said that the nutrition issue is particularly well suited to ESD, as it combines health, ecological, social, and economic aspects to a greater extent than most other topics with a regional-global scope. Teachings on this topic should aim to ensure that students understand nutrition as a system based on the four dimensions (cultural aspects should be considered under the social dimension) of sustainable nutrition. Interventions should be implemented to encourage students to give up their egocentric views and improve their ability to change perspectives. In addition, clear options for action and their effect on the food system should be communicated to increase the students' perceived effectiveness in the sustainable development of the food system.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/12/13/5242/s1; Figure S1: Chi-square test on the distribution of the statements regarding the different dimensions of sustainable nutrition, Figure S2: Chi-square test on the distribution of the different dimensions on the subsamples, Figure S3: Chi-square test on the distribution of the students on the number of considered dimensions, Table S1: Sociodemographic data, additional information of the participants and the interview duration, Table S2: Associations with the term sustainable nutrition that corresponded to the health dimension, Table S3: Associations with the term sustainable nutrition that corresponded to the ecological dimension, Table S4. Associations with the term sustainable nutrition that corresponded to the social dimension, Table S5. Associations with the term sustainable nutrition that corresponded to the economic dimension, Table S6. Associations with the term sustainable nutrition that corresponded to the cultural dimension.

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Personal Assessment of Reasons for the Loss of Global Biodiversity—An Empirical Analysis

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Abstract: The UN's sustainable development goals (SDGs), which aim to solve important economic, social, and environmental problems of humanity, are to be supported by education for sustainable development (ESD). Empirical studies on the success of the implementation of the SDGs in the field of education are still pending. For this reason, using the loss of global biodiversity as an example, this study examined the extent to which high school students, teacher trainees in biology, and biology bachelor students can identify the causes of the global biodiversity loss. A new questioning tool was developed and tested on 889 participants. In addition, the relationship between connection to nature and the personal assessment about biodiversity threats was examined. The factor analysis of the scale used showed that 11 out of 16 items were assigned to the intended factor. The comparison between high school students, teacher trainees in biology, and biology bachelor students showed no significant difference in overall assessment of the reasons for global biodiversity loss. When comparing the three risk levels in which the risk factors for biodiversity could be divided, across the three student groups, only minor differences were found. Therefore, a specific education of prospective teachers is necessary, as they have to pass on the competence as multipliers to their students. No significant difference could be found when examining the relationship between connection to nature and the overall scores of the assessment scale for the reasons of biodiversity loss. However, it was found that people who felt more connected to nature were more capable of assessing the main causes of risk for global biodiversity, while people who felt less connected to nature achieved better scores for the medium factors.

Keywords: biodiversity loss; environmental knowledge; connection to nature; connectedness to nature; INS; sustainable development goals (SDGs); education for sustainable development (ESD)

1. Introduction

In 2015, the 17 sustainable development goals (SDG) were ratified as part of Resolution 70/1 of the General Assembly of the United Nations [1]. These SDGs were the follow-up goals to the eight millennium development goals (MDGs) of the year 2000 that were an attempt to reduce global poverty, especially in developing countries, by 2015. Notable progress has been made in many countries, and some have even achieved most of the MDGs [2]. The main goal of reducing the number of people who have to survive on less than $1.25 a day by half was achieved before 2015, partly because of China's strong economic growth [3].

As successors to the MDGs, the SDGs have the task of initiating actions that are crucial for mankind and the planet [1]. The 17 objectives cover different topics and are closely related. From the point of view of environmental and sustainability education, objective number 15 is of particular importance. It aims to protect terrestrial ecosystems, promote their restoration and sustainable use, and put an end to the loss of biodiversity [4]. In particular, the objectives and targets of SDG 15 mention the conservation of biodiversity in different ecosystems, its appreciation, its sustainable use, and the reduction of its decline. Biodiversity also plays a special role in the indicators for assessing the success of SDG 15 [5].

Biodiversity is defined as the variability among living organisms [6]. It is usually classified in genetic diversity (diversity within a species), in species diversity (diversity between species), and ecosystem diversity (diversity of habitats) [7]. More recent definitions include not only the number of genotypes, populations, and ecosystems, but also the relative frequency, range of functional traits, spatial distribution, and vertical diversity [8].

Today, biodiversity is at greater risk than ever before. Prognoses for the 21st century predict a progressive decline [9,10]. The number of threatened species is also increasing from year to year. In 2019, the International Union for Conservation of Nature (IUCN) classified 30,178 of the evaluated 112,432 species as threatened with extinction [11]. The current extinction rate is about 100 to 1000 times higher than the background rate of extinction [12]. The background rate is in the order of 0.1 extinctions per million species-years (E/MSY), while the current extinction rate is about 100 E/MSY [13]. This persistent loss has strong negative consequences for ecosystems. For example, the loss of biodiversity reduces the stability of an ecosystem and decreases its productivity and many ecosystem services that are important for humans are closely related to biodiversity [14]. Particularly in marine ecosystems, biodiversity loss reduces the ability of the oceans to provide food, maintain water quality, and recover from ecosystem disruptions [15]. Important ecosystem services are lost not only in water, but also on land. Insects are responsible for 75% of the pollination of human food plants. Both the abundance and diversity of pollinators are currently declining rapidly worldwide, which has a major impact on food production. The loss of small vertebrates that act as pesticides could result in crop losses of up to 37% [16]. In addition, the loss of invertebrates could reduce nutrient cycling and decomposition in ecosystems [16]. It is fatal that particularly poor regions are affected by the loss of ecosystem services [8]. In addition to these arguments, there are a number of ethical reasons for preserving biodiversity. For example, the intrinsic value of nature or to preserve biodiversity for future generations [17].

The reasons for the loss of biodiversity are extremely complex. In particular, land use change, climate change, atmospheric CO_2 concentration, nitrogen deposition, and invasive species are considered to be the greatest threats to global biodiversity [10,18,19]. In the meantime, overexploitation must now also be counted among the main threats to global biodiversity [20–22]. In the following, the six main reasons for the decline of global biodiversity will be presented.

The main threats to biodiversity on land and in freshwater ecosystems are land use change and overexploitation [19].

- The largest factor currently influencing global biodiversity is land use change [18]. It has a drastic effect on biodiversity by changing the structure and composition of ecosystems and thus, also biodiversity [23]. Since the intensity of land use has increased drastically in recent decades, natural habitats have also declined dramatically. For this reason, many species have already become extinct on a global scale [24–26]. The main reason for land-use changes is cattle breeding, although oilseed production is also growing rapidly [27].
- Overexploitation is one of the main causes of the global decline in biodiversity [20–22] and poses a major threat, particularly to biodiversity in aquatic ecosystems. Here, the excessive exploitation and extraction of organisms from aquatic ecosystems plays a major role and causes lasting damage to biodiversity. Especially the use of trawl gear has a strong negative impact on the entire ecosystem [28]. However, overexploitation is also a threat to terrestrial ecosystems. Animals are excessively hunted for various reasons or trees are felled for raw material extraction. About 40% of vertebrates suffer from overexploitation [29]. One-third of the birds and mammals threatened with extinction can be attributed to overuse. Overexploitation is often linked to the destruction or fragmentation of habitats [30].

- The consequences of climate change are currently the subject of intense discussions. While land-use change is currently the main cause of biodiversity loss, climate change is likely to become an increasingly important factor over the next 40 years [31]. Climate change is closely linked to the increasing amount of CO_2 [32] or other greenhouse gases [33] in the atmosphere. The main victims of climate change will be species that have not yet been affected by human activity and whose habitats are not yet threatened [34]. The predictions vary, but most assume that climate change will have fatal consequences for biodiversity. The worst-case scenarios assume a sixth mass extinction in earth's history [35].

The threat of invasive species and the various types of pollution are also major causes of biodiversity loss [19].

- Invasive species are a major problem for endemic biodiversity. Organisms are either accidentally introduced into foreign habitats, deliberately released, or escaped from animal husbandry. Some of these alien species cope better with the living conditions in their new habitat and displace endemic species, leading to lasting damage to ecosystems [36]. The damage caused by invasive species is difficult to estimate, but it is assumed that in the United States alone, about 50000 species have immigrated, causing damage of approximately $137 billion annually [37].
- In addition to invasive species, the influence of **nitrogen deposition** on biodiversity is also often underestimated. The input of nitrogen from industry and agriculture is the third largest threat to terrestrial biodiversity after land use change and climate change. The effects of nitrogen exposure are assumed to be difficult to reverse [38]. Analyses show that, especially in biodiversity hotspots, nitrogen emissions are 50% higher than the global average. This could result in critical loads being exceeded in these areas in particular, which would have fatal consequences for biodiversity [39]. The accumulation of nitrogen compounds is the main reason for the change in species composition in various ecosystems, as the increased nitrogen concentration interferes with the competition between species. Other effects, such as the toxicity of nitrogen compounds, also play a role [40].

Besides these six main reasons for the global decline in biodiversity, there are a number of other factors that have a negative impact on biodiversity. In certain ecosystems, these factors may even have a major impact. These include world population growth [41,42], meat production [43,44], habitat fragmentation [45,46], plant monocultures [47], or hormone-like substances (endocrine disruptors) in the environment [48,49].

One important approach to raising people's awareness of the issue of biodiversity loss is environmental education [50,51]. It is an instrument to support sustainable development [52] and thereby also to achieve the SDG [53]. Therefore, in 2017, the UNESCO published a strategy paper describing learning contents that should contribute to the achievement of the 17 individual goals. For Goal 15, for example, the reasons for the threat to biodiversity and human connection to nature are proposed as topics [54].

For a long time, one of the basic goals of environmental education was to impart knowledge about environmental issues to teach people how to solve environmental problems [55]. However, the link between environmental knowledge and ecological behavior is controversial [56]. Although, the influence of knowledge on behavior was confirmed in some studies [57–59]. Knowledge about environmental issues and action strategies can have a positive influence on environmental behavior [60]. Nevertheless, this old paradigm is repeatedly criticized in current research and is even called a myth by some [61]. Moss et al. [62] found that the correlation between knowledge and pro-environmental behavior is very small. Otto and Pensini [63] also confirm that knowledge only has a small effect, if any, on environmental behavior. Although the influence of knowledge on behavior is controversial, knowledge is important to understand the issue of biodiversity and the decline of biodiversity [64]. In order to grasp this difficult and interdisciplinary topic, knowledge about species, extinctions, and ecosystem issues is essential [65].

Biodiversity and its threats also play an important role in educational research. There are numerous studies on this topic, both among students and teachers. Lindemann-Matthies and Bose [66] discovered in a survey of schoolchildren and adults that 60% have not yet heard of the term biodiversity. Most of those questioned considered the main source of information on this topic to be the media rather than schools. Furthermore, the local plant diversity was greatly overestimated. In contrast, Fischer and Young [67] found out in a series of focus group discussions that members of the general public have rich mental concepts of biodiversity independent of their knowledge. These include food chains, balances, and human–nature interactions. Yorek et al. [68] conducted semi-structured interviews and discovered that high school students tend to understand biodiversity as a holistic concept that focuses on people. Details such as energy flow and nutrition relationships were neglected. In a survey of pupils aged between 16 and 18, Menzel and Bögeholz [69] discovered that most of those interviewed were expressing ecological or economic aspects of biodiversity loss. Students with an ecological point of view often based their opinions on wrong facts and had problems to feel solidarity and compassion for people in an ecological resource conflict. In addition, the students were often unaware of the loss of biodiversity at local or global level. Through environmental education programs, it is possible to promote students' understanding of biodiversity. The positive effect of an environmental education program in which primary school students were taught to recognize the number and diversity of species on their way to school has been demonstrated [70].

Overall, it can be seen that students have some basic understanding of biodiversity, but there are gaps and differences. This could be related to the understanding and training of teachers.

Although teachers see biodiversity as an important subject for teaching, are well informed about the topic, and pass on important knowledge to their students, the teaching concepts often lack a comprehensible and linked understanding of biodiversity [71]. Dikmenli [72] reports that biology teacher trainees know the basic aspects of biodiversity, but there are deficits in some points. For example, in the conceptual framework of biodiversity, the diversity of ecosystems and species was often considered, but genetic diversity was not. In a study on teacher training in four European countries, Lindemann-Matthies et al. [73] discovered that due to time constraints, the main focus in teacher training is often on scientific aspects of biodiversity. Teaching approaches and teaching skills therefore fall by the wayside. As a result, teachers are not sure how to integrate the topic into their lessons, they lack examples, and appropriate expertise [74]. Falkenberg and Babiuk [75] were able to find a similar result in a Canadian case study: There is no systematic and focused preparation of teachers for teaching sustainability. Lindemann-Matthies [76] also came up with an interesting result: Teachers are more motivated to carry out activities such as outdoor activities within the framework of biodiversity education if they have had such experiences in their own school time or in their teacher training.

Navarro-Perez and Tidball [77] concluded in their literature review on challenges for biodiversity educators, that one of the most important starting points is the establishment of connection to nature.

The concept of connection to nature is defined as the "extent to which an individual includes nature within his/her cognitive representation of self" [78] (p. 67) and is a frequently used construct in environmental education research. Numerous studies have shown that there is a positive relationship between pro-environmental behavior and connection with nature [79–81]. Connectedness to nature is a predictor for more sustainable behavior [82,83] and shows a positive correlation with appropriate environmental behavior [84]. Environmental education programs often focus on increasing connection to nature [85–87]. This raises the question of whether nature-connected people also have other competences in relation to biodiversity in addition to more environmentally friendly and sustainable behavior. In this study, we will investigate whether people with a higher degree of connection to nature could better assess the reasons for global biodiversity loss than people with a lower degree of connection to nature. A personal assessment can provide information about whether a person considers a certain factor to be relevant or not. In our context, we asked how strongly people assess the influence of certain factors on global biodiversity. In contrast to a concrete knowledge survey, such a personal assessment can be measured on a Likert scale. This allows for a gradation that would not be possible with multiple choice questions, for example. Hence, the procedure can provide information on whether the relevance of a factor has been correctly identified, over-, or underestimated. It could be assumed that people with a higher degree of connection to nature, due to their higher attachment to the environment, have a better understanding of the reasons for the loss of biodiversity.

In addition, this study will use a newly developed test instrument to check whether the causes of the threat to global biodiversity can be correctly assessed and how well biology interested high school students, biology teacher trainees, and biology students in comparison can assess these causes of biodiversity loss. This procedure can be used to determine which group of participants can give a more accurate assessment and where there is still room for improvement. It could be expected that groups of people with a science education (biology teacher trainees and biology students) can provide better assessments than high school students.

2. Materials and Methods

2.1. Developing A Measurement Instrument for the Personal Assessment of Biodiversity Loss

In order to determine how well high school students, teacher trainees, and biology students can assess the causes of global biodiversity loss, it was necessary to develop a new test instrument. For this reason, 16 potential factors were selected and their impact on the global biodiversity should be rated by the participants on a 5-point Likert scale. The scale ranged from 1 (minor influencing factor) to 5 (major influencing factor). We divided the selected factors into three groups based on the current literature on biodiversity decline: Firstly, the main reasons (major influencing factors) for the global loss of biodiversity, which were identified by Sala et al. [18] and extended by other researchers [20,21]. These are land use change, CO_2 concentration in the atmosphere, nitrogen deposition, climate change, invasive species, and overexploitation. For the second group, five factors were selected, which are often mentioned in the literature as influencing factors with a strong negative impact on biodiversity but are not one of the main causes of global biodiversity loss mentioned above (medium influencing factors). These chosen factors are world population growth, intensive livestock farming, habitat fragmentation, plant monocultures, and hormone-like substances (endocrine disruptors) in the environment. The third group consists of five factors that we have selected and whose influence on global biodiversity plays a rather negligible role (minor influencing factors). However, some of the factors are repeatedly discussed in different contexts. These include nitrogen oxide emission, which is currently the subject of much debate because of the air pollution in cities, noise pollution from factories and traffic, the use of genetic engineering, hiking through nature reserves, and electro smog. The task emphasized that the influence of the factors on global biodiversity should be assessed (Table A1).

2.2. Evaluation of the Results of the Scale

A point system was used to evaluate the scale. A person was awarded a whole point if he or she could correctly estimate the influence of a factor on a Likert scale. In order to consider a correct tendency positively, partial points were awarded. The different scoring between the factors was selected in such a way that, if the factors were selected purely by chance, with the same probability for each box, the same average statistical score (0.4) would be achieved for each item. The scoring according to the three risk levels is shown in Figure 1. To calculate the total score of a person the achieved points of each item were summated, so a total of 16 points could be achieved.

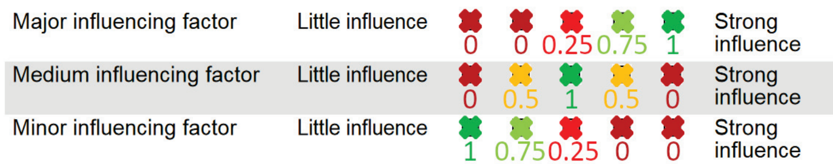

Figure 1. Evaluation system of the scale according to the three threat groups.

2.3. Measuring Connection to Nature: The INS-Scale

The Inclusion of Nature in Self Scale (INS) is a graphical single item measuring instrument to determine the connection to nature of a person. It was developed by Schultz [78] on the basis of the Inclusion of Other in Self Scale by Aron et. al [88]. The scale consists of seven circle pairs that differ in their degree of overlap. One circle represents nature, the other the person self. The scale ranges from no overlap (no connection to nature) to a complete overlap (one with nature). The tool is regularly used to evaluate environmental education programs [85–87] and shows a high positive correlation with other testing instruments for connection to nature [89,90]. Connection to nature is an important factor to explain human behavior in relation to nature. Thus, connectedness to nature correlates with ecologically sustainable behavior [82]. In addition, conservation behavior [83,91] strengthens the connection to nature, while a low connection to nature leads to a lack of pro-environmental behavior [92]. Connectedness to nature is a predictor of personal happiness [93] and wellbeing [94,95].

2.4. Participants

A total of 889 persons in Germany were surveyed (55.8% female, 43.7% male, 0.5% no answer). Approximately half of the participants (50.7%) were high school students from local schools with biology as basic or major course. The students were in the last two years of their school education, which they will complete by obtaining the general matriculation standard (age_{mean} = 17.46). At the time of the survey, the students should have already studied the topic of biodiversity at school according to the guidelines of the local curricula. They completed the questionnaire at events organized by the department of Bioscience Education and Zoo Biology of the Goethe University in Frankfurt. In order to prevent the program from influencing the participants, the questionnaires were completed before the actual program began. These programs include, for example, guided zoo tours or student laboratory days. For their participation, the groups received a discount on the participation fee. Prior to the survey, the parents were informed in writing about the questionnaire and asked for their written consent. If individual students did not take part in the survey, the whole group still received the discount. The remaining participants (49.3%) were students of the Goethe University Frankfurt with a biological focus. One hundred and eighty-eight were teacher trainees in biology (age_{mean} = 22.44; $semester_{mean}$ = 3.74) and 250 bachelor students in their freshman year biology (age_{mean} = 20.36). Participation in all surveys was voluntary and data protection regulations were met. The survey period was the winter semester 2018/2019.

2.5. Analysis

All statistical analysis was executed using IBM SPSS 24. To analyze the relationship between the 16 possible threats to biodiversity, a principal component analysis (PCA) with orthogonal rotation (varimax) was performed, after the Kaiser–Meyer–Olkin test and Barlett test verified sampling adequacy. All examined variables were tested for normal distribution using the Kolmogorov–Smirnov test. The Kruskal–Wallis test was applied to compare the results of high school students, teacher trainees, and biology students. When the Kruskal–Wallis test showed a significant result, a pairwise comparison was made using a post hoc test with Bonferroni correction. The effect size (r) was calculated according to Fritz, Morris, and Richler [96]. To make our results comparable with other studies, r was converted to Cohen's d using the formula $d = \frac{2r}{\sqrt{1-r^2}}$ by Bronstein et al. [97]. To observe the relation between connection to nature and the assessment of the reasons for global biodiversity loss the Spearman correlation was calculated, and additional Kruskal–Wallis tests were applied to assess the differences between the degrees of natural connection.

3. Results

The Barlett test was significant ($p < 0.001$) and the Kaiser–Meyer–Olkin test verified sampling adequacy (KMO = 0.854), so the requirements for a PCA were met. The PCA with varimax rotation forced the extraction of three-factors to reflect the theoretical assumption of the scale (a separation in a major, medium, and minor influencing factor). The first factor accounted for 28.23%, the second factor for 9.81%, and the third factor for 8.28% of the variance (Table 1; Figure 2).

Table 1. Result of the principal component analysis with orthogonal rotation for the 16 threats to biodiversity. Values above 0.3 are printed bold.

	Factor 1	Factor 2	Factor 3	Mean Value
Nitrogen oxide emission	**0.742**	0.238	0.060	4.06
Atmospheric CO_2	**0.727**	0.169	0.183	4.24
Nitrogen deposition	**0.690**	0.085	0.088	4.57
Climate change	**0.665**	0.101	0.112	4.52
Genetic engineering	0.156	**0.763**	−0.033	3.30
Entering nature reserves	0.060	**0.654**	0.213	2.79
Electromagnetic pollution	**0.370**	**0.632**	0.046	3.39
Hormone-like substances	0.094	**0.502**	**0.366**	3.63
Factory noise	**0.301**	**0.430**	0.285	3.42
Livestock farming	**0.330**	**0.457**	0.122	3.87
Changes in land use	**0.301**	−0.099	**0.669**	4.54
Overexploitation	0.148	0.049	**0.651**	4.40
World population growth	0.029	0.165	**0.602**	3.94
Habitat fragmentation	0.229	0.149	**0.557**	4.19
Monoculture	−0.096	**0.428**	**0.486**	3.59
Invasive species	−0.030	0.298	**0.464**	3.69

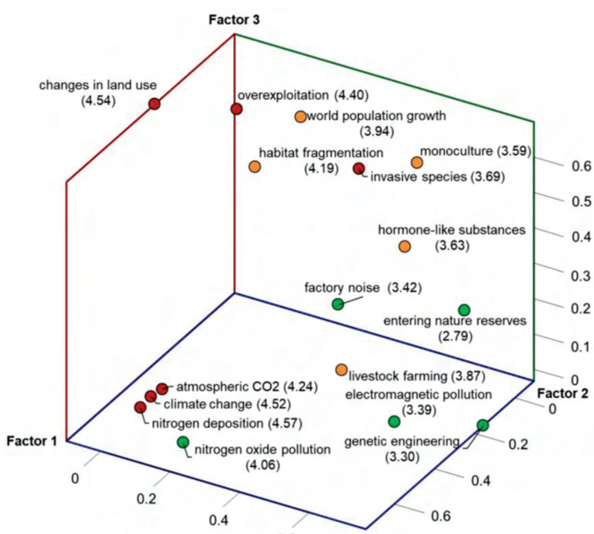

Figure 2. The results of the three-factor solution of the analysis presented in a three-dimensional coordinate system. The graphical illustration shows the separation of the items into a three-factor structure. The color of the items indicates if they are a major (red), medium (orange), or minor (green) influencing factor for global biodiversity. The value in brackets is the mean value.

The Kolmogorov–Smirnov test showed no normal distribution for all tested variables ($p < 0.001$). Therefore, non-parametric statistical methods were used.

The Kruskal–Wallis test of the overall scores showed no significant difference between the three education levels ($p = 0.068$). The same applied to the achieved scores for the high influencing factors from the theory ($p = 0.414$). For the medium influencing factors from the theory the Kruskal–Wallis test showed a significant result ($p = 0.02$). The post hoc comparison with Bonferroni correction revealed a significant difference ($p = 0.039$) between high school students and biology students. The calculated effect size is $d = 0.189$. For the minor influencing factors from the theory the Kruskal–Wallis test was significant ($p = 0.002$). The post hoc comparison showed a difference between the teacher trainees and biology students ($p = 0.001$) with an effect size of $d = 0.341$ (Figure 3).

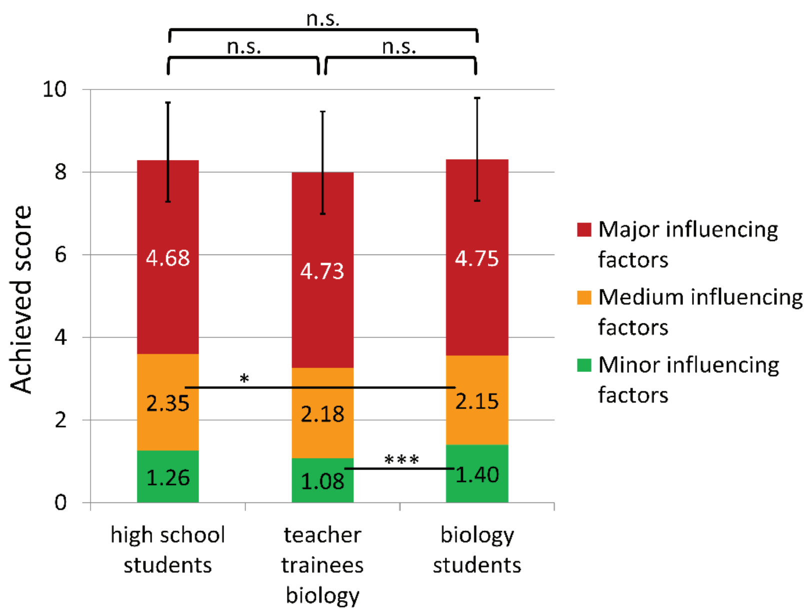

Figure 3. The scores of the potential reasons for global biodiversity loss split by influencing factors and education level. A maximum of six points could be achieved for the major influencing factors, while a maximum of five points was possible for the medium and minor influencing factors. The analysis showed no significant differences in overall scores between the three test groups. In the three sub-categories, a significant difference in the medium influencing factors between high school students and biology students was found, as well as between teacher trainees biology and biology students in the minor influencing factors. Significant shifts are marked with * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$.

The Spearman correlation between the biodiversity loss assessment scale and connection to nature was $r = -0.060$ ($p = 0.075$). The comparison between the scores for major, medium, and minor influencing factors over the different levels of connection with nature shows a highly significant difference for major and medium factors ($p = 0.001$). The minor influencing factors show no significant difference between the levels of connection to nature ($p = 0.052$; Figure 4).

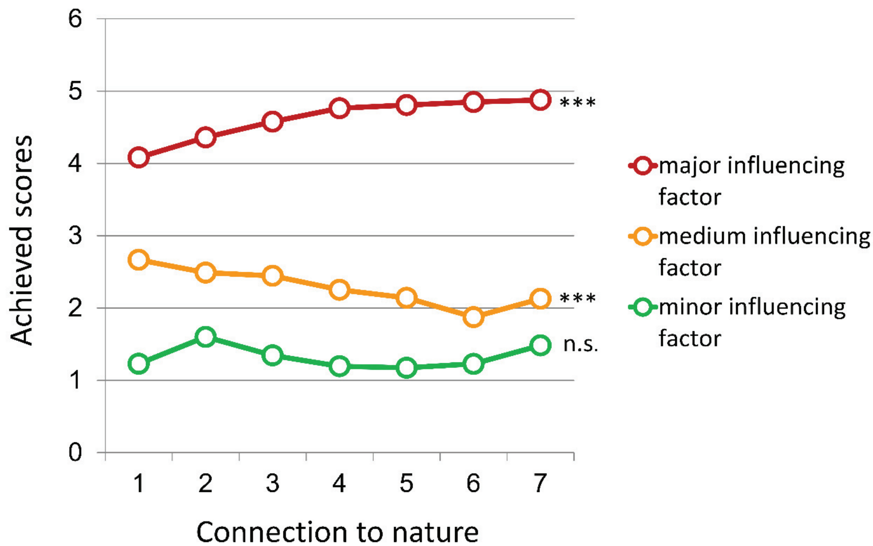

Figure 4. The scores achieved for the three threat levels assumed in the theory, categorized according to their connection to nature. Significant shifts of the Kruskal–Wallis test are marked with * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$.

4. Discussion

4.1. Factor Structure of the 16 Items

The 16 items show, as expected, a distribution among the three factors that represent the three levels of threat to biodiversity. Eleven of the 16 items are clustered according to the respective level of threat. The remaining five items that were not assigned to the expected threat level are nitrogen oxide emission, land use change, invasive species, industrial livestock farming, and overexploitation.

Nitrogen oxide emission, actually a minor factor of influence on global biodiversity, shows a high factor loading on the same factor as climate change, atmospheric CO_2 concentration, and nitrogen deposition. This means that there is a high statistical relationship between these variables and the participants rate the nitrogen oxide load similarly to some of the main biodiversity threats. The high mean value (4.06) confirms this assumption. One reason for this misjudgment could be the current reporting and media attention to this issue. At the beginning of 2018, the Bundesverfassungsgericht (one of the highest courts in Germany) ruled that diesel driving bans in cities are permissible in order to comply with the legal limit value for nitrogen oxides [98]. As a result, the topic was discussed continuously and received a great amount of media attention. In 2018, for example, the German television news reported more about diesel and nitrogen oxides than about the Brexit or the Football World Cup [99]. This constant media presence of the topic and the catchword nitrogen oxides may have led to the fact that the study participants no longer regarded nitrogen emission as a primary human toxicological problem [100,101], but at the same time assumed that it was a threat to global biodiversity.

While the nitrogen oxide emission was rather overestimated, the influence of invasive species was underestimated. It was not considered by the participants as one of the main threats for the loss of biodiversity. One possible reason could be the lack of knowledge about invasive species. In a study at Brookfield Zoo, more than 50% of the participants reported that they have little or no knowledge about invasive species [102]. In addition, many people have little knowledge about the extent and number of invasive species [103]. Often, it is not the replacement of endemic species that is regarded as the biggest problem of invasive species, but the inconveniences that arise for humans and the destruction of habitats. Opinions are divided on how to deal with invasive species. Almost as many people are in favor of their conservation as of their elimination [102]. Moreover, not all invasive species are evaluated equally. While aesthetic or large species are considered worth preserving [103], smaller and unattractive species such as rodents, possums, scorpions, snakes, and some plants are often considered undesirable [104]. The mixture of a lack of knowledge and acceptance of certain invasive species may have led the respondents to the survey to be unable to properly assess the risks to biodiversity.

In addition to invasive species, the currently largest influencing factor on global biodiversity, land-use change [18], was assigned to the same factor in the factor analysis as many medium influencing factors. The same applies to overexploitation. However, the mean value of land use change (M = 4.54) and overexploitation (M = 4.40) indicates that these factors were not underestimated. The assignment to this factor is probably due to the proximity of the content of the neighboring items. A change in land use is often accompanied by fragmentation of habitats, overuse, and overexploitation. It is therefore quite possible that the participants assumed a connection for these factors and therefore assessed them similarly. Another indication of this is the proximity of the three items in the questionnaire. The fragmentation of habitats and the change in land use followed each other (items 7 and 8). The overexploitation also followed shortly after at item 12.

Surprisingly, industrial livestock farming showed a high loading on the same factor as the five comparative variables with low impact on global biodiversity. Industrial livestock farming has a noteworthy effect on global biodiversity. For example, intensive animal husbandry emits greenhouse gases that exacerbate climate change [105] and mass livestock farming is a direct cause for the progressive change in land use and the fragmentation of habitats [106]. A possible explanation for the incorrect classification, which some participants in the study gave orally after the survey, could be that factory farming was only seen as an animal welfare problem. According to this argumentation, it would make no difference to biodiversity whether the same amount of animals are kept in mass animal husbandry or in ecologically sustainable husbandry, since the same amount of greenhouse gases or garbage is produced. What seems conclusive at first glance can be refuted with a small calculation example from Germany: In 2016, the area used for agriculture was 16.7 million hectares, which corresponds to just over 50% of the total area of Germany [107]. The cultivation of forage crops takes up about 60% of this area with 10 million hectares. The majority of forage crops for animals is cultivated in conventional agriculture (~91%) [108]. In order to produce organic meat, the EU Regulation (EG) No. 834/2007 Art. 5 (k) [109] prescribes that animals must be fed with feed from organic farming. It should be noted that organic farming in Germany is only about 50% as productive as conventional farming [110]. This means that an area of more than 20 million hectares would be needed to grow the same amount of feed that is currently produced in conventional agriculture. Feed production alone would exceed the current agricultural area in Germany and cover more than 50% of the country's total area. This does not include the increased space requirement of sustainably kept animals, but only the change caused by feed production. This small sample calculation shows that it would not be possible to keep and supply this number of animals in Germany ecologically. Only intensive livestock farming makes it possible to keep this large number of animals and produce meat in these quantities. For this reason, intensive livestock farming is a causal problem not only in terms of animal welfare, but also in terms of the loss of biodiversity.

4.2. Evaluating Group Differences by Educational Level with the New Developed Test Instrument

The measuring instrument was designed in a way that for each item between 1 and 0.5 (for medium influencing factors) or between 1 and 0.25 (for major and minor influencing factors) points could be achieved. If the questionnaire had been completed without understanding and only at random, with the same probability for each box, an average value of 6.4 points would have been achieved:

Major/minor influencing factors: $\left(\frac{1}{5}\times 1\right)+\left(\frac{1}{5}\times 0.75\right)+\left(\frac{1}{5}\times 0.25\right)=0.4$

Medium influencing factors: $\left(\frac{1}{5}\times 0.5\right)+\left(\frac{1}{5}\times 1\right)+\left(\frac{1}{5}\times 0.5\right)=0.4$

$0.4 - 16 = 6.4$

The mean value of all three groups was between 7.99 and 8.30. This value was above 6.4. Accordingly, each group had some understanding of the reasons for biodiversity loss. Overall, there was no significant difference in the biodiversity assessment scale between the three groups (high school students, biology teacher trainees, and biology bachelor students). It would have been expected that bioscience students (both teacher trainees and bachelor students) would achieve higher scores than high school students due to their science education. However, this is not the case. This finding is probably based on the content structure of biology studies in the first semesters. Here, the focus is on basic knowledge of the structure and function of organisms and the diversity of habitats. The loss of biodiversity and its consequences are not the main focus, but are treated only marginally, if at all. These contents will only be taught in the later course of biology studies.

The results are consistent with previous research findings. The results show that the assessment of the reasons for the loss of biodiversity is not directly related to their scientific knowledge [67], or in our case to the level of their scientific education. The participants of the study seem to be able to assess the reasons for risk to a certain degree, but a really precise assessment could not be achieved by students, biology teacher trainees, or bachelor biology students. This could be due to the fact that the concept of biodiversity is understood rather holistically, but details such as material cycles or energy flow are not taken into account [68]. However, it is precisely the understanding of such processes that would be necessary in order to be able to accurately assess factors such as nitrogen deposition. The limited understanding of the different levels of biodiversity [72] can also contribute to the misjudgment of factors such as invasive species. To a certain extent, the lack of difference between the scores of high school students and biology teacher trainees confirms the statement from Lindemann-Matthies et al. [73] that teacher training provides too little information and skills on the subject. At least in the first semesters, there seems to be no sufficient preparation of teacher trainees for the topic of biodiversity loss. Similar results were already noted for teacher trainees in Canada [75].

The comparison of the major influencing factors between the three groups shows no significant difference. Each group achieved a similarly high score in this category (4.68 to 4.75 out of 6). This means that, regardless of educational level, there was a good assessment of the main causes of global biodiversity loss. The reason for this is probably the high presence of these issues in society. A significantly lower score was achieved by all three groups in the assessment of the medium factors (2.15 to 2.35 out of 5). The mean values of the individual items indicate that these factors were overestimated rather than underestimated (between 3.59 and 4.19). The significant difference between high school students and biology students is only marginal. The p-value ($p = 0.039$) is just within the significant range and the strength of the effect is small, according to the common interpretation according to Cohen [111] with $d = 0.189$. A possible explanation for the occurring significance is the sample size. Due to the large sample size, it is possible that small and actually unimportant effects reach statistical significance [112].

The lowest score in all three groups was achieved for the minor influencing factors (1.08 to 1.40 out of 5). A higher score of 2.0 would have been achieved by randomly selecting the checkboxes. This shows that even factors that currently and globally play only a minor role for biodiversity loss were specifically overestimated by the study participants of all groups. There are certainly several possible reasons for this finding. People base their assessment on information that they have learned and stored in their memory. In particular, current topics, which are also very present in the media, are quickly available. Many topics that are covered in the media are subject to evaluation, both in a positive and negative direction. With regard to negative reporting, people tend to overestimate the probability of these topics [113]. Many people are familiar with the exhaust NO emissions scandal, noise pollution, radiation exposure, or genetic manipulation, as these factors are repeatedly discussed negatively in society. As a result, their impact on global biodiversity loss has probably been overestimated.

Biology students achieved a slightly better result than biology teacher trainees although both groups have to take the same biology courses in their freshman year at university. Students who decide to study biology for a bachelor's degree probably do so out of interest in the subject. Since teacher trainees in Germany usually study two different subjects and have to attend a number of other courses in addition to their studies. The division into two subjects means that teacher trainees have less time to deal with topics relevant to biology. In addition, it is not certain that the teacher trainees have chosen biology teaching as a subject simply out of interest. Often other reasons are given why people have chosen to become teachers. For example, that useful and influential work for the public wanted to be done, that working conditions (such as holidays and working hours) were attractive or that they wanted to work with children [114]. Therefore, it is also not guaranteed for biology teacher trainees that the subject is really chosen out of interest. However, it must also be taken into account that the effect is only small and therefore the difference is relatively low.

Overall, the results show that there is a general need to improve the understanding about the causes of global diversity loss. There are gaps in identifying the reasons for biodiversity loss, particularly in the identification of factors that have only a moderate or minor influence. For biology teacher trainees, it would be particularly important to accumulate more knowledge about these factors, since knowledge is particularly important for understanding biodiversity and the biodiversity crisis [64]. Better teacher training in their professional practice has a multiplier effect on the students [115]. In teacher training, focused preparation should take place [75], skills and knowledge should be imparted [73], practical teaching examples on the topic should be given [74], and experiences should be passed on [76]. In addition to this, the next generation of teachers sits among today's students. Good teaching experience can lay the basis for good teaching in the future [76]. For this reason, more courses focusing on the protection of species, nature, and the environment should be offered during teacher training. This topic should also be an integral part of biology lessons at school to educate as many people as possible. People see the loss of biodiversity as one of the most likely and influential global risk factors [116].

4.3. Connection to Nature and Assessment of the Reasons for Biodiversity Loss

The first assumption would be that people with a higher affinity to nature could better assess the reasons for the loss of global biodiversity because of their positive relationship to nature. Our results show, however, that there is an insignificant and slight negative correlation between the connection to nature and the overall score of the survey instrument on biodiversity loss ($r = -0.060$). This means that there is overall no significant link between connection to nature and assessment about the causes of global biodiversity loss.

The detailed analysis between the scores for major, medium, and minor influencing factors over the different levels of connection to nature, however, shows a different picture. There is no significant difference in the minor influencing factors in relation to nature connectedness. This means that the degree of connection to nature is not relevant for the assessment of the minor influencing factors. In contrast, the major and medium influencing factors show a highly significant difference with opposite tendencies. With increasing connection to nature, the score for the major influencing factors increases and reaches a plateau with medium values. This indicates that persons with a higher connection to nature are more capable, to some degree, of assessing the main reasons for biodiversity loss. The medium influencing factors show an opposite result. People with a lower affinity for nature achieve a better result with these factors than people with a high connection to nature (Figure 4). This means that people that are closer to nature are particularly good at estimating the high influencing factors, while the medium influencing factors are better estimated by people who are not so connected to nature.

The reason that nature-connected people perform slightly worse, especially in the medium influencing factors, could be due to a combination of two reasons. Firstly, the group of medium influencing factors receives special attention in school curricula. The increase in the world population, the emerging challenges and consequences for the environment, and the resulting increase in resource consumption is represented in the local curricula of various subjects, such as politics [117] and geography [118]. For example, livestock farming is not only a biological issue, but also an ethical or religious one [119]. Therefore, all participants in our study came into contact with these topics during their school career. As mentioned before, when a topic is reported negatively, people tend to overestimate the probability of its occurrence [113]. Secondly, nature-connected people have a special relationship with nature: They show more pro-environmental behavior and attitudes and were more concerned about environmental problems [82–84,120,121]. This particular concern about environmental issues may have led to an overestimation of the reasons in this group in particular. However, the two tendencies for medium and high influencing factors compensate each other in the overall assessment, so that there is no significant difference in the overall score.

In summary, it seems that overall connectedness to nature is no guarantee for a better estimation. This result confirms the results of previous studies. Otto and Pensini [63] found an equally small but positive correlation between connection to nature and environmental knowledge ($r = 0.13$). Very similar results were found by Cheng and Monroe [81] ($r = 0.13$) and Roczen [122].

This only small correlation between connection to nature and environmental knowledge can be explained by the factors that lead to an increase in connection to nature. Although environmental education is also a possibility to raise the connection to nature [85–87], the time a person spends in nature is the deciding factor [78,82,83,91,123,124]. Spending time in nature can potentially encourage people to become more involved with the topic, but this does not necessarily lead to an increase in understanding. As a result, a higher degree of connection with nature does not guarantee an increase in knowledge about environmental topics nor, as in this case, a better assessment of the reasons for global biodiversity loss.

5. Limitations

Although the study was performed with great care, it is necessary to address some limitations. It is important to note that our classification of the threats to biodiversity into the three groups is a snapshot of the current state of the literature. However, the reasons for global biodiversity loss are dynamic and change over time. For example, while in 2000, overuse was not yet counted among the most important factors [18], its impact has increased significantly in recent years and it is now one of the main causes of global biodiversity loss [20–22]. In the future, the consequences of climate change are likely to become the biggest biodiversity threats [31]. The close connection between the various factors also makes the classification more difficult. The increase in the world population can serve as an example here: It is possible that it could rise to over 12 billion people by 2100 [125]. This increase would probably also lead to an increase in other factors such as climate change, CO_2 production, or land use change. The evaluation of these dynamic and complex processes on a 5-point-Likert scale should therefore be interpreted with caution.

The order in which the items were arranged may also have had an influence on the participants' assessment. Especially if the participants' own opinion or an evaluation is asked for, as in this case, it is possible that items that were in the questionnaire earlier have an influence on items that come after.

One methodological limitation is the survey group. Most of the respondents were in the age group between 16 and 25 years and interested in natural sciences. Both high school students and university students had chosen a biological focus. It would be recommended for the following studies to compare the knowledge about biodiversity loss of different groups. For example, younger pupils or students with different focuses. Other age groups could also be surveyed.

6. Conclusions

The newly developed threat to biodiversity scale shows that, on average, the participants have a good assessment of the main factors influencing global biodiversity. Some factors in the factor analysis showed deviations, such as nitric oxide pollution. A possible explanation for this finding could be the public attention to this topic.

Against expectations, there were no significant differences between different levels of education. An analysis of the three threat levels between the groups also showed that there were only small differences, if any. It is therefore necessary to better educate future teachers about the causes of biodiversity loss, as they will later act as competence multipliers for their students. Nevertheless, the results of the three test groups are positive, since each group came on average above the random score of 6.4.

Only an insignificant correlation could be identified between overall assessment about biodiversity threats and connection to nature, which confirms the results of previous studies. In addition, however, we found that people with a high degree of connection to nature were particularly good at assessing the main reasons for biodiversity loss, while people with a lower degree of connection to nature were better at identifying the medium influencing factors.

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Appendix A

Table A1. Threat to biodiversity scale. The 16 items used in the survey in German with the English translation.

	German Items	English Translation
Task	Die Biodiversität (die Vielfalt der Arten, die Vielfalt von Ökosystemen, genetische Vielfalt) ist heute weltweit einemmassiven Wandel unterworfen. Bitte bewerten Sie, wie stark die folgenden Gründe für den Rückgang der **globalen Biodiversität** verantwortlich sind.	Biodiversity (the diversity of species, the diversity of ecosystems, genetic diversity) is today undergoing massive global change. Please assess the extent to which the following reasons are responsible for the decline in **global biodiversity**.
1	Umweltverschmutzung (z. B. durch Zunahme der **Stickstoffbelastung**)	Environmental pollution (e.g. due to increase in **nitrogen deposition**)
2	**Invasive** gebietsfremde **Arten** (Arten, die sich außerhalb ihres ursprünglichen Lebensraums rasch vermehren und einheimische Arten verdrängen)	**Invasive** alien **species** (species that rapidly reproduce outside their original habitat and displace native species)
3	**Hormonähnlichen Substanzen** in der Umwelt	**Hormone-like substances** in the environment
4	**Stickoxidbelastung** (z. B. durch Dieselfahrzeuge)	**Nitrogen oxide emission** (e.g. from diesel vehicles)
5	**Lautstärke von Fabriken** und Fahrzeugen	**Factory** and vehicle **noise**
6	**Massentierhaltung**	Mass **livestock farming**
7	**Zerschneidung von Lebensräumen** (z. B. durch Straßen, Zäune, ...)	**Fragmentation of habitats** (e.g. by roads, fences, ...)
8	**Veränderung der Landnutzung** durch den Menschen und daraus resultierender Zerstörung von Lebensräumen (z. B. durch Abholzung, ...)	**Changes in land use** by humans and the resulting destruction of habitats (e.g. through deforestation, ...)
9	**Klimawandel**	**Climate change**
10	**Gentechnik**	**Genetic engineering**
11	Elektrosmog	**Electromagnetic pollution**
12	**Übernutzung** (z. B. durch Überweidung, Überfischung, ...)	**Overexploitation** (e.g. due to overgrazing, overfishing, ...)
13	Erhöhte **CO_2-Konzentration** in der Atmosphäre	Increased **atmospheric CO_2** concentration
14	**Betreten von Naturschutzgebieten** (z. B. beim Wandern)	**Entering nature reserves** (e.g. while hiking)
15	**Anstieg der Weltbevölkerung**	**World population growth**
16	Pflanzliche **Monokulturen**	**Monocultures** of plants

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Exploring How Teachers Diagnose Student Conceptions about the Cycle of Matter

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Abstract: Students need an understanding of ecosystem properties and functions to face global issues related to ecological crises and to grasp the challenges and necessary actions associated with the Sustainable Development Goals 12–15. When addressing complex ecological constructs, such as material cycles, diagnosing students' pre-existing conceptions about such matters is crucial for making decisions about appropriate teaching strategies. In this study, we explored pre-service teachers' (n = 63) and in-service teachers' (n = 14) diagnostic skills in the context of education for sustainable development. To assess diagnostic skills, we showed teachers video-based clips from science lessons in which students express their alternative conceptions about material cycles. We found that teachers are generally able to notice students' comments indicating their conceptions about ecological concepts that are relevant for sustainable development. However, the teachers had difficulties in interpreting the students' comments correctly. This difficulty is a barrier to create effective lessons. Moreover, we identified teacher characteristics that could influence diagnostic skills. Our findings are discussed in the context of the role of diagnostic skills when teaching sustainable development goals. Finally, we present considerations on how teachers' diagnostic skills could be promoted.

Keywords: education for sustainable development (ESD); sustainable development goals (SDGs); diagnostic skills; cycle of matter; alternative conceptions; science education

1. Introduction

The 17 Sustainable Development Goals (SDGs) set by the United Nations General Assembly in 2015 are intended to globally secure a sustainable development on an economic, social, and ecological level. Education for sustainable development (ESD) is an important measure to catalyze and make the goals attainable but without allowing the students to be instrumentalized or indoctrinated [1–3]. With several goals having an ecological focus (in particular ensuring sustainable consumption and production patterns [SDG 12], taking action to combat climate change [SDG 13], halting biodiversity loss [SDG 13 and 14]), science education in schools plays an important role in equipping students to promote sustainable development. To face complex global issues, such as climate change, students need a profound understanding of the processes and relationships underlying complex ecosystems [4–6]. Put simply, students should learn how nature "economizes", that is, how it recurrently recycles and reuses all materials. Accordingly, this knowledge should become a model for sustainable human activity. In addition, they will learn where human intervention in the (global and local) material cycles introduces constraints or barriers to sustainable development with all its undesirable consequences. Such knowledge is part of a basic subject-specific sustainability competency [3,6]. However, research has repeatedly shown that students obtain alternative conceptions about relevant scientific concepts such as energy flow and material cycle [7–9]. Student conceptions often differ from valid scientific perspectives and tend to be resistant to change through conventional methods of instruction [10,11].

To be able to encourage students to reconstruct their alternative conceptions about ecological concepts towards valid scientific conceptions, teachers should link their instruction directly to their students' pre-existing conceptions [12–17]. Therefore, teachers need to be able to notice and interpret student utterances that indicate such conceptions [18]. The diagnostic processes of noticing and interpreting student conceptions in order to use them for further instruction are considered to be foundational for teachers' diagnostic skills [19]. However, performing diagnoses in highly complex real-life situations represents a challenging task, especially for novice teachers [20]. To support teachers in developing their diagnostic skills within the multi-faceted and complex field of teaching for sustainable development, research is needed to gain an understanding of how teachers diagnose student conceptions relevant for sustainable development [19].

In this study, we examined teachers' diagnostic processes of noticing and interpreting students' utterances about the cycle of matter. We further explored teacher characteristics that are likely to be associated with high levels of diagnostic skills. The results of this study offer insights into the current state of teachers' diagnostic skills in the context of ESD. Further, our findings can be used to inform the design of instructional support procedures, which facilitate the acquisition of teachers' diagnostic skills in specific content areas within education for sustainable development.

2. Teachers' Diagnostic Skills in the Context of ESD

2.1. The Relevance of Student Conceptions when Teaching SDGs with an Ecological Focus

Students enter the science classroom with various ideas and conceptions about the subject matter. Their conceptions can be described as the learners' ways of making sense of something [11]. Those conceptions are based on intuition, everyday experience, as well as preceding lessons [21]. Students' pre-existing conceptions are immensely important for the process of learning and teaching. Their learning builds on their prior knowledge [22]. In science education, one aspect of students' prior knowledge is their (alternative) conceptions, which are usually regarded as particularly relevant for further learning [23]. Student conceptions, often rooted in everyday experience, tend to be resistant to instruction [10]. Generally, ordinary forms of instruction such as discovery learning, lectures, or simply reading texts, may not sufficiently encourage students to reconstruct their alternative conceptions towards scientifically valid perspectives [24]. When teachers address their students' current conceptions about the concepts being taught, their teaching has a greater chance of leading to learning [25–27].

Different student conceptions require different teaching strategies [10,24,28]. For example, if a student's conception is correct, the teacher might build on the student's pre-existing conception by creating a bridge of examples to a new but related concept [28]. If a student's conception contradicts the scientific concept, the teacher might present the student with experiences that lead to cognitive conflict in the student [24,29]. Either way, teachers should know what their students think to be prepared to teach them accordingly [30]. This knowledge is particularly significant when teaching SDGs with an ecological focus. Processes in ecosystems are complex and are usually not observable. This complexity and invisibility make it difficult for students to understand that all substances, even gases, have material properties, and constantly interact with each other [7,31,32].

2.2. Typical Student Conceptions Relevant for Developing Sustainability Competencies

Baisch (2009) collected primary students' conceptions about ecological concepts that are particularly relevant in the context of ESD. As a specific topic, she chose the cycle of organic matter, which is difficult for students to understand because of the reasons previously outlined. However, an understanding of the cycle of organic matter is important because it provides insights into fundamental ecological principles and relations [7] (p. 91). Baisch used diagnosis tasks designed to elicit student conceptions about causes, processes, and products within the cycle of matter. She found, for example, that most students did not consider cyclical models as an explanation for decomposition processes. She also found that only a few students considered the role of microorganisms as a cause for decomposition processes [7]. These findings are in line with previous studies in various international school contexts [8,33,34]. Leach et al. (2008) found that many student conceptions regarding ecological processes were prevalent not only with primary school students but also with students from secondary schools [8].

2.3. Teachers' Diagnosing and Student Learning

Students' verbal expressions provide essential information for understanding their underlying conceptions [29,35]. Given that student conceptions have been collected in many studies for a large variety of ecological topics relevant for ESD (e.g., reasons for climate change, biological decomposition), teachers can prepare lessons that address frequent student conceptions [28].

Moreover, to teach adaptively, teachers have to be able to spontaneously and appropriately analyze what students say in the classroom to diagnose the underlying pre-existing and often misconceived conceptions that students may have, and that may hinder further learning [17,36,37]. Diagnosing means "differentiating" or "recognizing exactly" and may involve various practices of continuously gathering and evaluating knowledge about students [20,38]. Such practices have also been termed as "teacher assessment", "teacher decision-making" and "teacher judgment" [20,39]. The processes and activities underlying these teacher practices are related to what is considered to be "diagnosing" [19,38,40]. These diagnostic processes and activities include, for example, teachers choosing an appropriate question to learn more about a student's conceptions [41] or teachers evaluating the information given by a student in order to gain an understanding of this student's conceptions [36]. Growing research interest in those diagnostic processes and activities is one reason the term "diagnosing" has become increasingly prevalent in the educational field [19,20].

When teachers diagnose student conceptions, they make assumptions, or hypotheses, about their students' current state of understanding of a certain concept [20]. Such diagnostic judgments typically serve as decision points for further action [19,20,30]. For example, a teacher may ask students to elaborate on their ideas so that the teacher can clarify her or his understanding of a student's conception [42], or a teacher may provide feedback which moves student thinking forward [27]. In this respect, diagnoses during instruction are ultimately needed to enable teachers to choose appropriate teaching strategies [43] and thus support students' individual learning processes [18,27,44]. Diagnoses of student conceptions and the decision for a follow-up pedagogical action (e.g., feedback to the student) are deeply intertwined, yet distinct from each other [19,39]. For example, a teacher may very well diagnose a student's conception, but may not have the knowledge, techniques, or confidence to sufficiently respond to a student [37]. In the present study, we focus on teachers' diagnoses as one indispensable precondition for pedagogical action [19,20,30].

Situations that provide opportunities for teachers to diagnose student conceptions during instruction may be intentionally created by the teacher, for example, when asking a specific question. Further diagnostic opportunities may arise at virtually any time in a lesson (e.g., when a teacher overhears students expressing their conceptions in group discussions) [37]. When opportunities for diagnosis occur spontaneously during the course of a lesson, teachers need to be able to perform diagnoses on-the-fly [37,45]. In this study, we focus on such informal diagnostic situations which may often happen in the classroom, yet cannot or only to a limited extent be planned by the teacher [37].

As already stated, student conceptions are not directly observable, instead, they usually need to be inferred from students' expressions. Consequently, two cognitive processes are essential for a teacher to spontaneously construct a hypothesis about a student's conception: noticing and interpreting [19,20]. Teachers need to notice relevant student expressions among all other events taking place in the course of a school lesson [46]. That way, teachers select a certain situation that may inform further instruction [37]. Interpreting refers to the ways teachers make sense of students' expressions with regard to understanding student conceptions. For example, teachers' might evaluate only what students say as right or wrong from a scientific perspective, or they might attempt to further comprehend students' ways of thinking by identifying possible underlying conceptions [18,27,29,36]. Given teachers can only act on what they notice, and the interpretation of student thinking informs the pedagogical actions teachers might take (e.g., giving feedback), both diagnostic processes should be crucial for student learning [30,43].

The (cognitive) diagnostic processes of noticing and interpreting can be understood as the diagnostic skills which teachers need to successfully diagnose student conceptions in the course of a lesson [47]. In this study, we focus on these diagnostic skills in the context of ESD. Teachers' diagnostic skills can be viewed as one component of a more encompassing construct of diagnostic competence [47], and are generally assumed to be tied to certain teacher characteristics [19,47]. Such characteristics include content knowledge (CK), e.g., about ecological concepts and pedagogical content knowledge (PCK), e.g., about typical student conceptions pertaining to ecological concepts, as well as attitudes and motivation such as teachers' interest in individual students' thinking [19]. Young (pre-service) teachers seem to especially struggle to apply diagnostic knowledge in classroom situations. Thus, teaching experience with regard to diagnostic skills is of special interest [20]. To make inferences about teachers' diagnostic skills, one needs to refer to the teachers' observable performance (e.g., reactions to students or verbalizations of diagnoses) [19,47].

2.4. Research Goals and Research Questions

Although teachers' diagnostic skills are important for fostering students' understanding of the complex concepts fundamental to sustainable development, diagnostic skills have hardly been researched in the context of ESD. To prepare teachers for the challenging task of diagnosing student conceptions, understanding how teachers diagnose and learning about teacher characteristics that can influence diagnostic skills is essential. Respective findings can inform the design of support measures fostering teachers' diagnostic skills [19].

In this study, we explored teachers' diagnostic skills with regard to diagnosing students' ecological conceptions. We attempted to reconstruct and describe the diagnostic processes of teachers' noticing and interpreting and to further identify teacher characteristics relevant for diagnostic skills [19]. More specifically, we addressed the following research questions:

RQ 1: What do future science teachers notice, and how do they interpret students' expressions about the cycle of matter within the context of education for sustainable development?

RQ 2: What relevant teacher characteristics influence pre-service teachers' diagnostic skills?

RQ 3: Do in-service teachers show higher levels of diagnostic skills than pre-service teachers?

3. Materials and Methods

3.1. Participants and Design

Sixty-three pre-service teachers (50 female, M_{age} = 24.32 years; SD = 3.83) from the University of Education Freiburg and the University of Freiburg, Germany, and 14 in-service teachers participated in this study. All pre-service teachers were enrolled in a bachelor's or master's program (45 master's students) with a study focus in biology to become science teachers at various school levels (20 elementary education, 21 lower secondary education, 21 higher secondary education). All in-service teachers (11 female) taught in different elementary schools in the German federal state of Baden-Württemberg. Their professional experience varied from 1.5 to 40 years (M = 18.21, SD = 11.65). Although all in-service teachers taught science classes on a regular basis, only nine had studied sciences during teacher education. All in-service teachers taught curricula that highlighted ESD as a guiding principle for instruction.

The study followed an exploratory empirical research design. Following the collection of background data, each of the participants took part in a video test. The dependent variable was the teachers' diagnostic skills. Following the video test, we used a paper-and-pencil test to measure the pre-service teachers' professional knowledge as a pre-requisite for correct diagnoses.

3.2. Materials

3.2.1. Questionnaire

In addition to collecting socio-demographic data, we asked all participants to provide the teacher education program in which they were enrolled. To make inferences about the participants' teaching experience, we asked them which particular teaching internships in the course of their teacher education programs they had already attended. For pragmatic reasons, the in-service teachers were not required to take the paper-and-pencil test. We asked them about the subjects they had studied during teacher education to make inferences about their professional knowledge in the area of teaching ecological concepts in the context of ESD.

3.2.2. Vignette-Based Test

To track and assess the teachers' diagnostic skills, a vignette-based test with two 2-min videos was developed [46]. The video vignettes were scripted based on authentic classroom situations [48]. Each video showed a group of four students working on tasks about the cycle of matter. The tasks were designed in a way that encouraged students to share their conceptions [7]. Accordingly, students expressed their conceptions about the subject matter during group discussion (see Figure 1) [37].

…

Student 1:	(*reads task out loud*) Each year trees shed the leaves. What happens to the leaves on the ground?
Student 2:	I find… I think that they turn to soil. Those leaves… on the ground.
Student 3:	No. I suppose that they get shredded to smaller and smaller pieces. At some point… they're gone.
Student 1:	Yes… and I find that maybe earthworms take them to their holes… (*Student 2 and student 3 laugh out loud*). Now, ehm, do you want to add anything? (*looks to student 4*)
Student 4:	(*gesticulates with her hands*) No, that's it… no.

…

Figure 1. Transcribed episode from a video vignette. Students discuss the process of decomposition and the reasons for it.

The student conceptions expressed in the video vignettes were selected among frequent students' alternative conceptions about the cycle of matter. The conceptions we chose had been collected in various studies [7,8,15,31,49] and can be found with students on both elementary and secondary levels [8]. In the scripted vignettes, we selected a total of 24 situations in which students' utterances hint at their conceptions about particular aspects of the cycle of matter (see Table 1).

The participating teachers were given information about the students' age, school level, and the task and material the students had received. The participants were asked to analyze the videos and to note down their observations, describing precisely what they had noticed and in what way this seemed to be relevant for further teaching and learning. We used an open question format, which allows determining various levels of diagnostic skills [50]. To depict the fleetingness of the classroom environment, video players had been manipulated in a way that the videos could only be paused to note down observations. Complete videos or single episodes could not be watched again [51].

Table 1. Example for a selected situation relevant for understanding student thinking.

Time	Quote	Domain	Category	Concept	Definition
[00:06]	"I find … I think that they turn to soil. Those leaves … on the ground."	Ecology	Student conceptions about the products of decomposition	Soil or humus are regarded as only products of decomposition	Soil or humus are depicted as the only products of decomposition. For example, inorganic products of cellular respiration, as well as further mineralization and decomposition, are not taken into account.

3.2.3. Paper-and-Pencil Test

We measured the pre-service teachers' professional knowledge using a paper-pencil test consisting of multiple-choice items. The test included subscales for both CK and PCK relevant for diagnosis. The CK items addressed various biological aspects of the complex domain of the main cycles in ecosystems. The items for PCK included knowledge about diagnosing student conceptions in the science classroom and general and specific knowledge about student conceptions. Two item examples (see Figures 2 and 3) may illustrate the CK and PCK test.

Biological decomposition is defined as…

- □ … the process of plants and animal substances being broken down into smaller molecules or elements through physical (frost, wind, precipitations) or chemical (acids, oxidation) influences.
- □ … the process by which organic waste (e.g. in the form of fallen off leaves, twigs, fruit, animal excrements, carcasses) is being broken down by destruents, or more specifically their enzymes.
- □ … the decay of organic substances caused by climatic conditions, with the products of decomposition being absorbed by plants.
- □ … the degradation of organic substances, which then leads to a higher-grade mineralization in plants and animals.

Figure 2. Item example for assessing content knowledge (CK) about the cycle of matter.

When students apply the concept of isolation as a reason for the decomposition of leaves, they possibly assume that…

- □ … processes of decomposition are activated by separating single leaves from other leaves.
- □ … processes of decomposition are activated because leaves on the ground are easier to reach for destruents.
- □ … an epidermal modification facilitates decomposition processes inside the leaves.
- □ … leaves have lost the connection to their mother plant, and thus lose adequate provision.

Figure 3. Item example for assessing pedagogical content knowledge (PCK) about common alternative student conceptions in the field of the cycle of matter.

For reliability analysis, Cronbach's α was calculated to assess the internal consistency of the subscales for CK and for PCK. The values obtained for the subscales failed to meet the generally accepted values of $\geq$0.70 (see Table 2). Nevertheless, we decided to include the data from the knowledge test into our analysis because fairly low α values are common and acceptable in the context of meaningful learning [52].

Table 2. Reliabilities (Cronbach's α) for professional knowledge.

Scale	Number of Items	Cronbach's α
Content knowledge (CK)	10	0.54
Pedagogical content knowledge (PCK)	10	0.50

3.3. Data Analysis

To obtain a detailed assessment of the participants' responses to the video vignette in the discussions, a coding scheme was developed, following the qualitative content analysis by Mayring [53]. In the course of data analysis, we aimed for a reconstruction of the diagnostic processes of noticing and interpreting from the participants' written data [19,54,55]. Consequently, the codes contained information about whether a relevant student verbal expression in the video had been noticed and about the quality of the participants' interpretation. The quality of interpretations was assessed, for example, according to whether teachers' responses were evaluating the scientific correctness of student conceptions, or whether teachers' responses were more comprehensive with respect to more interpretative approaches of understanding student conceptions [29]. We also found interpretations which were descriptive in the sense that teachers had precisely outlined the most relevant aspects of the student expressions that hinted at the underlying conceptions. However, teachers did not engage in further analysis of specific features of the students' underlying conceptions. Moreover, some teachers' comments referred to the student's behavior in a more general way (e.g., "That student engages in the discussion for the first time."). Hence, the information given in those comments was deemed irrelevant with regard to understanding student conceptions. We determined interrater agreement (Cohen's kappa coefficients) for the coding scheme consisting of 18 categories. Ten percent of the data was double-coded. We obtained a mean Kappa coefficient of 0.68, indicating substantial agreement between raters [56].

With the help of the coding scheme, we were able to assess the diagnostic processes of noticing and interpreting individually to gain a differentiated representation of teachers' diagnostic skills [19]. The number of selected (relevant) situations irrespective of the teachers' interpretations served as a measure for teachers' noticing, and the codes contained information about the participants' interpretations as previously outlined (irrelevant, evaluative, descriptive, or comprehensive).

Furthermore, we used the coding scheme to develop an encompassing measure for teachers' diagnostic skills comprising both processes of noticing and interpreting. The coding scheme was converted into a six-level scale for diagnostic skills (1 = very low level of diagnostic skills, 6 = very high level of diagnostic skills). Each participant comment about a scene in the videos that contained a student expression relevant for understanding their conceptions about the cycle of matter (see Table 1) received a score between 1 and 6. The total score determined the proficiency level for each participant's diagnostic skills. The scale for diagnostic skills appeared to be in line with a wide-spread consensus in science education on how to appropriately interpret students' expressions about scientific concepts [15,18,27,29,57]. Lower levels of diagnostic skills are associated primarily with evaluative comments judging students' expressions as right or wrong from a scientific perspective. Higher levels of diagnostic skills feature more interpretative approaches of understanding the students' expressions. We obtained high interrater-agreement ($ICC = 0.938$) [56] for the conversion of the coding scheme into the six-level scale for diagnostic skills.

For all calculations, we used IBM SPSS Statistics 25.

4. Results

An alpha level of 0.05 was used for all statistical tests. Table 3 displays descriptive statistics for the pre-service teachers' and in-service teachers' performance in the vignette-based test. Note that the number of selected situations refers only to the diagnostic process of noticing, but the score for diagnostic skills encompasses both diagnostic processes of noticing and interpreting.

Table 3. Descriptive Statistics for Pre-Service Teachers' (n = 63) and In-Service Teachers' (n = 14) Performance.

Measure	Pre-Service Teachers		In-Service Teachers		*U*
	M	*SD*	*M*	*SD*	
Selected Situations	10.35	6.92	2.86	3.80	155.5 ***
Diagnostic Skills	16.32	14.23	3.57	5.37	134.5 ***

The Mann-Whitney test examined the difference between pre-service teachers' and in-service teachers' performance across measures; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

4.1. RQ 1: What do Future Science Teachers Notice and How do They Interpret Students' Verbal Expressions about the Cycle of Matter within the Context of Education for Sustainable Development?

To ascertain what pre-service teachers notice, we calculated the mean score of relevant situations the pre-service teachers had selected as a measure for pre-service teachers' noticing. To gain insight into how pre-service teachers interpreted students' expressions, we calculated the absolute frequency of participants who engaged in particular ways of interpreting students' expressions.

We found that pre-service teachers were generally able to notice some student expressions relevant to understanding student conceptions. The pre-service teachers selected, on average, nearly half of the relevant situations containing relevant students' expressions (M = 10.35; SD = 6.92) (see Table 3). In our analysis of how pre-service teachers interpreted students' expressions they had noticed, we found that only a few pre-service teachers provided comments that were comprehensive with regard to interpreting student conceptions (see Figure 4). Some pre-service teachers interpreted students' expressions that indicated their behavior in the classroom in a general way. Hence, the information given in those comments was irrelevant to understanding student conceptions about the cycle of matter. Most pre-service teachers provided comments that tended to be evaluative, that is, the student expressions were judged as right or wrong from a scientific perspective. Moreover, a majority of the pre-service teachers provided comments that were descriptive. Students' expressions had been filtered by those participants but had not been further interpreted.

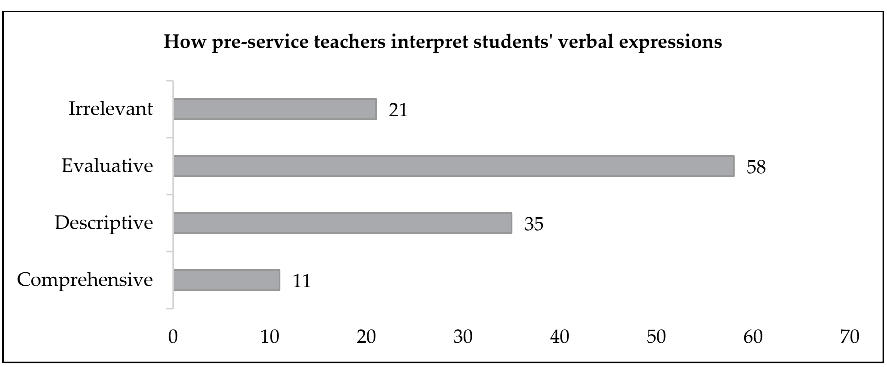

Figure 4. (Absolute) frequency of pre-service teachers that mentioned aspects (n = 63).

4.2. RQ 2: What Relevant Teacher Characteristics Influence Pre-Service Teachers' Diagnostic Skills?

To examine this research question, we computed the Pearson correlation coefficient. Table 4 displays a correlation matrix comparing pre-service teachers' diagnostic skills and various teacher characteristics that might be relevant for successfully diagnosing student conceptions about the cycle of matter. When examining correlations between pre-service teachers' characteristics and their diagnostic skills, we found significant and moderate correlations between diagnostic skills and content knowledge (r = 0.35, $p < 0.01$) and between diagnostic skills and the number of previous teaching internships as an indicator of the pre-service teachers' teaching experience ($r = 0.42$, $p < 0.01$). However, the relevance of pre-service teachers' teaching experience must be interpreted with caution because the number of teaching internships also moderately correlates with the pre-service teachers' CK and PCK. We found smaller and significant correlations between the pre-service teachers' diagnostic skills and PCK ($r = 0.26$, $p < 0.05$).

Table 4. Correlations between diagnostic skills, CK, PCK, and teaching practice.

	M	*SD*	1	2	3
1. Diagnostic Skills	16.32	14.23			
2. CK	5.71	1.99	0.35 **		
3. PCK	6.24	1.78	0.25 *	0.35 **	
4. Teaching Experience	1.37	0.50	0.42 **	0.42 **	0.26 *

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 5 shows correlation coefficients for the relationship between diagnostic skills and educational level and school type. We calculated the Pearson correlation coefficient for the correlation between diagnostic skills and educational level [58]. For the correlation between diagnostic skills and the school type that the pre-service teachers intended to teach in, we calculated the eta coefficient [59]. A t-test revealed that the pre-service teachers enrolled in master's programs scored significantly higher than the pre-service teachers enrolled in bachelor programs, t (56.96) = −3.80, $p < 0.001$. We found a nonsignificant relationship between diagnostic skills and the school type (elementary school, lower secondary school, or higher secondary school).

Table 5. Correlations between diagnostic skills and educational level/school type.

	Educational Level	**School Type**
Diagnostic Skills	0.34 **	0.19

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

4.3. RQ 3: Do In-Service Teachers Show Higher Diagnostic Skills than Pre-Service Teachers?

Table 3 displays descriptive statistics for the pre-service teachers' and in-service teachers' diagnostic skills. A Mann-Whitney U test indicated that the diagnostic skills were far greater for pre-service teachers than for in-service teachers, $U = 134.5$ $p < 0.001$. This finding implies that professional teaching experience alone does not seem to be a decisive factor when developing diagnostic skills with regard to noticing and interpreting student conceptions.

5. Discussion

To explore what (future) teachers notice and how they interpret student conceptions in the context of ESD, we first investigated the quantity of relevant situations the participants had selected and the quality of interpretations. We elicited those diagnostic processes by presenting classroom video material of students' expressions of their conceptions about the cycle of matter in a group work situation. We further examined the relationship between several teacher characteristics and diagnostic skills. The discussion of the results is organized by the research questions.

5.1. RQ 1: What do Future Science Teachers Notice and How do They Interpret Students' Expressions about the Cycle of Matter within the Context of Education for Sustainable Development?

Our findings indicate that pre-service teachers were able to notice student expressions relevant for understanding student conceptions, yet they experienced difficulties interpreting those expressions from a perspective that would help them to make decisions about adequate teaching strategies for individual learners [27,36]. Only a few participants offered interpretations indicating an attempt to comprehend the ways students think beyond evaluating whether the thoughts were correct from a scientific perspective. Some participants interpreted students' expressions about their behavior in a more general way, which were not related to the subject content relevant for ESD. Van Es (2011) suggested that providing comments with regard to student behavior in the classroom and also evaluative comments are preceding steps to more interpretative comments, for example, reasoning about student conceptions and understanding the roots of an idea [60]. Accordingly, to inform teachers' perspectives on how to appropriately link their instruction to student conceptions, pre-service teachers need to shift from a merely evaluative interpretation of student conceptions (right or wrong) to a more comprehensive interpretation of the way students think about ESD-related concepts such as the cycle of matter [27,29]. This may include recognizing that student conceptions are complex and span a continuum of understanding [27].

About half of the pre-service teachers provided comments that we labeled "descriptive", meaning that the most relevant aspects of students' expressions that would inform an understanding of student conceptions had been filtered and were not further analyzed. Such descriptive comments may be viewed as a necessary yet not sufficient precondition for an appropriate and comprehensive interpretation of student conceptions. Pre-service teachers might lack specific knowledge about typical ways of student thinking (e.g., knowledge about students' alternative conceptions), which may be conveyed in teacher education illustrated by students' expressions that indicate the alternative conceptions [57].

5.2. RQ 2: What Relevant Teacher Characteristics Influence Pre-Service Teachers' Diagnostic Skills?

The results from the correlational analysis across all pre-service teachers confirmed support for the assumption that teachers' diagnostic skills are related to their professional knowledge. We found stronger results in diagnostic skills with pre-service teachers who were already enrolled in a master's program, which can be associated with higher levels of pre-service teachers' professional knowledge. We also found a significant and moderate relationship between teachers' CK and diagnostic skills and a significant but slightly weaker relationship between teachers' PCK and diagnostic skills. Professional knowledge relevant for diagnosis seems to be a decisive factor that influences diagnostic skills. This finding is in line with research results in other contexts other than ESD [50,61]. Despite these promising results, given that PCK, in particular, comprises various facets of teachers' knowledge [62,63], the specific components of teachers' professional knowledge that contribute to the development of higher levels of diagnostic skills with regard to diagnosing student conceptions about the cycle of matter are still unknown [39]. Although the importance of CK appears certainly plausible, we also found that the interpretations of students' expressions were often made from a perspective of evaluating scientific correctness (see RQ 1). For teachers to interpret students' expressions in more comprehensive ways, additional knowledge components related to specific aspects of PCK (e.g., knowledge about students' alternative conceptions concerning ecological concepts) might be considered beneficial [50].

In our study, we found the largest correlation between pre-service teachers' teaching experience and diagnostic skills. Teaching experience is likely to be a key factor in the pre-service teachers' development of diagnostic skills, but experience also correlated with professional knowledge. This finding is reasonable because, given the organization of teacher education, pre-service teachers who have completed more teaching internships tend to also have completed more university courses. The practical experience itself can also contribute to the acquisition of professional knowledge [64]. The pre-service teachers' professional knowledge and teaching experience seem to be an intertwined construct we could not disentangle based on the data we collected from the participants in this study.

5.3. RQ 3: Do In-Service Teachers Show Higher Levels of Diagnostic Skills than Pre-Service Teachers?

To further explore the role and impact of teaching experience, we measured diagnostic skills of in-service teachers who taught topics relevant to ESD. With regard to diagnosing individual students' conceptions about the cycle of matter, the in-service primary school teachers performed poorly and were by far exceeded by the pre-service teachers' diagnostic skills. This result might come as a surprise, but it becomes more plausible when considering the assumptive requirements for diagnoses of student conceptions (see chapter 2.3). One speculative explanation from the present study may be related to a lack of professional knowledge in the area of teaching specific ecological topics. Although all participating in-service teachers currently taught science classes, only about half of them had studied sciences during teacher education. In contrast, all participating pre-service teachers were presently enrolled in teacher education programs covering in-depth study of biological concepts. Thus, relevant aspects of ecological CK may have been more available to the pre-service teachers while diagnosing. Moreover, an emphasis on diagnosing individual students' conceptions and linking instruction to those ideas have been relatively recent developments in science education and science teacher education [15,21,37,65]. Most of the participating in-service teachers have probably not been supported in developing corresponding competencies during their teacher education. This interpretation is supported by one of the participating in-service teachers' comments on the classroom situation used in the video vignettes. He stated that "nothing usable for the remaining parts of the lesson" had been shown. This remark suggests that attending to and using individual students' conceptions for further instruction might not be in the scope of teaching objectives for some in-service teachers. It also has to be taken into account that all participating in-service teachers taught on the primary level. To enhance findings about in-service teachers' diagnostic skills, more research among secondary school teachers is needed.

Based on our findings and previous research, we suggest that teaching experience in itself is not a predictor for teachers' skills in specific domains such as diagnosing student conceptions, even when the subject content (e.g., ecological concepts) is part of the curricula [66,67]. Instead, diagnostic skills with regard to the processes of noticing and interpreting student conceptions in the course of instruction might result from reflective and deliberate practice [66,68], presumably based on specific professional knowledge [69].

The in-service teachers' lack of diagnostic skills is also consistent with findings in a recent study on what teachers think and know about ESD and its implementation in class [70]. The authors highlighted the in-service teachers' desire for more training and knowledge of how to implement ESD in practice. Training teachers' diagnostic skills and corresponding teaching strategies may serve as a concrete measure for supporting teachers with the implementation of ESD in the science classroom [71].

6. Conclusions

When teaching for SDGs, teachers should essentially attempt to understand their students' conceptions about complex content matter. To achieve this understanding, teachers need to be able to diagnose their students' conceptions. Neither pre-service teachers nor in-service teachers seem to be sufficiently equipped for this challenging task. With regard to developing diagnostic skills in the field of ESD, both professional knowledge relevant for diagnosing (e.g., CK about the multiple cycles in ecosystems and knowledge about typical alternative student conceptions about such matters) and reflected practice opportunities seem to be relevant. Ultimately, we assume by augmenting teachers' diagnostic skills on topics related to sustainable development, teaching SDGs has a greater chance of leading to learning. Stated more succinctly, teachers' diagnoses determine the instructional decisions they can make to effectively support students' understanding of complex ecological concepts necessary for promoting sustainable development.

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Virtual Reality Nature Experiences Involving Wolves on YouTube: Presence, Emotions, and Attitudes in Immersive and Nonimmersive Settings

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Abstract: As some nature experiences, such as viewing wild animals, may be difficult to implement in science education, immersive virtual reality (VR) technologies have become a promising tool in education. However, there is limited knowledge regarding the effectiveness of nature experiences in VR. In this study, 50 German university students (M = 23.76 years, SD = 3.73 years) from diverse disciplines were randomly assigned to an immersive (head-mounted display; Oculus Quest) or a nonimmersive setting (external computer screen; desktop computer) and individually watched two 360° videos from the social media site YouTube about wolves in their natural habitat. Besides measuring participants' attitudes towards wolves, we investigated their feeling of presence in the virtual environments with the Spatial Presence Experience Scale (SPES) and the retrospective emotions of interest, joy, and fear with the Differential Affect Scale (M-DAS). The immersive head-mounted display induced higher levels of presence and interest compared to the nonimmersive external computer screen. While higher interest in the screen setting was associated with more positive attitudes towards wolves, such a correlation could not be found in the head-mounted display setting. Thus, our study found that immersive technology could induce interest in a nature experience related to the tested socio-scientific issue, even among people who did not already hold positive attitudes toward the issue. Overall, our findings suggest that 360° videos using immersive technology provide nature experiences with positive affective learning outcomes, even though the study focused on nature experiences in VR and was not an educational experience per se. As we were unable to assess the role of novelty of VR experiences, the application of VR technologies and its effects in larger teaching and learning settings needs to be evaluated in further studies.

Keywords: virtual reality; nature experiences; immersion; presence; emotions; education for sustainable development; return of the wolf

1. Introduction

The destruction of the natural environment has reached an alarming pace and is accompanied by a steady loss of biodiversity [1]. This challenge can only be solved by a change in thinking and a significant increase in our efforts to safeguard natural resources and species conservation, which are also linked to the quality of life for all people on our planet [2–4]. Therefore, the international community has undertaken groundbreaking initiatives like the 2030 Agenda, which includes 17 goals for the sustainable development of our planet, known as the Sustainable Development Goals (SDGs) [5]. While the overarching aim of the SDGs is to address global challenges that are crucial for the survival of humanity, they also touch upon the underlying ecological, economic, and social dimensions of the respective issues [5].

To overcome these challenges, society needs to make informed and responsible decisions for sustainable action. One major approach for achieving the SDGs and to prepare citizens for making such decisions is Education for Sustainable Development (ESD) [6]. As part of a holistic education, learners require the knowledge, skills, values, and attitudes that empower them to contribute to sustainable development [7]. Therefore, ESD focuses on integrating deeper learning experiences rather than just acquiring knowledge [8].

One way to achieve the goals of ESD is to encourage personal learning experiences connected to relevant environmental issues, as it has been demonstrated that acquiring knowledge alone does not facilitate learning or change behavior [9]. Instead, individuals should be given the opportunity to actively engage with the learning content [10]. Within the context of ESD, having more direct nature experiences is one approach to actively engage learners [11].

Generally, following the theories of John Dewey, experiences can be differentiated into primary or secondary experiences [12,13]. While primary experiences represent unmediated material interactions with the physical and social world, secondary experiences are indirect and more reflective ways of experiencing the world [13]. In ESD, especially primary experiences of the natural world may be called nature experiences [11] and may include objects such as landscapes, animals, and flowers. Primary experiences of these objects may extend beyond personally relevant concerns and induce people to engage in proenvironmental behaviors [11,14,15] and are positively related to environmental attitudes [16]. However, especially in formal education, personal nature experiences may be difficult to arrange, expensive, and potentially dangerous. Therefore, several recent research studies have proposed virtual reality (VR) learning experiences as a way to simulate reality and allow students to experience environmental issues in an emotionally engaging way beyond what is possible in classrooms [17]. The possibilities offered by immersive VR experiences are especially promising for ESD, as immersive VR affords lifelike, high-quality experiences [18,19].

At the moment, however, our understanding of how such experiences affect viewers is limited. An explorative study involving a nature documentary, for example, showed that proenvironmental attitudes can be fostered [20]. Another study found that a greater involvement in nature could be achieved using immersive VR technology [21]. However, there is scant research on implementing issues suitable for ESD in formal learning settings, such as universities. Moreover, prior studies have focused primarily on cognitive learning outcomes, which is why our study focused on affective learning outcomes. More particularly, we investigated the effects of two 360° videos on selected affective variables that may be relevant to foster proenvironmental behavior and could be applied to science learning in higher education.

2. Theoretical Background

2.1. Sustainable Development Goals in Science Education

In 2015 the United Nations (UN) General Assembly adopted the 2030 Agenda for Sustainable Development [5] with the aim to address the global challenges that are crucial for the survival of humanity [6]. At its core are 17 SDGs that lay the foundation for shaping global economic progress in accordance with social justice and within the planet's ecological limits. ESD is explicitly acknowledged in the SDGs as part of Target 4.7 [5], which aims to provide all individuals with sustainability competencies to address the challenges of each SDG [22]. Accordingly, "ESD empowers learners to take informed decisions and responsible actions for environmental integrity, economic viability and a just society, for present and future generations, while respecting cultural diversity" [22]. These competencies include the required knowledge and skills, but also values and motivations to enable proenvironmental behavior [23].

In order to achieve these competencies and for them to be applicable to education, educational initiatives aligned with the ESD goals need to address environmental issues in a manner that allows for socio-scientific decision-making [24] and includes not only cognitive but also socio-emotional and behavioral learning outcomes [8]. In research on science education, such issues are referred to as socio-scientific issues (SSIs). To accommodate the controversial nature of environmental discourse, SSIs should be based on an issue of sustainable development and fulfil specific criteria [25]. For example, the underlying debates should be based on deep premises, such as the values and attitudes of different groups, involve a substantial number of people and, lastly, it should not be possible to settle them through scientific evidence alone [25]. Taking these criteria into consideration, the example of returning wolves in Germany represents a suitable issue for learning in the context of ESD.

2.2. Returning Wolves as an Educational Topic

Wolves were once a widespread, native mammal species in several countries in central Europe, such as Germany [26]. Over the centuries, however, they were eradicated by humankind because they posed a threat to livestock and thus to agriculture [26]. Benefitting from European and national protection guidelines for the wolf and other wildlife species, wolves have been able to settle back in Germany since 2000 and are regaining some of their former habitats [27]. However, even though the proportion of people who depend on making a living on agricultural activities has fallen significantly, the return of wolves still causes conflicts [28,29]. While some environmental organizations celebrate their return as a success for the protection of biodiversity [30], for some farmers the return of an apex predator has had negative economic consequences due to livestock killings [27,31]. Besides these direct negative consequences, other socio-psychological factors affect people's perceptions and attitudes, such as values, beliefs, societal factors, and cultural norms [32].

The ecological (biodiversity), economic (cost of lost livestock), and social dimensions (conflict between farmers and conservationists) of returning wolves makes the issue quite complex and thus suitable in the context of ESD. Furthermore, it may explicitly address SDG 15, "Life on land", which aims to protect ecosystems and promote their sustainable use in order to halt biodiversity loss [5]. Finally, the issue sets a good example in biology education because the context aligns with curricular learning aims by referring to ecology, which is a traditional topic in biology education.

Besides the content-related aspect of the topic, wild animals like wolves allow for direct experiences and may provoke emotional responses. Experiential and learner-centred learning may be fruitful in ESD, for example to develop environmental awareness and skills related to managing sustainability issues [33]. However, experiential learning outcomes are sometimes difficult to incorporate in science education because they can realistically be achieved only with visits to zoos or science centers. The use of immersive VR, which allows for high-quality experiences that have been found to be similar to real-world experiences, may offer an alternative to these visits [18,19,34].

2.3. Immersive Virtual Reality as an Option in Education for Sustainable Development

While VR generally refers to all computer-mediated environments that aim to simulate reality [17], it also includes the interface in which users are able to interact with the artificially created realities [35]. Such digital realities were found to be beneficial for science learning in prior studies, for example in the topic of anatomy [36], although some studies showed positive effects of immersive teachnologies for affective, but not cognitive learning outcomes [37]. Regarding technological implementation, prior research used the level of immersion as a key element to differentiate among specific applications of VR [38]. The level of immersion depends on the quality of the system's technology and can therefore be regarded as an objective measure of vividness and interactivity while shutting out the physical reality [39]. Display equipment with a high level of immersion is characterized by the congruence of real actions and actions perceived in the artificial space [17,34].

The most effective way to achieve high levels of immersion is through the use of a head-mounted display (HMD) that covers the user's eyes, thus isolating them from the external world [40]. It separately delivers 2D computer-generated images to each eye in order to create a realistic perspective for the viewer. In combination with the continually captured position of the user's head and other channels of human perception, such as audio or haptic feedback, the HMD creates the illusion that the user is located in a three-dimensional space and can explore that space [17,35]. When an HMD device may not be available, the possibility of free exploration of the digital environment can also be achieved in a nonimmersive VR setting in which the HMD is substituted by an external screen, for example [35].

Whereas fully immersive VR is characterized by a high level of interactivity by which the user is able to move within the environment and interact with objects, 360° videos are limited to a specific point of view from which the user can turn and look in all directions [17,41]. Due to the limited interactivity of 360° videos, there are contradictory views on whether they qualify as VR [17]. Slater and Sanchez-Vives [17] argued that 360° videos cannot be excluded as VR by definition. Instead, 360° videos capture a real environment and can then be manipulated using computer graphics to provide an interactive rendering of the same space. Compared to fully immersive VR, 360° videos have low costs and good accessibility [42]. The video platform YouTube, for example, offers a way to easily access 360° videos. Not only are users provided with a variety of different scenarios, but the videos are also free of charge.

Several studies have indicated the persuasive potential of immersive media, as their rich sensory impressions are perceived as unmediated [20]. The regions of the brain that are activated when accessing experiences that were created in VR are similar to those that are activated when accessing experiences from real life, which is why immersive VR experiences are remembered in similar ways as real experiences [18,19]. Interestingly, researchers were able to transfer this realness to relevant learning scenarios about environmental issues, suggesting that experiences in immersive VR may be an effective tool to promote involvement in environmental issues [20,21,43,44].

2.4. Aim of the Study and Hypotheses

Despite the potential of VR technologies for ESD, there is a lack of understanding of how VR may affect proenvironmental behavior and affective learning in the context of ESD. Therefore, in this study we investigated the effects of two 360° videos about wolves on selected variables that may be relevant to foster proenvironmental behavior and may be applied in science learning in higher education. As experimental variation we randomly assigned the participants to either an immersive group (HMD) or a nonimmersive group (external computer screen). Although the study was not embedded in an explicit educational experience, the selected videos may nonetheless be applied in educational settings. The following subsections further elaborate on the selected dependent variables and present the underlying hypotheses that were investigated in the study.

2.4.1. Spatial Presence

Spatial presence refers to the subjective perception of physically being in a specific environment [45,46]. It represents the extent to which an individual experiences a mediated environment as the one in which they are consciously present [39]. Wirth et al. [45] regarded presence as a two-dimensional construct characterized by the perception of being located in the mediated environment and the possibility to interact with objects in that environment. Presence arises from experiences induced by the immersive properties of the media [38,39,45]. However, presence is not limited to the experience of using sensory-rich VR technology. It can also occur when using less immersive media or text-based media with no direct sensory input [45,46]. Although technological factors are not sufficient to elicit feelings of presence, they can be considered as supporting elements [38,45].

As described above, presence gives rise to the feeling that events in the virtual environment are really happening [17]. Belief in the authenticity of an event gives it the feeling of being a real experience [18,47]. Therefore, presence is one of the prerequisites of a successful ESD experience. If VR experiences may lead to a higher level of presence, they may be suitable for creating higher-quality experiences also in formal learning contexts such as university courses.

Several studies assessing different degrees of immersion reported higher presence in more immersive VR settings than in less immersive settings. Such effects have been found in studies comparing different types of equipment: Cave Automatic Virtual Environment (CAVE) vs. HMD [47];

HMD vs. computer monitor [20,21,35,41]; and video wall vs. computer monitor [48]. Furthermore, Cummings and Bailenson [38] reported that the immersion features of the equipment are more important for presence formation than those creating a photorealistic environment. Based on theoretical considerations and empirical results reported in the literature, we therefore propose our first hypothesis:

Hypothesis 1 (H1): *Viewers who use immersive HMDs will report more intense feelings of spatial presence than viewers with nonimmersive external screens.*

2.4.2. Emotions

Emotions recently gained more attention in educational learning and were shown to have substantial influence on academic achievement [49]. Another reason for including emotions in our study was that research has found extensive evidence of a connection between emotions and proenvironmental behavior [50,51]. Especially in the context of returning wolves, research has shown that emotions toward wolves predict the acceptance of these predators [52]. Behavioral changes are necessary to overcome the ecological crisis and to promote sustainable development. Hence, we included emotions in the study.

Emotions can be defined as psycho-physiological phenomena that are perceived as emotional episodes evoked by a variety of stimuli [53,54], including real and imagined objects, situations, or persons [55]. Furthermore, emotions are of limited duration; this differentiates them from other affective psychological variables, such as attitudes [55]. Besides being episodic, emotions are often described with the help of appraisal theories. These theories assume a multidimensional concept of emotions. Starting from a certain stimulus, a mostly unconscious evaluation ("appraisal") of the situation takes place, which causes subsequent psychological action tendencies. The appraisal process also entails physiological changes which prepare motor activities that eventually transfer the emotional reaction to the external world. The subjective feeling component may be consciously experienced [53,54].

Different approaches describe emotions as either specific emotion schemas ("discrete emotions"; [56]) or general affective reactions ("dimensional emotions"; [55]). While dimensional emotions are characterized by two bipolar dimensions of valence (negative–positive) and activation (activation–deactivation), in the discrete approach specific emotions can be distinguished from one another using qualitative features [55]. Due to the fact that the latter approach allows for a more nuanced view and further differentiates between similar emotions, this study used discrete emotions to classify an emotional reaction.

As our study focused on emotions in education, we chose three of Izard's [56] basic emotions that are particularly relevant for learning: interest, joy, and fear. It has been shown that these emotions have a substantial influence on academic achievement. Interest motivates exploration and information-seeking, while joy signals pleasure and satisfaction generated from that activity [57]. In contrast to interest and joy, which contribute to academic achievement, fear inhibits cognitive performance [58]. It plays an especially significant role in the issue of returning wolves. Wolf behavior that matches the human notions of evil and danger is associated with negative feelings, especially fear [59].

Prior studies have already found evidence of the influence of presence on emotional reactions. Although there is limited research on the connection between presence and emotions in education [41,60,61], correlations between presence and emotional experiences in VR have been investigated in the field of VR exposure therapy [62–65]. Whereas the latter studies have found that fear increases with a higher level of presence, studies on emotions in an educational setting could not report analogous findings. Instead, these studies reported more positive emotions with an increased level of immersion [41,60] and less negative emotions with an increased level of spatial presence [41]. The differences regarding the correlation of presence and fear have been explained with the use of different emotion-triggering materials in the studies. As our study was in the field of education and was not explicitly designed to elicit specific emotional reactions in selected participants, we propose the following hypotheses:

Hypothesis 2 (H2): *Viewers who use immersive HMDs will report more intense feelings of interest than viewers with nonimmersive external screens.*

Hypothesis 3 (H3): *Viewers who use immersive HMDs will report more intense feelings of joy than viewers with nonimmersive external screens.*

Hypothesis 4 (H4): *Viewers who use nonimmersive HMDs will report less intense feelings of fear than viewers with immersive external screens.*

2.4.3. Attitudes Towards Wolves

As discussed above, emotional responses vary depending on media content and technological factors. However, personal differences among individuals may also be a determining factor for media experiences [66]. To further understand individual differences in emotional responses to VR media, we incorporated relevant personality differences regarding attitudes towards the chosen topic of returning wolves.

An attitude is a positive or negative evaluation [67,68] of an object of thought, including things, people, ideas, and situations [69]. As they influence the way we feel, perceive, and act, attitudes serve to quickly classify objects and evaluate our environment [68]. While prior studies showed how general attitudes towards sustainable development may affect peoples' decision-making and behavior in environmental domains [70], within more specialized domains, such as species conservation, more specific attitudes also proved to be relevant [71].

Within the selected socio-scientific issue of returning wolves, attitudes towards wolves concentrate solely on the species and evaluate its existence. More particularly, they describe the positive or negative evaluation of wolves living in a specified area [72]. Such attitudes are seen as an important factor influencing the relationship between humans and wildlife, as they have a major impact on environmental consciousness and human behavior [71]. Thus, attitudes contribute to enhancing acceptance of species protection [73,74] and wildlife policies [75,76]. Prior studies also found that attitudes influence emotional dispositions: in a given scenario, participants with an already negative attitude towards wild animals demonstrated a more negative emotions towards wolves [76]. Therefore, we propose the following final hypothesis:

Hypothesis 5 (H5): *Viewers with positive attitudes towards wolves will report higher interest and joy, and less fear.*

3. Materials and Methods

3.1. Research Design and Sample

The study employed a randomized, controlled, between-subject design with pre- and post-tests. Participants were randomly assigned to one of the experimental groups. The study was conducted at a medium-sized university in Lower Saxony, Germany. In total, 50 university students from various disciplines participated in the study individually, with 36 of them (72%) being female and 14 (28%) male. Participants' ages ranged from 18 to 36 years (M = 23.76 years, SD = 3.73 years). Overall, 28 participants had a background in teaching (56%), eight in engeneering (16%), five in science (10%), and three in computer sciences (6%). Furthermore, two participants each studied design, management, and psychology (each 4%). While the selected university has a high proportion of students from teacher education, differences between the applicability of VR with students from different study backgrounds may be of interest for further investigations. The sample size of 50 was set prior to any data collection and calculated with G*Power [77].

The participants, whose anonymity was assured, were informed via written and oral communication about the course, purpose, and objectives of the study and documented their consent to the data collection before filling out the pretest questionnaire in a paper-and-pencil format. After being randomly assigned to one of the groups, each participant individually watched two 360° videos about wild wolves in their natural habitat on the video platform YouTube (video 1: youtube.com/watch?v=vC8EVirfuMM; video 2: youtube.com/watch?v=rjQ5-UHQWC0; links checked on 30.04.2020). The order of these videos was randomized and both videos played automatically after each other, which was assured by assigning the videos to a playlist. The total duration of the two videos combined was 3 min and 36 s.

The participants either watched the videos on a normal external computer screen (nonimmersive group) or using an Oculus Quest HMD (immersive group). Each participant in the nonimmersive group watched the videos while seated in a chair in front of a desk on which a computer and screen had been placed. The same chair was also used for the participants in the immersive group, but it was positioned in the middle of a room so that the participants were able to freely rotate in the chair. After the videos had ended, the participants were asked to fill out the post-test questionnaire. The total duration of the procedure was less than 30 min and each participant was compensated with 5€.

The study was conducted in accordance with the relevant national guidelines and laws of the study country, the selected university, the Helsinki Declaration, and the Code of Conduct of the American Psychological Association (APA). All ethical and legal standards, such as guaranteeing the anonymity of participants and participation on a voluntary basis, were observed. At all times the participants had the opportunity to skip individual questions or the whole questionnaire, and to refuse to participate in the study. Approval by a local ethics committee was not required, as the study had no medical aspect and assessed no sensitive personal information. Finally, all participants were above 18 years and introduced to the aims of the study.

3.2. Measures

The questionnaire was structured using a pre–post-test design. The pretest comprised scales to assess sociodemographic characteristics and attitudes towards wolves. In the post-test we included scales to capture the sense of presence, emotional reactions, and attitudes towards wolves. The questionnaire was implemented in German. The English wording of all items can be found in the Appendix A.

To assess attitudes towards wolves, we selected a measure of general attitude towards wildlife from Kaczensky, Blazic, and Gossow [72] and adapted it to the animal context of the study. We therefore replaced the word 'bear' in the original scale with the word 'wolf.' Furthermore, we changed the original location in one item (Slovenia) to Germany, as this is the country where the study was conducted. The overall scale comprised six items, with the final item being reverse-coded. The translation into German was validated using backtranslation.

To measure the viewers' sense of presence, the Spatial Presence Experience Scale (SPES) by Hartmann et al. [78] was used. The scale measures two perceived dimensions: self-location and possible actions. For our study, we used a translated German version of the SPES [79]. The scale comprises eight items on a 5-point Likert scale.

To capture emotional reactions, we used the validated and modified German version of the Differential Affect Scale (M-DAS), which builds on Izard's Differential Emotion Scale [80]. It measures the quality and intensity of subjectively perceived feelings in media reception. We selected the discrete emotions of interest, joy, and fear. Each emotion was measured with three items utilizing a 5-point Likert scale with which the participants were asked how strongly they experienced each of the discrete emotions while watching the videos. The order of items for this scale was randomized.

3.3. Statistical Analysis

In order to ensure the validity of the scales, exploratory factor analyses (EFA) were carried out. The factor analyses showed meaningful factor loadings of all items on the corresponding scales (>0.40; [81]). In line with our theoretical assumptions, all scales also showed appropriate factor structures (for example eigenvalues above 1.00). Reliability was then calculated using Cronbach's alpha as a further measure of internal consistency; it showed sufficient reliability for all scales (Table 1). The strong correlation between the pre- and post-test scores for attitudes also illustrates the good measurement abilities of these scales, as this may be interpreted as retest reliability [81]. All items of each scale were merged to generate an overall index of the corresponding construct. Cases with missing values were excluded from further analysis, but no outliers were removed from the dataset.

Due to the significant deviation from normality with respect to skewness and kurtosis of some variables (see Table 1), we selected robust statistical procedures. After inspecting the intercorrelations and descriptive statistics (see Table 1), mean value comparisons using the Mann-Whitney U test were carried out in order to test whether the sense of presence (H_1) as well as the emotional reactions (H_2–H_4) differed between the immersive and nonimmersive groups. Finally, the correlation coefficient Spearman rho was used to analyze the connections between the attitudes towards wolves and the other variables (H_5). All statistical analyses were performed using IBM© SPSS© software 26. Due to the relatively small sample size of our study, we also calculated bootstrapped correlation coefficients with the built-in function in SPSS [81]. The dataset and the SPSS output for the replication of all analyses are available in the Supplemental Material of the paper. Information of the participants' study background were exluded from the dataset in order to gurantee their anonymity.

3.4. Intercorrelations and Descriptive Statistics

As shown in Table 1, most variables showed a slightly negatively skewed distribution. This concerned all variables except for presence and fear. The skewness was mainly due to relatively high values for both the attitude reported in the pretest (M = 4.48; SD = 0.92; Mdn = 4.67) and the post-test (M = 4.57; SD = 1.01; Mdn = 4.83). Also, the emotional reactions of joy (M = 3.15; SD = 1.14; Mdn = 3.00) and especially interest (M = 4.24; SD = 0.61; Mdn = 4.33) showed high values. Only presence (M = 2.98; SD = 0.86; Mdn = 3.00) and fear (M = 2.17; SD = 0.87; Mdn = 2.00) skewed positively.

Concerning the correlations of the whole sample described in Table 1, there was a significant negative correlation between group and presence with a large effect size ($r = -0.55$, $p < 0.001$) and group and interest with a medium effect size ($r = -0.32$, $p < 0.05$).

We were not able to detect significant correlations between the demographic variables of age and gender with any of the other variables. An explicit investigation of gender differences for the variable of presence may nonetheless be interesting for further studies, as gender showed a small correlation with presence, although it should be noted that the correlation was not significant due to our small sample size ($r = -0.21$, $p > 0.05$). Female participants reported a higher presence, a result that contrasted prior studies, which showed a larger presence for male users of VR [82]. This result may be explainable either by the context of wolves or nature experiences in general.

Table 1. Bivariate Spearman rho correlations with bootstrapped 95% confidence interval (95% CI) in upper half and descriptive statistics of the study variables (n = 50 university students).

	1	2	3	4	5	6	7	8	9
1. Group	-	−0.34, 0.21	−0.19, 0.36	−0.33, 0.27	−0.32, 0.25	−0.73,−0.35	−0.57,−0.03	−0.35, 0.24	−0.41, 0.16
2. Gender	−0.08	-	−0.12, 0.44	−0.20, 0.41	−0.27, 0.32	−0.47, 0.06	−0.38, 0.16	−0.31, 0.21	−0.25, 0.29
3. Age	0.10	0.17	-	−0.24, 0.37	−0.31, 0.31	−0.35, 0.23	−0.27, 0.36	−0.39, 0.19	−0.29, 0.24
4. Attitudes Pre	−0.02	0.10	0.08	-	0.87, 0.97	−0.36, 0.22	−0.04, 0.56	0.07, 0.63	−0.60,−0.04
5. Attitudes Post	−0.03	0.02	0.01	0.94 ***	-	−0.29, 0.25	0.06, 0.61	0.13, 0.65	−0.63,−0.10
6. Presence	−0.55 ***	−0.21	−0.07	−0.10	−0.03	-	0.19, 0.62	−0.22, 0.42	−0.13, 0.46
7. Interest	−0.32 *	−0.13	0.04	0.27	0.37 **	0.42 **	-	0.06, 0.65	−0.39, 0.17
8. Joy	−0.05	−0.06	−0.12	0.37 **	0.42 **	0.10	0.38 **	-	−0.65,−0.20
9. Fear	−0.13	0.02	−0.03	−0.34 *	−0.38 **	0.18	−0.11	−0.45 **	-
Items	-	-	-	6	6	8	3	3	3
Mean	-	-	23.76	4.48	4.57	2.98	4.24	3.15	2.17
Median	-	-	23	4.67	4.83	3.00	4.33	3.00	2.00
SD	-	-	3.73	0.92	1.01	0.86	0.61	1.14	0.87
Skewness	-	-	1.53 **	−0.58	−1.08 **	0.11	−0.66 *	−0.06	0.59
Kurtosis	-	-	3.09 **	0.06	1.76 **	−0.46	−0.18	−0.78	−0.16
Cronbach's α	-	-	-	0.89	0.90	0.89	0.79	0.95	0.80

Note. * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$. Group was coded as (1) HMD and (2) computer screen; gender was coded as (1) female and (2) male. Significant skewness and kurtosis indicate a significant deviation from normality [81].

In addition, presence correlated significantly positively with interest with a medium effect size (r = 0.42; $p < 0.01$). Regarding the attitudes reported in the pretest, there was a significant positive correlation with joy with a medium effect size (r = 0.37, $p < 0.01$). Also, the post-test attitudes correlated significantly positively with joy (r = 0.42, $p < 0.01$) as well as interest (r = 0.37, $p < 0.01$) with a medium effect size. Furthermore, there was a significant negative correlation between both the attitude reports in the pretest (r = −0.34, $p < 0.05$) and post-test (r = −0.38, $p < 0.01$) and the emotion of fear with a medium effect size. Furthermore, there was a strong correlation between the attitudes in the pre- and the post-test (r = 0.94; $p < 0.001$). Besides indicating that there were only small changes in the attitudes due to the intervention, this may also be interpreted as retest reliability, as we found similar results at both times. Due to these meaningful correlations between the variables, we continued with the further analysis.

4. Results

4.1. Group Differences

To test the first four hypotheses, we conducted Mann-Whitney U tests to determine whether there were differences in the feelings of presence and emotional reactions between participants who watched the immersive video with an HMD and the nonimmersive video on an external computer screen. As displayed in Table 2, we found significant differences for the dependent variables of presence and interest, but not for the other variables.

Table 2. Descriptive statistics and results of the mean value comparison of the study variables for the head-mounted display (HMD) and screen groups.

	HMD (n = 25)			Computer Screen (n = 25)			Mann–Whitney Test	
Dependent Variable	**M**	**SD**	**Mdn**	**M**	**SD**	**Mdn**	***Z***	***D***
Attitudes Pre	4.50	0.86	4.67	4.46	0.99	4.67	−0.039	0.01
Attitudes Post	4.63	0.86	4.83	4.50	1.14	4.67	−0.097	0.03
Presence	3.46	0.75	3.50	2.51	0.69	2.50	−3.954	1.35 ***
Interest	4.43	0.53	4.67	4.06	0.63	4.00	−2.197	0.66 *
Joy	3.19	1.08	3.33	3.11	1.22	3.00	−0.480	0.14
Fear	2.29	0.97	2.00	2.04	0.74	2.00	−0.821	0.23

Note. * = $p < 0.05$, *** = $p < 0.00$.

The largest differences were found for the variable of presence, which differed between the HMD group and the screen group with a large effect size (Z = −3.954, d = 1.35, $p < 0.001$). In comparison, the participants within the immersive HMD group showed a significantly higher interest with a medium effect size (Z = −2.197, d = 0.66, $p < 0.05$). However, there were no significant differences between the groups in the emotions of fear (Z = −0.821, d = 0.23, $p > 0.05$) and joy (Z = −0.480, d = 0.14, $p > 0.05$). Figure 1 illustrates the distributions of, and differences between, the dependent variables presence, interest, fear, and joy in the two experimental groups.

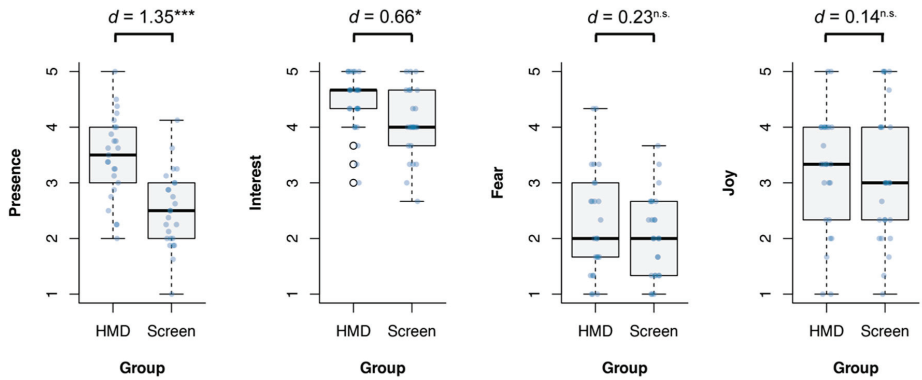

Figure 1. Mean value comparisons of the variables presence (H_1), interest (H_2), fear (H_3), and joy (H_4) for the HMD and computer screen groups. [n.s.] = not significant, * = $p < 0.05$, *** = $p < 0.00$.

Concerning attitudes reported prior to the videos (Z = 0.039, d = 0.01, $p > 0.05$) and after the videos (Z = −0.097, d = 0.03, $p > 0.05$), there was no significant difference between the groups. Using a Wilcoxon test we also tested whether there was a difference between the attitudes prior and after the videos for both groups. We found a larger effect size in the HMD group (Z = −1.929, d = 0.84, $p > 0.05$) than in the screen group (Z = −0.703, d = 0.28, $p > 0.05$), but there was no significant difference between the pre- and post-test attitudes in both groups.

4.2. Impacts of Attitudes Towards Wolves

4.2.1. Prediction of Emotions

To test the predictors of the reported emotions, we conducted regression analyses with the groups, presence, and attitudes from the post-test as predictors of interest, joy, and fear. As displayed in Table 3, presence (β = 0.32, 95% CI = [0.01,0.44], $p < 0.05$) and attitudes from the post-test (β = 0.33, 95% CI = [0.06,0.35], $p < 0.05$) were predictors of interest, while the group was not a significant predictor (β = −0.11, 95% CI = [−0.60,0.26], $p > 0.05$). This shows that attitudes are a slightly stronger predictor of interest than presence. Overall, this model predicted 23% of the variance for the reported interest (adj. R^2 = 0.23).

Table 3. Results from regression analyses for the reported emotions of all participants (n = 50) with standardized regression coefficients (β), standard error (SE), and bootstrapped 95% confidence interval (95% CI).

	Interest		**Joy**		**Fear**	
Predictor	**β (SE)**	**95% CI**	**β (SE)**	**95% CI**	**β (SE)**	**95% CI**
Group	−0.11 (0.18)	−0.60, 0.26	0.04 (0.36)	−0.66, 0.86	0.00 (0.28)	−0.49, 0.52
Presence	0.32 * (0.11)	0.01, 0.44	0.08 (0.21)	−0.36, 0.57	0.31 (0.16)	−0.07, 0.63
Attitudes Post	0.33 * (0.08)	0.06, 0.35	0.44 ** (0.15)	0.20, 0.75	−0.30 * (0.12)	−0.50, −0.09
Model results						
F (*df*)	5.806 ** (3)		3.696 * (3)		3.241 * (3)	
R^2	0.28		0.19		0.17	
Adj. R^2	0.23		0.14		0.12	

Note. * = $p < 0.05$, ** = $p < 0.01$.

As in the case of perceived interest, attitudes were also predictive of perceived joy (β = 0.44, 95% CI = [0.20,0.75], $p < 0.05$). The group (β = 0.04, 95% CI = [−0.66,0.86], $p > 0.05$) and presence

(β = 0.08, 95% CI = [−0.36,0.57], $p > 0.05$), however, were not found to be significant predictors of joy. The regression was able to explain 14% of the variance (adj. $R^2 = 0.14$).

Furthermore, attitudes were identified as a negative predictor for the reported fear (β = −0.30, 95% CI = [−0.50, −0.09], $p < 0.05$), while the group (β = 0.00, 95% CI = [−0.49,0.52], $p > 0.05$) and presence (β = 0.31, 95% CI = [−0.07,0.63], $p > 0.05$) were not significant predictors. This model predicted 12% of the variance (adj. $R^2 = 0.12$).

4.2.2. Correlational Differences within the Groups

Concerning the correlation differentiated by group, within the HMD group there was no significant correlation between the reported attitudes towards wolves in the pretest and the emotions of interest, joy, and fear. The attitudes reported in the post-test and fear had a significant negative correlation with a medium effect size (r = −0.46, $p < 0.05$). However, the post-test attitudes did not correlate significantly with the variables presence, interest, and joy (Table 4).

Table 4. Bivariate Spearman rho correlations between the study variables for the head-mounted display (HMD) group (n = 25) with bootstrapped 95% confidence interval (95% CI) in the upper half of the correlation matrix.

	1	2	3	4	5	6
1. Attitudes Pre	-	0.68, 0.97	−0.63, 0.25	−0.40, 0.53	−0.43, 0.41	−0.66, 0.05
2. Attitudes Post	0.89 ***	-	−0.59, 0.23	−0.30, 0.58	−0.37, 0.45	−0.74, −0.11
3. Presence	−0.21	−0.19	-	−0.27, 0.55	−0.40, 0.51	−0.28, 0.56
4. Interest	−0.07	0.17	0.17	-	−0.18, 0.66	−0.45, 0.29
5. Joy	−0.01	0.06	0.04	0.25	-	−0.69, 0.02
6. Fear	−0.32	−0.46 *	0.18	−0.09	−0.40 *	-

Note. * = $p < 0.05$, *** = $p < 0.001$.

Within the screen group, attitudes reported in the pretest were positively correlated with interest with a medium effect size (r = 0.48, $p < 0.05$). Also, joy and pretest attitudes had a positive correlation with a large effect size (r = 0.68, $p < 0.001$). Regarding the attitudes reported in the post-test, there was a significant positive correlation with interest (r = 0.54, $p < 0.01$) as well as joy (r = 0.72, $p < 0.001$) with a large effect size. There was no significant correlation between attitudes and fear (r = −0.32, $p > 0.05$) (Table 5).

Table 5. Bivariate Spearman rho correlations between the study variables for the screen group (n = 25) with bootstrapped correlation coefficients in the upper half of the correlation matrix.

	1	2	3	4	5	6
1. Attitudes Pre	-	0.86, 0.99	−0.36, 0.42	0.10, 0.76	0.33, 0.87	−0.76, 0.16
2. Attitudes Post	0.96 ***	-	−0.28, 0.49	0.17, 0.81	0.43, 0.89	−0.76, 0.13
3. Presence	0.03	0.10	-	−0.15, 0.67	−0.36, 0.46	−0.33, 0.56
4. Interest	0.48 *	0.54 **	0.29	-	−0.09, 0.81	−0.67, 0.15
5. Joy	0.68 ***	0.72 ***	0.05	0.40	-	−0.72, −0.09
6. Fear	−0.32	−0.35	0.16	−0.29	−0.52 **	-

Note. * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

5. Discussion

5.1. Being Present with Wolves

Consistent with hypothesis H_1, the results showed a significant influence of the immersive qualities of the head-mounted display on the participants' sense of presence. Thus, in comparison to nonimmersive 360° videos, immersive 360° videos were able to elicit higher levels of presence. This finding is in line with prior research [20,21,35,60] and suggests that the mediated experience of wolf contact was perceived as more real with an HMD. Interestingly, a significant difference in presence between the two groups could be identified even though the videos in our studies were very short. This may be especially relevant in formal education, as even short periods with HMDs may foster students' perception of presence, allowing such methods to be easily integrated into teaching. Even if we did not apply VR as part of an educational experience, other studies have shown how presence allows VR experiences to be felt as if they were real [45]. Therefore, we believe our findings suggest that immersive VR videos may complement field trips to zoos and science centers, for example in the preparation of such trips introducing students to specific contents of the real experiences.

We explicitly do not state that VR experiences may be able to replace real-world field trips, because even though VR may be better than just watching videos, field trips nonetheless enable unique learning experiences, for example by giving children the chance to explore freely [83]. Even though some VR apps allow a freer exploration of digital environments, they nonetheless need to be programmed and therefore anticipate specific learning pathways. However, in education this also represents an opportunity, as the prior programming may be a way of better guiding students in the learning process, which has often been mentioned as a requirement for successful discovery learning [84]. Most importantly, such videos also facilitate the opportunity to see wolves up close, which would be both difficult and dangerous in real life. Nonetheless, future research still needs to illustrate when and how such virtual nature experiences may be beneficial in formal educational settings.

Further studies are also needed to assess the role of novelty with VR experiences. Novelty was found to be one cause for interest [57], which is why the students could have experienced interest mainly because they were novices to VR. In further studies the same VR equipment could be applied using different videos in the same class over a larger time frame. This would allow researchers to evaluate if the interest may be due to the novelty of VR or the specific experiences. In the first case, the interest should systematically decline over time and the time points should explain a significant amount of variance in students' interest. In the latter case, there should be no systematic variation of interest with regard to the time points and most of the variance should be explained by variables that refer to the specific experiences.

Similar effects might have also occurred in this study regarding presence. However, given the alignment of this result with results from prior studies, we believe our results to be rather robust.

Notably, our study employed 360° videos available on YouTube. Although 360° videos inhibit interactivity due to their static camera position, by using immersive VR technology, higher levels of presence could nevertheless be detected. This illustrates how even low-threshold digital activities in social media platforms may allow life-like experiences of nature. Besides this, it needs to be considered that the videos only had a short duration of less than 5 min. Such short video clips may only allow for an incomplete picture of the livelihood of wolves in their natural habitat. Hence, it would be interesting to evaluate the results of longer videos that allow for other experiences, including, for example, the dynamics within wolf packs, the hunting behavior of wolves, or their reactions on humans. Further investigations in this direction seem promising, as we were already able to find significant results with very short video clips. Concerning YouTube as a platform, future studies could further investigate the role of such social media activities in proenvironmental motivation [85]. The lower cost and wide and simple accessibility compared to fully immersive VR environments represents a final advantage for (formal) education, as 360° videos may be easy to implement when the corresponding devices are available [42]. Yet, with the increased interactivity in fully immersive VR, presence is higher [17]. Watching a 360° video using VR technology is not the same as engaging with a fully immersive VR environment [41]. As the link between presence and learning is not yet clear [37], many questions regarding the effectiveness of VR videos remain open.

5.2. Differences between Emotional Reactions

There was a significant difference in interest (H_2) between the groups, but not for the other emotions of joy (H_3) and fear (H_4). Participants watching the 360° videos with the HMD reported higher interest, which is in line with prior research [41]. Notably, the regressions showed that presence was a stronger predictor of interest than the group. Thus, it may be presence and not the group that influences the arousal of interest. This result suggests that the variance in interest may be based primarily on the prior finding that more immersive devices lead to more presence, due to a more direct interactivity with the digital environments [17,39,45]. The findings are in line with previous literature on media research, which stated that media in themselves do not make a difference in learning, but rather the activities that arise from the capabilities of the medium [86].

Research has shown that situational interest can be a first step in promoting learning, as it facilitates the intrinsic motivation to learn more about the content targeted in that situation [87]. Therefore, our study implies that using immersive VR technology can have a positive impact on learning. However, our research also implies that a fully immersive setting with interactivity that allows an even higher sense of presence might result in a higher level of interest. In addition to immersive equipment, the effectiveness of more interactive VR material should therefore be investigated in further research. It should be noted, however, that this effect could also be due to the first-time experience and novelty of HMDs, and that the effect may change over time [88]. This is an interesting issue that could be especially important for future research.

In contrast to other studies and our own hypothesis, there was no significant difference in joy between the groups. While Allcoat and von Mühlenen [60] as well as Rupp et al. [41] showed that greater immersion and presence led to increases in positive affect, in our study neither the group nor presence showed any significant influence on joy. We believe this result may be explained by the fact that the 360° videos in our study lacked interactivity, whereas Allcoat and von Mühlenen [60] provided the participants with a fully interactive environment. Another reason for the difference in results might be the short duration of the videos, whereas Rupp et al. [41] utilized video material twice as long. The specific context of wolves could also have affected the results, as we discuss below.

Concerning the emotion of fear, we did not find a difference between the groups. This finding is in line with prior research on emotions in education [41,60], but it contrasts with studies on exposure therapy that reported an increase in fear with more immersion [62–65]. We explain the difference in results with the choice of video material. Unlike videos in exposure therapy research, the material in our study was not chosen to elicit specific emotional reactions in selected participants. However, Allcoat and von Mühlenen [60], as well as Rupp et al. [41], also reported a positive influence of presence on negative affect, while in our study there was no connection between presence and fear. The mentioned studies used a dimensional approach, whereas we chose the discrete approach to emotions. Although fear is a part of negative affect, the difference may be due to the different approaches. To assess the general affective reactions and still have a nuanced view, future studies should assess both the dimensional and discrete approaches.

Overall, as presence and immersion did not have an effect on joy and fear and a significant difference between the groups was not found, the arousal of these emotions may be explained by variables connected to the content and visuals, as these were the same in both groups, which is also suggested by the predictive ability of attitudes towards wolves. Particular to our study compared to others, the chosen topic of returning wolves is embedded as an SSI in the context of ESD. As described earlier, within this issue there are deeply rooted values and beliefs belonging to the different groups involved [30,32,59], which might have also caused emotions in VR media usage.

5.3. Views on Wolves

In the overall sample, the attitudes towards wolves before and after the videos correlated with the emotion of joy, and post-test attitudes also correlated with interest (H_5), implying that positive attitudes towards wolves had an effect on positive emotions. In contrast, there was a negative correlation between attitudes and fear before and after the videos. Hence, more positive attitudes towards wolves resulted in less fear (H_5). The regressions further illustrate the relation between attitudes and emotions, as attitudes were the only consistent predictor of every emotion. As described above, only interest was also significantly affected by presence. This result suggests that attitudes are more important than the feeling of presence for evoking emotions, except for interest. This shows the importance of attitudes within the appraisal process of emotional episodes.

The connections between attitudes towards wild animals and emotions have already been demonstrated by previous studies [76]. Our results show that existing attitudes influence the evocation of emotions while watching the 360° videos, even though this effect was not strong in the HMD group. Our results suggest that within the context of returning wolves, positive attitudes are decisive to elicit emotions that support positive learning outcomes. Nonetheless, the sense of presence also has a supportive effect on positive learning outcomes. The use of VR technology can therefore contribute to learning.

Interestingly, however, group-specific differences in correlations must also be considered with regard to interest. In the screen group, prior and post attitudes towards wolves showed significant correlations with interest, implying that only people with existing positive attitudes felt more interest. In contrast to our hypothesis, such effects were not found in the HMD group. Notably, these findings were not based on a difference of attitudes between the groups prior to the videos, as no difference in pretest attitudes could be found. However, our study found a difference in interest between the groups, with the HMD group experiencing significantly more interest while watching the 360° videos. Therefore, immersive VR technology may be useful to make content interesting for people who do not already have a positive attitude towards it.

Previous research has shown that emotions mediate the attitudes towards wild animals and the acceptance of lethal control, implying that positive attitudes lead to positive emotional dispositions and ultimately decrease the acceptance of lethal wildlife management [76]. In this regard, our findings are particularly interesting, as positive emotions could be elicited through the use of immersive VR technology even in the absence of pre-existing positive attitudes. Notably, concerning the difference in attitudes before and after the videos, we detected a larger difference in the HMD group than in the screen group. Due to the study's small sample size, however, this difference could not be tested as significant. The findings of our study thus cannot show whether interest can increase the acceptance of wolves or even the attitudes towards them, but this would be an interesting question for future research to investigate. Nonetheless, we were able to show that the use of HMDs is a suitable method to engage participants with the SSI of returning wolves. These and all other findings need to be considered carefully due to the rather selective sample with an overall good education and young age. Such a sample may hold more positive views about wolves than the general public, which was also illustrated by the high mean and the skewness of the attitudes towards wolves in our sample.

5.4. Limitations

There are several other limitations that need to be considered regarding the generalization and representativeness of the data. Our sample comprised students from only one university; it differs from the overall population, and it may also differ from the population of university students in Lower Saxony and Germany. Further studies should investigate how these results can be transferred to other educationally relevant samples, such as school students. Future research should therefore attempt to expand the participant base. We also recommend larger sample sizes; the small sample size in the present study made it difficult to identify significant differences and correlations with smaller effect sizes, as only effects with large and medium effect sizes could be detected as significant. One example for this may be the effect of gender on presence, for which we were unable to find a significant result due to the small sample size. In future studies, the samples should be more balanced concerning the gender ratio, as our study included a larger proportion of female participants. Nonetheless, even with this small sample size we were able to identify important effects of HMDs on the selected dependent variables.

Besides the sample, the chosen video material may also represent a limitation. First of all, we explicitly wanted to take publicly available videos that may directly be applied in the classroom. However, these videos may not be the best choice for educating students about wolves. More particularly, the videos were rather short and therefore may only be able to give an incomplete view of the life of wolves. For further studies, the explicit application of purposefully created videos may allow for deeper insights and changes in other variables such as attitudes, which were not affected by the 360° videos in our study.

Furthermore, it must be noted that we only used self-reported questionnaires. Although these were all validated and have been effectively tested in several studies, the use of physiological measures may help to obtain a more comprehensive and objective understanding of the users' responses. This would be especially helpful for the emotional reactions, as the physiological response towards a stimulus makes up one component of an emotional episode [53,54].

Finally, our study only focused on the influence of immersive VR technology on emotions that are known to have a positive influence on relevant learning outcomes. However, other recent studies have shown a negative connection between low-immersive VR technology and cognitive learning outcomes [37,89]. So far, research has not addressed the complementary perspective of both cognitive and affective learning, especially with regard to topics that involve deeply rooted beliefs and values, as is the case with SSIs suitable for ESD. In order to make a profound statement about the effect of VR technology on learning outcomes, a comparative study with low- and high-immersive VR material that also includes the role of affective factors is needed. Such a study will hopefully lead to a better understanding of the link between affective factors and cognitive processing during learning.

6. Conclusions

Our study shows how immersive VR technology is connected to affective learning outcomes in the context of ESD. In more detail, with the use of VR technology, a difference in presence and interest could be found, leading to the result that feeling present in a virtual environment was associated with generating increased interest. Our study also identified other personality variables that influence affect in media usage. While pre-existing attitudes influence affect in nonimmersive VR technology, for immersive VR technology we found that attitudes play a smaller role in the feeling of interest. Nonetheless, our findings suggest that not only VR but also the level of presence is decisive for positive learning achievements. As presence was strongly affected by the group, our findings suggest that immersive VR technology may strengthen digital ESD due to its ability to generate higher levels of presence.

With regard to implementation in formal education, the results of our study show that immersive VR technology can be used to meet the requirements of ESD in a learner-oriented approach. Although the present study was not part of a larger educational experience such as a university seminar about the biology of wolves, the videos may nonetheless be applied in an educational setting with similar results. For example, immersive VR technology may be used in formal education to address affective learning outcomes. These results can be achieved by using readily accessible 360° videos, as well as short materials available on YouTube, which is another advantage for the implementation of VR in formal education. In this respect, VR technology has been shown to have a positive impact on learning by encouraging information-seeking and exploration. Understanding how to utilize the affective outcomes of virtual environments is a fundamental concern for learning, since research shows that initial interest can be a first step in promoting long term interest [87], and that an emotional reaction can have a significant impact on the learner's academic performance [90]. Future studies should also try to further differentiate among specific learning contents. For example, VR may be good for affectively oriented learning experiences about nature, but it may have less merit when other types of content are investigated. Furthermore, it may be interesting to investigate the suitability of 360° videos in other contexts, such as teacher education, as prior studies have shown that teacher education also needs to address affective learning outcomes such as values and emotions [91]. VR technologies may prove interesting in this regard.

Concerning the influence of immersive technologies on emotional reactions, our study shows that the use of immersive technologies has an advantage over nonimmersive technologies. Not only did the former technologies manage to evoke higher interest in general, but they also elicited interest in people without any pre-existing positive attitudes towards wolves. This is where the strength of immersive VR technologies becomes apparent. The findings show that with the use of immersive VR technology, an attitude change or a higher acceptance of wolves may be possible, as prior studies have found positive emotions to be a mediator between attitudes and acceptance of wolves [76]. Our study also found more positive attitudes in the post-test. Proenvironmental behavior could also be strengthened by triggering positive emotions [52]. It will be particularly interesting for further studies to investigate whether the evoked interest can lead to a deeper attitude change or foster proenvironmental behavior.

However, our study did not include cognitive learning achievements. Further research needs to investigate whether and how cognitive learning outcomes can be achieved. In order to achieve knowledge gains while watching immersive VR videos, text and audio commentaries were included in previous studies. These studies have so far shown contradictory results in this regard. While some studies showed less learning with an increasing sense of presence [37], other studies found a positive cognitive learning outcome with immersive VR experiences [41,44]. However, all of these studies were mostly conducted on novices to the technology. Therefore, it is necessary to conduct longitudinal studies that investigate whether long-term use of immersive VR technology leads to knowledge gains. In this context, it is also necessary for further studies to investigate the extent to which VR experiences should be integrated in teaching. Should immersive VR only serve as an experience to address affective learning, or is it also suitable to achieve cognitive learning outcomes?

Overall, especially when external circumstances make it difficult or even impossible, VR offers the possibility to provide students with life-like nature experiences. This is especially the case with the return of wolves. Students can have simulated close-up experiences with wolves and observe them from a close distance in their natural habitat, which would not be possible in reality. This may also be transferred to other SSIs in relation to ESD. Our study therefore shows that immersive VR has great potential. In that regard, the improved affordability and convenience of devices like the Oculus Quest is a further advantage. However, in future research it will be necessary to test the extent to which VR should be included in teaching to strengthen ESD in formal education. A successful implementation will hopefully lead to well-prepared future citizens who can overcome the conflicts between humans and wildlife and contribute to the achievement of the SDGs.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/12/9/3823/s1, Table S1: Original SPSS data sheet (VRExperienceswithWolves.SAV), File S2: Output file from SPSS (Output_VRExperienceswithWolves.spv).

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Appendix A

Table A1. Scales of the study and their corresponding items.

Construct	Item
	Attitudes towards wolves (ATTWO)
ATTWO01	I have a positive attitude towards the return of wolves to Germany.
ATTWO02	It is important for Germany to have a viable population of wolves.
ATTWO03	Wolves living in Germany are important, even if I never see one.
ATTWO04	Wolves are a sign of an intact nature.
ATTWO05 *	Because many wolves live in other countries, there is no need to have wolves in Germany.
	Spatial Presence Experience (PRES)
PRES01	I felt like I was actually there in the environment of the presentation.
PRES02	It seemed as though I actually took part in the action of the presentation.
PRES03	It was as though my true location had shifted into the environment of the presentation.
PRES04	I felt as though I was physically present in the environment of the presentation.
PRES05	The objects in the presentation gave me the feeling that I could do things with them.
PRES06	I had the impression that I could be active in the environment of the presentation.
PRES07	I felt like I could move around among the objects in the presentation.
PRES08	It seemed to me that I could do whatever I wanted in the environment of the presentation.
	Differential Affect Scale (MDAS)
	How strongly did you experience the following feelings while watching the videos?
Joy	
MDASJ01	Delighted
MDASJ02	Happy
MDASJ03	Joyful
Fear	
MDASF01	Scared
MDASF02	Fearful
MDASF03	Afraid
Interest	
MDASI01	Attentive
MDASI02	Concentrating
MDASI03	Alert

Note. * = Items were reversely coded for the analysis.

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Article

The Importance of Different Knowledge Types in Health-Related Decisions—The Example of Type 2 Diabetes

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Abstract: Noncommunicable diseases (NCDs, e.g., type 2 diabetes) are a burden to humanity and hence addressed in the Sustainable Development Goals (SDGs) (target 3.4). One way of tackling NCDs is by health education as part of science education. Yet, the role of knowledge for health-promoting actions, and thus, the role of science teaching in health education, is not sufficiently clarified. Therefore, the author proposes to differentiate three knowledge types: System Health Knowledge (SK), Action-related Health Knowledge (AK), and Effectiveness Health Knowledge (EK). Accordingly, we designed a questionnaire that asked students to evaluate different questions about sugar consumption and type 2 diabetes according to their relevance for deciding their future sugar consumption. We found that students considered all questions as rather important (3–4.3, out of 5) with an assigned mean importance for SK with a mean of 3.8, for AK with a mean of 4.0, and for EK with a mean of 3.9. This research indicates that knowledge is important for decision-making and that all three types of knowledge should be recognized in health education.

Keywords: health education; science education; knowledge; decision-making

1. Introduction

1.1. Problem

Chronic or noncommunicable diseases (NCDs, e.g., cardiovascular disease, stroke, cancer, or type 2 diabetes) are "the leading cause of mortality in the world," and according to the World Health Organization (WHO), 80% of premature deaths attributed to NCDs could be prevented [1]. To meet this challenge, the UN Sustainable Development Goals (SDGs) include target 3.4: "By 2030, reduce by one-third premature mortality from non-communicable diseases through prevention and treatment and promote mental health and well-being" [2]. This target is specified, e.g., in indicator 3.41 "[m]ortality rate attributed to cardiovascular disease, cancer, diabetes, or chronic respiratory disease" [2]. Here, the nutritional status is crucial, since unhealthy diet (e.g., excessive sugar consumption) is a significant risk factor for NCDs [1]. Regarding type 2 diabetes, the number of people affected is increasing, especially in developed countries with western lifestyles [3], and "diabetes was the seventh leading cause of death in 2016" according to recent estimates [4]. Consequently, one of the "Grand Challenges and Opportunities for Science and Technology in the medium term Future" is the improvement of nutrition [5] (p. 8).

NCDs like type 2 diabetes have (besides genetic predispositions) physiological risk factors such as, e.g., overweight, and obesity and raised blood glucose. These physiological problems, in turn, can be favored by various behavioral risk factors, e.g., physical inactivity, and an unhealthy diet [6]. The last one is linked to the disproportional intake of fat, fruits, and vegetables as well as sugar (e.g., in sugar-sweetened beverages [7]) and alcohol. On the one hand, the reasons for these behaviors are conditioned by the environment or setting and socioeconomic status. On the other hand, individual motivational factors (e.g., attitudes, needs, values) and, in many places, the role of knowledge, are discussed as potential causes for (un)healthy behavior [8] (Figure 1).

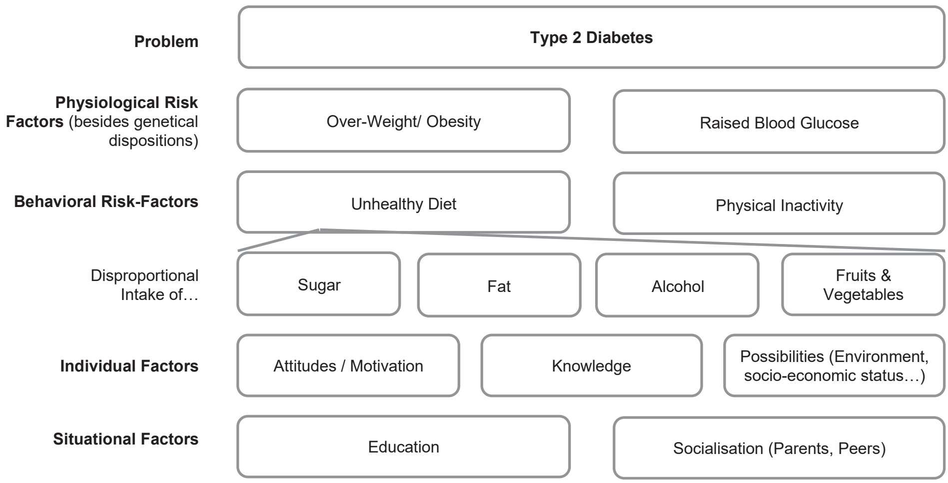

Figure 1. Schematic representation of possible causes of NCDs [6,9,10]. NCD: noncommunicable diseases.

For preventing premature mortality from NCDs, Cao et al. [9] suggest "[h]igh-level political commitments to effective and equitable national surveillance and prioritized prevention, early detection, and treatment programs tailored to the major NCD types" (p. 1288), especially in lower-resourced settings. In higher-income settings, access through prevention and education—namely health literacy—can also play a significant role. Consequently, it is essential to teach students how to make healthy decisions, especially regarding nutrition. However, how can people be encouraged to change their behavior, e.g., their diet? To find possible answers to this question, this paper focuses on the NCD "type 2 diabetes" and the risk-factor "unhealthy diet," especially in disproportional intake of sugar, especially free sugars (e.g., in sugar-sweetened beverages [7]). High sugar consumption can influence weight-gain overweight (simply because of the excessive calorie intake), which in turn can lead to insulin resistance. On the other hand, high sugar consumption can lead to high blood glucose levels, which can also lead to insulin resistance [10,11]. Nevertheless, it should be explicitly mentioned that type 2 diabetes is multifactorial and sugar consumption does not directly cause diabetes, as shown in Figure 1.

The WHO defines health promotion as "a process of enabling people to increase control over, and to improve, their health" [12] (p. 17). One of the priorities of health promotion lies in empowering individuals, which "demands more consistent, reliable access to the decision-making process and the skills and knowledge essential to effect change" [13] (p. 17). Accordingly, this paper takes a look at what role knowledge can play for making health-related decisions in this context. Since science and health issues can be of mutual benefit [14–16], science education can have a significant impact on preventing NCDs like type 2 diabetes. To figure out possibilities for prevention through (school-) education, this paper looks at the issue from a science education perspective.

1.2. Theoretical Background

Science education aims at enabling learners to make competent behavioral decisions in various science-related issues, e.g., in health issues. Health education, in turn, strives for enabling learners to "make informed decisions about their future lives and health" [17] (p. 99). These decisions can relate to either individual or political behavior [18–20]. As a precondition for taking competent behavioral decisions on an individual level, the need for learners to develop an understanding of the concepts and principles within science is imperative [21]. Also, learners need to be able to reflect on the driving forces behind their own behavioral decisions and to recognize the role those decisions may have in the development of the abovementioned future challenges [18,22,23]. Health education has a long tradition in science and biology teaching, as scientific/biological facts, relationships, and principles play a central role in understanding organ functions and the body as a system. However, the role of knowledge for the following health-promoting action or the decision for this, and thus, the role of science and biology teaching in health education, is not yet sufficiently clarified [8].

Health action or behavior can be described as "(a)ny activity undertaken by an individual, regardless of actual or perceived health status, for the purpose of promoting, protecting or maintaining health, whether or not such behavior is objectively effective towards that end." [24] (p. 355). Hence, health action is deliberate and, accordingly, the action is based on cognitions and decision-making processes that lead to intention and, ultimately, action [25]. Health actions can be further divided into protective behavior (e.g., exercise or diet), risk behavior (e.g., smoking or drug use), or detection behavior (e.g., screening) [26]. In the context of this study, the focus is on protective behavior (including preventive behavior), and exemplarily nutritional behavior is discussed. Recent studies show that, e.g., German adolescents consume too much sugar and salt, too many fats, and high-fat foods, drink too much alcohol, and consume too little fruit and vegetables [27,28]. These behaviors are regarded as causes of NCDs such as obesity, diabetes, cancer, and cardiovascular diseases. Accordingly, health education should find ways to positively influence such behaviors in the long term [29].

It is essential to identify conditional factors for this behavior to promote positive behavior [30]. Research in health education is influenced by two research lines, social-cognitive and behavioral research (Health Behavior Change), which focuses on motivational factors of health action, and health literacy research, which focuses on basic education and knowledge [31]. On the behavioral research side, there are several international models explaining health action. Most of these models are prediction models that include several factors that are suitable for predicting health action. These models are called continuous, because a person can be assigned a certain probability of healthy action along a continuum [32]. The prediction models allow identifying factors that can be individually manipulated to promote healthy actions. Prominent examples of prediction models are the social-cognitive theory of Bandura (social-cognitive theory, SCT; [25,33]), the theory of reasoned action (TRA; [34]), and the theory of planned behavior (TPB; [35–37]), the model of health belief (HBM; [38,39]), the protection motivation theory (PMT; [40,41]) and the model of the health action process approach (HAPA; [32,42,43]). Research following this paradigm found that nutritional behavior is determined by attitudes and motivational factors towards nutrition [27,44]. Accordingly, different motivational factors can play a role in decision-making processes [23]; for example, perceived susceptibility and perceived severity of associated diseases (e.g., type 2 diabetes), efficacy expectations (e.g., concerning the reduction of sugar) and the personal evaluation of this action, as unpleasant, expensive, or stressful. Even more, the expectation that a particular action leads to the desired outcome (e.g., the prevention of type 2 diabetes) is not easy to calculate and prone to subjective assessments as well as the value of this outcome, not to forget the social norm, which, e.g., might lead one to eat sweets to be socially recognized.

In addition to motivational aspects, an essential role in the context of health actions is attributed to knowledge [15,45–47]. The numerous definitions of health literacy that describe the procurement, understanding, and use of information as the basis of health literacy [48] support the role knowledge has. However, the influence of knowledge on intention formation or directly on behavior, especially in the area of nutrition, has not been clarified yet, and findings about the role of information or knowledge, in decision-making (or intention formation) and action, however, are inconsistent [49,50]. There is a corpus of studies indicating that knowledge about nutrition issues is associated with behavioral intention and performance (e.g., [51–53]). Other studies, however, point to the exact opposite (e.g., [54,55]). Reasons for this inconsistency can be found in the subject matter and its complexity, as well as in the process of human decision-making [56].

A lack of correlation can be attributed to a lack of specificity in the operationalization of knowledge and intention or action [34,50]. For example, it is conceivable that the measured correlation in the global issue of "healthy nutrition" is smaller than, for example, in "sugar consumption." Also, Worsley [50] argues that different types of knowledge (e.g., declarative and procedural knowledge) must be taken into account. Furthermore, he argues that it may not be possible to grasp the connections between knowledge and action because they are not directly present, but are mediated, for example, by motivational factors [50]. However, models that take into account different types of knowledge and integrate both knowledge and motivational factors in a meaningful way, so that mediation correlations can also be taken into account, are still lacking. Thus, an adequate description of the role of knowledge is not possible, and corresponding interventions in science and biology teaching based on knowledge transfer remain explorative. To make appropriate models usable for science/biology teaching and to avoid the danger of training action routines instead of promoting knowledge-based decision-making, Arnold proposed a model [23]. This model identifies different knowledge types and systematically places it in connection with well-established motivational factors. Here, Kaiser and Fuhrer [57] used a threefold division of knowledge underlying ecological behavior, which can be transferred to health behavior like, for example, sugar consumption ([23]; Figure 2):

1. *System Health Knowledge (SK)*, which is the "knowledge about health, the body, and its (mal-) functioning" [23]. It includes knowledge about the use of carbohydrates and how carbohydrates are metabolized in the body, the mechanisms and risk factors that lead to insulin resistance and type 2 diabetes, and the impact of type 2 diabetes on health. This knowledge might especially influence the evaluation of susceptibility and severity of coming down with type 2 diabetes (perceived health threat). Moreover, it influences the following knowledge types.
2. *Action-related Health Knowledge (AK)* is the "knowledge about possible actions to preserve functioning and prevent malfunctioning of body and health" [23]. It includes knowledge about recommendations about sugar intake, about foods that contain carbohydrates and sugars, and knowledge about actions to reduce the intake of sugar. This knowledge is hypothesized to influence the attitude towards health action.
3. *Effectiveness Health Knowledge (EK)*, which is the knowledge about the relative potential of actions that lead to the desired prevention of diseases [23]. It includes, e.g., the ability to decide on foods that contain less sugar. This knowledge is hypothesized to influence the attitude towards the health outcome.

The proposed three-dimensionality has been tested, and it was shown that health knowledge concerning the reduction of sugar consumption in favor of type 2 diabetes prevention could be treated as three-dimensional, hence consisting of SK, AK, and EK [56]. Since this three-dimensionality of health knowledge was derived from theory and adopted in a model for decision-making [23], it needs validation. The question arises whether learners perceive the three knowledge types as important for their decisions, too. In the presented study, we examined which knowledge students consider being relevant for health decisions, again using type 2 diabetes as an example. Hence, the goal of this study is to identify the ascribed importance of different health knowledge (dimensions) for decision-making processes. If students would not find all types of knowledge important, it would have a corresponding influence on the model, or at least on teaching according to the model. This study is therefore a first step towards validating this model with empirical evidence.

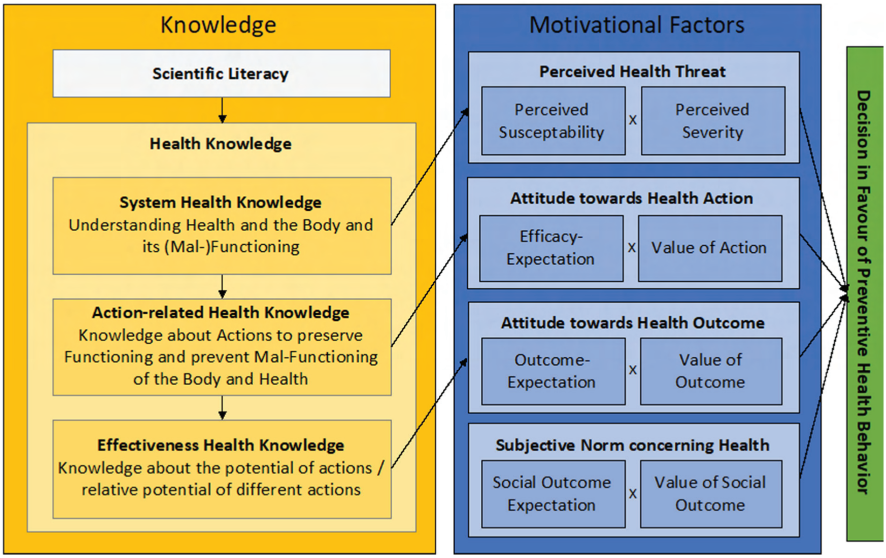

Figure 2. Integrated Model of Decision-Making in Health Contexts for Science Education [21] with possible correlations.

2. Materials and Methods

In the first step, we asked students ($N = 56$) from vocational school (mean age: 20.1; 91.07% female) via an open-ended questionnaire-item, what knowledge they would need to form a decision regarding their sugar consumption: *"Chocolate, gummi bears, cakes, and coke are delicious! However, too much sugar can lead to health problems. For example, it may be a cause of type 2 diabetes. Imagine that you should decide today if you wanted to reduce your sugar intake for one year to prevent type 2 diabetes. What information would you need for your decision? Write at least three questions that need to be answered for your decision."* Of these 56 students, 13 had a special relationship to biology, chemistry, or nutrition, e.g., through a subject or course of study. We chose this older and more-experienced sample, as it has been shown that younger pupils give few answers to these open questions. The answers were categorized inductively and deductively assigned to the three knowledge dimensions. For example, the students asked the following questions: "How is type 2 diabetes triggered?" "I should know what particular foods can cause this disease," "Where exactly is the problem, is it inherited or a real threat to me from my diet?", "How does type 2 diabetes get into my body?" or "How do I get type 2 diabetes?". These questions have been combined into the category "causes of type 2 diabetes" and attributed to the SK dimension.

Finally, the categories were formulated as questions in Likert-scale items, e.g., "What are the causes of type 2 diabetes?". Additionally, we added six items covering the SK concerning sugar and its processing in the (un)healthy body, because there were no such questions in the students' questions. Yet still, we wanted to see all the possible knowledge types of the model covered.

In a second step, the resulting quantitative questionnaire was used for the reported study. The questionnaire consisted of 34 items in three scales. This second sample consisted of students from the 10th grade ($N = 81$) of a rural city in southern Germany (mean age: 15.9; 56.10% female). The sample contained no diabetics, 11 vegetarians, no vegans, 2 persons with lactose intolerance and no persons with fructose or glucose intolerance or allergy. On a scale of 0 to 3, students described themselves as having little dietary experience ("My dietary experience is great"; 0.35), rather nutrition-conscious ("It is important to me to know what I eat and drink"; 1.81), rather health-conscious ("I live very health-consciously"; 1.63) and rather less sugar-consciously ("I take care to eat little sugar"; 1.30).

These students were asked to rate the importance of information for their decision-making on a six-point Likert scale (0 = unimportant, 5 = important; see Table 1).

Table 1. Scales and examples for Likert-scale items (the complete item set is presented in Table 2). Introduction: "Imagine that you should decide today if you want to reduce your sugar intake in the future to prevent type 2 diabetes. How important would the following information be for you?"

Scale	No. of Items	Cronbach's α	Examples
System Health Knowledge (SK)	15	0.92	What is sugar? What are the symptoms of type 2 diabetes? Why does my body need sugar?
Action-related Knowledge (AK)	15	0.94	What can I do to prevent type 2 diabetes? How can I reduce my sugar consumption? Which foods contain how much sugar?
Effectivity Knowledge (EK)	4	0.86	What is the likelihood that my sugar consumption will cause me to develop type 2 diabetes? What is the probability that I will develop type 2 diabetes if I reduce my sugar consumption?

Descriptive analyses were conducted (means and standard deviations for each question) to identify the ascribed importance of single health information for the decision-making process. This allowed for ranking the questions in terms of importance. Furthermore, means and standard deviations for the three knowledge types (scales) were calculated to describe their importance.

3. Results

The descriptive results are displayed in Table 2 and show the 34 questions sorted by their ascribed importance. As can be seen, the range of the attributed importance ranges from an average of 3–4.3 (with a maximum of 5) points. Accordingly, it can be assumed that the students surveyed find all the questions somewhat necessary when it comes to deciding on reducing sugar consumption. The six questions that have been added subsequently, which relate to sugar and its processing in the body, are among the least important questions. Then, we find a mixture of items from all three scales with the questions "What is type 2 diabetes?", "What can I do to prevent type 2 diabetes?" and "What are the causes of type 2 diabetes?" being the most important questions to be answered to form an intention to reduce one's sugar intake.

Table 2. Questions concerning sugar and type 2 diabetes and how important students think they are for forming decisions about reducing sugar intake.

Question	Scale	Importance	
		Mean	SD
How is sugar structured?	SK	3.02	1.31
What is sugar?	SK	3.23	1.23
Why does my body need sugar?	SK	3.49	1.19
What types of sugar are there?	SK	3.52	1.17
How is sugar processed in a healthy body?	SK	3.57	1.18
How effective are individual low-sugar alternatives to prevent the onset of type 2 diabetes?	EK	3.65	1.16
Which organs of my body are involved in sugar processing?	SK	3.69	1.10
Where can I find information on the sugar content of foods?	AK	3.78	1.16
Which types of sugar should I consume preferably?	AK	3.8	1.09
Are all sugars equally harmful?	AK	3.88	1.13
What influences my blood sugar level?	SK	3.89	1.08
How much sugar can I eat every day to stay healthy?	AK	3.89	1.08
How is sugar processed in the body if you have type 2 diabetes?	SK	3.89	1.08

Table 2. *Cont.*

Question	Scale	Importance	
		Mean	SD
What is the probability that I will develop type 2 diabetes if I reduce my sugar consumption?	EK	3.90	1.08
Which foods contain the least amount of sugar?	AK	3.91	1.18
To what extent should I reduce my sugar intake to prevent type 2 diabetes?	AK	3.94	1.05
What is the likelihood that I will develop type 2 diabetes if I reduce my sugar intake?	EK	3.96	1.16
What are the alternatives to sugar?	AK	3.96	1.21
What is the likelihood that my sugar consumption will cause me to develop type 2 diabetes?	SK	3.96	1.10
What role does sugar play in the development of type 2 diabetes?	SK	3.96	1.03
What are the consequences of type 2 diabetes for me and my well-being?	SK	4.02	1.11
Which foods contain how much sugar?	AK	4.04	0.97
Which foods contain the most sugar?	AK	4.06	1.14
What low-sugar alternatives are there?	AK	4.06	1.13
How can I reduce my sugar consumption?	AK	4.09	1.10
What are the consequences of reducing my sugar intake for my body?	EK	4.09	0.95
What types of sugar should I avoid?	AK	4.10	1.02
How high is my current sugar consumption?	AK	4.12	1.03
How does type 2 diabetes develop?	SK	4.22	0.99
What are the symptoms of type 2 diabetes?	SK	4.22	1.07
Which foods should I consume, preferably, and which should I consume in moderation to reduce my sugar intake?	AK	4.24	1.05
What is type 2 diabetes?	SK	4.27	1.00
What can I do to prevent type 2 diabetes?	AK	4.27	0.99
What are the causes of type 2 diabetes?	SK	4.31	0.97

Looking at the descriptive data of the knowledge scales (SK, AK, and EK; Figure 3), it can be seen that all three types of knowledge are assessed as rather relevant, since the mean values with a maximum number of five are each close to four with a standard deviation of less than one making (M_{SK} = 3.7, *SD* = 0.74; M_{AK} = 4.0, *SD* = 0.81; M_{EK} = 3.9, *SD* = 0.90). This means that, on average, the importance of the respective types of knowledge is estimated to be rather high for decision-making.

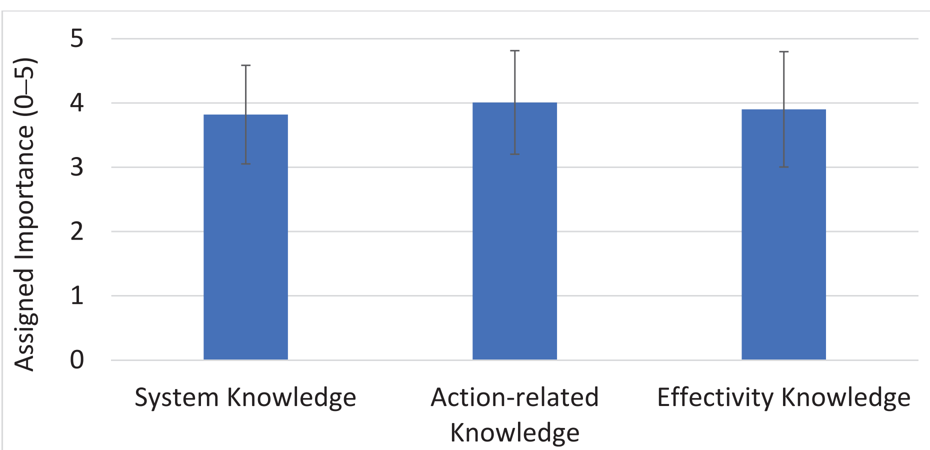

Figure 3. Students' answers to the questionnaire about the importance of knowledge for decision-making.

4. Discussion

This study shows that students think information is important for forming a decision about changing their actions, since all questions are rated above the mean. This fits with the results of other research, where, e.g., students had to decide about vaccination and were rather hesitant because they wanted more information [58]. Hence, even if research has not yet been able to prove uniformly that knowledge influences decisions, the results of this study show that information is (subjectively) highly relevant for the people who make decisions. Furthermore, it could be shown that all three types of knowledge, as assumed in the model (Figure 2), are relevant. Accordingly, the results of this study support the model assumptions.

However, the study's results are limited to some extent. On the one hand, this concerns the sample, which does not permit generalization but yet gives valuable insight into how students value information for decision-making. On the other hand, the object of investigation is limited because we chose to examine the very close relationship between sugar consumption and type 2 diabetes. This limitation is, on the one hand, necessary to achieve sufficient depth of knowledge, because tests and questionnaires can only have a certain length, and one has to decide whether the topic is covered in depth or breadth. This, of course, means that other factors influencing the onset of type 2 diabetes, such as exercise and diet in general, as well as genetic factors, cannot be adequately assessed. On the other hand, this close connection also follows the law of specificity [34]. According to Fishbein and Ajzen [34], a lack of correlation between knowledge and action is due to a lack of fit between knowledge and the dependent variable [50]. Furthermore, only the significance of knowledge for the decision was inquired. This investigation cannot examine to what extent the knowledge influences the actual action. Additionally, this study takes a look at decision-making from a very individualistic point of view. For reasons of feasibility, it is assumed that the individual decision or action depends solely on the individual and his or her personal assessment. Social, political, and economic reasons are neglected for this purpose. It is assumed that people who decide to take action and notice that external limits are imposed on them are more willing to change such conditions [19,20].

5. Conclusions and Outlook

This study's results indicate that students want and need a solid understanding of all three knowledge types to form informed decisions. Accordingly, if teachers want to support students in making health-related decisions, they should include all three types of knowledge in their teaching. Accordingly, it is not enough to simply explain the causes of a disease (SK) or even to convey what health-promoting behaviour would be (AK). The data indicate that it makes sense to convey knowledge about the disease and its causes (SK) and possible alternative courses of action (AK), but also how effective different courses of action can ever be (EK). Using type 2 diabetes as an example, this would mean that both diabetes and its development would be discussed, and the role of sugar in this would be addressed (SK). In addition, ways of reducing sugar intake should be shown (AK), but also its effectiveness (possibly in connection with other behaviours) should be discussed (EK).

The next steps in research will be to gather data from a larger sample as well as for other health contexts in order to broaden the message. However, now that we have found hints that, consistent with the model, learners find the three types of knowledge relevant to their decisions, further research can be done in this direction: if these knowledge types are important, are they included in curricula and do students have knowledge in all three dimensions to the same extent and, if so, do they use it in decision-making processes? These are questions that we will ask in following studies. Yet despite all this, it becomes clear that although knowledge seems to be relevant, the respective knowledge for all possible health decisions can neither be learned nor taught. Therefore, the goal of the project is to shed light on the actual role of knowledge and, in a first step, the three dimensions in decision-making and intention formation. Then, implications for school science shall be formulated about how to prepare students to be able to adapt to different situations, e.g., by learning how to gather and reflect information and, thereby, to become responsible decision-makers. The question then is, how can science education equip people to be able to get the necessary information and use it? Or, in connection to the model in Figure 2, what is the scientific literacy underlying that specific knowledge? Here, four "tools" can be suggested [18]: (1) Systems Thinking, because the body can be seen as a system (and yet part of other systems), which can lead to complex interdependencies. Yet, if students have an understanding of systems, they are more likely to understand the system and reflect on the borders of knowledge (e.g., [59–61]). This point leads to (2) knowledge and understanding of the Nature of Science. This is important to understand and appreciate, e.g., that scientific knowledge is tentative, provisional, and uncertain and can be influenced by values and bias (e.g., [61,62]). However, not only is science influenced by values, every person has values, and decisions cannot be purely objective, because (3) affectivity plays a role, and subjective judgments (e.g., [15]) and personal values must be taken into account for action decisions as suggested by many health behavior models (e.g., [24,32–43]), as summarized in [23]. Finally, one needs (4) critical thinking to be able to reflect one's point of view, question information critically, and be able to change perspectives (e.g., [63,64]).

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Addressing Sustainable Development: Promoting Active Informed Citizenry through Trans-Contextual Science Education

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Abstract: This article seeks to identify the role of science education in promoting an active, scientifically literate, citizenry ready to address sustainable development goals as envisaged by the United Nations (2015). In so doing, a conceptual model is put forward to address citizenry development, extending beyond an informed scientific and technological decision making ability and encompassing constructive activities addressing sustainable development at the local, national and global level. The operationalisation of the model builds on an initial student-relevant, societal issue-related contextualisation involving STEM (science, technology, engineering, mathematics) while focusing on developing science conceptual learning. The model extends to not only considering socio-scientific issues, but seeks to promote trans-contextualisation beyond the school setting, seeking to raise awareness of an active informed citizenry, related to environmental, economic and social sustainability. The components of active informed citizenry are described and a trans-contextual science teaching example based on the model is put forward in this article.

Keywords: active informed citizenry; education for sustainable development (ESD); global citizenship; science education; trans-contextualisation

1. Introduction

A growing concern is addressing sustainable issues within school teaching-learning activities, thus seeking to promote Education for Sustainable Development (ESD) [1]. This is considered a key to achieving target 4.7 emphasising Global Citizenship Education [2]. Through emphasising a link between promoting scientific literacy and addressing societal engagement, both individually and collectively, there have been calls for educational reforms [3], and the need to take into consideration paradigmatic challenges in science education, related to preparing students for societal changes [4]. In fact, it has been suggested that the existing teaching-learning approaches are '*unsustainable*' [5].

Within school science education, the inclusion of socio-scientific issues (SSI) has emerged as an important educational construct [6]. This enables emphasis on preparing students to participate as citizens within a democratic society, well-acquainted with scientific conceptualisations and their engagement in society issues involving science, or the wider perception of STEM (interrelating the scientific conceptualisations with technological ideas, engineering procedures and mathematical enhancements) [7]. While SSI, in the literature, is seen as controversial [8], ill-structured [9], focussing on socially embedded issues [10], requiring an understanding of the nature of science [11], its inclusion in science education is being recognised as playing a role in promoting global citizenship [12,13].

One important goal of SSI is to effectively address attributes promoting future citizens through science education [12,14,15]. In addressing this goal, the literature recognises the need to draw attention to students acquiring personally responsible, participatory decision making skills. Besides promoting an appreciation of opportunities to address future careers [16], such skills draw attention to the needed roles to be played by the society, especially in the areas of environmental protection, health, and social adhesiveness. Nevertheless, it has been pointed out there is a danger of underestimating students' ability to identify constructive measures and assume a sense of responsibility to take personal initiatives towards collective engagement in order to resolve SSI and sustainable development issues [17]. Furthermore, it is suggested that insufficient research exists linking an individual's decision-making through SSI, within the school setting, to the potential of student activity and community involvement outside the classroom [18]. This points to a potential gap between the desired SSI informed decision making outcomes and students' preparation through gained socio-scientific attributes as a desired citizen. In fact, it has even been pointed out [19] that ineffectiveness in socially embedded science instruction within the classroom (e.g., about vaccination, or nuclear explosion) can result in activities that have a negative socio-economic repercussion (e.g., anti-vaccination campaigns, siting nuclear plant concerns).

Not teaching controversial issues in the science classroom (for example, with respect to sexual and reproductive health, HIV, teenage/unintended pregnancy) can impact on the ability of students to make well thought out future decisions regarding their personal life [20]. This raises a concern that including socio-scientific issues in teaching without a vision of the need to prepare students to make informed decisions, as and when required, can result in failure to achieve the expected learning [21], or even in some cases, such as uncontrolled, irresponsible alcohol or tobacco consumption, leading to counter-productive outcomes [22]. Uncertainty in seeing how to deal with any SSI aspect, stems from its multi-disciplinary, complex nature. This is illustrated when reflecting on uncertainty in situations that can be considered as have the potential to lead to chaos when common agreed intent is lacking (as per the cynefin framework) [23].

The aim of this article is to address a proposed need for school education to go beyond developing the individual and focus on socio-scientific decision making as a preparation towards handling complex situation by promoting a desired citizenry (Although the science education literature tends to use the terms 'citizens', 'citizenship' and 'citizenry' interchangeably with a similar meaning, this article intentionally uses the terminology 'citizenry' to mean a collected group of citizens who have a commonality in their social purpose, as opposed to individual citizens, and where citizenship is conceptualised as a status of these individual citizens.), able to strive, in particular towards attaining sustainable development within the society. In so doing, the article proposes the need to go beyond SSI decision making and introduces the need for a trans-contextual society impacting stage, still within an education through science approach [24]. The significance of this article is two-fold. First, it lies in the conceptualisation of a desired 'Active Informed Citizenry'. Subsequently, it puts forward the need to operationalise this through a motivational school science education learning model [23], in which an additional model component pays attention to ways to address sustainable development goals [2] beyond the classroom.

2. Importance of Promoting Citizenry for Sustainable Development of the Society

The education role, in addressing citizenship in the 21st century and its relationship with education, needs to go beyond the individual and engage at the society, or even the global, level [25] and be in line with the 2030 agenda for sustainable development [2]. The agenda draws attention to the need to promote the knowledge and skills necessary to achieve a sustainable lifestyle, recognise and protect human rights, promote gender equality, establish a culture of peace and non-violence, conceptualise global citizenship and develop an appreciation of cultural diversity and of culture's contribution to sustainable development. This is suggested as a step towards citizenry.

While school curricula mention the need to develop students' capabilities to function as citizens [26], it is suggested there is a further need to develop students' capabilities to become 'good' citizens, based on their collective actions towards a better world [16]. This 'citizenry' role is not only limited to the local, or national level [27]; it is recognised as a necessity for preparing societies at a global level [12].

3. Role of Science Education in Promoting a Desired Citizenry

Typically, science taught in school has largely been a cognitive endeavour [28], but developments over the last 20–30 years have emphasised the need for a wider focus (e.g., the STS movement followed by the emphasis for the inclusion of SSI – [10]). Within this wider focus, the need for a changing perception through addressing the function of the society in the total teaching-learning process is being recognised [29].

In science, or STEM education, there is increasing attention to social inter-relationships [30], especially inter-disciplinary [31], and even towards a trans-disciplinary focus [32]. Within school science curricula, the focus on enhancing scientific literacy is well established [33,34], implying the involvement of student learning as going beyond cognitive capabilities and encompassing social and career aspects [16]. This is intended to lead to better informed citizens. Nevertheless, it is argued that emphasising only informed citizens is insufficient. A desired citizenry needs to be participatory, allowing citizens to be able to play an active role in the resolving of issues within the society [35]. Such a scientific literacy shift, pays more attention to promoting a socially responsible and competent citizenry, in line with sustainable development goals. It can be expected to go beyond solely active citizenship [36], and informed citizenship [37], and embrace the wider aspects of science education at a global, or international level. Recent studies [38] imply that such a more contemporary science education can be seen to be contributing to this.

4. Conceptualising Active Informed Citizenry within Science Education

The concept of an active informed citizenry is intended to give an 'all-embracing' idea of citizens acting together who are meaningfully informed, educated not only to play a role at a national level, but also actively prepared to embrace wider, global issues, recognising these may also impact at a national, or even local level. Science education can be expected to play a role in such an endeavour noting that each component in the expression–active informed citizenry–has its own interpretation. Thus:

- the term 'active' indicates a willingness and preparedness to participate and engage in science-influenced personal, societal and even political demands. Besides gaining knowledge and conceptualisation of scientific issues, students need to engage in meaningful science-influenced activities [39]. Curriculum emphasis can be given to enable the learners to observe experts, or even teachers, while engaging in an action, practice the skills in a specific context, take responsibilities to plan and organise the actions, engage in critical evaluation of the plans and actions from the teacher and the peers during the action and afterwards;
- the term 'informed' relates to achieving a level of scientific literacy relevant to the engaged school curriculum and out-of-school experiences. The characteristics of scientifically literate individuals are suggested as possessing a profound knowledge and understanding of science for problem solving, critical thinking, risk and benefits of science [40], identifying evidence, drawing conclusions, communicating and demonstrating conclusions based on science [41], advocating a central role for scientific knowledge and perceiving scientific literacy for a social benefit [34];
- the term 'citizenry' indicates the plurality of citizens of a particular region, recognising an educational need to prepare citizens with a sufficiently meaningful scientific behavioural activity and engage in socio-scientific issues as a collective citizenry. From a science education point of view, a collective citizenry can be visualised [35] as, for example,
    - organise responsible groups;
    - write and distribute letters and petitions to the respective authority;
    - boycotting products and practices from a socio-scientific point of view;
    - take initiatives to promote positive citizenry behavioural change;
    - take the initiative for resolving ethically fair, science-influenced issues, and
    - promote innovative solutions for local, or even, global problems.

The term 'active informed citizenry' actually appears in the literature e.g., [42,43], although it is identified more at a national level, focusing on consideration of the duties and rights of a citizen. The term, as used in this paper, goes further and additionally encompasses collective, globalised aspects. It strives to recognise that a more idealist view of citizenry suggests both the need for the development of informed citizens (here in a scientific literacy sense) and active citizens (in the sense of playing a meaningful role). These are subsequently brought to bear on the SSI-derived, consensus decision so as, potentially, to drive a collective society development leading to an active, informed citizenry.

In conceptualising a desired citizenry model, to be achieved through science education, Figure 1 highlights different attributes that can be grouped, contributing to the desired active, informed citizenry (AIC) target.

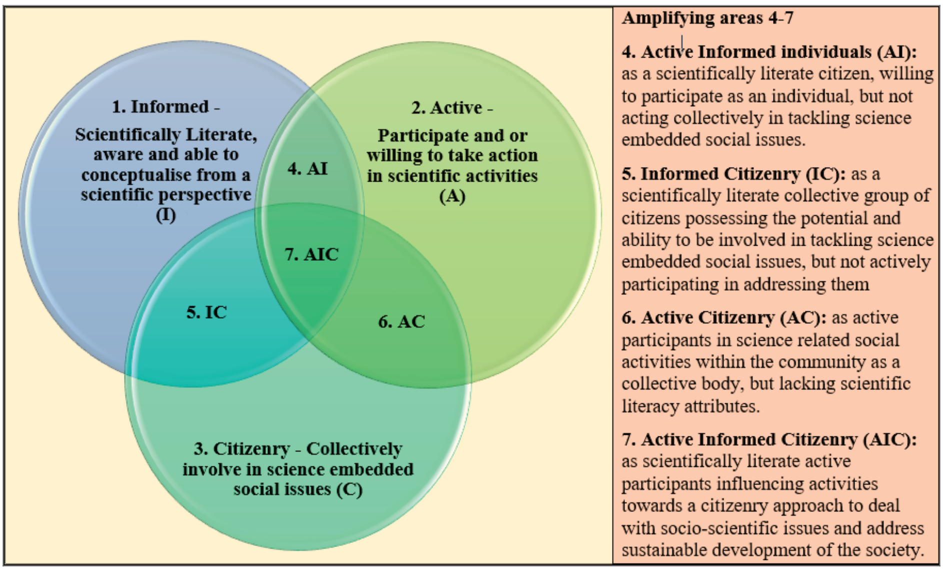

Figure 1. Illustrating Active Informed Citizenry and associated attributes to be derived through science education.

Figure 1 identifies attributes to be developed though science education, building on a SSI baseline (1, 2 and 3), going beyond active informed individuals (associated attribute 4), or informed citizenry (attribute 5), or even active citizenry (attribute 6) so as to better address sustainable development goals. In developing an active informed citizenry, there is a need to go beyond an interdisciplinary learning approach and build a wider learning platform linking school to the society.

5. Trans-Contextualisation Promoting Active Informed Citizenry through Science Education

In this paper, trans-contextualisation is envisaged as moving from a within-school learning setting to a wider development platform within the society where big changes in social behaviour can be involved. In so doing, it strives towards building on students' informed decision making in the school setting to extend this to a wider societal audience, thereby seeking to stimulate justified active informed actions and enable sustainable development within the society.

The rationale and the particular characteristics for a continuum within science education, leading to promoting trans-contextualisation, can be illustrated through a 4 stage process. The first 3 stages are based on an 'education through science', as opposed to a 'science through education' philosophy [24], leading to a contextualisation, de-contextualisation and then re-contextualisation model [23].

Initial Contextualisation Stage: Using a familiar and relevant social context, portrayed as a societal issue or concern, involving a science component, to initiate learning that can more motivationally relate to science. To address the inadequate relevance of science education to students' daily lives, potentially resulting in lack of interest and motivation towards science learning [43], the contextualising of the science learning within a social context, seeks to focus on:

(a) motivating and identifying relevance for students through a familiar social issue or concern;

(b) incorporating students' perspectives on the relevance of the context towards establishing educational value;

(c) determining the level of students' prior science and science-related learning related to meaningfully addressing the issue from a science conceptual perspective;

(d) recognising and identifying students' need to gain further, or more in-depth, science conceptual learning to be able to address the issue.

De-contextualisation Stage: De-contextualising, from the social setting, to address the need to acquire relevant science competences. The de-contextualising of the learning, involves students acquiring new science, driven by a 'need to know' based approach. In involving the students in science, or science-related [STEM] learning, the teacher may utilise a structured, guided, or open inquiry learning approach, as befitting the students' prior learning. In this phase, teaching is expected to mainly focus on:

(a) recognising that science learning is needed to address the social issue;

(b) appreciating how to address the required science learning;

(c) promoting scientific conceptualisation and skills, through meaningful challenges, and

(d) enabling students' self-actualisation through the learning process.

Re-contextualisation Stage: Applying the acquired science learning from the de-conceptualisation stage. The gained science conceptualisations, alongside meaningful consideration of other social factors, are involved within a group interaction to undertake socio-scientific decision making through argumentation. The goal is to resolve, in a class consensus manner, the socio-scientific issue identified in the initial contextualisation stage. A major outcome is expected to be enhancing students' ability to discuss, debate, make informed decisions on social issues, based on a scientific background [13].

The teaching focus within the re-contextualisation stage emphasises:

(a) applying acquired scientific conceptualisation to address a social issue;

(b) developing transformative competences in line with the goals of education (e.g., argumentative reasoning, justified decision making, role playing, etc.) within the social context, and

(c) promoting justified and scientifically informed decision making skill in a consensus, democratic way.

Trans-contextualisation Stage: Applying the science learning, within a sustainable development arena, to promote engagement in social issues, having a science component. This relates to everyday life both within, and even outside, classroom considerations. This stage seeks to enhance awareness and involve active participatory approaches to controversial issues of a local, national, or global nature. It further seeks, through collective actions, to stimulate a sense of commitment to undertake unified actions beyond the school, leading to active informed citizens.

The added stage is based on a concern that there is a perceived lack of attention, linking an individual's decision-making (re-SSI) to societal activity outside the classroom. This stage is intended to encourage students to take constructive post-consensus, action measures, thereby gaining a sense of responsibility for taking personal initiatives. Such initiatives are instigated by recognising the need to promote collective engagement beyond the classroom in order for active and informed operations within the society [17,18]. The trans-contextualisation stage seeks to engage students in transferring their learning from an educational institutional environment to the wider environmental, economic, social (at a local, national, and/or global) arena, thus addressing the sustainable development of the society. The trans-contextualisation stage builds on the theory of collective activism [34,43,44], which recognises actions that may include, for example,

- changing one's own behaviour (for example, recycle, reduce, reuse, increase energy efficiency);
- proposals for innovative solutions to social problems;
- encouraging active participation in volunteer initiatives;
- developing ways to seek to persuade and educate others (such as through exhibitions, social network activities, blogs), or
- stimulate the operations of lobby groups.

6. An Example to Illustrate Trans-Contextual Activities within a 4-Stage Teaching Approach

The following figure (Figure 2) illustrates a trans-contextual stage, extending beyond the 3 stage approach based on an 'education through science' philosophy [24,44,45]. The example is based on a suggested grade 10–11 science (chemistry) level topic - thermoplastics and thermoset plastics.

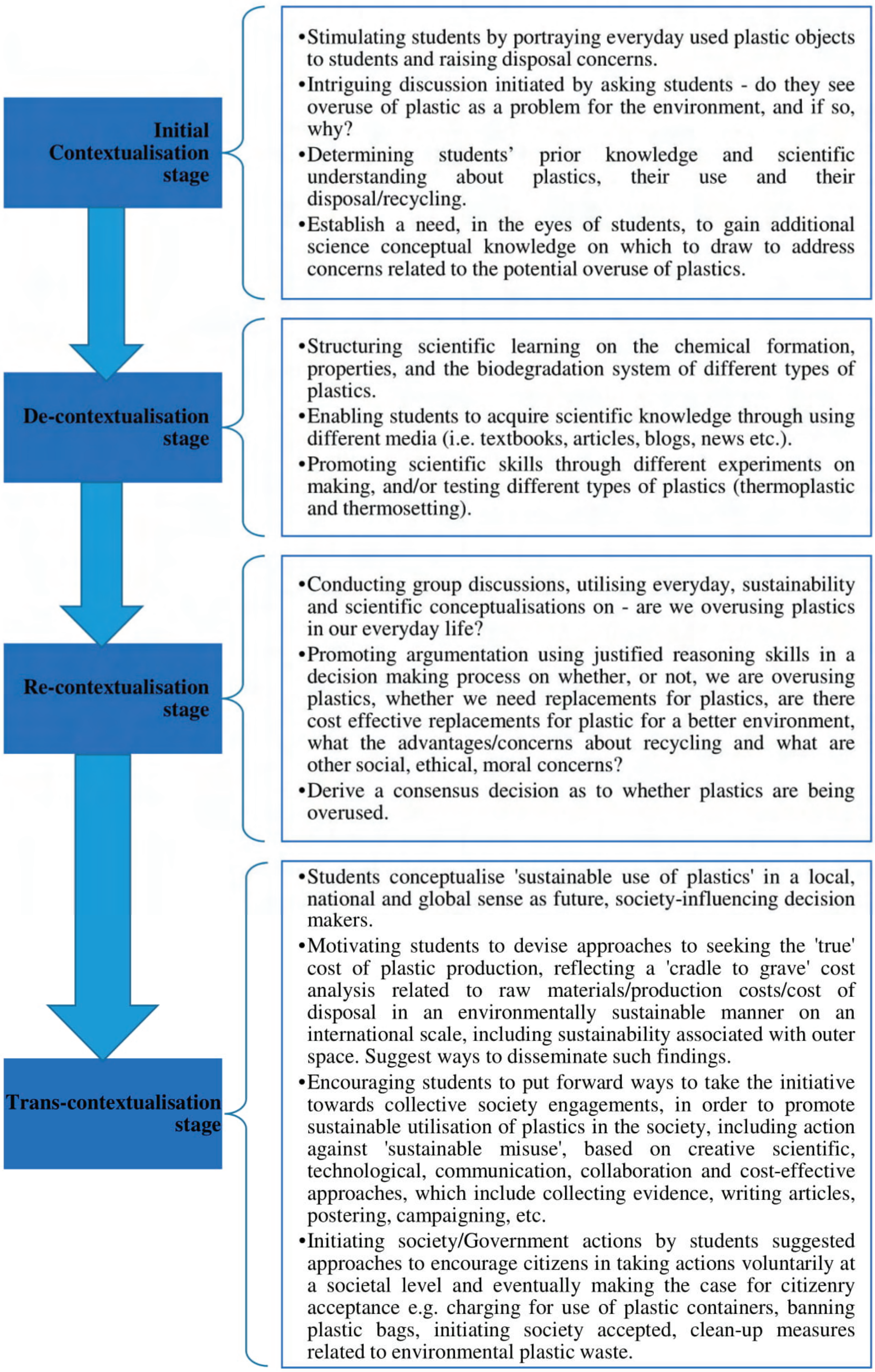

Figure 2. Illustrating exemplary activities within each stage of the 4-stage model.

7. Conclusions

The paper focuses on promoting a wider goal for science education, by adding a trans-contextualisation component, important with regard to the sustainable development of a society. It puts forward the role of science education as not only developing citizens as individuals, such as through promoting SSI, but going further to develop an active informed citizenry, thereby stimulating a willingness by the society to engage in sustainable development activities.

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sustainability

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Article

Development of Environmental Health Competencies through Compulsory Education. A Polyhedral Approach Based on the SDGs

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Abstract: This paper focuses on the competencies in environmental health acquired by students during compulsory education. Questionnaires addressing environmental health problems were completed by 923 students of primary and secondary schools from five different Spanish regions. The results for five challenging situations related to hunger, consumerism, climate change, pollution in the cities and allergies are analysed according to the internal coherence of each sub-competency, i.e., addressing knowledge, skills and attitudes towards these topics. Our results show that problems related to air and water pollution were the most commonly described by the students. Focusing on competency achievement, the higher the educational level, the higher the score students obtained, especially regarding pollution and climate change, two problems that appear directly in the school curriculum. The complexity of the concept of environmental health matches with the necessary holistic perspective of the Sustainable Development Goals in a polyhedral approach including as many factors (facets) as necessary to complete the approach to this evolving concept.

Keywords: competency; compulsory education; climate change; pollution; consumerism; hunger; allergies; SDG

1. Introduction

The current situation of planetary emergency [1] marked by a series of closely-related and mutually-reinforcing socio-environmental and health problems (climate change, poverty, demographic explosion, major social inequalities, pollution and degradation of ecosystems, depletion and destruction of vital resources, unsustainable imbalances, epidemics and pandemics, etc.) is posing an immense and serious challenge to the continuity of our species on planet Earth. The approval of the 17 Sustainable Development Goals (SDGs) and the 169 targets at the 2015 United Nations Summit embodied in the 2030 Agenda (UN, 2019) stands out as the most important international initiative in recent years to address the immense challenge that our species is facing. The current development model is causing a significant environmental degradation, which leads to numerous problems with negative impact, not only on natural areas, but also on social, economic and health aspects of our lives [2,3]. Since Rachel Carson's Silent Spring [4], the interplay between environmental factors, human activities and health has increased social unrest and it has undergone extensive research [5–9]. This relationship between human´s health and the environment is known as environmental health (EH).

The concept of EH is more than the addition of terms health and environment, just as an ecosystem is a superior entity to the addition of the biocenosis and biotope and is nourished by the research on the complexity of the concept of sustainability and its holistic vision [10]. It emerges from three conceptual shifts: (a) the evolution of the concept of health from 'the state of complete physical, mental and social well-being' [11], to more dynamic, ecological and globalizing visions, which include the environment either from an individual or social perspective [12–15]; (b) the consideration of the environment as all that surrounds us, including the relationships established between its components (physical, biological, cultural, social and economic) [16]. Thus, the city, the neighbourhood, the air we breathe, the water we drink, the work we do, the unemployment, hunger, wars, food supplies become part of our environment [17–20]. Moreover, in the same way that the environment influences people, people also influence the environment, modifying or creating it. Lastly, (c) the increasing global awareness of human effect on the environment and the need of a sustainable development, in which the relationships between human groups and with the environment are reconsidered. Sustainability has become one of 'the most central unifying ideas at this moment in the history of mankind' to face the situation of planetary emergency [1,21]. Summing up, EH refers not only to the elements of the environment that affect people's health, but also the individual and social actions that affect the environment.

Environmental health literacy (EHL) is an emerging framework [22] that aims to promote competent citizens that are able to know, give value and contribute to the creation of a healthy environment and to improve the quality of life [23,24]. Despite having a different objective, EHL shares similarities with other literacies like health literacy (HL) or environmental literacy (EL) [23]. However, contrary to HL or EL, the assessment of EHL has received little attention [25,26], and in many cases, this assessment has been constrained to the knowledge, attitudes and behaviour of different communities regarding specific environmental health problems. In the same line, the number of tools to measure EHL is scarcer [27,28].

In many countries, at the end of compulsory education, students should have acquired sufficient knowledge about the environment and health as the official curricula include topics related to the human body, health and ecology. Moreover, some schools are enrolled in programs to promote healthy lifestyles or to be environmentally responsible [29–32]. However, the inclusion of EH topics in primary and secondary schools is still limited (e.g., [33,34]). The question that arises is whether the mere acquisition of environmental and health contents is enough to develop competencies in EH. Moreover, becoming competent (being able to mobilize knowledge to solve problems in an autonomous and creative way and adapted to the context) requires not only the acquisition of concepts (knowledge), but also the development of skills and attitudes. Thus, the development of a competency on EH during primary and secondary school requires that these three dimensions (knowledge, skills and attitudes/behaviours (KSA)) must be attended. Nowadays, there are few examples of evaluation of EHL along compulsory education (e.g., [35–38]) and more information is needed about how these KSA dimensions regarding EH are developed during compulsory education. This information can help to approach more effective EH problems—educational or real problems addressed from a formative perspective—that specifically target the KSA dimensions that need to be reinforced.

The Spanish educational context regarding EH is not different for what was mentioned above. Most of the health and environmental content during compulsory education (primary education: 6 courses from age 6 to 12, secondary education: 4 courses from age 12 to 16) is covered in those subjects related either to biology (i.e., Knowledge of the Natural, Social and Cultural Environment, Natural Sciences, Biology and Geology, etc.) or physical education [39]. Moreover, topics like the problem of consumerism, the consequences of catastrophes (natural or caused by human beings, such as wars, hunger, etc.), the importance of environmental quality on health, the effect of radiation, gases, particles or pollen, the recognition of the environmental cost of goods and services of usual consumption, solidarity with vulnerable people, etc., are not usually raised in the official curricula [40].

The objective of this research is to know if Spanish students who complete primary and secondary education have developed competencies in EH that allow them to integrate into a society in continuous change. We explore (a) the level of awareness on environmental health problems, (b) the level of competency achievement and (c) the internal coherence of the KSA dimensions of competency.

In particular, we approach EH from a pentagonal point of view, considering five facets of the polyhedron: climate change, consumerism, pollution of cities, allergies and world hunger. We also explore the possible influence of different variables such as educational level, school typology and gender on the acquisition of these competencies.

2. Materials and Methods

A questionnaire was developed in order to study the level of awareness towards environmental health and competency achievement regarding five specific EH problems. This questionnaire was validated through three steps: expert validation, pilot test and single-case validation. Internal consistency was evaluated using Cronbach's α [41] and total omega (ωt) [42]. Both reliability indices were calculated using R package psych [43].

Demographic variables such as age and gender, educational level (primary or secondary) and school typology (rural or urban) were documented. The rural/urban distinction was based on populations size (fewer or more than 20,000 inhabitants) as defined by the Spanish Law 45/2007 for the Sustainable Development of Rural Areas [44]). The study included students in the last year of either primary (age $\approx$ 12) or secondary education (age $\approx$ 16). The sampling method consisted in a convenience group which included students from 16 primary/secondary schools from five regions across Spain (País Vasco, Cuenca, Las Palmas, Teruel and Valencia).

Environmental health awareness was measured using an open question survey asking students about what EH problems they were aware of. The environmental health problems pointed out by the students were grouped into general categories. Independency tests were carried out to determine differences among these categories and the variables educational level, gender and school typology. Fisher exact test for R x C tables were used. Differences in the number of problems detected due to educational level, gender and school typology were also assessed using Kruskal-Wallis rank sum test. In both cases a Holm correction for multiple comparisons [45] was applied. Effect size was calculated for both types of tests [46]: Cramer's V for the contingency tables using R package *vcd* [47] and η^2 for the Kruskal-Wallis test.

The level of achievement of EH competency was measured using open questions regarding five different environmental health problems: climate change, consumerism, pollution of cities, allergies and world hunger (Appendix A). Each of the environmental health problematic situations links with at least one different Sustainability Development Goal as shown in Figure 1. Our approach to environmental health competencies is made from a polygonal approach, in this occasion from a pentagonal point of view.

Figure 1. Relationship between environmental health problems approached in this study and five Sustainability Development Goals.

The questions about each environmental problem included three sub-questions were students were asked for the three dimensions of competency: (1) what they know about the problem (knowledge),

(2) what they can do (skills/procedures) and (3) which attitude they show towards the problem (attitudes). Answers to each of the three sub-questions within each question regarding the three competency dimensions were scored using a 0-1-2 scale: 0 when no answer was provided or the answer was not addressing the question, 1 when only one correct answer/opinion was provided and 2 when two or more answers were provided or the answer included the implications both from an individual and a collective perspective. Scores were agreed by at least two researchers. A total question score (ranging from 0 to 6) for each of the five open questions was obtained by adding the sub-questions scores. Thus, a score of 6 will indicate the competency (i.e., knowledge, skills and attitudes) is fully acquired. Differences in question score due to type of environmental problem, educational level, gender and school typology were assessed using a general linear model, which included all main effects, all possible double interactions, and all triple interactions that include type of environmental problem. Normality of residuals of the model was assessed using Shapiro-Wilk normality test. As normality was not accomplished, a robust ANOVA was used to test the linear model using the robust R package [48]. Tukey's HSD test was used for post-hoc comparisons. Partial effect sizes (η^2) were computed using R package *lsr* [49]. To assess the score differences between sub-competencies (knowledge, skills and attitudes) for each of the five problems, an ordinal logistic regression was performed using R package *MASS* [50]. All statistical tests were performed using R statistical software v 3.2.3 [51].

The present study is part of a broader study on health competencies regarding eight different areas of health education (accidents, addictions, environmental health, hygiene, mental health, nutrition and physical activity and sexuality and health promotion). The five questions regarding EH problems were part of a collection of 24 open questions survey designed to measure student's health competency which was subjected to a thorough validation process [52]. In order to avoid excessive extension and exhaustion of students, questions were grouped into two different questionnaires with 12 questions each one. One of the questionnaires (Model A) included questions regarding climate change, consumerism and hunger, and the other (Model B) questions concerning city pollution and allergies (Appendix A). All questionnaires included the open question regarding EH awareness.

3. Results

A total of 923 students of 16 primary and secondary schools (average 57.7 students per school) from five different Spanish regions (184.6 students per region) answered the survey; 458 completed model A and 465 model B. Age of the participants ranged from 11 to 26 years old (average 12.5 for primary school students and 16.1 for secondary school students). Distribution by gender, educational level and school typology can be found on Table 1. Only one questionnaire out of 923 (0.1%) was discarded as all the questions were left blank. Both questionnaire models showed a high reliability: model A had a Cronbach's $\alpha = 0.80$ and $\omega_t = 0.85$ and model B $\alpha = 0.78$ and $\omega_t = 0.88$.

Table 1. Distribution of number (N) and percentage (%) of participants by educational level, gender and school topology.

Variables		N	%
Educational level	Primary	516	55.9
	Secondary	407	44.1
Gender	Male	464	50.3
	Female	459	49.7
School typology	Rural	396	42.9
	Urban	527	57.1

3.1. Environmental Health Awareness

On average, students identified 0.59 problems (median = 1, range from 0 to 4). Statistically significant differences were found due to educational level (multiple comparisons corrected p-value = 0.003, $\eta^2 = 0.01$) and rural/urban typology (corrected *p*-value < 0.001, $\eta^2 = 0.03$), but not gender.

On average primary school students detected 0.54 problems vs. 0.67 problems by secondary school students (median 0 vs. 1 of primary and secondary school respectively) and students from urban areas detected 0.69 problems vs. 0.47 of those in rural schools.

In total, students stated 549 problems related to environmental health. 86.5% of them (475) could be grouped into six different categories (Figure 2), being the problems related to air and water pollution the most commonly described (32.6% of the students). Health problems derived from consumerism and catastrophes are hardly considered. Among the problems that could not be grouped deforestation, viral diseases and other types of pollution, were the most mentioned. It should be noted that in most of their descriptions, students, instead of mentioning EH problems, pointed out their effects on human health.

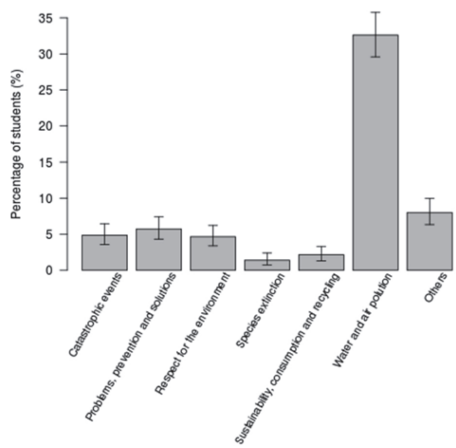

Figure 2. Problems related to environmental health (EH) identified by the students. Error bars represent the 95% confidence interval for the binomial distribution.

When comparing the differences of the frequency of the different categories of problems (Table 2), the Fisher exact test showed that statistically differences exists among educational level (corrected *p*-value < 0.001, Cramer's V = 0.296) and school typology (corrected *p*-value < 0.001, Cramer's V = 0.272), however no statistically significant differences were observed when considering gender. Primary school students highlight more frequently catastrophic events (10.8%) and problems regarding respect for the environment (12.3%) than secondary students (5.2 and 3.3% respectively). On the contrary, secondary school students were more aware of water and air pollution (64.7 vs. 45.1%). Regarding the differences due to school typology, rural students mention catastrophic events (14.6%) and problems, preventions and solutions (14.1%) more than their urban counterparts (4.9 and 7.4% respectively). On the other hand, urban students are more concerned about pollution (61.3 vs. 42.2%).

Table 2. Distribution of the percentage of answers among the different problem categories by educational level, gender and school topology. Total number of answers is shown in brackets.

	Educational Level		**Gender**		**Typology**	
	Primary	Secondary	Male	Female	Rural	Urban
Catastrophic events	10.8 (30)	5.2 (14)	10.2 (28)	6.2 (17)	14.6 (27)	4.9 (18)
Problems, prevention and solutions	8.3 (23)	11.2 (30)	9.1 (25)	10.2 (28)	14.1 (26)	7.4 (27)
Respect for the environment	12.3 (34)	3.3 (9)	7.3 (20)	8.4 (23)	6.5 (12)	8.5 (31)
Species extinction	0.7 (2)	4.1 (11)	2.9 (8)	1.8 (5)	1.1 (2)	3.0 (11)
Sustainability, consumption and recycling	5.8 (16)	1.5 (4)	3.6 (10)	3.6 (10)	1.1 (2)	4.9 (18)
Water and air pollution	45.1 (125)	64.7 (174)	51.6 (142)	58 (159)	42.2 (78)	61.3 (223)
Others	17.0 (47)	10.0 (27)	15.3 (42)	11.7 (32)	20.5 (38)	9.9 (36)

3.2. Environmental Health Competency Achievement

The competency achievement varied among the different problems (Figure 3a). The global score of achievement was found to be affected by type of problem, educational level, gender and school typology. The robust ANOVA revealed that the triple interaction (type of problem × educational level × school typology), two out of three double interactions (type of problem × educational level and type of problem × school typology) and all main factors have a significant statistical effect (Table 3). The post-hoc test (Figure 3a) showed that in the questions regarding hunger and city pollution students achieved the highest level of competency (25.9% and 31.7% of students scored higher than 4, respectively) (Figure 3b), whereas the question regarding climate change is the one with the lowest achievement of competency and only a 10.6% of students scored more than 4 points (Figure 3b).

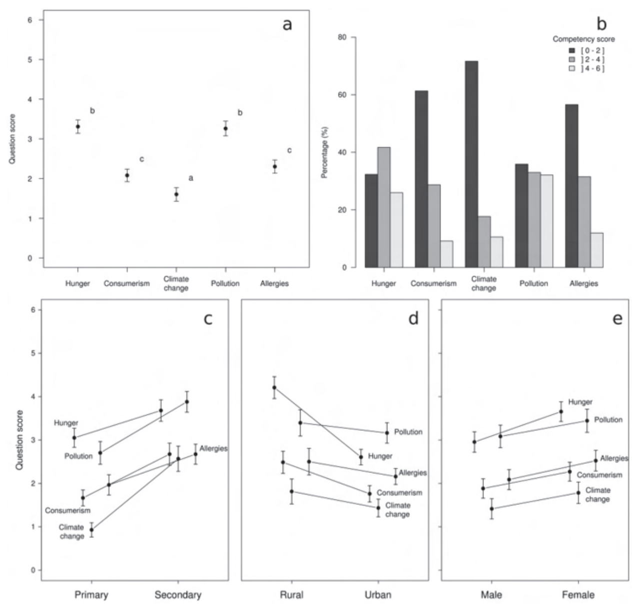

Figure 3. Competency achievement among the different problems: (**a**) Question score for each of the five EH problems; (**b**) Distribution of scores for each problem; (**c–e**) Differences in question score for each EH problem due to educational level, school typology and gender. Whiskers show the confidence interval at 95%.

As expected, the higher the educational level, the higher the score (Figure 3c): secondary school students obtained a higher question score than primary students. However, the improvement varied among problems, and the questions regarding climate change and city pollution showed a higher increase. In the case of hunger and consumerism students from rural areas performed better than students from urban areas (Figure 3d). For the other questions, no differences were found between rural/urban students. Regarding gender, no interactions were found with type of questions, although in general, females tended to outperform males in all questions (Figure 3e).

Table 3. Results of robust analysis of variance (ANOVA). Effect of EH problem, educational level, gender and school typology on level of competency achievement measured as question score.

Factor	df	Robust F	Pr(F)	η^2	$\eta_{partial}^2$
Problem	4	90.62	<0.001 *	0.115	0.136
Level	1	209.34	<0.001 *	0.075	0.093
Gender	1	27.44	<0.001 *	0.009	0.012
Typology	1	125.77	<0.001 *	0.041	0.053
Problem × Level	4	6.50	<0.001 *	0.007	0.010
Problem × Gender	4	1.11	0.350	0.002	0.003
Problem × Typology	4	11.75	<0.001 *	0.015	0.020
Level × Gender	1	0.89	0.345	0.000	0.000
Level × Typology	1	0.36	0.548	0.000	0.000
Gender × Typology	1	1.14	0.286	0.000	0.001
Problem × Level × Gender	4	0.75	0.560	0.001	0.001
Problem × Gender × Typology	4	1.05	0.382	0.001	0.002
Problem × Level × Typology	4	5.04	<0.001 *	0.007	0.009

* Statistically significant at $\alpha = 0.05$.

3.3. Student's Answers to Environmental Health Problems

Students answers were classified and categorized for each problematic situation. Some patterns could be found, the main results are presented below.

- Hunger. Two trends were found in their answers: an individual and subjective (e.g., 'I feel sad', 'it is due to selfishness', 'it should not exist'), and another more social, pointing out injustice, inequality, exploitation of poor countries, right to food, etc. When asked about their skills and procedures, the answers kept in the personal level, mentioning actions directed towards volunteering: helping NGOs, sponsoring a child, offering food, not throwing away food, etc. When attitudinal aspects were approached, the answers concentrated on giving opinion 'it's wrong', 'you have to donate', 'you have to think about others', justifying the answers in most of the cases.
- Consumerism. Approximately 30% of the students did not know and less than 10% mentioned the environmental effects of problems related to consumerism. Those who answered presented two aspects in their responses, a personal one: 'I lose money', 'I waste time', 'the addiction that it entails', and another more social, since they mentioned child exploitation, excessive consumption or pollution. When addressing procedural (knowing-how-to-do) issues, most of them offered answers of personal behaviour: 'not consuming', 'continue using devices while they work', 'you have to settle for what you have', etc. However, others added general or social aspects: 'money should not be wasted', 'my parents will not let me', 'it is about whims'. In response to the question directed towards attitudes or expressing opinions, some responses were focused on the awareness of people: 'we must raise awareness among young people', 'try not to exploit the poor', while other responses were more social: 'avoid planned obsolescence', 'reduce production', 'do not take so many models', 'raise the market price', etc.
- Climate change. 60% of responses showed an absence of knowledge, either by leaving questions unanswered or considering their mistakes. Most of the answers focused on the effects of climate change on the environment: 'temperature increase', 'acid rain', 'greenhouse effect', 'loss of biodiversity', etc. About 20% mentioned individual health consequences (cancer, respiratory problems, skin burns, etc.). The answers that focused on what can be done were all in the personal sphere, with predominance of the three Rs (reduce, reuse and recycle), also pointing out the importance of keeping clean streets, or the environment, not wasting water and using public transport. When asked about knowing-how-to-be or their attitude, the answers were more social and collective: 'make people aware', 'pay attention to scientists', 'increase information in the media' or 'carry out collective actions'.

- Pollution in the cities. Considering the conceptual dimension of the problem, student responses showed two aspects, the first referring to the environment itself, and most of them stated atmospheric or air pollution, but also acoustic and light pollution; less mentioned were the decrease of the ozone layer, global warming, pointing the use of cars as the great cause. The least mentioned type of pollution is soil pollution. The other aspect referred to health problems generated by these environmental alterations, mentioning heart, respiratory and skin problems, insomnia, bad mood, stress, deafness, etc. When asked on what can be done, most of the answers inclined towards the adoption of personal behaviours, such as saving electricity, using electric cars, using litter bins, mentioning once more the importance of the three Rs, including also global behaviours and governmental measures such as collaboration between countries, limiting the use of private cars, promoting alternative energies, carrying out awareness campaigns to reduce garbage, etc. When faced with the question of attitudinal aspects or knowing-how-to-be, the great majority pointed out the alarming situation of our planet due to global warming, greenhouse effect, ice melting at the poles, situations that can still get worse. With a social vision they pointed out the need to promote people´s awareness, to pay attention to scientists insisting on the fact that the permanence of this problem means the deterioration of our planet and with it our own extinction.
- Allergies. When asked about conceptual issues, most noted both the causes of allergies (dust, acarus, certain bacteria) and the effects on the body: breathing difficulties, sneezing and mucus, skin reactions, headaches, eye redness, etc. When asked about skills or procedures, on the one hand, they pointed out the adoption of preventive actions such as getting vaccinated, cleaning up more, going to the countryside to breathe fresh air and, on the other hand, actions to avoid polluting sources such as 'getting away from places with dust', 'avoiding certain cleaning jobs', etc. When asked about attitudinal predisposition, the answers were directed towards possible causes such as not having immunity, avoiding transgenics, and excessive cleaning, this last appointed at the same time as improper hygiene.

3.4. Knowledge, Skills and Attitudes on Environmental Health

When considering the level of competency achievement on each of the competency dimensions (knowledge, skills and attitude (KSA)), the results showed that all three components were correlated within problem (average correlation 0.44, all p-values < 0.001). Despite some level of variation, this correlation was similar among the five different environmental problems (range from 0.28 to 0.57). The ordinal logistic regression (Figure 4) shows significant differences among components; 11 out of 15 possible comparisons (3 dimensions × 5 problems) were statistically significant (odds ratio ≠ 1, p-value < 0.05), although the effect of the dimensions was not the same in all problems.

Regarding the problems related to climate change, city pollution and allergies, both, the skills and attitude dimensions showed odd ratios (OR) lower than one when compared with the knowledge dimension (i.e., students were more likely to perform better in the knowledge dimension than in the other two). The same relationship (OR < 1) was found when comparing attitude versus skills. In the case of allergies these differences were quite pronounced, mainly due to the low level of competency achievement in the attitudinal dimension. In the case of hunger and consumerism, the relationship between the KSA dimensions was different. When comparing the achievement on the skill dimension to knowledge, higher scores were expected for the consumerism problem (i.e., student are more able to do things than the knowledge they possess), but no difference was expected in relation to hunger issues. Regarding attitude vs. knowledge, OR > 1 were found for both problems (i.e., students have a better attitude/behaviour than knowledge about those problems). Finally, in the attitude vs. skills dimension the pattern is reversed, higher scores were expected for hunger problem, but no differences were expected regarding consumerism problem. Interestingly, the same results for all five problems were found when analysing separately primary and secondary school students.

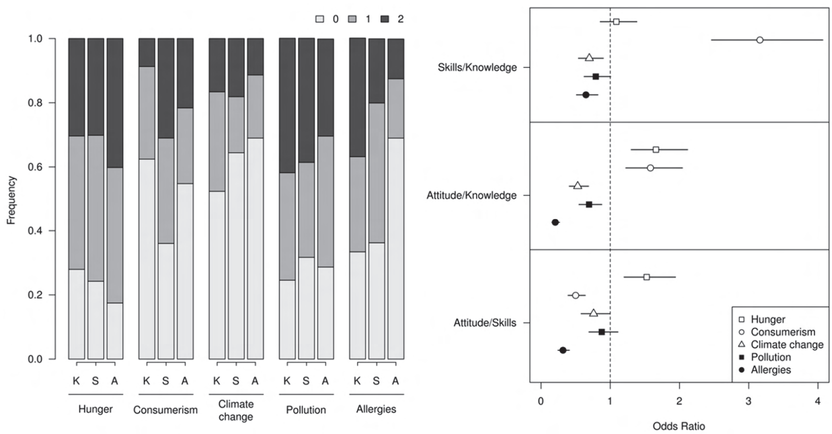

Figure 4. Distribution of sub-question scores (left panel) and odds ratios of the ordinal logistic model of the effect of knowledge, skills and attitude components on competency achievement (right panel).

4. Discussion

The proper development of environmental health competencies in their three dimensions (knowledge, skills and attitudes) is essential to form educated citizens able to participate and act within a society in continuous change, particularly under the challenge of a planetary emergency situation. Extensive studies of the level of EH literacy achievement, which are currently scarce, and the creation and validation of instruments able to measure it are crucial to take evidence-based actions than can help to improve EHL. In this paper we explore whether compulsory education in Spain is able to fulfil this educational and formative need through an instrument to measure the level of achievement of these competencies in their KSA dimensions.

Almost 1000 students from primary and secondary schools from different Spanish regions have taken part in this study, which provides a detailed overview of the current situation of compulsory education. During primary and secondary education in Spain, as in many other countries, several subjects cover topics regarding environment and health, however, the inclusion of specific EH topics is still limited. In fact, when the students were asked to specify health problems related to the environment, only 60% were able to mention at least one, and only a few were able to state more than one. The effect of compulsory education is limited: despite students at the end of secondary education can recall more EH problems than primary school students, the median of EH problems that can be identified by student at the end of compulsory education is one. This shows the little interrelation they perceive between health and the environment, that translates into a poor awareness of environmental health problems. The most commonly recognized EH problem (32.6% of students) is air and water pollution. Interestingly, pollution is also the problem where they show a greater degree of competency with great internal coherence—a balanced relationship between knowledge, skills and attitudes. The results concur with other studies that found that pollution is the main environmental issue perceived by different social groups in Spain [53,54]. Heras-Hernández and co-workers [55] point out four groups of styles in risk assessment when addressing climate change of the Spanish population: 'carefree', 'distant', 'conscious' and 'alarmed' finding a significant relationship between personal beliefs on climate change and the predisposition to develop actions in favour of climate. We find these same styles and relationships among the youth surveyed according to the answers they offer to the three sub-questions of this problem (sub-dimensions of the competency).

When focusing in EHL achievement regarding the five different environmental health problems (hunger, consumerism, climate change, pollution of cities and allergies), we found that the best results of competency were obtained for pollution, as stated above, and hunger, whereas climate change was the problem for which students show less competency. Attending to the development of the three competency dimensions (knowledge, skills and attitudes), our results show that pollution and climate change are those with greater balanced development among KSA. In the other three problems, at least one of the dimensions tends to outperform the others. For example, in the case of hunger, students tend to show a better performance regarding attitudes or knowledge is more developed in the case of allergies. In relation to situations of excessive consumption, students show poorer levels of knowledge and attitudes than skills, which could indicate the difficulty in modifying their behaviour. Studies developed more than 20 years ago highlighted in the students the persistence of misconceptions, confusion related to the ozone layer and global warming, and the belief that all acts harmful to the environment cause climate change [56].

Considering all the problems together there is an increase in competency acquisition in secondary school in relation to primary education, especially regarding pollution and climate change, two problems that are addressed at school and that appear directly in the official curriculum. The problems of hunger, consumerism and allergies do not appear explicitly in the curriculum and the increase in competencies that students show during school time is lower; an evidence of the school-curricular action and the effective action of schooling and its educating role.

Beside the primary role of the school curriculum of compulsory education in the acquisition of EH competencies other formative sources should not be underestimated like the potential of the work of teachers and teachers' attitudes and the complement of textbooks, which often fill the gaps that we detect in the official curriculum. However, in order to be effective, a proper teacher training in relation to EH problems is needed. Studies analysing the understanding of these same problems by primary and high school teachers and pre-service teachers often indicate misconceptions and lack of knowledge [57–63]. The extracurricular environment (including social media, families, etc.) also plays an important role in the acquisition of EHL, although it has limitations. In the end, what really matters is competency achievement of students not only as future but also as nowadays´ citizens who make decisions in their daily lives that comprise both their health and that of the environment. That is why the focus of this paper included a polygonal point of view including five issues (pentagonal approach) but considering the balance (consistency) of the three dimensions of competencies (KSA), which necessarily forces a polyhedral vision of environmental health (in our case, a pentahedral vision).

5. Conclusions

Science-Environment-Health pedagogy necessarily deals with complex systems in which students have to develop the "art of decision making" [64]. Along this paper we have been working with global and interrelated concepts under construction and in continuous evolution, building a multifaceted model dealing with aspects such as hunger or overconsumption, considered as part of social sustainability. Based on the results of this study, we comprehend that there are issues that have been addressed in greater depth in different investigations, while the abovementioned problems of hunger in the world or consumerism should be analysed in more detail.

It is important to highlight that the results in relation to climate change are of great interest, as they precede the Fridays for Future movement and the emergence of Greta Thunberg as a youth leader on climate change. It would be very interesting to repeat the same questionnaire in the current conditions and see to what extent young people have improved their competencies in relation to climate change issues.

In this sense, more research is required from the sustainability prism considering the wide range of SDGs related to environmental health education with the aim of adding facets to the polyhedron that will provide an increasingly complex vision. Research should be aimed at addressing the perceptions and competencies of students, as well as the contents of official curricula, textbooks and teacher training, the latter being a key element in addressing environmental health issues through the prism of sustainability with a *glocal* perspective [65].

The results of this study support the importance of addressing environmental health throughout compulsory education in a holistic way and establishing bases that help students to become citizens capable of discerning among the large amount of information they receive. As some authors have pointed out [66], a greater number of students with low knowledge about certain topics are more likely to trust untrustworthy sources of information, being unable to differentiate between relevant and irrelevant criteria when distinguishing reliable from unreliable sources.

There is no doubt that when addressing environmental health, we are dealing with emerging, complex, interrelated and evolving concepts. The current idea of the environmental health encompasses not only the parameters of the environment (climate, biological diversity, balances, etc.) but extends to the cultural and social issues that human beings construct in their relationships. On the other hand, the vision of health is not limited only to personal or individual aspects, but also encompasses the social and environmental spheres, given the mutual influence they have on each other. That is why science environmental health education needs of a polyhedral approach that includes this variety of elements that conform the complexity of the concept in a holistic way considering the necessary three dimensions (KSA) of competencies. This global perspective is essential when approaching environmental health competencies from the prism of sustainability, by ensuring the overall effects that each individual action has. In this sense, it is convenient to insist on the necessary *glocal* approach which implies keeping touch with the local when responding to global forces or challenges, that is to articulate global needs and requirements with local possibilities and practices. *Glocality* also refers to situations that students encounter in their daily life as polluting fumes, for example, that affect foremost those living in the vicinity of the emitting sources; but those fumes are diluted in the common atmosphere and end up affecting the whole planet. There are no borders to these fumes, there are no boundaries for radioactivity and many other forms of pollution [67,68].

There are currently 17 Sustainable Development Goals and 169 targets proposed by the United Nations to combat the increasingly serious global emergency. We are talking about social sustainability [10], environmental sustainability, health sustainability, etc. The concept becomes more and more polyhedral, with smaller edges, getting closer to a circumference, until it becomes a global and complex vision. In this paper we have addressed the competencies acquired by Spanish students throughout compulsory education with a complex approach in an effort to specify, by means of a questionnaire, those basic aspects of environmental health that primary and secondary school students must face in their daily lives. This polyhedral approach tries to avoid putting each aspect that is studied, each characteristic that is analysed, in a different and isolated box, but rather strengthening some visions through others, offering the spherical view that the situation, and the concepts that they raise, require.

This polyhedral perspective must be considered from an educational viewpoint of the development of competencies, which also requires a global and multi-dimensional focus, since it is necessary not only to achieve knowledge and abilities, but also to achieve a predisposition to informed and well-done action. A globalised educational initiative that considers complex and global issues, considering the three dimensions of competencies (knowledge, procedures and attitudes) is essential. Hence, our educational proposal is aimed at considering as many faces of the polyhedron of sustainability as possible while addressing them from the three dimensions of learning competencies.

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Appendix A. Questionnaires provided to students (translated into English from the Spanish)

ENVIRONMENTAL HEALTH COMPETENCIES Model A

The present questionnaire is anonymous. Think carefully before answering. Thank you very much for your cooperation.

A. Personal information

Gender: • Male • Female Age: ______ School: ______________________________________

B. Environmental health problems

Point out those health problems that you know that are related to the Environment____________________

____

C. Actions addressing the problems. What would you do in these cases?

1.- At the end of the break you see pieces of bread and sandwiches on the floor. However, you know that there are children who go hungry and have nothing to eat for lunch.

What can you say about hunger in the world?
What can you do about it?
What do you think about these two situations occurring in today´s world?

2.- For a year now you have had a mobile phone that works perfectly. However, an impressive new model that you love has come on the market.

What problems can excessive consumption cause?
What would you do with your old phone? Would you continue with it or replace it? Why?
What measures could be adopted to reduce overconsumption in developed countries?

3.- The idea of climate change is being widely used in the media.

How does climate change arise? What consequences could it have on health?
What can you do to slow down this process?
What opinion do you have about alerts from scientists and the media?

ENVIRONMENTAL HEALTH COMPETENCIES Model B

The present questionnaire is anonymous. Think carefully before answering. Thank you very much for your cooperation.

A. Personal information

Gender: • Male • Female Age: ______ School: _______________________________________

B. Environmental health problems

Point out those health problems that you know that are related to the Environment____________________

____

C. Actions addressing the problems. What would you do in these cases?

1.- Pollution in cities is a fact repeatedly highlighted by the media.

What types of pollution do you know? What consequences can it have on citizens?
What do you propose to prevent it?
Do you think it is an alarming situation or is it being exaggerated? Why?

2.-You have a cousin who leaves the room when it's being cleaned. He says he has a "dust allergy".

What does "dust allergy" mean? How is it recognized?
What could be done to minimize his allergy?
The health authorities say that there are more and more people with allergies. What do you think this is due to?

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Article

Education for Sustainable Development in STEM (Technical Drawing): Learning Approach and Method for SDG 11 in Classrooms

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Abstract: Five years after proclamation of the Sustainable Development Goals promoted by the United Nations, Spain joined this process of transforming the world socially, economically, and environmentally. This research covers the route taken and results obtained during subsequent years in Spain and proposes, as a general objective, to observe whether it is feasible to work in the technical drawing classroom on an eco-urban project, following the learning approach and method proposed by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) in 2017 Education for Sustainable Development Goals: Learning objectives, in order to reinforce cognitive, socio-emotional, and behavioral objectives, as well as the key competences established in Sustainable Development Goal 11. The phases of the project were related to the learning objectives and key competences, the results of which were complemented by a questionnaire that provided information on the sustainable consciousness of the students after completing the project, and could serve as a starting point for future educational projects. We agree with other authors, and in particular with UNESCO, that implementation of this type of project in the classroom is a key learning method for SDG.

Keywords: sustainable awareness; SDGs; sustainable cities and communities; eco-urban technical project

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1. Introduction

1.1. History of Sustainable Development Goals in Spain 2015–2019

In September 2015, the United Nations established the roadmap towards improving the planet from different social, economic, and environmental perspectives, and the Sustainable Development Goals (SDGs) were born. Four years after the 2030 Agenda, we ask whether future generations are aware of the Goals; whether it is possible to inculcate a sustainable conscience in society, and what have been the results to date.

On the 18th of June 2018, the Government of Spain created the High Commissioner for 2030 Agenda, whose duties are set out in Article 11 of Royal Decree 419/2018 [1]. These are to:

(a) Monitor the actions of the competent bodies of the General State Administration concerning compliance with the goals of sustainable development and the 2030 Agenda.
(b) Promote the preparation and development of the plans and strategies necessary for Spain to comply with the 2030 Agenda.
(c) Evaluate, verify, and disseminate the degree of progress towards the compliance with the goals of the 2030 Agenda.

(d) Collaborate with the Ministry of Foreign Affairs and Cooperation in Spain's international dialogue concerning global implementation of the 2030 Agenda.
(e) Promote the information and statistical systems necessary to accredit the progress made in achieving the goals of the 2030 Agenda.

In the same way, the Spanish Government created a website specifically dedicated to the 2030 Agenda [2], which offers general information on the SDGs and the government's current actions, and ontains a presentation from the High Commissioner and a resources section. This website is similar to the official website of the United Nations.

One month later, on the 18th of July 2018, the action plan for the implementation of the 2030 Agenda (Towards a Spanish Strategy for Sustainable Development) was published. According to this document published by the Ministry of Foreign Affairs [3], the educational model of the country must respond to the commitments agreed on in September 2015 "by including in the educational curriculum mechanisms that provide students with tools to understand the world, with socio-affective skills to manage it and to give critical capacity, so that values of human dignity, equality, justice, solidarity and participation are fostered" (p. 29). The same section of the document establishes that it is essential to include competencies in the educational framework that are directly related to ethical values favorable to social, environmental, and economic sustainability in the curricular contents of formal education at all levels. Likewise, it states that "it is essential that the proposed educational model responds to the commitments acquired within the framework of the SDGs."

Spain has been part of the negotiations on the 2030 Agenda, and is committed at an international level to the establishment of the SDGs and in favor of international cooperation, such as in the Ibero-American Conference and its General Secretariat, the Economic Commission for Latin America, and the Organization of American States.

In its 2016 report, The Policy Coherence for Development Index, a tool created to measure, evaluate, and compare the commitment of countries to sustainable, fair, and equitable human development, the following results, which can be seen in Figure 1 [4], were described.

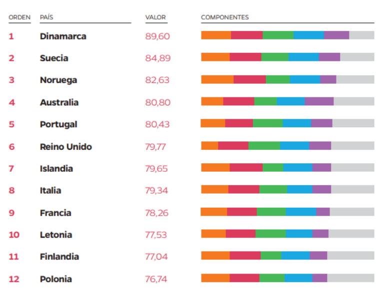


Figure 1. Policy Coherence for Sustainable Development Index (PCSDI) 2016 Ranking.

The most redistributive countries were those at the top of economic ranking, led by the Nordic countries. Respect for the social component produced good overall results, while those concerning the global component showed that the countries best-placed in the PCSDI (Policy Coherence for Sustainable Development Index) occupied the highest positions. An overview of the environmental component revealed very uniform results, in which countries tended to have relatively similar scores. However, these scores concealed enormous differences in development models, whereby certain countries that, although they were responsible for creating strongly negative environmental pressure, had the capacity to incorporate policies that "compensated" for their failings. The productive component identified only one European country, Denmark, among the first 20 places in the ranking.

What conclusions can be drawn from this study with respect to Spain?

As can be seen in Figure 2, the results of the report show that the Spanish index is among the top 15 countries in the ranking of the 133 participants in the study. Comparing Spain with its performance in each of the components, it can be seen that this country fares badly in almost all them, and the global component is the only one in which its position is high.

Desempeño de España por componentes					
ICPD	Económico	Social	Global	Ambiental	Productivo
13	33	41	4	44	66
Baja/sube	-20	-28	+9	-31	-53

Figure 2. Spain's score for each component. PCSDI 2016.

Compared with other EU countries, Spain's position is medium-high, as it ranks tenth. Two conclusions that are considered important for the present research can be drawn from the report:

- Spain has ample room for improvement in terms of policy coherence for development, especially in social, environmental, and productive areas.
- The countries of the European Union present great heterogeneity in terms of their observance of policies for development, although in some components, including the global performance.

In October 2018, the Spanish Network for Sustainable Development published a report entitled Looking to the Future: Sustainable Cities. In the presentation of the report, reference is made to the following: [5].

The SDGs offer a set of integrated goals for more prosperous, fairer and environmentally sustainable cities. In particular, SDG 11 calls for our cities to be inclusive, safe, resilient and sustainable. The SDG Agenda gives us an impartial and long-term framework for achieving these ambitious and noble goals.

The Report reviews the 17 SDGs and presents the challenges that eco-urbanism represents as a model city in terms of mobility, health, inequalities, and climate change.

According to the latest report by the Sustainable Development Solutions Network (SDSN), Spain ranks 21st in the "SDG 2019 Index". Figure 3 shows both the current assessment and the trend for each of the Sustainable Development Goals for Horizon 2030.

Figure 3. Sustainable Development Report 2019.

The report includes contributions from Professor Jeffrey D. Sachs (Columbia University), the Office of the Prime Minister of Finland and the World Business Council on Sustainable Development (WBCSD). For the first time, the results of the study were statistically audited by the European Commission.

From the data provided, it can be seen that, as of June 2019, Spain did not obtain the highest possible rating for any component and none of the SDGs are green, so that if the trend continues, Spain will not reach any SDG by the 2030 horizon. The greatest challenges are the SDGs relating to No Poverty, Climate Action, Industry, Innovation, and Infrastructure, and the country obtains its best results for SDG 6 (Clean Water and Sanitation) and SDG 7 (Affordable and Clean Energy). The top three countries of the 162 in the study are Denmark, Sweden, and Finland.

1.2. Denmark, Sweden, and Finland: the Model to Follow

According to the latest report of the Sustainable Development Solutions Network [6], Denmark is the first country in the ranking to achieve the SDGs: Figure 4 shows how the trend in both SDG 4 Quality Education and SDG 11 Sustainable Cities and communities is on track to achieve the Goals in 2030.

Figure 4. Sustainable Development Report 2019. Denmark.

Analysis of the Danish education system points to the principles on which the Danish Ministry of Education and Vocational Training system is based [7]: "Education for all, high standards of quality, lifelong learning, active participation and project work". According to the document "The World is Studying Spanish. Denmark", published on the website of the Ministry of Education and Vocational Training, compulsory primary and secondary education takes place from six to sixteen years of age. In its last reform, the Danish education system made a change in the total number of teaching hours as well as in the distribution of subjects. The subjects with the highest number of hours are Danish and STEM.

The latest report published on Sustainable Development Solutions [8] identifies Sweden as the second-ranked country for fulfilling SDGs, and Figure 5 shows how the trend in both SDG 4 Quality Education and SDG 11 Sustainable Cities and Communities is on track to attain the corresponding goal in 2030.

Figure 5. Sustainable Development Report 2019. Sweden.

Finland is the third country in the ranking for fulfilling SDGs: SDG 4 Quality Education has been achieved, and the SDG 11 Sustainable Cities and Communities is in a better position than its Danish counterpart (Figure 6).

Figure 6. Sustainable Development Solutions Report 2019. Finland.

1.3. The Educational City: Towards a Sustainable Awareness

In any analysis of environmental education, it is necessary to refer to the Intergovernmental Conference on Environmental Education organized by UNESCO with the collaboration of PNUMA in

Tbilisi in 1977. This conference discussed new ideas on environmental education and its dimension. The final report of the paper states [9] that,

> *Environmental education is an integral part of the education system, should be problem-oriented and interdisciplinary. It should tend to establish a sense of values, contribute to collective well-being and concern for human well-being.*

Thus affirming that environmental education should form part of any educational system, and emphasizing the value placed on the collective well-being of humanity.

Subsequently, in 1980, UNESCO put into practice the main guidelines of the Tbilisi Conference, based on the 41 recommendations made in the conference, by establishing the purposes and pedagogical characteristics of environmental education.

However, the concept of sustainable development was not introduced until 1987, when the Brundtland Report, in Chapter 2 "Towards Sustainable Development", described it as development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs [10].

In recent decades, the commitment to environmental education in different countries has become evident from public investment, information, and educational programs, etc., although measures for sustainable change have not been developed in the same way in all European societies. It is undoubtedly in the field of education that we must put greater energy and establish the necessary means so that, from the earliest ages, children grow up with a real idea of sustainable consciousness. Certain authors [11], advocate proposals for the "environmentalization" of educational centers and curricular sustainability, which would involve introducing sustainable and environmental content and criteria into the curriculum. Others insist on the importance of environmental education research at an early age [12].

> *With the progressive development that environmental education research has been experiencing from the university world, a more solid argument and a more grounded response about its usefulness is offered to society, less based on intuition and sporadic speculation; and more based on the valorization of empirical arguments to justify and document claims, prove achievements, compare evolution and justify changes at different levels.*

From this perspective, it is true that many experts have participated in the Seminar on Education and Communication on Climate Change, which has been organized in Spain every year since 2004 with the aim of diagnosing the development in Spain of the Framework Convention on Climate Change, related to education, awareness, access to information, and participation on issues connected with climate change. Among other aspects, these training courses encourage to [11]:

> *Analyse the effectiveness of activities under the Climate Change Convention and examine the links between these activities, the implementation of policies and measures to mitigate change and Encourage the exchange of ideas and experiences and collaboration between people working on the promotion of renewable energy, energy saving, sustainable mobility and education.*

At a local level, in Spain, we could say that the ESD has been visible in our educational system since 1990, with the Law of General Organization of the Educational System (LOGSE), since when educational projects and programs have been executed, such as School Agenda 21 in many Spanish regions, Green Schools in Catalonia, Educational Centers towards sustainability in La Rioja, or Sustainable Schools in Navarra. These programs have been consolidated through networking, such as the ESenRED network and schools towards sustainability online, which began in 2012 and involve almost 55,000 teachers and more than 1,100,000 students [13]. However, we still have a long way to go. We need to make the school curriculum sustainable so that, through sustainable projects, we can inculcate high levels of awareness among our students [14]. Sauvé, L. analyses that environmental education cannot be isolated from the contemporary social dynamic, characterized by various social movements of indignation and the progressive emergence of a citizenry that is increasingly aware of the inseparable links between social and ecological realities, and that calls for a renewed democracy to promote the common good. It is therefore necessary to prepare a critical eco-citizenship; emphasizing not only the economic and environmental, but also the social character in order to achieve a quality environmental education; parameters similar to those used for eco-urbanism as a methodological instrument are similarly mentioned by Del Cerro, F. and Lozano, F. [15].

To do so, from the educational point of view, it is essential to adapt the content, skills, and values that correspond to the teacher's performance, the social aspects, and consider the impact of their professional activity on the environment and its protection with sustainability criteria. This requires the epistemological bases that support a model based on the solution of the contradiction established to be defined between the cognitive, professional skills, and modes of action [16].

Del Cerro, F. and Lozano, F. [15] analyzed how sustainable development at its origin, later consolidated by the SDGs, encompass environmental, social, and economic aspects. At the same time, these characteristics converge with the pedagogical principles included in the Organic Law for the improvement of Quality Education. They affirm that:

> *Education is a fundamental way to achieve sustainable development. Classrooms are spaces where teachers can promote and instill values and attitudinal changes that allow achieving the goals of the SDGs. Therefore, it is easy to understand that SDG 4, Quality Education is fundamental to achieve, expand and effectively implement the rest of the SDGs.*

The 2019 SDG Index and Dashboards Report for European Cities (prototype version) [17] looks at the scores obtained by 45 European cities. Figure 7 shows that the three cities with the highest overall score are Oslo, Stockholm, and Helsinki, with more than 70 points, while the Spanish cities of Madrid and Barcelona ranked 28th and 30th, respectively, with scores in the 55–60 range.

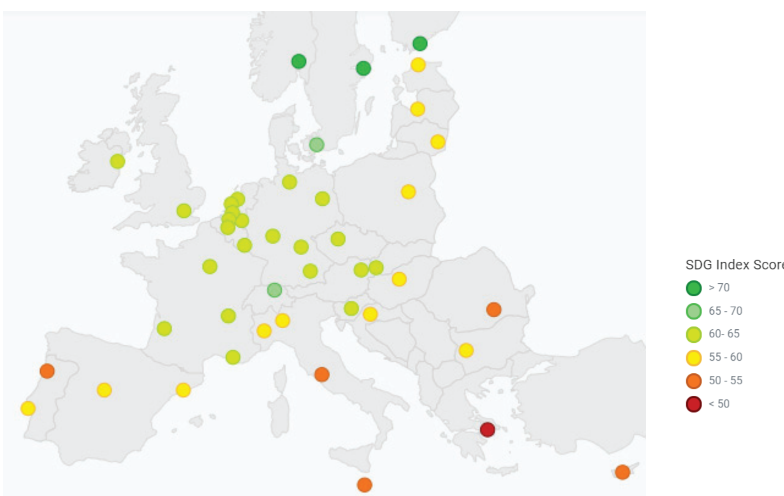


Figure 7. European Cities Sustainable Development Goals (SDGs) Index. Prototype Version (2019).

If we analyze the data from Oslo, the city occupying first place in the ranking, and compare the same with Madrid, we observe that, as shown in Table 1.

Table 1. European Cities SDG Index. Prototype Version (2019). Quality Education.

Oslo		Madrid	
Early leavers from education (18–24%)		Early leavers from education (18–24%)	
8.50	Yellow	13.90	Orange
Adults with higher secondary education (25–64%)		Adults with higher secondary education (25–64%)	
84.20	Yellow	72.90	Orange
NEET rate (15–24%)		NEET rate (15–24%)	
4.00	Green	10.40	Yellow
Satisfaction with schools (%)		Satisfaction with schools (%)	
80.00	Green	50.00	Red
Four-year-olds in early childhood education (%)		Four-year-olds in early childhood education (%)	
96.20	Green	98.10	Green
Adult participation in learning (%)		Adult participation in learning (%)	
22.50	Green	11.50	Orange
University appearances in rankings		University appearances in rankings	
4.00	Yellow	9.25	Green

Sustainable cities and communities	
(green)	SDG achieved
(yellow)	Challenges remain
(orange)	Significant challenges remain
(red)	Major challenges remain
d	Data missing

The most significant difference between all the indicators is the degree of satisfaction with the educational centers. In the case of Madrid, it is the only important challenge still to be faced (marked in red).

For UNESCO, education is fundamental, because it is a basic universal right and the foundation of peace and sustainable development. This United Nations agency maintains that education is fundamental to achieving the 17 SDGs included in the 2030 Agenda. Likewise, UNESCO has a follow-up plan, the Global Programme of Action on Education [18].

We live in a time where ESD is at its peak. It is sufficient to look around us and see how we live, what the model of our cities is, our habits, the conditions of the oceans, the quality of the air, the scarcity of water, etc. Only recently, in November 2018, did Madrid begin to restrict the access of certain vehicles to the city centre through Plan A for Air Quality and Climate Change; through this action, environmental and social objectives were pursued in relation with a reduction in NO_2 emissions, a decrease in the level of noise, and the freeing up of public space. As Xabier Querol indicated: "In Europe there are 280 cities with traffic restriction zones, in Spain one". In his interview [19] in the digital newspaper El Diario.es, the researcher states that the measure is correct, but insufficient; he comments that in Germany ("inventors of the truth"), there are 50 cities with areas that limit the entry and circulation of the most polluting cars [20]. One of the most significant challenges worldwide is improving air quality; exposure to high levels of air pollutants can cause irreparable damage in humans and even death. The World Health Organization has established that 91% of the world's population lives in places where air quality "exceeds established limits", and that 4.2 million deaths each year occur as a result of exposure to air pollution [21].

There is no doubt the overpopulation and the erroneous model of our cities and settlements can only worsen the current situation, although certain countries are taking measures to curb the levels of emission of NO_2 and O_3, among others [22].

> *The most developed societies have been applying, for years, emission reduction policies that have generated, for the majority of pollutants, a decrease in pollution levels. On the other hand, the world population continues to grow markedly and the global tendency to concentrate the population in large and dense cities ... All this has led to problems of urban air quality, not only because of an increase in the concentration of pollutants in many cases, but also because when moving to the city the population is more exposed to them.*

It seems that certain sectors of society do worry about the condition of our planet, among them, international organizations, associations, NGOs, and the National Government itself, which are implementing actions and intervention plans to promote Sustainable Education. From the website of the Ministry for ecological transition, citizens are informed about energy poverty (manifestation of poverty and social exclusion), the heating allowances, the ITAIWP (Illegal Trade and International Wildlife Poaching) Plan, etc. Similarly, the Government, in its National Strategy against Energy Poverty 2019–2024, established measures to prevent situations in which households cannot cover their basic energy supply needs [23].

This research highlights other actions aimed at promoting ESD through education, more specifically through project's methodology. Indeed, this should be the responsibility of governments, the private sector, civil society, and every human being on the planet. The acquisition of SDGs is a universal task that must be carried out at local level, taking into account the environmental context and the socioeconomic aspects of each place. Irina Bokova, Director-General of UNESCO, states: [24].

> *A fundamental change is needed in the way we think about the role of education in global development, because it has a catalytic effect on the well-being of individuals and the future of our planet ... Now more than ever, education has a responsibility to keep pace with the challenges and aspirations of the 21st century, and to promote the right kinds of values and skills that will lead to sustainable and inclusive growth and a peaceful life.*

From our position, we wonder, how we can enhance the training of our students to achieve a sustainable consciousness? STEM subjects can contribute to this, and, in the case that concerns us, Technical Drawing, must introduce practices relative to the projection of spaces of eco-urban coexistence, solving social, economic, and environmental problems. Today, there is an abyss between the reality of 21st century society, our technological and consumption-centered society, and the response of different educational systems, in which students are not educated on competent sustainability. Neither is this possible if teachers do not work from sustainable perspectives [25].

In 2017, UNESCO published the document Education for SDGs, Learning Objectives, which aimed boost ESD by offering a guide for teachers. Table 2 shows the list of specific learning objectives for SDGs and key competencies for sustainability.

This guide identifies specific learning objectives and suggests themes and activities for each SDG [26]. The document is designed to guide education professionals in the use of ESD in learning for SDGs and, consequently, for achieving them.

The technical project as a methodological tool has numerous benefits [27].

> *Several emerging pedagogies review the educator learner relationship and treat them, both, as partners in change or change agents. Moreover, they enable learners to experience authentic learning environment by working in inter and transdisciplinary teams to help communities overcome sustainability challenges with mutual benefits.*

Similarly, key competencies for sustainability are described, as well as specific Learning Objectives for SDGs that allow people to be called "sustainability-conscious citizens" [28].

Table 2. List of specific learning objectives for the SDGs and key competencies for sustainability.

Specific Learning Objectives for the SDGs	Key Competencies for Sustainability
The **cognitive domain** comprises knowledge and thinking skills necessary to better understand the SDG and the challenges in achieving it.	**Systems thinking competency**: The abilities to recognize and understand relationships; to analyze complex systems; to think of how systems are embedded within different domains and different scales; and to deal with uncertainty.
	Anticipatory competency: The abilities to understand and evaluate multiple futures—possible, probable, and desirable; to create one's own visions for the future; to apply the precautionary principle; to assess the consequences of actions; and to deal with risks and changes.
	Normative competency: The abilities to understand and reflect on the norms and values that underlie one's actions; and to negotiate sustainability values, principles, goals, and targets, in a context of conflicts of interests and trade-offs, uncertain knowledge, and contradictions.
The **socio-emotional domain** includes social skills that enable learners to collaborate, negotiate, and communicate to promote the SDGs as well as self-reflection skills, values, attitudes, and motivations that enable learners to develop themselves.	**Strategic competency**: The abilities to collectively develop and implement innovative actions that further sustainability at the local level and further afield.
	Collaboration competency: The abilities to learn from others; to understand and respect the needs, perspectives, and actions of others (empathy); to understand, relate to, and be sensitive to others (empathic leadership); to deal with conflicts in a group; and to facilitate collaborative and participatory problem solving.
	Critical thinking competency: The ability to question norms, practices, and opinions; to reflect on own one's values, perceptions, and actions; and to take a position in the sustainability discourse.
The **behavioral domain** describes action competencies.	**Self-awareness competency**: The ability to reflect on one's own role in the local community and (global) society; to continually evaluate and further motivate one's actions; and to deal with one's feelings and desires.
	Integrated problem-solving competency: The overarching ability to apply different problem-solving frameworks to complex sustainability problems and develop viable, inclusive, and equitable solution options that promote sustainable development, integrating the above-mentioned competences.

Awareness that there is an environmental problem, a product of the way in which the planet has evolved and grown, is widespread. The spectator observes the deterioration around them, develops a cognitive and emotional dimension, knows what the problem is, and, for instance, feels the need to act. Nevertheless, the destruction of the environment is a fact. What is happening? A mere concern for the environment is not enough to stop its tarnishing; a sustainable consciousness is necessary in order to reactivate the tangential behavior that we have shown in the face of the problem. We acquire an environmental commitment when we reach an environmental consciousness, a multidimensional concept, in which several dimensions can be identified [22].

Cognitive: Degree of information and knowledge about environmental issues. This refers to ideas.

Affective: Perception of the environment; beliefs and feelings on environmental matters. This refers to emotions.

Conative: Willingness to adopt pro-environmental criteria in behavior, expressing interest or predisposition to participate in activities and make improvements. We talk about attitudes.

Active: Carrying out environmentally responsible practices and behavior, both individual and collective, even in compromised or pressure situations. We are talking about behaviors.

Therefore, integral Environmental awareness (EA) establishes a connection between several psychological constructs (knowledge, information, norms, values, attitudes, beliefs, etc.) that trigger behaviors that make it possible to coexist with the environment, preserve it, and transform it according to one's own needs, without compromising the possibility of future generations to satisfy theirs [29].

This concept is mentioned, almost in the same way, in the Brutland report in 1987, in which part 1 is [10,30].

- Common concerns.
- Common tasks.
- Common efforts.

The current deteriorating environmental situation is of concern to a wide range of sectors, including psychologists. The cessation of the excessive exploitation of our natural environment requires a change in the way that people face it [31]. The New Environmental Paradigm (NEP) created by Dunlap and Van Liere in 1978 was born as an instrument to evaluate beliefs towards the environment. The scale consists of 12 items grouped in three dimensions, called: Limitations to the growth of society, the human capacity to alter the environmental balance, and the right of human being to govern or reign over nature. High scores in the NEP indicate an ecocentric orientation or commitment to the preservation of the environment, while low scores mean a predominance of anthropocentrism, that is, beliefs in favor of the exploitation of natural resources [32].

In 2000, Dunlap and collaborators included two new dimensions in the NEP scale, creating the New Ecological Paradigm (NEP), and increasing the number of items on the scale from 12 to 15. Of these, eight offer a vision in favor of ecology and seven of them against ecology, objectifying people's environmental beliefs and therefore measuring them better than their previous version [33].

The question arises: Is it possible to link the phases of an Eco-urban Project in the technical drawing classroom, with the objectives and key competencies of SDG 11, and to put a value on Education for Sustainable Development?

The ultimate purpose of this research is to observe whether working on an eco-urban technical project in the classroom, using the methodological approach proposed by UNESCO (2017), strengthens the Learning Objectives (cognitive, socio-emotional and behavioral) and key competences established by UNESCO for SDG 11, sustainable cities and communities, and thus put a value on Education for Sustainable Development.

After the qualitative research has been carried out, a questionnaire is completed to observe, for information purposes only, the level of sustainable awareness that the students have reached at the end of the project.

2. Materials and Methods

2.1. Method and Procedure: Project Phases, UNESCO Learning Objectives and Key Competencies

As first part of the methodological design of the research, we detail the four phases of the eco-urban technical project carried out by the students:

- Background and current status analysis.
- Social study and feasibility of the area of action.
- Knowing your city: Planning space for coexistence.
- Design of the coexistence space. A 3D model.

Once the learning objectives and key competences have been described within the theoretical framework (see Tables 3–6), we relate each of the phases to the corresponding objectives and competencies by providing photographs, designs, and sketches related to the different work phases.

Table 3. Phase 1 of the project: Background and analysis of current status.

Phase of the Project	Learning Objective	Key Competence
During the study phase, students carry out a critical analysis of the school's living spaces. To this end, they analyze the entire school complex, its facilities, and spaces in order to study the best area for action. The students study the historical and urban background of the school and analyze photographs taken as a result of the research. They work meticulously on the original construction, the materials used, and the possible construction techniques used at the time.	**Cognitive learning objective 1.2.11.1** The learner understands basic physical, social, and psychological human needs and is able to identify how these needs are currently addressed in their own physical urban, peri-urban, and rural settlements. **Cognitive learning objective 1.2.11.3** The learner understands the historical reasons for settlement patterns and, while respecting cultural heritage, understands the need to find compromises to develop an improved sustainable system.	**Systems thinking competency**: The abilities to recognize and understand relationships; to analyze complex systems; to think of how systems are embedded within different domains and different scales; and to deal with uncertainty. **Anticipatory competency**: The abilities to understand and evaluate multiple futures—possible, probable, and desirable; to create one's own visions for the future; to apply the precautionary principle; to assess the consequences of actions; and to deal with risks and changes.
		

Source: Own preparation: Photographs in the library and newspaper archives of the center, as well as current photos.

Table 4. Phase 2 of the project: Social study and feasibility of the area of action.

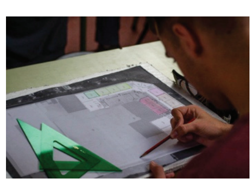
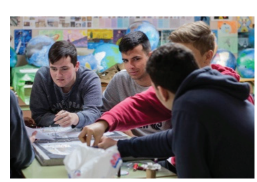
Phase of the Project	Learning Objective	Key Competence
Students conduct interviews with peers and the educational community to learn about their concerns and suggestions. By means of flow diagrams elaborated with models and colored threads, they analyze the spaces of the center more and less transited by their companions and evaluate future decisions of the project, taking into account the needs of the educational community, evaluating the possible impacts of their decision. Through brainstorming and sharing, they reflect on the best choice of sustainable opportunity space. They highlight the social component that is essential for ESD. They take into account and value aspects related to accessibility and mobility of the future space of coexistence.	**Socio-emotional learning objectives 1.2.11.2** The learner is able to connect with and help community groups locally and online in developing a sustainable future vision of their community. **Socio-emotional learning objectives 1.2.11.4** The learner is able to contextualize their needs within the needs of the greater surrounding ecosystems, both locally and globally, for more sustainable human settlements. **Socio-emotional learning objectives 1.2.11.5** The learner is able to feel responsible for the environmental and social impacts of their own individual lifestyle.	**Anticipatory competency**: The abilities to understand and evaluate multiple futures—possible, probable, and desirable; to create one's own visions for the future; to apply the precautionary principle; to assess the consequences of actions; and to deal with risks and changes. **Normative competency**: The abilities to understand and reflect on the norms and values that underlie one's actions; and to negotiate sustainability values, principles, goals, and targets, in a context of conflicts of interests and trade-offs, uncertain knowledge, and contradictions.
		

Table 5. Phase 3 of the project: Knowing Your City. Approach to the Design of the space of coexistence.

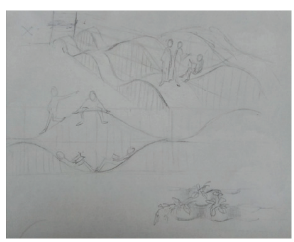
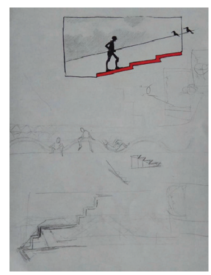
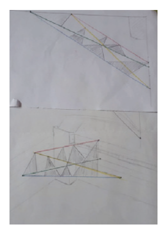
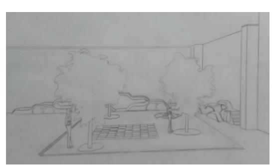
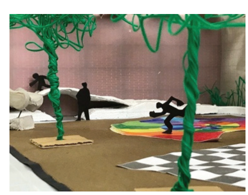
Phase of the Project	Learning Objective	Key Competence
Students discuss what to draw inspiration from to project their space of opportunity. Talking among themselves, they come to the conclusion that they are from Cartagena, a maritime city, and that their lives are linked to the marine environment. Ideas, sketches, and sketches of "future ergonomic steps" inspired by the waves of the sea are emerging. They stroll through the city and admire the marine architecture, typical of the city of Cartagena. In their visit to the city they analyze how Cartagena has developed in aspects related to green spaces, accessibility, transport; evaluate the decision making of the council, in this case the Mayor of the city, when investing money in the public work. The students thought of placing pergolas at the beginning to offer shaded areas, but finally they understood that eco-urbanism is important when designing, and decided to place steel cables and suspended from them photovoltaic fabrics to take advantage of sunlight. The steel cables would allow them to hang their work at exhibition points in the same way. The triangular shape of the photovoltaic fabrics were inspired to fit in with the marine environment by simulating the sails of ships.	**Socio-emotional learning objective 1.2.11.3** The learner is able to reflect on their region in the development of their own identity, understanding the roles that the natural, social, and technical environments have had in building their identity and culture. **Cognitive learning objective 1.2.11.2** The learner is able to evaluate and compare the sustainability of systems in their own and other settlements in meeting their needs, particularly in the areas of food, energy, transport, water, safety, waste treatment, inclusion and accessibility, education, integration of green spaces, and disaster risk reduction. **Cognitive learning objective 1.2.11.5** The learner understands the role of local decision-makers and participatory governance and the importance of representing a sustainable voice in planning and policy for their area. 	**Critical thinking competency**: The ability to question norms, practices, and opinions; to reflect on their own values, perceptions, and actions; and to take a position in the sustainability discourse. **Self-awareness competency**: The ability to reflect on one's own role in the local community and (global) society; to continually evaluate and further motivate their actions and to deal with their own feelings and desires.  

Table 6. Phase 4 of the project: Design of the living space. 3D model.

Phase of the Project	Learning Objective	Key Competence
The students, using specific techniques and constructive elements from the Technical Drawing area, design their space of opportunity: A rest and meeting area consisting of an ergonomic tier, trees and flowerbeds of vegetal soil, games area, and pergola to offer shade. The tier would allow them to hide, rest, foster social relations, and act as an ideal space for relaxed reading as well as for social gatherings. The green area would offer an ecological and pleasant environment. The design of the games is inspired by nature. They design a board game to be projected on the floor, recreating the shape of an ammonite. Around the recreational area, a drain is projected that will collect runoff water when it rains. The objective is to use the same water to irrigate the trees. All the materials used in the project are ecological. Once the design was finished, using advanced computing tools, our students made a 3D design that allows better visualization of the projected environment. To finish, they created a model in the classroom workshop that provided a physical view of the project. The students defended their project in the presence of a special panel of the University of Cartagena and were later awarded first prize in the 1st Architecture Olympiad of the Region of Murcia.	**Cognitive learning objectives 1.2.11.4** Students know the basic principles of sustainable planning and building, and can identify opportunities for making their own area more sustainable and inclusive. **Socio-emotional learning objectives 1.2.11.3** The learner is able to reflect on their region in the development of their own identity, understanding the roles that the natural, social, and technical environments have had in building their identity and culture. **Behavioral learning objective 1.2.11.1** The learner is able to plan, implement, and evaluate community-based sustainability projects. **Behavioral learning objective 1.2.11.2** The learner is able to participate in and influence decision processes about their community. **Behavioral learning objective 1.2.11.3.** The learner is able to speak and organize their views against/in favor of decisions made for their community. **Behavioral learning objective 1.2.11.4.** The learner is able to co-create an inclusive, safe, resilient, and sustainable community **Behavioral learning objective 1.2.11.5** The learner is able to promote low carbon policies at local level.	**Strategic competency**: Students develop their abilities to collectively implement innovative actions that further sustainability at local level and further afield. **Collaboration competency**: The students develop the ability to learn from others; to understand and respect the needs, perspectives, and actions of others (empathy); to understand, relate to, and be sensitive towards others (empathic leadership); to deal with conflicts in a group; and to facilitate collaborative and participatory problem solving. **Integrated problem-solving competency**: Developing the ability to apply different problem-solving frameworks to complex sustainability problems and develop viable, inclusive, and equitable solutions or options that promote sustainable development, integration of the above-mentioned competencies.





Our students participated in the First Olympiad of Architecture in the Region of Murcia and, with the project detailed above, obtained first prize.

2.2. Triangulation Instrument (NEP Scale) to Measure the Level of Sustainable Awareness of Participants

The instrument used to measure sustainable consciousness was the so-called revised NEP Scale. Due to its simplicity of application, this instrument has been widely used by many authors worldwide; the scale is considered appropriate in research into pro-environmental awareness [34].

The authors consider that the revised scale better encompasses the various facets of an ecological worldview; balances the number of pro- and anti-NEP items; and updates the terminology of the first version. "This scale assesses attitudes, beliefs, values and worldviews regarding the environment. Previous studies have found different underlying factorial structures, while evidence of internal consistency is acceptable" [35].

This is a 15-item Likert questionnaire that deals with 5 facets of the relationship between humans and the environment [36].

The existence of limits to the growth of human societies -items 1, 6 and 11-; the right of humanity to use nature to its advantage or anti-anthropocentrism -items 2, 7 and 12-; the fragility of the natural balance -items 3, 8, 13-; rejection of human exceptionalism -items 4, 9 and 14-; and the possibility of ecological crises -items 5, 10 and 15-.

The eight odd items are written in such a way that adherence to them indicates a pro-environmental or ecocentric point of view, while the seven items are written so that adherence to them indicates an anthropocentric attitude.

Students fill in the questionnaire, assigning values from 1 to 5:

1 = Strongly Disagree. 2 = Disagree. 3 = Doesn't matter. 4 = OK. 5 = Totally agree

We therefore have 15 categorical variables whose measurement scale in SPSS will be ordinal. After the students answer the questionnaire, we obtain 15 items, each evaluated from 1 to 5 points each.

As can be observed in Tables 7 and 8, in order to measure the level of sustainable consciousness, two new variables are generated. The first, "ecocentric grouped" variable that makes up the 8 ecocentric items, and a second "anthropocentric grouped" variable formed by the 7 anthropocentric items, thus establishing two new evaluation scales:

Table 7. Clustered Ecocentric Variable.

Clustered Ecocentric Variable	
Points	**Level of Awareness**
0–8	Very low
9–16	Low
17–24	Medium
25–32	High
33–40	Very High

Table 8. Variable: Anthropocentric grouped.

Variable: Anthropocentric Grouped	
Points	**Level of Awareness**
0–7	Very low
8–14	Low
15–21	Medium
22–28	High
29–35	Very High

For the first variable, 8 items and 5 values imply a maximum of 40 points. Table 9 shows the Revised NEP Statements.

Table 9. Revised NEP (New Environmental Paradigm) Statements.

Revised NEP Statements
1. We are approaching the limit of the number of people the Earth can support.
2. Humans have the right to modify the natural environment to suit their needs.
3. When humans interfere with nature, it often produces disastrous consequences.
4. Human ingenuity will ensure that we do not make the Earth uninhabitable.
5. Humans are seriously abusing the environment.
6. The Earth has plenty of natural resources if we just learn how to develop them.
7. Plants and animals have as much right as humans to exist.
8. The balance of nature is strong enough to cope with the impacts of modern industrial nations.
9. Despite our special abilities, humans are still subject to the laws of nature.
10. The so-called "ecological crisis" facing humankind has been greatly exaggerated.
11. The Earth is like a spaceship with very limited room and resources.
12. Humans were meant to rule over the rest of nature.
13. The balance of nature is very delicate and easily upset.
14. Humans will eventually learn enough about how nature works to be able to control it.
15. If things continue on their present course, we will soon experience a major ecological catastrophe

For the second variable, 7 items and 5 values imply a maximum of 35 points.

3. Results

Table 10 shows the results obtained after applying the methodological approach recommended by UNESCO. Learning objectives and key competencies acquired in each of the four phases of the project.

Table 10. Learning objectives and key competency achieved according to UNESCO (2017).

Phase of the Project	Learning Objective	Key Competency
1—Background and analysis of current status.	Cognitive	Systems thinking, Anticipatory competency
2—Social study and feasibility of the area of action.	Socio-emotional	Anticipatory competency, Normative competency
3—Approach to the design of the space of coexistence.	Socio-emotional, Cognitive,	Critical thinking, Self-awareness
4—Design of the living space. 3D model.	Cognitive, Socio-emotional, Behavioral	Strategic, Collaboration, Joint problem-solving

Tables 11 and 12 show the results of the NEP questionnaire. The environmental awareness levels of the students are high: 77.8% have a high level of ecocentric awareness, and 22.2% a very high level. Similarly, 77.8% of them have an average anthropocentric level, and 22.2% have a low anthropocentric level.

Table 11. Ecocentrist (grouped).

		Frequency	Percentage	Percentage (Valid)	Percentage (Cumulative)
Valid	High	7	77.8	77.8	77.8
	Very High	2	22.2	22.2	100.0
	Total	9	100.0	100.0	

Table 12. Anthropocentric (grouped).

		Frequency	Percentage	Percentage (Valid)	Percentage (Cumulative)
Valid	Low	2	22.2	22.2	22.2
	Medium	7	77.8	77.8	100.0
	Total	9	100.0	100.0	

4. Discussion

Following the announcement in 2015 of the Sustainable Development Goals and 2030 Agenda, national and local governments have begun to follow the guidelines in order to achieve these goals by the 2030 horizon.

Since the start of the journey made in 2016, the Network of Solutions for Sustainable Development, in collaboration with the UN, carried out assessments for different countries, indicating the state of achievement of the SDGs by 2030 horizon. As far as our country is concerned, Spain will not achieve any SDGs by the established date, with several SDGs far from being reached, as is the case of SDG 11 "Sustainable Cities and Communities".

This article proposes a methodological route that, supported by the indications of UNESCO, can serve as a classroom guide to work the SDGs in a transversal way, in the case described SDG 11. The aim is also reinforce Education for Sustainable Development and finally to strengthen the level of sustainable awareness in students. The project presented relate each of its phases to Learning Objectives and Key Competences for SDG 11 "Sustainable Cities and Communities" by means of the methodological approach proposed by UNESCO (2017). The methodology used has focused on students of STEM subjects, in this case technical drawing, is action-oriented and transformative since students, as described in the phases of their eco-urban project, were able to establish sustainable solutions for their environment, in a socio-cultural and historical context, valuing the cognitive, socio-emotional, and behavioral learning objectives for ESD. In the same way, all the objectives are related to the key competencies for sustainability that generally regarded as crucial for attaining sustainable development [25].

We agree with the Action Plan for the implementation of the Spanish Government's 2030 Agenda, as we consider it important that ESD is implemented in educational curricula.

We agree with UNESCO that the type of project presented in this article is a "key learning method for SDGs" [25]. In addition, the project that we present coincides with one of the "Examples of learning approaches and methods for SDG 11 "Sustainable Cities and Communities", Table 1.2.11b" (UNESCO 2017). We agree with Ugarte, A. on the need to communicate SDGs in context, and that they should be adapted socially and culturally [37].

The results obtained are interesting, as they show high levels of sustainable awareness of the importance of the environmental, social, and economic dimensions that underline the principle of sustainability [38,39]. The findings have encouraged us to continue working with the NEP in the classroom. Another point worth highlighting is that students have been trained in the environmental competencies and skills reviewed by other authors like Cabero, J.; and Llorente, M. [40]. We agree with Wals (2015) that, by working on these dimensions, we train "sustainable citizens" because this project has allowed us to evaluate Education for Sustainable Development and to work with our students, not only on a given topic, but also on the learning approaches and methods suggested by UNESCO.

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Article

Getting Involved with Vaccination. Swiss Student Teachers' Reactions to a Public Vaccination Debate

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Abstract: Vaccination is an explicit topic of the United Nations' 2030 Agenda for Sustainable Development. The present article explores a new way of involving student teachers into the vaccination debate. To this aim, 273 students at a Swiss university for teacher education were invited to read a debate between a vaccination proponent and a vaccination opponent that had been published in a free local newspaper. Then, they were asked to judge five of the main arguments of each discussant and to take a (hypothetical) general decision in favor or against vaccination. This decision, the judgements, and students' comments were investigated with a mixed method approach in order to better understand the students' needs and to refine the new approach. It was found that the students eagerly took part in the intervention, but that they were very ambivalent concerning the arguments. They could be classified into three groups. Two groups, called the acceptors and the rejectors, supported the proponent and the opponent, respectively, and decided accordingly in favor or against vaccination. However, there remained a considerably large group that was called the hesitators. They were particularly ambivalent towards both types of argumentation, but, as structural equation modelling revealed, they eventually were more influenced by the arguments in favor than by those against vaccination. In their comments, these students wanted to know more about the prevented diseases, and they often referred to their personal experience but not to the experts' arguments. It was concluded that this group would benefit most from the new type of intervention. A shared-decision approach, as is today prominently discussed in medicine, could improve its impact, and ways should be found to more seriously and consistently include empathetic understanding in pedagogical settings—for example, by adapting the three-step model from medicine or the reflective equilibrium approach from applied ethics.

Keywords: vaccination; vaccination hesitancy; decision making; teacher education; education

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1. Introduction

Vaccines are a suggested topic of the education for sustainable development goals, as they are included in the educational part of the 2030 Agenda for Sustainable Development, which was adopted by all United Nations member states in 2015. Schools could be important places for improving vaccination acceptancy in society. Dubé et al. point out that "ensuring education and knowledge about vaccines in younger individuals (children, adolescents, young adults), possibly through school-based programs, may provide a good opportunity to encourage future vaccine acceptance by parents and adults and minimize the potential for development of hesitancy" [1]. These authors indicate that more research is needed to evaluate such a strategy.

The present research has been conducted in the context of a Swiss teacher education university. In this institution, one week per year is reserved for health issues in schools. In this special week (called "Impulswoche," a week for new impulses), all future teachers for primary and lower secondary levels learn about a variety of health issues in school, such as the management of chronic diseases in school, first-aid issues, common health problems in daily school life, and issues of prevention and health promotion in school.

The basic idea of this study was to test an intervention about vaccination during this special week. To achieve this, a vaccination debate published in a free local newspaper was presented to the students. Choosing a population of future teachers met Dubé et al.'s request for more strategy evaluation in two ways. First, many of these student teachers will indeed be parents themselves in a few years. Second, once on the job, they will teach children and adolescents about health issues. Therefore, it is important to understand how they react to vaccination information in the media. This may allow teacher training to be tailored to their needs.

2. Theoretical Background

Vaccine hesitancy is the dynamic and challenging period of indecision around accepting a vaccination. This hesitancy captures the concerns about the decision to vaccinate oneself or one's children [2]. As the World Health Organization points out, the concept is complex and context-specific varying across time, place, and vaccines, including factors such as complacency, convenience, and confidence. The spectrum of hesitancy is wide and varying, going from "accepters," who do not question vaccination at all, to "hesitaters," who are unsure in their decision, to finally the "rejecters," who outrightly reject vaccination [1].

Today, according to many public health experts, vaccination hesitancy is increasing among parents [3]. A number of surveys over the past two decades have concluded that, although parents generally consider immunization to be important, a majority of them reported vaccine concerns [4]. There is a broad range of factors contributing to these concerns. For example, parents are uncomfortable about mandatory vaccination, they feel unable to control potential adverse reactions, they prefer "natural" risks to "manmade" risks, and they have little to no experience of diseases prevented by vaccines, such as polio, measles, and diphtheria [4].

However, contrary to some experts' explanations, parents' decision against vaccination is not simply thoughtless, irrational, or the result of a lack of knowledge about vaccines. Detailed studies have shown that vaccine-refusing parents are well-informed individuals with considerable interest in health-related issues and who actively seek information [5].

Many other communication tools that help healthcare providers to discuss vaccination with vaccine-hesitant parents have been published, but they have seldom been evaluated [1]. In fact, there is still a significant lack of solid empirical information on effective strategies to address vaccine hesitancy [4]. In light of this, the SAGE Working Group on Vaccine Hesitancy emphasizes the importance of understanding the specific concerns of the various groups of vaccine-hesitant individuals [1]. In particular, studies are needed that test the effectiveness of delivering information to parents through different media in order to better inform public health awareness initiatives [3].

Many motives for non-compliance have to do with deliberate avoidance. Extensive research literature has suggested that reasons for opposing vaccination in general include concerns about vaccine safety and efficacy, as well as a distrust of the conventional medical establishment and government as health information sources [6,7]. People also avoid vaccination against diseases that they perceive as not serious or eradicated in their areas.

A good example is the case of Human Papilloma Virus (HPV) vaccination. Here, individuals often express concerns about HPV vaccine being too new to have accumulated sufficient long-term safety data. Parents are also concerned about the perceived connection between HPV vaccination and early sexual activity [8]. As a result, many parents of children and adolescents are reluctant to vaccinate their children. For example, in the US, according to the Center for Disease Control, only 43% of adolescents are up-to-date on their HPV vaccination [9]. In Switzerland, the estimated HPV immunization rate is 57%, following the vaccination campaign of 2008/09, which is still unsatisfactorily low [10].

Public health brochures and websites typically discuss vaccination via factual statements about its safety, effectiveness, and benefits, and they provide practical vaccination information (e.g., places to get vaccination). Usually, these documents do not introduce biological concepts that may be essential to addressing safety information needs and dismantling misunderstandings around vaccination.

In a qualitative study, Zeyer and Sidler investigated the impact of reading a standard HPV vaccination information flyer on the participants' attitudes towards HPV vaccination. They found that reading the flyer had no impact on the students' interest in receiving the vaccine, with pre-test misconceptions not affected by the flyer [11]. This raises questions about the sufficiency of factual information for belief changes and asks for different approaches to vaccination education.

Another place where individuals may encounter information about vaccinations is the school system [12]. However, the science education systems of most countries do not include the coverage of microbiology and immunology that would constitute conceptual basis for understanding vaccination [13]. Studies have suggested that European and US students at all grade levels have a limited understanding of viruses, contagion, vaccination, and vaccine-preventable diseases. For example, in a study with a sample of 11-year-olds in the UK, Byrne and Grace found that while most participants knew that microorganisms could cause diseases, their understanding of vaccination-induced prevention was very limited [14]. Many thought that vaccines attacked and killed pathogens, thus essentially viewing vaccines as medicine. While these students were young, other studies suggest that misinformation about microorganisms, infection and vaccination persist into later school years [15]. Focusing on knowledge about influenza, Romine, Barrow, and Folk discovered that Midwestern US high school students (grades 9–12) hold a number of misconceptions about vaccine and vaccination, including the belief that a vaccine acts as medicine [16].

In this context, it is be essential to know the attitude of teachers towards vaccination and the role of education in this context. Unfortunately, these questions seem to have been widely neglected in research thus far, e.g., [12]. In a small qualitative study, Zeyer and Di Rocco investigated problems with HPV vaccination in a Swiss lower secondary school. Interviews with students, teachers and parents revealed, that—besides the well-known reluctance of parents, particularly mothers—about half of the interviewed teachers questioned this vaccination and, generally, their role in the vaccination issue. The authors concluded that involving student teachers with vaccination issues would be an important and rewarding task in the education for sustainability [17].

3. Research Context, Research Question and Hypothesis

This study made use of an article in a free local paper, distributed to more than a million Swiss households. This free paper, provided by a Swiss supermarket chain, is very popular in Switzerland, and it is read and shared within families, particularly among parents and grandparents. Besides containing advertisements and marketing information, it also includes highly appreciated articles about issues of daily life and health.

The article used in this study included a debate on vaccines between the pro and the contra vaccination community in Switzerland [18]. The pro vaccination exponent was a professor for pediatric infectious diseases at Basel University Hospital. The contra vaccination exponent was a Swiss general practitioner, well known in Switzerland for his pointed rejection of vaccines and for attracting a great number of vaccination rejecters around him. In the article, both exponents presented their viewpoints by answering an interviewer's questions, and they also were given the opportunity to directly contest their opponent's statements. The article included a biographical sketch of each person but refrains from making an editorial comment.

The approach taken in this study was to give the article to the student teachers and to let them read it. Then, the students had to judge five core statements of each expert and to answer the question of how they would decide if they were parents and had to vaccinate their child.

The research question with this procedure was:

(RQ1) How and to what extent do the judgements relate to each student's vaccination decision?

It was hypothesized that the pro and the contra arguments would have an approximately equal but inverse influence, i.e., that agreement with the pro vaccination argumentation would entail a positive vaccination decision and vice versa. Structural equation modelling provided an appropriate method for testing this hypothesis.

At the end of this procedure, the students had the opportunity to make comments about their vaccination decision.

The research question in this context was the following:

(RQ2) Can students' comments be qualitatively classified into groups of different attitudes, and how do these groups relate to the students' vaccination decision?

4. Method

4.1. Questionnaire

Five core statements of both standpoints were identified by carefully reading the article and discussing it with students of another group in another university. Each statement had to be judged on a scale between −3 (full dissent) and +3 (full consent). In this way, a questionnaire with 10 items was created, with 5 items representing the construct pro vaccination and 5 questions representing the construct contra vaccination. In a pre-test with 35 students, a classical factor analysis was done. Both constructs showed a high face validity and a good statistical reliability [19].

The items of the questionnaire are displayed in Tables 1 and 2 below. The questionnaire included an additional item (No. 11). In this item, students were asked to imagine that they were parents and how they would "generally" decide about their child's vaccinations: "In general, would you rather accept or reject vaccination for your child?" The students had to choose between "rather accept" (1) and "rather reject" (0).

Table 1. Items of the "pro vaccination" construct, showing means and standard deviation (SD).

Number	Item	Mean	SD
Item p1	After two doses of the vaccine, the body's immunity is equal to that after the illness.	0.39	1.767
Item p2	By vaccination, the illness, and thus severe complications and long-term consequences, are prevented.	1.28	1.447
Item p3	Vaccination does not trigger epilepsy. This has been shown in many studies.	0.36	1.524
Item p4	Complications of vaccination can be severe, and therefore vaccination is needed.	1.27	1.524
Item p5	Vaccination complications are much less probable than those of the illness itself.	1.26	1.505

Table 2. Items of the "contra vaccination" construct, showing means and standard deviation (SD).

Number	Item	Mean	SD
Item c1	Having the illness results in a better immunity than being vaccinated.	1.31	1.574
Item c2	Having the illness strengthens children's immunity and fosters their development.	0.56	1.685
Item c3	In practice, you often experience that vaccination triggers epilepsy.	−1.22	1.338
Item c4	If you strengthen your body, for example by homeopathy, then it can withstand the germs and you do not need vaccination.	−0.32	1.762
Item c5	There are no studies demonstrating the safety of vaccination.	0.69	1.657

4.2. Sample and Procedure

Data were collected during two "special weeks" of two consecutive years at a Swiss university of teacher education (see introduction). The definitive sample comprised 272 student teachers (see descriptive measures below).

Permission for participation and ethical approval was given by the authority of the Lucerne University of Teacher Education (Prorektorat Forschung Pädagogische Hochschule Luzern), which, in Switzerland, is the institutional board responsible for approving minimal-risk research, conducted with adult participants in an established educational setting. Before data collection, all students were informed about their right not to participate. All participants were adults over 18 years of age. No personally identifiable information was collected in the survey. There was no key connecting the answers to students. The students read the vaccination debate in the article. The questionnaire was distributed. At the end of the session, the volunteers were invited to contribute their completed questionnaire for the present study. A proctor, not connected to the course, collected contributed materials. Students not willing to contribute their materials retained them.

According to the Swiss Coordination Office for Research on Human beings (Kofam), this research project did not come under the scope of application of the Human Research Act, because the health-related data were collected anonymously [20].

4.3. Statistical Analysis

A classical statistical analysis was done by means of IBM SPSS (Version 25) [21]. For structural equation modelling (SEM), IBM SPSS AMOS 21.0 and the maximum-likelihood estimation approach were used [22].

4.4. The Structural Model

Structural equation modelling (SEM) is a statistical method that takes a confirmatory approach to a structural theory underlying some phenomenon. Hypothesized causal relations between involved factors are modelled by structural graphs and statistically tested in a simultaneous analysis of the entire system of variables. Its particular strength is the testing of theoretical constructs which are represented by latent variables [23]. The modeling estimates impact factors of causal influences and calculates covariances between variables. Because this study was particularly interested in the impact of experts' arguments (condensed in two latent variables) on students' decision making, SEM, a widely used method in social sciences, was considered to be appropriate [24].

The tested structural model reflected the research hypothesis. Thus, the two endogenous variables, representing the pro vaccination construct (5 items) and the contra vaccination construct (5 items) were designed to model a symmetric causal impact on the variable vaccination decision (exogenous discrete variable). In other words, it was expected that the impact of the variable contra vaccination on the variable vaccination decision would be negative and the impact of pro vaccination on vaccination decision would be positive. Furthermore, SEM assumes as a standard—that the two variables pro vaccination and contra vaccination covary. The covariance was expected to be negative because the model represents a controversy between two experts of opposing opinion (see Figure 1).

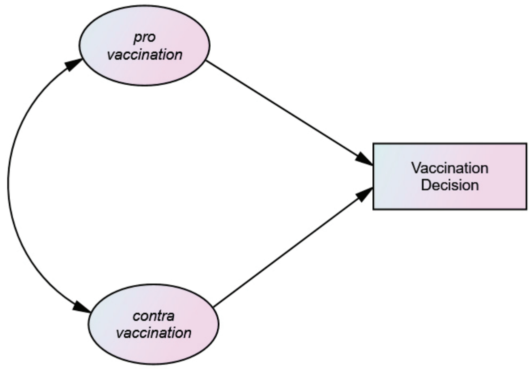

Figure 1. Basic structure of the structural model.

A two-step process was established to test the model [23]. As a first step, the pro vaccination and contra variation measurement models were tested through a confirmatory factor analysis. The five items of each of these variables were then combined, not in a Likert scale, but rather with weighted factors that the program calculated. This allowed for a better fit of the full model. In a second step, the two measurement models and the decision variable were combined into the full model for the vaccination decision.

5. Results

Generally, it can be stated that the intervention was implemented without problems. The students were interested and focused. Though their participation in the study was explicitly declared as voluntary, the majority of the students filled in the questionnaire and completed the survey with a short comment.

5.1. Descriptive Measures

The data were collected from a total of 273 students. Data were excluded if a student had not answered every question or if answers could not definitively be identified. After this raw data cleaning, the sample included 255 students (18 omitted cases, 6.59%), 170 females (66.6%) and 85 males (33.3%). The mean age was M_{age} = 23.2 years (SD = 3.26).

5.1.1. Statistics of the Pro and Contra Vaccination Statements and of the Vaccination Decision

Tables 1 and 2 display the pro vaccination and the contra vaccination statements, their means, and their standard deviations.

The Cronbach's alpha for the five pro vaccination statements was 0.797, and it was 0.682 for the five contra vaccination statements, i.e., both scales were of acceptable internal reliability. The mean of the pro vaccination statements was 0.92 (SD 1.16), i.e., these statements were, on average, judged as slightly positive by the students. The mean of the contra vaccination statements was 0.22 (SD 1.06), i.e., the average judgment of these items was almost neutral.

The average student mean for the pro vaccination arguments was 0.0922 (SD 1.16), i.e., the students, on average, agreed slightly with the pro vaccination arguments. The average student mean for the contra vaccination arguments was smaller (0.023, SD 1.06), but the students, on average, also slightly agreed with the contra vaccination arguments. All in all, the students were, on average, almost neutral towards both groups of arguments, with a small advantage for the pro argumentation.

Two hundred and eight students answered that they would, in principle, vaccinate their child (76.6%). Forty-six students answered that they would decide against vaccination of their child (16.8%). Eighteen students (6.6%) did not answer this question.

5.1.2. Qualitative Content Analysis of Students' Open Answers

The qualitative content analysis of the open question yielded four different student groups of different sizes. In the following, each of these groups is shortly described.

The rejectors group (15 students, 5.6%) reproduced arguments provided by the contra vaccination expert. Examples include:

To me, it is important that a child would go through the real disease. That makes them more immune than vaccination would do (stud8#38).

I believe that one should vaccinate as little as possible. The body does it itself. It gets then stronger (stud8#59).

There are no studies that investigate which other diseases can be triggered by vaccination (immunodeficiency, allergies, children's diseases, etc.) (stud8#116).

In their open answer, the acceptors group reproduced arguments provided by the pro vaccination expert. This group contained of 68 students (26.7% of the sample). Examples of argumentation include:

Complications of the original disease are too dangerous. Children should be protected (stud 8#14).

Additional security. Vaccination complications are smaller, less probable (stud8#33)

I'd never expose my child to the risk of long-term effects, if I can prevent these (stud8#79).

We call the third group the evaluators. This group included 49 students (19.2%) and conveyed that they would not want to decide "in principle" but their decision would be dependent on the (perceived) severity of the illness. Many of them referred to concrete diseases that they perceived as severe and others they perceived as harmless and did not see a need to vaccinate against them. Here are some examples:

I'd vaccinate against measles by all means. For all other diseases I'd apply only the minimum (stud10#93).

I'd vaccinate against hepatitis, etc. Against the measles, [I'd vaccinate] only when the child is getting older (stud10#58).

Vaccination against children's diseases only in adulthood, if the child has not already gone through it. Yes for vaccination against polio (stud10#008).

Finally, the last group referred to personal experience for motivating their decisions (Label "experiencers," 35 students, 13.7%). Examples are:

I've been vaccinated myself—and I never experienced complications (stud10#60).

I've never got into the issue deeply, but I've been vaccinated myself and it did no harm to me (stud8#149).

I've never been vaccinated and it did no harm to me (stud9#131).

92 (36.1%) students did not provide a statement that could be coded (Label "not coded"), either because they didn't write an answer or because the answer was not readable.

Tables 3 and 4 bring the four essential groups into relation to the statistical results. Table 3 provides the numbers and the percentage of pro vaccination and contra vaccination decisions for each group. The percentage was calculated "within group." That is, within the group of rejectors (15 students), fourteen students, i.e., 93.3% of them, answered that, in general, they would not vaccinate their child. One student, i.e., 6.7%, answered that, in general, they would vaccinate their child.

Table 3. Numbers and the percentage of pro vaccination and contra vaccination decisions for each group.

Group Label		*Contra Vaccination*	*Pro Vaccination*	Total
Rejectors	Number	14	1	15
	% within group	93.3%	6.7%	100.0%
Acceptors	Number	2	66	68
	% within group	2.9%	97.1%	100.0%
Evaluators	Number	13	29	42
	% within group	31.0%	69.0%	100.0%
Experiencers	Number	5	30	35
	% within group	14.3%	85.7%	100.0%
Not coded	Number	12	83	92
	% within group	12.2%	87.8%	100.0%
Total	Number	46	209	255
	% within group	18.0%	82.0%	100.0%

Table 4. Mean averages for pro vaccination and contra vaccination arguments per group (z-values).

Group		*Pro Vaccination*	*Contra Vaccination*
Not coded	Mean Average (z-value)	0.082	−0.022
Rejectors	Mean Average (z-value)	−1.48	1.40
Acceptors	Mean Average (z-value)	0.60	−0.55
Evaluators	Mean Average (z-value)	−0.63	0.47
Experiencers	Mean Average (z-value)	0.21	−0.18

Table 4 displays how every group, on average, judged the core statements of the pro vaccination and the contra vaccination expert. In this table, we used the z-value, which shows how much each group, on average, deviated from the mean, as indicated in standard deviations. For example, if the z-value is −1, this shows, that the judgement of the respective group was one standard deviation more negative than the average judgement of all students. The same holds for the third column, which shows the z-values of the contra vaccination statements for each group.

Tables 3 and 4 show that the situation with the rejecters was the most salient. They would generally decide against vaccination for their child (93.3%), and they were much more in favor of the contra vaccination argumentation (z-value 1.4) and against the pro vaccination argumentation (z-value −1.5) than the average student. Conversely, almost all of the acceptors (97.1%) generally decided in favor of vaccination. They were, on average, more in line with the pro vaccination argumentation than the average student and agreed less with the contra vaccination argumentation (z-value −0.55). Much more inconsistently appeared the constellation of the evaluators. They disagreed more than the average student with the pro vaccination arguments (z-value −0.63), but they agreed more with the contra vaccination arguments (z-value +0.47) than the average student. Nevertheless, they tended to decide for generally vaccinating their child (69%). Finally, very much in line with the average student, and thus very ambivalent, were the experiencers. They tended slightly more towards the pro vaccination arguments (z value +0.22), and slightly less towards the contra vaccination arguments (−0.18). Nevertheless, the clear majority of them (85,7%) opted, generally, in favor of vaccinating their child.

Table 5, finally, compares the distribution of the four groups in the general sample with the situation among those student teachers who had chosen science as one of their educational subjects. There were, in percentage terms, less acceptors within the science students (13.6%) than within the non-science students (26.8%), and less rejectors (2.3% vs. 6.1%). Among science students were more evaluators (27.3%) than among non-science students (16.2%). As to the experiencers, their percentage was approximately the same for both subgroups (13.6% vs. 12.7%).

Table 5. Group percentages. Comparison between non-science students and science students.

Group		Non-Science Students	Science Students
Not coded	Number % within subject	75 35.1%	17 43.2%
Rejectors	Number % within subject	14 6.1%	1 2.3%
Acceptors	Number % within subject	61 26.8%	6 13.6%
Evaluators	Number % within subject	37 16.2%	12 27.3%
Experiencers	Number % within subject	29 12.7%	6 13.6%

5.2. The Structural Model

Structural modelling can add more insights to these findings, because it combines calculated impacts between different variables in one model. The full structural model for vaccination decisions is displayed in Figure 2. This figure includes all standardized regression weights.

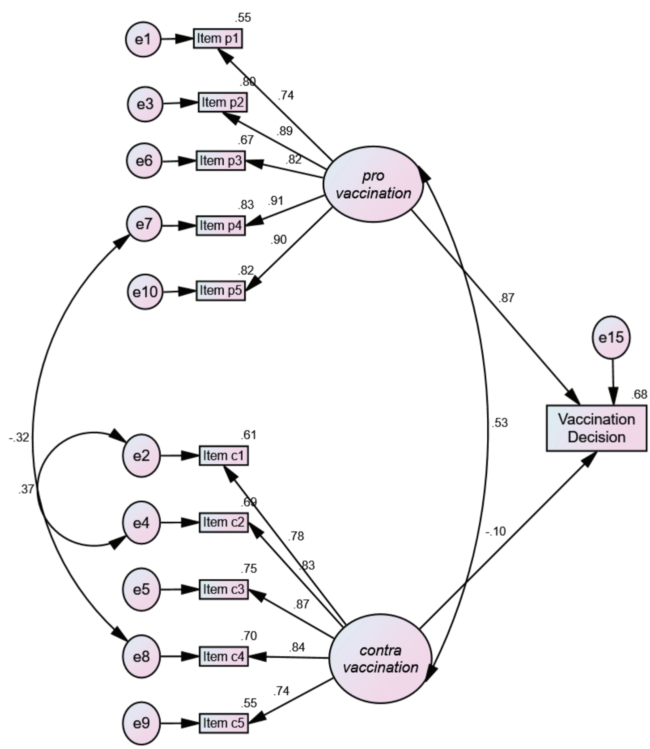

Figure 2. Structural model for vaccination decisions.

As a first step, the fit of the model was investigated. The model was well-fitting and produced highly significant results. In technical terms, this means:

All factor loadings of the measurement model were statistically highly significant ($p < 0.001$), except the factor loading of contra vaccination on vaccination decision. The corresponding signs concurred with the hypotheses. The standardized estimates confirmed the formal validity of the individual items [23].

Descriptively, the model worked well, which was first indicated by a highly acceptable goodness-of-fit index (GFI) of 0.95 (>0.9 for good fit; for fit measures, see [25] p. 551ff). Second, the baseline comparison, the comparative fit index (CFI), was excellent (CFI = 0.989 (>0.9)).

From an inferential point of view, the model was compatible with the data (CMIN/DF = 1.496, $p = 0.023$). Finally, RMSEA = 0.048 (<0.05) and PCLOSE = 0.517 (>0.5) also indicated a good fit.

As a next step, the relations between the variables were evaluated. It was found that, in accordance with the hypothesis, the explanatory power of the variable pro vaccination was very high. Indeed, its standardized regression weight on the variable vaccination decision was very high and highly significant (.874, $p < 0.001$). This means that the variable pro vaccination explained more than half of the variance of the variable vaccination decision (64%).

However, in contrast to the hypothesis, there was only a low and not significant impact of the variable contra vaccination on the variable vaccination decision (−0.101, $p = 0.06$), i.e., this variable had no statistical impact on the decision.

Furthermore, and also different from the hypothesis, the covariance between the two variables pro vaccination and contra vaccination was positive (0.53, $p < 0.001$). This suggests that most people who agreed with the pro vaccination also did with the contra vaccination and vice versa.

In addition, during the confirmatory process, two error correlations were added in order to improve the model fit. Both may have a straight forward interpretations. The negative covariance between the errors of items 7 and item 8 takes into account that these two statements are directly opposed, while the positive covariance between item 2 and item 4 reflects that these two statements are related in content.

6. Discussion

This study aimed to model the vaccination decision of student teachers after reading a debate between a person who supports vaccination and one who opposes it. The tested structural model reflects the hypothesis that agreeing with the arguments of the pro vaccination proponent would have a direct positive impact on the (hypothetical) decision of student teachers to vaccinate their own child. Conversely, it was assumed that the belief in arguments of the contra vaccination proponent would have a negative impact on that decision.

The model strongly confirmed the first part of the hypothesis. The pro vaccination variable explains 48% of the variation of the variable vaccination decision. The second part of the hypothesis, however, was not confirmed. In fact, there was no effect at all of the contra vaccination variable on the decision. This result was unexpected. Since the contra vaccination expert strongly argued against vaccination, one could assume that agreement with his arguments would entail rejection of vaccination.

The situation found its explanation in the descriptive statistical results. They produced four different groups. We called them the acceptors, the rejectors, the evaluators and the experiencers. The acceptors, the group that strongly believed in the pro vaccination argumentation, generally decided pro vaccination. The rejectors, the group that decisively reproduced the contra vaccination argumentation, consistently decided against vaccination. However, there were two considerable groups of students, the evaluators and the experiencers, who tended to be pro vaccination but were deeply unsure. The evaluators, in particular, tended strongly towards the contra argumentation but indicated that, in general, they would decide to vaccinate their child. The experiencers tended towards the pro argumentation, but they did not clearly disapprove of the contra argumentation. They also, in general, would decide to vaccinate their child.

The structural equation model mirrored this insecurity of many students in a highly positive covariance between the pro vaccination and the contra vaccination variables. It confirms that many students who believed in the pro vaccination argumentation also accepted the contra vaccination argumentation and vice versa. The two groups together, the evaluators and the experiencers, seem to represent those people who often are called the hesitators (see Introduction). In our sample, this group was rather large (77 of 160 coded students), and it explained the unexpected finding of the lack of impact of contra vaccination on vaccination decision. Many of the hesitators were positive, or at least non-negative towards the argumentation of the vaccination opponent. However, when it comes to a general decision for or against vaccination, they seemed to make a positive decision towards vaccination.

We conclude from this constellation that the hesitators represent a high potential target group for pro vaccination persuasion work. Actually, they are, in principle, pro vaccination. However, the impact of both the pro vaccination and the contra vaccination arguments on their general vaccination decision was small. Obviously, since they accepted both types of argumentation, their decision remained vastly unimpressed by the debate between the two experts.

Other factors seemed to be important in their decision-making process. The decision of evaluators depended on the type of vaccinations and on the diseases they aim to prevent. Their remarks in the survey showed that they want to know more about these contexts—and not about the general vaccination process—in order to be able to make an informed decision.

The second group of hesitators, the experiencers, based their decision on their personal experience with vaccinations in the past. If these experiences with concrete vaccinations were problematic, they decided against vaccination. In the other case (which is more frequent), positive vaccination experiences entailed a positive general decision. Again, both experts' argumentations did not seem to decisively impact the decision making process.

An interesting group, finally, were the future science teachers. The percentage of acceptors among them was only half as large as in the non-science teacher group. Almost none of them belonged to the rejectors. If they were hesitators, they tended to belong to the evaluators, i.e., they wanted to know more about the diseases prevented by the different types of vaccinations. Only a small minority of them decided based on personal experiences.

7. Limitations

There were some limitations with this study. One limitation was the sample, as it was a census of two consecutive school years in a university of teacher education. However, because these students come from every part of Central Switzerland, they very much represent the teacher population there, with students from rural and urban areas, as well as students from different socio-economic backgrounds. In addition, the majority of females in the sample reflects the fact that more women than men become teachers for primary and secondary one levels. This statistical weakness was also tolerated because in daily life, it is mainly mothers who decide the vaccination status of their children.

Another limitation was that the structural model represented a very basic decision between "acceptors" and "rejecters." The students were forced to decide between these two alternatives, which reflect only the two extremal points of vaccination hesitancy. This simplification was a consequence of the approach of using an article that only presented arguments of acceptors and rejecters.

8. Conclusions

All in all, it can be stated that the presented intervention at the university of teacher education was able to involve students and to successfully spark reflection and discussion. However, the results show that there is space for more. Obviously, the four groups that were identified have different needs and may benefit from different approaches.

The acceptors, the group that identifies with the pro vaccination argumentation in the text, seemed to be fine with this intervention and did not need further information. Conversely, the rejectors apparently followed the contra vaccination argumentation and did not ask for more information. Both groups seemed to have made up their minds and may be difficult to persuade to move away from their standpoints.

This is not the case for the two other groups, the evaluators and the experiencers, which together formed the group of hesitaters in this population. Tending basically towards vaccination acceptance, they nevertheless were insecure about the pro and contra argumentation's value, and they eventually relied upon other points of view than those presented by both experts. The first group, the evaluators, asked for more concrete information about the prevented diseases. The experiencers ultimately based their decision on personal experience.

These results suggest that the chosen strategies of both experts, be they pro or contra vaccination, are fairly inappropriate for promoting vaccination. Both appeal to one group of students that is already convinced of their arguments, and, thus, each of them fails to have an impact on the fluid group of the hesitators that is still ready to change position.

Indeed, our findings suggest that hesitators need a different approach that may be captured best by the shared decision-making model, which is probably today's most popular model in patient-centered medicine [26]. Shared decision-making has been defined as an approach where clinicians and patients share the best available evidence when faced with the task of making decisions. However, patients are also supported to consider personal options and to achieve informed preferences [27]. This description has also been condensed to the formula of *getting both evidence and preferences into health care* [28] (p. 407). Actually, this is more than a nice label, as Elwyn et al.'s (2017) article in the influential *British Medical Journal* pointed out:

"Instead of assuming that decisions should be guided by scientific consensus about effectiveness, shared decision making proposes that informed preferences—by which is meant what matters to patients and families—should play a major role in decision making processes. Shared decision making is more than being attentive to patients' needs or concerns—it represents an important shift in the roles of both patients and clinicians." [29] (p. 1).

Interestingly, in our newspaper article, the two experts (who both are physicians), addressed the evidence side of shared decision making. Surely, from the point of view of school medicine, the evidence of the pro vaccination expert was much better than that of the contra vaccination expert. Nevertheless, the latter also referred to evidence in the sense of experience and observed cases.

The hesitators in the student teachers' collective, however, were found to be concerned with preference questions and asked for the opportunity to find out more about them. An adequate approach could be inspired by the three-step model of shared decision making [29], which has been developed to help physicians and patients to find their way between evidence and preference. It starts with choice talk, wherein the importance of respecting individual preferences is underlined and the role of uncertainty in medicine is explained. In a second step, the options talk, options are listed and potential harms and benefits are clarified. The process ends with step 3, the decision talk, wherein preferences are elicited, and, eventually, a decision is made or else deferred.

In this three-step model, the choice between scientific evidence and alternative evidence should be supported. Students obviously feel disconcerted and unsure vis-a-vis two completely disparate epistemic claims. The finding that science teacher students opted three times more for scientific evidence than other evidence suggests that science education could have a role here.

In the field of public understanding and public engagement of science, two strategies for dealing with such conflicts are well known and hotly debated [30]. The first strategy, called "learning orientation," typically focuses on learning and understanding scientific content that, at least in principle, can be understood by the non-expert public. This approach fits with the direct positive impact of the pro vaccination argumentation on the vaccination decision. The second strategy, called "communications orientation," focuses on improving attitudes about science and trust in scientists. This approach seems to be particularly suitable for dealing with the indirect negative attitudinal effect of the contra vaccination argumentation.

The two orientations differ in a fundamental way and normally are conceived as controversial in the field of public understanding of science [31]. Interestingly, the presented model suggests that both orientations seem to be indispensable for a successful campaign to increase vaccination acceptance, as they complement each other. The learning orientation obviously is present in research on vaccination hesitancy [1]. Indeed, the learning and understanding of vaccination content is one of the factors that has been demonstrated to be efficient [2]. The learning orientation has been investigated in a number of disciplinary communities, including educational psychology, learning sciences, and science education.

However, the communications orientation, aimed at attitudes and perceptions about science (so-called "nature of science attitudes"), seems to be a fairly new perspective for vaccination hesitancy. Nevertheless, it also has a long research tradition in communication sciences, social psychology, and, to some degree, in sociology and science and technology studies [30].

This research has been carried out in the context of teacher education in Switzerland. Qualitative research in Swiss schools has already been able to document how teachers' negative nature of science attitudes can have a negative impact on the HPV vaccination decision [12,17,32]. Thus, a communications-oriented teacher education could have a considerable impact on this goal of the education for sustainable development.

Because the study's findings so closely reflect the shared decision making approach, which is a widely accepted concept in medicine (see above), the respective conclusions may hold more generally. Sustainability interventions may often focus too much on evidence arguments and may tend to neglect the preference approach. For educational situations, this argument has recently been taken up and theoretically reframed by a newly emerging science pedagogy called Science|Environment|Health, which is interested in the mutual benefit between the three interdependent educational areas [33]. In complex living systems, this pedagogy argues, evidence-based practice has, for systems-theoretical reasons, a limited outreach and necessarily has to be completed by a preference approach. However, while evidence-based practice is based on systematic scientific understanding, the shaping of preferences needs empathetic understanding, which is, as a recent *Science* article expands, something completely different [34].

The present study shows that getting involved with vaccination needs more than what experts and public health brochures normally provide us with. Hesitators obviously do not want to hear solely experts' talk and then decide for or against it on an epistemic level of understanding. In order to get really involved, they want to know more about the issue, particularly on the level of personal concerns. It has been suggested that, in Science|Environment|Health contexts (and vaccination is such a context), it could generally be wise to more seriously and consistently include empathetic understanding. It can be concluded that more research should be done on how to realize this in pedagogical settings, for example by adapting the three-step model (see above) from medicine or the reflective equilibrium approach from applied ethics, e.g., [35]. This request may also provide new impulses to future directions of research in sustainability education.

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Roles of Environmental System Knowledge in Promoting University Students' Environmental Attitudes and Pro-Environmental Behaviors

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Abstract: This study aims to investigate the role of environmental system knowledge in promoting pro-environmental behaviors. Relationships between environmental knowledge and environmental attitudes as well as environmental knowledge and pro-environmental behaviors were analyzed. Environmental system knowledge includes knowledge of political ecology, sustainable development, environment and ecology, and environmental situations. This study included 128 students enrolling in the elective course entitled "Environment and Development" provided by the King Mongkut's University of Technology Thonburi in Bangkok city of Thailand and 150 students who were not participating in this course. The results revealed that environmental attitudes of students participating in the course was significantly higher than that of students not attending the course. Only knowledge of the environment and ecology highly correlated with environmental attitudes; on the other hand, diverse environmental knowledge significantly correlated with pro-environmental behaviors. The result also demonstrated that indirect impact environmental behaviors reported by both groups were statistically different, but there was no significant difference in direct impact environmental behaviors. This study suggested that environmental knowledge provided through a formal education could promote environmental attitudes, but it may not contribute to students' engagement in direct impact environmental behaviors.

Keywords: environmental knowledge; pro-environmental behaviors; environmental attitudes; political ecology; sustainable development

1. Introduction

Many higher education institutes have tried to promote students' pro-environmental behaviors (PEBs). Students are expected to participate in both direct and indirect impact PEBs. Direct impact PEBs include the acts that directly contribute to environmental improvements such as reuse and recycling behaviors and energy-saving behaviors; however, indirect impact PEBs refer to the acts that have no direct effects on better environmental change, but potentially shape the way how the environment is managed [1]. Indirect impact PEBs are include supporting environmental policy and preference to work with environmentally responsible organizations. Students could take an important role in bringing sustainability to the society by participating in both types of PEBs. Formal environmental education, such as providing environmental courses, has been used as one of important channels to educate students with environmental values and significance of environmental conservation and protection in order to promote environmental citizenship among university students [2,3]. The study of Pizmony–Levy & Michel [4] found that learning about environmentalism and sustainable issues in class and being a member of campus-based environmental groups could promote student's participation in PEBs. Similarly, the study of Borchers et al. [5] found that environmental education could enhance people's environmental knowledge and attitudes towards nature. Jurdi–Hage et al. [6] suggested that to promote environmental literacy and students' sustainable life styles, students should learn about environmental knowledge, awareness, and critical thinking skills. Educating students with environmental knowledge that could promote positive ecological attitudes and students' engagement in PEBs is an important goal of environmental education [7–9], but it remains challenging. Though environmental knowledge is provided, students are still reluctant to engage in PEBs. Therefore, environmental education research that could support the development of effective environmental education is currently required [10].

With regard to value belief norm theory, environmental attitudes—defined as an individual's environmental worldviews—significantly influence PEBs [1,11]. Environmental attitudes represent people's beliefs about the interconnection between humans and the environment; thus, having positive environmental attitudes allow people to identify the negative consequences of behaviors for the environment. Consequently, they will construct a sense of obligation to act in an environment-friendly manner, which can, in turn, lead to a decision to engage in PEBs. Many previous studies affirmed that having positive environmental attitudes eventually leads to a decision to participate in PEBs [12–14], and most of those studies applied the New Ecological (Environmental) Paradigm proposed by Dunlap et al. [15] to measure individuals' environmental attitudes. The study of Abun & Aguot [16] revealed that eco-centric concern attitude could promote people's engagement in environmental movement activism and conservation behavior. Similarly, the study of Kim et al. [17] and Kukkonen et al. [2] revealed that if they have greater emotional empathy toward nature, people are more likely to participate in PEBs. However, some studies also found a weak relationship between environmental attitudes and PEBs [18–20]. Vermeir and Verbeke's [21] study demonstrated that environmental attitudes alone were a poor predictor of PEBs. Manaktola and Jauhari [20] discovered that though having positive attitudes toward environment-friendly practices in the hotel industry, customers did not translate their attitudes into a willingness to pay more for taking services from green hotels. However, PEBs can be predicted by diverse factors. Literature review suggests diverse viewpoints of PEB predictors. Many scholars indicated that PEBs were strongly predicted by social factors such as social relationships and social network [22,23]. Some scholars strongly believed that participation in PEBs was predicted by normative goals, intention, and gain [1,24,25]. For instance, the study of Heeren et al. [26] revealed that environmental knowledge was not as important as social norms, attitudes toward PEBs, and perceived capability to perform PEBs to promote American students' participation in PEBs. Many studies also revealed significant roles of socioeconomic characteristics in predicting PEBs. Those socioeconomic factors included gender [27], age [28], educational level [29], and income [30].

Regarding students' participation in PEBs, environmental knowledge could play an important role in cultivating students' positive environmental attitudes and PEBs [12,31–33]. Environmental knowledge can be generally defined as any information that constitutes the formation of environmental attitudes and people's participation in environmental behaviors [18]. Put differently, environmental knowledge can be defined as people's capability to identify numerous ecological symbols, concepts, and characteristics of behavior concerning environmental protection [34]. Hines et al. [35] defined two types of environmental knowledge, including knowledge of environmental phenomena and knowledge of environment-friendly action strategies. Several studies referred environmental knowledge as knowledge of environmental issues [33,36,37] and problem-solving actions and strategies [18,38]. Fryxell and Lo [39] defined environmental knowledge as environmental issues and general environmental knowledge about the facts, concepts, and relationships in the surrounding environment and ecosystems. Mostafa [36] also conceptualized environmental knowledge as people's understanding of environmental influence, environmental values and appreciation, negative relationships potentially destroying the environment, and collective responsibility.

In terms of knowledge measurement, environmental knowledge is divided into two types, including subjective and objective knowledge [31]. Subjective knowledge refers to people's own perception of understanding about the environment, whereas objective knowledge refers to actual knowledge that people possess [40]. Martin and Simintiras' [41] study found no correlation between these two types of knowledge. People's misunderstanding of their actual knowledge might cause ineffective decision making to take environmental actions. In terms of scale, environmental knowledge can be classified into two types: general environmental knowledge and specific knowledge [12]. General environmental knowledge is defined as "general knowledge of facts, concepts, and relationships concerning the natural environment and its major ecosystems," while specific environmental knowledge means knowledge relevant to particular environmental issues such as knowledge and behavioral consequences related to particular environmental behavior [39]. Taufique et al.'s [42] study measured levels of general knowledge by analyzing the degree to which people are familiar with contemporary pressing environmental issues, such as "climate change," "greenhouse gas," etc. Previous studies revealed diverse findings regarding the impact of both general and specific environmental knowledge on PEBs. Ellen [43], Frick et al. [10], and Ogbeide et al. [44] found in their studies that specific environmental knowledge has a more significant impact on environmental behavior. The study of Polonsky et al. [12] revealed that both general and specific environmental knowledge levels assist US consumers in making environment-friendly consumption decisions. A more recent study by Taufique et al. [42] found that both general environmental knowledge and issue-specific environmental knowledge (e.g., eco-label knowledge) positively influence consumer attitudes toward the environment in driving ecologically conscious consumer behavior.

In universities, several environmental knowledge-related subjects are taught to students to cultivate their understanding of ecological values, problems, awareness, and preferred environmental practices, but the actual contribution of that educated knowledge to positive environmental attitudes and engagement in diverse types of PEBs is not clear. While many previous studies have investigated the relationship between environmental knowledge and attitudes, as well as association among environmental knowledge, attitudes, and behaviors, it was noticed that environmental knowledge explored by those studies was mostly investigated based on measurement of subjective knowledge, which may not reflect their actual knowledge (objective knowledge). Kaiser and Fuhrer [38] also added that the influence of environmental knowledge on pro-environmental behavior has been underestimated because the underlying structure of environmental knowledge has not been addressed adequately. They suggested that it is necessary to consider different forms of environmental knowledge to understand their effects on pro-environmental behavior.

This study aims to investigate how several types of environmental system knowledge taught in a university are essential to promote students' environmental attitudes and PEBs including both direct and indirect impact PEBs. The study also explores whether positive environmental attitudes are associated with students' participation in both types of PEBs and investigates types of environmental system knowledge that correlate with environmental attitudes and PEBs. Objective environmental knowledge of students will be measured based on the evaluation of actual knowledge acquisition. Namely, students will be taught environmental knowledge, and their knowledge will be tested. Types of environmental knowledge included in this study are knowledge of political ecology, sustainability, natural characteristics of the environment and ecology, and knowledge of environmental situations. The results of this study clearly indicate whether environmental knowledge could affect students' environmental attitudes and PEBs and provide an implication for developing an effective environmental education.

2. Roles of Environmental Knowledge in Promoting Environmental Attitudes and Pro-Environmental Behaviors

2.1. Types of Environmental Knowledge

Kaiser and Fuhrer [38] and Frick et al. [10] suggest that environmental knowledge can be classified into three types: system knowledge, action knowledge, and effectiveness knowledge. System knowledge refers to the natural characteristics of environmental and ecological systems regarding the relationship between organisms and ecosystem functions. It also includes human-environment relationships such as causes of environmental problems due to human development systems. For instance, people educated with this type of knowledge should be able to understand why carbon dioxide (CO_2) is a problem, where groundwater comes from, why ozone is a problem, and how long it will take for complete regeneration of the ozone layer after all ozone-destroying emissions are eliminated [10]. Dietz et al. [45] propose that to manage resources at an organizational level sustainably, responsible organizations should acquire this type of knowledge including both resource systems and human-environment interactions to understand natural variability, uncertainty, and the relative causes of and effective solutions to environmental change. Berkes et al. [46] add that the combination of different knowledge systems potentially contributes to effective judgment on the ways to tackle environmental change. Moreover, Díaz–Siefer et al. [47] found that at an individual level, environmental system knowledge focusing on global environmental problems closely related to pro-environmental behavior of students.

Action knowledge is relevant to behavioral choices and course of environmental actions that can reduce the environmental problems we face [10]. Other scholars also define action knowledge as a type of environmental knowledge that should be understood by individuals and organizations to create the capacity to minimize and eliminate environmental problems [18,38]. People educated with this knowledge should be able to understand the types of actions that potentially solve environmental problems. Effective knowledge refers to the effectiveness of environmental actions or behaviors in solving environmental problems or protecting the environment. It emphasizes the qualification of actions that can contribute to the greatest environmental benefit [10]. For instance, people educated with these types of knowledge should be able to recognize the types of packing that is the most or least damaging to the environment.

It can be stated that action and effective knowledge potentially enhance people's capacity to perform PEBs and could finally contribute to people's decision to participate in PEBs. The results concerning the influence of system knowledge on people's environmental attitudes and behaviors are diverse. Frick et al. [10] indicated no effect of system knowledge on PEBs. In contrary, other scholars noted the possibility of system knowledge to influence PEBs [48,49]. System knowledge can enhance people's understanding of environmental values as well as the interaction between human and nature; thus, environmental attitudes can be formed, leading to the decision to engage in PEBs. Fielding and Head [49] suggested that human-environment system knowledge can induce an internal locus of control in relation to the environment and/or guilt for the environment, which is known to improve PEBs.

Considering types of system knowledge that are in the environmental discipline, several concepts and issues reflecting both environmental and ecological systems and functions (geography-environment system knowledge) and environmental problems caused by human development systems (human–environment system knowledge) have been developed and taught in environmental courses. Political ecology and sustainable development are the concepts relevant to the human–environment system knowledge; on the other hand, the knowledge issues relevant to geography–environment system knowledge are basic knowledge of environmental and ecological systems and the current state of environmental situations. These concepts and issues can be explained as follows:

Political ecology is the concept that illustrates the interconnection between environmental and political, socio-economic conditions [50]. The concept addresses the contribution of state policies to land use and environmental change and the ways global forces influence national, regional, and local scales of environmental governance [51].

Sustainable development (SD) is the concept that relates environmental issues with economic and social development [52]. The concept was published in Brundtland Report and disseminated in 1987 by the World Commission on Environment and Development. In the Brundtland Report, SD was conceptualized as "the development that meets the needs of the present without compromising the ability of the future generations to meet their own." [53]. More simply, the concept of SD refers to the development approach that aims to reach a dynamic equilibrium between the social and economic aspects while caring for the natural environment [54].

Concepts related to environment and ecology refer to the fundamental understanding of environmental characteristics and ecological systems. Ecology is the scientific knowledge of interactions among organisms and their environment. The concept also provides an understanding of diverse ecosystems and their functions. The environmental characteristics focus on the interactions among the chemical, biological, and physical components of the environment and the effects of these interactions on all types of organisms [55].

Environmental Situations refer to knowledge relevant to environmental issues, including global and local environmental problems, which have concerned the general public and society. These problems include climate change, global warming, ozone depletion, depletion of natural resources, deforestation, and loss of biodiversity [56]. This includes scientific knowledge explaining the causes of environmental problems, their situations, potential impacts, and effective solutions.

2.2. Relationship between Environmental Knowledge, Environmental Attitudes, and Pro-Environmental Behaviors

The relationship between environmental knowledge and environmental attitudes has been widely explored across the world. The results are diverse, depending on regions and types of PEBs. Some studies found a strong relationship between knowledge and positive environmental attitudes [32,57,58]. Conversely, it has also been contended that high levels of individual environmental knowledge may not necessarily lead to the development of positive environmental attitudes [59]. The study of Kollmuss and Agyeman [18] and Olli et al. [19] revealed a weak relationship between environmental attitudes and PEBs. Arcury [60] applied NEP (New Environmental Paradigm: Dunlap and Van Liere 1978) to measure environmental attitudes, and their results showed a positive relationship between knowledge and attitudes, up to $r = 0.33$. Similarly, Bradley et al. [61] investigated the effect of environmental science knowledge on environmental attitudes of students. The result revealed that attitudes significantly correlated with knowledge in the pre-test (Pearson's $r = 0.19$ with $p = 0.004$) and the correlation value also increased in the post-test (Pearson's $r = 0.27$ with $p < 0.001$), after learning program participation.

Environmental knowledge is also found to correlate with PEBs. Environmental knowledge can enhance people's capability as well as drive their motivation to perform PEBs. In addition, knowing current environmental situations could allow people to construct environmental concerns and a sense of urgency, which would, in turn, affect their decision to take environmental actions. Barber et al. [31] stated that people who have greater knowledge of environmental problems would be more motivated to act toward the environment in more responsible ways. Conversely, inadequate knowledge or having contradictory environmental information potentially limit PEBs [62]. Many studies insisted that having a more in-depth knowledge of environmental issues enhances individuals' likelihood to participate in environment-friendly actions [18,38,63]. Oguz et al. [33] also supported this finding; namely, people with a proper understanding of environmental problems, relative causes, and potential impacts are more willing to behave responsibly toward the environment. Environmental knowledge potentially contributes to people's formation of environmental awareness and concerns. Thus, the decision to participate in PEBs can be consequently made [25,64]. Barber et al. [31] also added that knowing environmental problems and actual causes allow people to construct motivation, leading to the decision to participate in PEBs. In contrary, many studies provided empirical evidence that there was no significant relationship between environmental knowledge and pro-environmental behavior [34,65].

For instance, Bartiaux [65] and Oguz et al. [33] demonstrated that although people acquired knowledge of environmental issues, their knowledge did not positively correlate with their environmental actions.

3. Hypotheses

This study will first investigate whether environmental system knowledge contributes to university students' environmental attitudes and PEBs by comparing levels of environmental attitudes and PEBs reported by university students who were taking environmental course and who were not taking the course. PEBs in this study include direct and indirect impact environmental behaviors. Stern [1] stated that direct impact PEBs refer to behaviors that directly contribute to environmental protection and/or improvement, and indirect impact PEBs refer to practices that indirectly promote or support environmental protection and/or improvement. For the investigation, this study selected PEBs that university students can practice on an everyday basis and are heavily promoted by the university. These behaviors are energy saving and sustainable waste management including waste separation, waste avoidance, and reuse and recycle activities. For indirect impact PEBs, this study investigates students' environmental policy support and environmental organization support. In consideration of environmental knowledge, this study will explore objective environmental knowledge, reflecting actual knowledge possessed by students. According to Kaiser and Fuhrer [38], environmental system knowledge refers to the following: (1) knowledge of environmental and ecological systems (geography–environment system knowledge) and (2) knowledge of environmental problems caused by human development systems (human-environment system knowledge). This study will explore four types of environmental contents—which reflect the core concept of system knowledge—on their contribution to environmental attitudes and PEBs. They include the concept of political ecology, SD, environment and ecology, and environmental situations. Such contents provide understandings on how environmental and ecological systems function, how each element in ecological systems is interconnected with the other, how the environment and human influence each other, and how the current environmental problems are. It is assumed that if students acquire these understandings, they will have a recognition of environmental values, awareness, concerns, and motivation to behave environmentally. Thus, students will have positive environmental attitudes and/or decide to participate in both direct and indirect ecological impact behaviors. The first research hypothesis is defined as follow:

Hypothesis 1. *Students who participate in the environmental course have more positive environmental attitudes and higher levels of PEBs (both direct and indirect environmental impact behaviors) than those who do not participate in the course.*

Second, the study will explore the correlation between environmental attitudes and PEBs including both direct and indirect impact PEBs. Many previous studies revealed diverse findings. This study assumes that students with positive environmental attitudes relatively engage in both types of PEBs at a significantly higher level. The research hypothesis is defined as follow:

Hypothesis 2. *Environmental attitudes highly correlate with direct and indirect impact PEBs.*

Third, the study will investigate types of environmental system knowledge (political ecology, SD, environment and ecology, and environmental situations), which could promote students' environmental attitudes and engagement in both types of PEBs. The research hypotheses are defined as follows:

Hypothesis 3. *Every kind of environmental system knowledge differently correlates with environmental attitudes.*

Hypothesis 4. *Each type of environmental system knowledge differently correlates with direct and indirect impact PEBs.*

4. Methods

4.1. Participants and Ethical Issue

Participants of this study were bachelor students of the King Mongkuts' University of Technology Thonburi, in Bangkok city, Thailand. The participants were divided into two groups including those who were taking an elective course entitled "Environment and Development" in the academic year of 2018 (experimental group) and those who were not taking this course (control group). Regarding the experimental group, there were 131 students enrolling in the course; however, 128 students decided to participate in this research. In addition, the simple random sampling method was applied to select the participants who were not taking this course. One hundred fifty participants were not taking this elective course, and these participants had similar characteristics with those who were taking the course. Namely, they relatively were in the same educational level and from the same academic disciplines. This research had received ethical approval from the ethical research community of the School of Liberal Arts. Before the data collection, all participants were informed about the research objectives, data collection methods, and the right to withdraw from the study and informed that their participation was voluntary. A group of participants enrolling in the "Environment and Development" course were additionally informed that their participation or non-participation would cause no impact on their academic performance evaluation.

Characteristics of participants in the experimental group and control are illustrated in Table 1. Participants in both groups had similar characteristics. The proportion of male participants in the experimental group and the control group were 40.63% and 43.3%, respectively. Female participants accounted for 59.38% in the experimental group and 56.7% in the control group. The average age of participants in both groups were almost equivalent, 21 years old. Their average grades were almost equivalent, 2.65 for the experimental group and 2.71 for the control group. Regarding the school level, most participants were in the third and fourth years of university level. The number of participants who were in other levels such as the second year or more than the fourth year was small in both the experimental and control group. The majority of participants in both groups were from the school of engineering and sciences, and a very small number of participants were from other schools such as technical education and information technology.

Table 1. Characteristics of participants.

Items	Experimental Group		Control Group	
	Mean/N	S.D./(%)	Mean/N	S.D./(%)
		Gender		
Male	52	40.63%	65	43.3%
Female	76	59.38%	85	56.7%
Age	21.44	0.82	21.38	0.77
Grade	2.65	0.44	2.71	0.46
		School level		
3rd year	11	8.6%	16	10.7%
4th year	108	84.4%	126	84.0%
Others	9	7.0%	8	5.3%
		Affiliation		
Engineering	61	47.7%	72	48.0%
Sciences	60	46.9%	66	44.0%
Others	7	5.50%	12	8.0%

4.2. Data Collection and Analysis

4.2.1. Measurement of Environmental System Knowledge

The experimental group, participants taking "Environment and Development" course, were taught about relevant environmental contends that included the concept of political ecology, SD, knowledge of environment and ecology, and environmental situations. These contents are normally taught in this course, but their contribution to promoting students' environmental attitudes and PEBs was never tested. The learning and teaching activities had lasted for seven weeks (three hours per week); after that, participants participated in the examination where their knowledge acquisition was evaluated based on their understanding. Characteristics of the test are demonstrated in Table 2. Each type of knowledge acquisition will be evaluated based on the scale of three ranging from 0 = no knowledge acquisition to 3 = full knowledge acquisition.

Table 2. Characteristic of environmental contents and tests.

Types of Environmental Contents	Characteristics of the Materials Taught in the Course	Questions in the Test
Political ecology	- Relationship between environmental problems and politics - Relationship between environmental problems and economic systems - Rights to use and manage natural resources - Environmental movements	- Regarding the concept of political ecology, please explain the influence of politics on the emergence of environmental problems. - How does each type of economic systems cause environmental problems? - Please explain why environmental movements have occurred in industrial development areas.
Sustainable development	- Three pillars of sustainability - Diverse SD approaches - Green growth & green GDP - Environmental sustainability - Indicators measuring sustainability in development	- Please explain the goal of SD. - What do environmental sustainability and green growth mean?
Environment and ecology	- Characteristics and components of environmental and ecological systems - Interaction among organisms in environmental and ecological systems - Ecological services	- Please explain the components of ecological systems and how they are related. - Please indicate the services provided by ecological systems.
Environmental situations	- Climate change - Ozone depletion - Pollution and solid waste problems - Ecological depletion	- Please explain how climate change, ozone depletion, air pollution, waste management problems, and ecological depletion occurred? - Please explain the potentially devastating consequences of those problems?

4.2.2. Measurement of Environmental Attitudes and PEBs

Questionnaire surveys were conducted with the experimental group and control group after teaching and testing activities were completed. Content validity of the questionnaire was performed based on face validity technique, and it has been tested with 20 students whose characteristics were similar to the sampling group. The questions used to measure environmental attitudes were applied from the New Ecological (Environmental) Paradigm proposed by Dunlap et al. [15]. Originally, the revised New Ecological Paradigm contains 15 items reflecting an individual's belief about human-nature relationship. In this study, in measuring students' environmental attitudes, only 6 items were selected based on the consideration of students' ability to interpret and understand the items. This could avoid errors in data collection. For measuring the participation in PEBs, participants were asked to indicate their frequency of involvement in a list of direct and indirect impact PEBs. Items for measuring students' participation in both types of PEBs were developed based on students' capability to perform and be involved in, and based on the current situation which some types of PEBs were being promoted by the university. Those were such as denying receiving a plastic bag when purchasing a few items from a convenient store or using cotton bags instead of plastic bags. Questions used for data collection are mentioned in Table 3.

Table 3. Variable, questions, and response categories.

Variables	Questions	
Environmental attitudes	The balance of nature is very delicate and easily upset.	1 = completely disagree 5 = completely agree
	Nature is strong. It can cope with the negative consequences caused by human activities.	1 = completely agree 5 = completely disagree
	Naturally, the existence of plants and animals is for human use.	
	The earth is like a spaceship with finite room and resources.	1 = completely disagree 5 = completely agree
	If things continue on their present course, we will soon experience a major ecological catastrophe.	1 = completely agree 5 = completely disagree
	Humans have the right to modify the natural environment to suit their needs.	
Participation in direct impact PEBs	Do you segregate waste before disposing it?	1 = never 5 = regularly
	Do you switch off the light or the air conditioner when you are not using it?	
	How often do you use cotton bags instead of plastic bags?	
	Do you deny receiving a plastic bag when purchasing a few items from a convenient store?	
	Do you purchase food or drinks using reusable containers?	
	How often do you reuse or recycle things such as plastic bags and bottles?	
Participation in indirect impact PEBs	To what extent do you agree that political leaders should have environmentally sustainable views?	1 = completely disagree 5 = completely agree
	I prefer to work with an organization that cares about the environment.	
	I support goods and services from enterprises that take care of the environmental issue in their business operation.	
	Both public and private organizations should have environmental strategies allied with organization goals.	

4.2.3. Data Analysis

All corrected data were inspected. The internal consistency of the scales, which were used for measuring environmental attitudes and PEBs, were tested by Cronbach's alpha. The results revealed that the values of Cronbach's alpha were above 0.7. This represents reliability of data gain form the surveys. Kolmogorov–Smirnov (K–S) tests were first performed to test the normality of distribution. Subsequently, a *t*-test was conducted to measure the difference in the mean of environmental attitudes and the engagement level in PEBs reported by experimental group and control group. Moreover, the analyses of correlation between environmental knowledge and attitudes, between knowledge and PEBs, and between attitudes and PEBs were analyzed by using SPSS 22 (Statistical Package for Social Sciences) software. Finally, the discussion of the results was carried out.

5. Results

5.1. Environmental Knowledge, Attitudes, and Pro-Environmental Behaviors (PEBs)

In Table 4, levels of engagement in direct and indirect impact PEBs, environmental attitudes, and environmental knowledge are reported. Levels of engagement in direct and indirect impact PEBs and environmental attitudes were analyzed based on data collected from questionnaire surveys with the measurement based on the scale of 1–5. Overall, participants reported a higher level of engagement in indirect impact PEBs than direct impact PEBs in many items. For environmental knowledge, participants' knowledge acquisition was evaluated based on a scale of 0–3. The results revealed that participants gained the highest average score in knowledge of political ecology; however, the average scores of knowledge of SD and environment and ecology were almost equivalent and relatively low. Moreover, Table 4 also demonstrates the reliability of the scales used in the questionnaire as measured by Cronbach's alpha. All the variables exhibited good reliability, with Cronbach's alpha values greater than 0.70. Therefore, the data gained from the survey were reliable and proper for statistical analyses.

5.2. Characteristics of Participants, Environmental Knowledge, Attitudes, and Pro-Environmental Behaviors (PEBs)

First, the Kolmogorov–Smirnov (K–S) tests were performed to test whether data regarding students' environmental attitudes, and levels of participation in both direct and indirect impact PEBs were normally distributed. The results revealed that the distribution of environmental attitudes met the normality assumption indicated by K-S; $Z = 0.72$, $p = 0.08$. The distribution of data regarding both direct and indirect impact PEBs also met the normality assumption indicated by K-S; $Z = 0.77$, $p = 0.09$ and $Z = 0.88$, $p = 0.10$ respectively. Then, the difference in mean scores of environmental attitudes and levels of engagement in PEBs reported by the experimental group and control group was analyzed by performing a *t*-test (see Table 5). The result revealed that students participating in the environmental course reported significantly higher levels of environmental attitudes (M = 3.44, SD = 0.46) than students who did not participate in the environmental course (M = 3.28, SD = 0.42), $t(276) = -3.09$, $p = 0.00$. It was also found that their self-reported engagement in indirect impact PEBs was also significantly different. Students participating in the environmental course had reported a higher level of indirect impact PEBs (M = 3.79, SD = 0.59) than students not participating in the environmental course ((M = 3.63, SD = 0.63), $t(276) = -2.20$, $p = 0.03$. There was no a significant difference in the level of engagement in direct impact PEBs reported by both groups. However, the mean score of engagement level in direct impact PEBs reported by the experimental group (M = 3.59, SD = 0.58) was slightly higher than ones reported by the control group (M = 3.51, SD = 0.51).

Table 4. Variables, questions, and statistics.

Variables	Items	N	Mean	SD.	Cronbach's α
Direct Impact PEBs	Do you segregate waste before disposing it?	278	3.48	0.78	0.801
	Do you switch off the light or the air conditioner when you are not using it?	278	4.42	0.74	
	How often do you use cotton bags instead of plastic bags?	278	3.06	0.98	
	Do you deny receiving a plastic bag when purchasing a few items from a convenient store?	278	3.91	1.05	
	Do you purchase food or drinks using reusable containers?	278	2.68	1.20	
	How often do you reuse or recycle things such as plastic bags and bottles?	278	3.72	0.96	
Indirect Impact PEBs	To what extent do you agree that political leaders should have environmentally sustainable views?	278	3.35	0.84	0.723
	I prefer to work with an organization that cares about the environment.	278	3.91	1.00	
	I support goods and services from enterprises that take care of the environmental issue in their business operation.	278	3.72	0.80	
	Both public and private organizations should have environmental strategies allied with organization goals.	278	3.84	0.80	
Environmental Attitudes	The balance of nature is very delicate and easily upset.	278	4.29	0.76	0.704
	Nature is strong. It can cope with the negative consequences caused by human activities.	278	3.36	0.90	
	Naturally, the existence of plants and animals is for human use.	278	3.08	0.97	
	The earth is like a spaceship with finite room and resources.	278	4.28	0.80	
	If things continue on their present course, we will soon experience a major ecological catastrophe.	278	2.33	0.92	
	Humans have the right to modify the natural environment to suit their needs.	278	2.80	0.90	
Environmental Knowledge	Political ecology	128	2.11	0.90	-
	Sustainable development	128	1.54	1.04	-
	Environment and ecology	128	1.59	0.92	-
	Environmental situations	128	1.89	0.82	-

Table 5. Results of *t*-test analysis ($n = 278$).

Dependence Variables		N	Mean	S.D.	df	Difference	*t*	*P*
Environmental attitudes	Control group	150.00	3.28	0.42	276	−0.16	−3.09	0.00
	Experimental group	128.00	3.44	0.46				
Direct impact PEBs	Control group	150.00	3.51	0.51	276	−0.09	−1.31	0.19
	Experimental group	128.00	3.59	0.58				
Indirect impact PEBs	Control group	150.00	3.63	0.63	276	−0.16	−2.20	0.03
	Experimental group	128.00	3.79	0.59				

5.3. Correlations between Environmental Knowledge and PEBs, Knowledge and Attitudes, and Attitudes and Pro-Environmental Behaviors (PEBs)

First, the result of correlation analysis revealed that environmental attitudes did not significantly correlate with both direct and indirect impact PEBs and had a significantly positive correlation with the knowledge of environment and ecology. However, the size of correlation was small, $r(127) = 0.24$, $P < 0.01$, two-tailed. Regarding direct impact PEBs, the result demonstrated that knowledge of environmental situations and political ecology had a positive correlation with direct impact PEBs, $r(127) = 0.43$, $P < 0.01$, and $r(127) = 0.27$, $P < 0.01$. Participants' engagement in indirect PEBs was significantly and positively correlated with knowledge of SD, $r(127) = 0.39$, $P < 0.01$. In addition, knowledge of political ecology and environmental situations were also significantly and positively correlated with indirect impact PEBs, $r(127) = 0.24$, $P < 0.01$, and $r(127) = 0.18$, $P < 0.05$. It was also found that each type of PEBs was significantly correlated with each other, $r(127) = 0.38$, $P < 0.01$. Moreover, most types of knowledge were also correlated with others. For instance, knowledge of political ecology significantly correlated with knowledge of SD, environment and ecology, and knowledge of environmental situations. The result of the analysis is depicted in Table 6.

Table 6. Means, standard deviation, and Pearson correlation matrix ($n = 128$).

	M	S.D.	1	2	3	4	5	6	7
1.Environmental attitudes	3.44	0.46	1						
2.Direct impact pro-environmental behaviors (PEBs)	3.59	0.58	−0.08	1					
3.Indirect impact PEBs	3.79	0.59	−0.10	0.38 **	1				
4.Political ecology	2.11	0.90	0.04	0.27 **	0.24 **	1			
5.Sustainable development	1.54	1.04	−0.06	0.14	0.39 **	0.35 **	1		
6.Environment and ecology	1.59	0.92	0.24 **	−0.03	0.03	0.37 **	0.14	1	
7.Environmental situations	1.89	0.82	−0.02	0.43 **	0.18 *	0.48 **	0.25 **	0.15	1

Note: ** Correlation is significant at the 0.01 level, * Correlation is significant at the 0.05 level.

6. Discussion and Conclusions

First, the results of this investigation clearly revealed that there was significant difference in environmental attitudes and the engagement in indirect impact PEBs between students participating in the environmental course and students not participating in the course. A significant difference in students' engagement in direct impact PEBs was not found. Particularly, students who participated in the environmental course for seven weeks did not engage in direct impact PEBs at a significantly higher level than students who did not participate in the course. It is possible that a decision to act in an environment-friendly manner can be based on other more influential and diverse factors (e.g., infrastructure, motivation, sense of responsibility, and social norms) and require some time for students to act upon. Vicente–Molina et al. [62] suggested that motivation and perceived effectiveness of PEBs were very powerful to predict university students' engagement in PEBs. Heeren et al. [26] also indicated environmental knowledge was important, but not as important as social norms, attitudes toward PEBs, and perceived capability to perform PEBs to encourage American students in PEBs engagement. Based on this study's finding, formal environmental education can greatly bring some positive change to students' environmental attitudes and influence them to partake in indirect impact PEBs. The engagement in indirect impact PEBs such as supporting environmental policy in organizations and supporting goods and services from responsible business sectors may require fewer efforts and greatly rely on one's cognitive judgment based on self-awareness. Therefore, the role of environmental knowledge in influencing indirect impact PEBs could be sufficiently influential. For the engagement in direct PEBs, environmental knowledge provided through a formal environmental education might not be strong enough to bring a positive change. This finding can be supported by the study of Varoglu et al. [66], which reported a moderate relationship between environmental knowledge and environmental attitudes of students in secondary school level in North Cyprus and found a weak relationship between environmental knowledge and PEBs.

However, this study did not find significant relationships between environmental attitudes and both of types of PEBs including direct and indirect impact PEBs. This means that students might not act in an environmentally responsible manner despite having high positive environmental attitudes. This result is consistent with the study of Mifsud [67], which investigated several types of environmental knowledge, environmental attitudes, and direct impact PEBs of students attending postsecondary institutions in Malta. The results revealed that students exhibited strongly positive toward the environment but reported their engagement in few positive environmental actions. Similarly, Paço and Lavrador [68] also reported a weak relationship between environmental attitudes and PEBs of students from the University of Beira Interior. Unlike the study of Mifsud [67] and Paço and Lavrador [68], an investigation carried out by Heyl et al. [69] revealed the potentiality of positive environmental attitudes in predicting PEBs of engineering students in a Chilean university.

For this study, it can be concluded that environmental knowledge provided through a formal environmental education can constitute students' environmental attitudes, but it is uncertain that the attitudes would turn to PEBs. Knowledge may influence PEBs through other variables such as motivation, social norms, and perceive self-efficacy, according to the suggestion of Vicente–Molina et al. [62]. The study of Mtutu & Thondhlana [70] and Heberlein [71] also exhibited that though having a positive environmental attitude, people may not always decide to participate in PEB because of external factors which are beyond the control of individuals. External factors, for instance, include infrastructure condition or access to relevant infrastructure. Students will engage in waste separation, if they can access to recycling bins. This study found that the result of *t*-test analysis demonstrated that students participating in the environmental course reported a significantly higher level of engagement in indirect impact PEBs than students who did not participate the environmental course, but a significant relationship between environmental attitudes and indirect impact PEBs was not found. It could imply that knowledge might influence indirect impact PEBs through other attributes. This finding contradicts with the study of Oreg and Katz–Gerro [72], which stated that environmental knowledge potentially fosters an environmental attitude, which in turn influences any environmental behaviors.

In consideration of types of environmental contents that potentially foster environmental attitudes and contribute to students' engagement in both types of PEBs, it is hard to find relevant works of literature that investigate roles of specific environmental content in promoting types of PEBs. Therefore, the discussion in this part will be made based on only the results found in the study. This study has revealed that students having a high level of knowledge related to environment and ecology relatively reported a high level of positive environmental attitudes; on the other hand, other types of environmental contents were not significantly correlated. While studying about environment and ecology, students would be taught about interactions among organism in environmental system, ecosystem function, and environmental services. Therefore, having this basic knowledge, students would have the potential to evaluate environmental values and susceptibility of the environment and ecological systems to human behaviors; thus, a positive attitude toward the environment could be formed. For the knowledge relevant to students' engagement in direct PEBs, the result displayed that knowledge of environmental situations (e.g., the potential impact of climate change, pollution, ozone depletion, and ecological degradation) and knowledge of political ecology were positively and significantly correlated with such PEBs. It is possible that by understanding these issues, students could understand the seriousness of the current environmental problems and their root causes.

Consequently, a sense of urgency to take some actions can be constructed, and it can potentially affect students' decisions to perform environmentally. However, the result of *t*-test revealed no significant difference in the level of direct impact PEBs reported by students participating in the environmental course and students not participating in the course. This could be because knowledge of environmental situations and relevant knowledge of political ecology such as environmental politics were generally available in other informal sources such as media, public demonstrations about the environment, and environmental activities carried out by universities. The study of Zhang et al. [73] revealed positive relationships between news media use and people's engagement in two types of PEBs including environmental activism and consumerism. Similarly, Yu at. al. [74] indicated that people's understanding of environmental problems and media exposure significantly and positively contributed to the engagement in PEBs. However, to drive a significantly positive change in students' direct impact PEBs, other types of potential determinates should be further investigated, and environmental education should cooperate with those potential determinants.

Regarding indirect impact PEBs, the result revealed that knowledge of SD was moderately and significantly correlated with students' engagement in indirect impact PEBs. Knowledge of political ecology and environmental situations were also significantly correlated with such PEBs, but the relationships between them were weak. However, it could suggest that the combination of these environmental contents could allow students to recognize ultimate goals and benefits of SD in term of sustainably solving current environmental problems. Educated with knowledge of political ecology and environmental situations, students could understand several causes of environmental problems generated from political and socio-economic systems along with their seriousness. Students could, therefore, understand and recognize the significance of their roles in promoting sustainability goals through the support of environmental actions at an organizational level and regional level.

In conclusion, this study confirms a significant role of environmental knowledge and formal environmental education in fostering students' environmental attitudes and promoting indirect impact PEBs. However, students' engagement in direct impact PEBs (e.g., waster separation, energy-saving behavior, and reuse and recycling behaviors) cannot be enhanced by only students' participation in an environmental course. As found in the study of Geiger et al. [75], though people had a high level of both general and environmental knowledge such as knowledge of ecological systems, sustainability issues, effective actions and environmental situations, their engagement in PEBs was merely average. Several studies indicated the influence of other factors on PEBs engagement. Those are such as situational conditions [76], current behavior patterns [77], and also socioeconomic characteristics including gender [27], age [28], educational level [29], and income [30]. Students' engagement in direct PEBs can be also influenced by internal factors (e.g., awareness, personal norms, motivation, and perceived efficacy) and external factors (e.g., social norms and availability of infrastructure) [62,78].

However, it does not mean that environmental knowledge is not essential. This study demonstrated that students who possessed a high level of environmental situations and knowledge of political ecology relatively reported a higher engagement in direct PEBs, even though their relationships were not strong. Therefore, it could be suggested that both formal and informal environmental education should be provided in order to promote students' engagement in direct impact PEBs. This study also confirms that different types of environmental knowledge have distinct influence on each kind of PEBs. This conclusion is also supported by the work of Barber et al. [31], which also indicated that different types of environmental knowledge contributed to different types of environmental behavior. This study revealed that knowledge of environmental situations was the most significant in promoting direct impact PEBs, whereas knowledge of SD was most significant in supporting indirect impact PEBs.

However, no single knowledge can totally influence students' PEBs; therefore, a combination of diverse environmental knowledge is suggested. This study found that knowledge of political ecology, SD, and environmental situations positively correlated with indirect impact PEBs. Therefore, providing diverse environmental contents is suggested to develop an environmental course for promoting student's attitudes and environmental behaviors.

Finally, there is a limitation in this research which should be addressed. Majority of participants in this study were in third and fourth year of bachelor's degree, and all of them were studying in the field of sciences and technology. Therefore, the results might not be proper to generalize for all university students. For the recommendations for future research, it can be suggested that students' participation in PEBs can be influenced by diverse factors which should be comprehensively and deliberatively investigated. In addition, it is also important to develop effective strategies for organizing environmental courses which can finally encourage students to engage in PEBs. Therefore, research on environmental education with respect to content structure and learning tools for university students are heavily essential.

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sustainability

Review

Socio-Problematization of Green Chemistry: Enriching Systems Thinking and Social Sustainability by Education

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Abstract: The current research on systems thinking criticizes the additive nature of green chemistry (GC) not being supportive of systems thinking to achieve holism in its practices. This paper argues that systems thinking should comprise of the social issues, and, therefore, it studies renowned papers by GC pioneers and reviews on the field regarding how they address the social dimension of sustainability. It points out how GC has ignored social sustainability in its discourses, practices, and evaluations, leading to a reductionist interpretation of sustainability. Then, this paper presents some challenges to be overcome in order to achieve balanced sustainability. A systemic chemical thinking is advocated, considering chemistry in culture and chemistry as culture, expanding the chemistry rationality from ontological and technological dimensions into the epistemological and ethical ones. It is then discussed how chemistry education can help to promote sustainability in a broad and systemic way.

Keywords: green chemistry; bildung education; social participation in science; democracy in science; social sustainability; chemistry education; chemical thinking

1. Introduction

A quarter of a century after the emergence of green chemistry (GC), it has been verified that its practices towards sustainable chemistry may be more incremental than transformative if the twelve principles are not considered as a cohesive system setting the hows and whys of chemistry practice [1–3]. One of the causes of this problem is the lack of systems thinking in GC [2], which leads to chemical practices that focus on specific aspects and do not address the complexity of the unsustainability issue [3,4].

Following the Responsible Care Program, an autonomous initiative of large chemical corporations initiated in 1989, GC rose as an academic and industrial pursuit of economically viable technological innovation to reduce waste emission, prevent pollution and minimize health hazard in chemical activities. Some positive correlation between GC and sustainability has been verified, but this relationship has not always been clear, and the role of GC is not explained [5]. Concerns have arisen from the genesis of GC amidst the industrial system, and from its definition, which emphasizes the compatibilization of economy and environment [6], as stated by Anastas and Beach, "It has been said that the term green chemistry was derived from the dual connotations of the word "green" concerned with the environment and the color of the US dollar. There is an additional connotation of the word "green," which is young, fresh, and new" ([7], p. 20).

Chertow [8] and Commoner [9] proposed that environmental impact is a function of three factors—population size, consumption (or affluence), and technological level—and, therefore, sustainability is based on three pillars (triple bottom line model): society, environment, and economy [10]. At the Stockholm Conference 1972 [11] and in its The Limits to Growth report [12], economic growth and environmental preservation are said to be incompatible, although the concept of sustainable development presented in the Brundtland Report, fifteen years later, denies this incompatibility, promoting technological development as a means to overcome it [13].

When action is carried out, society may be invited to monitor and evaluate its performance and impacts. Because the action always has a degree of unpredictability, it is necessary to monitor its results. On the basis of these considerations (the need to balance the economy, society and the environment, and the tendency of the concept of sustainable development in the Brundtland Report to focus on the economy at the expense of the environment and society), the relationship between GC and sustainability is put to question. The main interest of this paper is to discuss how the social dimension appears in GC research, and reflect on how education can contribute to a more complex and systemic vision of what sustainability is, and the role of chemistry in achieving it.

Quality education is defended as the fourth Sustainable Development Goal proposed by UNESCO as a means to achieve social sustainability (ending inequality in access to education and promoting training to better jobs) and as a means to develop a mentality towards sustainability [14,15]. Chemistry deals with the manipulation of matter and energy to create useful products for society, and therefore it has a major role in promoting sustainability [16,17], and chemistry education should focus on this aim. Anastas and Zimmerman argue that GC is the chemistry of sustainability and that enabling system conditions is a conceptual framework of GC. Nonetheless, several authors propose that systems thinking should be incorporated in chemistry education [17–19], improving the quality of education and promoting sustainability.

The next section discusses social sustainability, its definition, limits, and assessment. The Section 3 analyzes how social participation in scientific endeavors is possible and why it should be done. Sections 4 and 5 present methods and results, respectively. Finally, Section 6 advocates for a chemistry education that allows a complex understanding of sustainability in its multiple dimensions, which provides for an understanding of (green) chemistry as culture and within culture, and that aims at full human development.

2. Social Sustainability: Definition and Assessment

Social sustainability is a complex concept where the basic idea is that there is something in society that must be maintained and sustained. However, defining what this ideal state of society is and how to assess it is a complex task. In a compilation on the understandings of the social dimension of sustainability, Dillard, Dujon, and King [20] use a work definition of social sustainability that considers it in two aspects: as a means to achieve environmental and economic sustainability, and as an end to an action, aiming at well-being and social health. Social sustainability is a necessary condition and an end for sustainability in general, which allows us to infer that, without social development, there is no way to reduce environmental impacts and promote economic development, hence its importance for GC as well.

Boström [21] analyzes the difficulties in conceptualizing social sustainability, identifying in the literature a confusion between substantive aspects (what is social sustainability) and procedural aspects (how to achieve social sustainability). The author [21] argues that the substantive aspect of the social dimension has to do with quality of life, well-being, and happiness as well as with the fulfillment of basic needs: food, home, income, fair distribution of advantages and disadvantages, rights equality, access to social and environmental infrastructure, opportunities for learning and self-development, security, health, social cohesion, cultural diversity, respect to traditions, sense of belonging and social recognition. Social welfare is achieved through the procedural aspects of social sustainability, which involves broad participation in decision-making and regulation of scientific and technological activities, e.g., access to information about the project (transparency), participation in the decision-making throughout the project, proactive communication between the stakeholders, empowering participation (education, divulgation, and economic compensation), participation in defining the assessment criteria and indicators, and social monitoring of the working project. In other words, what must be achieved and sustained is the welfare of society, and the path for that it is promoting autonomy, competence, and relatedness [22,23].

Promoting sustainability is a complex problem, and social sustainability is perhaps its most difficult tenet to be promoted and analyzed. Sustainability assessments have disregarded the social dimension [21] because of the complexity of establishing and measuring social indicators [24–26]; the high stakes of social sustainability and the difficulty in conciliate it to the environment and the economy; the close relationship between the historical and institutional development of sustainability, on the one hand, and environmental sustainability, on the other; the inefficacy of market-based strategies to promote social justice; and lack of attention to the relationships, synergies, and trade-offs between the three tenets, usually regarded as independent dimensions.

The United Nations Environment Program (UNEP) and the Society of Environmental Toxicology and Chemistry (SETAC) propose the social life cycle analysis (SLCA) as a suitable methodology for analyzing social impacts (negative or positive consequences on the welfare of stakeholders) arising from an activity [27]. However, the indicators for SCLA are not clear and vary in the depth and breadth of its consideration of the social dimension.

From an ethical or normative point of view, SLCA is not efficient in determining whether a process should be carried out or not [28]. Its assessment may indicate whether an action may have impacts and to what degree, but it is not enough to determine whether the action is really necessary. Hence, there is a need to actively involve multiple stakeholders during the entire process of design, implementation, and running of a technological enterprise [21,27]. Broad social participation helps to curb enthusiasm (technological optimism) by redefining what is possible and what must be compromised, to explain the political nature of sustainability where the aims of society are democratically discussed, and to reinterpret the environment in light of social justice to embody the urban environment, the discussion on racism and gender equality, home access, poverty and so on [21].

It is also needed to approach social sustainability as a complex concept with a different epistemological nature than the environment or the economy, requiring research conducted jointly by social and natural scientists in order to fully develop its fundaments as well as to find ways to integrate and compare the three dimensions of sustainability regarding their intrinsic differences, and avoiding applying the same assumptions on them [28]. Democratization, in the debate about the concept and how to assess it, is a condition that determines the success of social sustainability and is also a valued attitude in any process.

3. Social Participation in Science

In the past, when greater social participation in science and technology was proposed, it was common to hear the following provocation: How can society decide between a continuous flow or batch process? How can the layman decide between toluene or water as a solvent? These are valid points, but not altogether unassailable, as their speakers consider chemistry only as a hypothetical technical activity detached from the real world. The following questions may be added: What problem does a given action aim to answer? What solution is being proposed? Who are the beneficiaries, who is excluded, who is harmed? Is this process necessary, good, or fair? Here, chemical activity is set in the real world; chemistry is not a mere theoretical activity (only explaining what the world is), but a practical one, that intervenes in the world and transforms it [29–31].

If a chemical activity is viewed as purely theoretical, without any relevant application to society or any environmental or social impact, that will deny the very history of chemistry and its responsibility. The fact is that chemistry produces materials, interferes with the world, engages in problem-solving, reviews its practices, as well as theoretically researches the world. The intention or desire to practice chemistry is not exclusive to scientists; it may be a collective desire of society. The use of the verb may underscore the need not to presume the wishes of society, but it highlights the importance of investigating them systematically.

A practical activity is born by desire, but it is implemented by deliberation [32], i.e., by collecting and analyzing all the possible strategies, tools, and methods to achieve the goal. At the deliberation stage, it is important to recognize that solving a practical problem requires more than knowing how to apply universal knowledge (the laws of science) because science is built on models and idealizations of the world [33]. Practical problems are idealizable, not ideal; its numerous variables cannot be forcibly eliminated [32]. Thus, experts in only one branch of knowledge are unable to make a broad survey of possible alternatives to achieve the previously formulated desire. Also, understanding what the problems are and the best way to solve them requires acknowledging the needs, desires, and practices of lay people. Dialogue among different social groups is necessary.

The great contribution of science lies in its ability to systematically investigate the possible alternatives arising in the deliberation stage. From this space of alternatives created with broad participation of society, it is possible to evaluate which means are effective and most efficient. However, society is also required to debate their preferences and the acceptable types and patterns of risks inherent in the process. It is necessary to discuss with the population which risks they consider acceptable or intolerable in a given context if the action should prioritize speed in results or low costs (efficiency issues), especially taking into account the people who will be directly impacted.

Some cases make this point clear. According to Irwin [34], the measures to control the health crisis caused by bovine spongiform encephalopathy (mad cow disease) were imposed without any dialogue with the slaughterhouse workers who were to put them into practice, who regarded the experts' recommendations as unrealistic or without any practical sense. Mats Utas' [35] research on Ebola control failure as a result of expert determinations that ignored the context of vulnerable populations, and imposed regulations that the population did not understand the need for and which, sometimes, defied their own beliefs and culture. Michel Callon [33] reports one mode of relationship between science and society, where lay people act as co-producers of knowledge, being a concerned group—a collective of very interested or highly impacted individuals. The author mentions patients suffering from the same rare genetic disease gathering effort to produce data about the characteristics and development of their illness when the experts themselves had given up.

Society can influence science much more than just by being responsible consumers who choose the more environmentally benign product. Society can influence scientific agenda, debating the problems that should be addressed by scientists, backing up their research, and even organizing and collecting data to enrich the investigation. As Fiorino [36] argues, democratic social participation in decision-making processes about scientific-technological enterprises is justified by instrumental, normative, and substantive arguments:

- Instrumental argument (because it works): Democratic participation enables less social resistance, greater technological adoption, popular support for entrepreneurship, and greater trust in institutions;
- Normative argument (because democracy is a value in itself): Participating in the decision-making of processes that affect public life is an inalienable characteristic of being a citizen, which is ultimately the basic characteristic of the subject living in society;
- Substantive argument (because it alters the very nature of the enterprise): Lay people have different but equally useful knowledge for decision making. The general population, especially those directly involved with a technological alternative, have more knowledge of the problems and the context in which they are inserted, their goals, and their desires. Addressing this knowledge in decision-making gives greater complexity and greater adequacy of solutions to real problems.

4. Materials and Methods

As discussed above, social sustainability is a necessary condition and a desired end of sustainability. It is important, therefore, to analyze how the social dimension of sustainability has appeared in the works that spread and debate GC.

We investigated 37 (13 + 24) papers regarding the role of society in the relationship between GC and sustainability. Those papers were selected according to the following criteria:

- Nineteen reviews mentioning sustainability issues were analyzed because of their importance in establishing the boundaries of the GC domain, as they are authored by pioneers of the GC field and referenced in GC textbooks (as previously discussed by Marques and Machado [5]). Thirteen papers address social sustainability and therefore are reported here;
- Twenty-four papers were carefully chosen from the Green Chemistry Journal, relating GC and social sustainability (search terms: social life cycle sustainab *; social metric sustainab *). These papers were retrieved in March and November 2019, and no period of publication was delimited.

Those publications were fully read, their mentions of the social dimension of sustainability were extracted and analyzed regarding the role of society in GC practices, either in the definition of the research agenda, the development of the research and its regulation, or in the impacts imposed on society. It was considered how societal questions influenced the motivations and grounded the problems addressed in the research, as well as how the papers approached social participation in GC, either by political means or participatory decision-making. Finally, careful attention was paid to the indicators and tools to assess the social dimension of sustainability.

The excerpts representing the relationships between GC and society were extracted and grouped into the following analytical themes:

- Society implied in social responsibility
- Compatibility between the environment and the economy, and indirect benefits to society
- Green chemistry and regulation through policies
- Lack of public participation and GC as an elite social movement
- Lack of social life cycle indicators

Below we present the results. The analytical themes were not discussed separately as they emerged interconnected.

5. Results

5.1. Green Chemistry: Environment, Economy, and Society?

Some papers acknowledge the triple nature of sustainability [3,16,37,38], but the relationship between the three dimensions (society, the economy, and the environment) is not fully established or developed, although it is said that environmental issues are the most important, and that social and economic dimensions are of secondary importance ([37], p. G72).

When papers cite the social dimension (which they seldom do), it appears in a triad: environmentally benign, economically viable, and socially responsible [39–42]. The notion of social responsibility is strong in GC [43] and has its origins in the Responsible Care Program, aimed at better environmental and safety performance, and improving the public perception of chemistry [44]. The program emerged as a response to chemical disasters in the late 20th century [40] with the initial intention, as King and Lennox [44] point out, to avoid costs for companies with lawsuits and rigid regulatory policies, which corroborates GC's intention to be a non-regulatory movement focused on the self-adherence of the industrial sector [43,45]. The program reveals that chemists acknowledge their responsibility for some major environmental impacts and will engage in actions to avert it. However, its contradiction, according to Givel [46], is trying to reconcile the interests of corporations with those of the community while precisely intending to change the public's perception of chemistry, and also opposing to restrictive regulations of processes and products so as not to increase costs for corporations.

Society is, therefore, considered to be just consumers dependent on chemical industries to produce their goods and being influent on the economy by their behavior [3,39,47,48]; hence the importance of constructing a good image of the corporations. This can be seen in the statement [3] (p. 1950) "Those necessary interactions [for GC development] include a supply of educated and aware chemists, collaborators in the broad range of disciplines, recognition of value of sustainable products and processes by consumers, investment by businesses and venture capital, and stable funding of research" [3]. Responsible action benefits society by minimizing impacts on health and the environment [39,41,43,49], showing a limited understanding of society as a whole: humans are more than their physical bodies, and society also deals with complex relations and wills of its subjects [40]. Thus, the idea of social responsibility becomes the strongest link of GC with social sustainability, but its lack of clarity in its definition may hide a corporate maneuver to keep economic interests above environmental and social issues.

Contrary to the idea that economic growth and environmental maintenance are contradictory [12,50], GC is based on possible compatibility between these two dimensions [39,43,51,52]. Winterton [53] argued that the demand for materials and services to maintain the lifestyle of a growing population can increase the environmental impact unless technologies are created that allow for more efficient use of resources. Manley, Anastas, and Cue [39] are very straightforward in saying that trying to "balance" economic, environmental, and social dimensions will inevitably result in trade-offs, so GC should seek a synergistic interaction through technological innovation that allows the improvement of efficiency and adds value to products, serving as a differential in the growing commodities market.

Technological innovation is the great theme of GC [1,7,38,39,48,51,53,54], their basic type of action alluding to the idea that GC has an instrumental nature [6], and that technological innovations are a categorical value [55], as seen in the following statements: "The challenge facing industry and society at large is extending technological innovation in a way that is sustainable both economically and environmentally" ([43], p. 5) and "Green Chemistry is about innovation—continuous improvement" ([39], p. 745).

Nevertheless, GC's technological optimism is an illusion that can hinder the pursuit of sustainability [6]. Technologies do not work isolated but are inserted in a technological system relying on multiple conditions to work properly [56]. That is why green technologies may not be enough to fight environmental degradation if they do not see the complex technological and social systems in which the chemical industry is positioned. That is why we need to develop systems thinking [57]. It should be remembered that the technological system encompasses all the process, inputs, and outputs from the cradle to the grave (or cradle to cradle) and the cultural domains in which it occurs, as recently pointed out by Anastas and Zimmerman [16]. Hence technological innovation is not simply additive, a mere change of apparatus, but a complete revolution on the ways people interact and produce. Think of the communication and information technologies and its relation to society; even the press was involved in a great cultural transformation around the world. Systems thinking in GC should take the social embeddedness of technologies into consideration when addressing sustainability issues [57–59].

Some GC researchers are aware of this, and consider that GC is a necessary condition for sustainability that needs political support to be effectively implemented, even if they do not agree on which type of policy should be implemented. Many of them promote GC as a normative institution, being self-organized, fighting restrictive regulations (taxes, bans, and additional costs) [1,43], and proposing positive policies [16,47,48,54] (e.g., funding for research on green technologies, tax incentives for the adoption of eco-efficient technologies). On the other hand, Thornton in 2001 (p. 1231) had already considered that GC will only contribute to sustainability if "it is conceived as part of a new policy based upon precautionary [principle]," enabling the management and even the banning of entire classes of chemicals (such as organochlorides). Later investigations consider that the regulation on the registration, evaluation, authorization and restriction of chemicals (REACH) has some background on a precautionary and restrictive approach, although it also has a technocratic aspect, relying primely on natural science data and ignoring social issues and broad social participation.

GC, nonetheless, has kept itself away from public debate, acting as an "elite movement" [45], a social movement that relies on internal transformation via the education of its academic elite, and influencing the industry with the economic advantages of green technologies. Society is seen as the consumer, affected by the new image of the "green corporations" indirectly changing the market. This elite movement has been appointed as a slow process with no guarantee of success [45]. Green chemists themselves state that positive policies are needed to influence changes in the direction of GC. Matus [40] goes further and finds that a mix of regulations (positive and negative policies) and normative institutions (principles, self-organized commitments) is much more effective in promoting changes, proposing that GC tighten its relations to organized civil society in order to facilitate knowledge transfer, increase awareness of environmental problems, reward achievements in environmental protection, highlight the gaps of industrial activity and enrich the overall process. Hence the importance of GC in relation to environmental movements and non-governmental organizations is to promote its practices and gain both social backup and a broad set of supervisors and shareholders.

It should be emphasized that current studies show that the positive/negative correlation between technological innovation and production depends on the country's economic context and of changes in the entire technological system, not just of a single technology. In the case of GC, it must be acknowledged that technological innovation does not guarantee increased productivity (wealth) or environmental protection if there is not a political, social and technological system that supports these innovations, which means that changes in both the industrial and social structures are necessary to achieve a more environmentally benign approach.

Another point of contention in the supposed compatibility between economy and environment through innovation is the intrinsic inefficiency of technologies. As postulated by the second law of thermodynamics, any process only occurs with the degradation (anergy) of a part of useful energy (exergy) and transformation of matter from a low entropy state (high organization) to a high entropy state (low organization, high stability) [5,50]. Thus, the idea of a circular (or closed) economy is inconceivable (although it has permeated GC discussions) [3,60–67], since the total energy is maintained throughout the process, but the possibility of its use is always diminished [50,68,69]. Besides the physical limits imposed on technologies, which inexorably lead to environmental degradation, there are also problems of technological efficiency, i.e., it is not always that theoretical yields are attained in practice [53]. GC can effectively act to improve this technological efficiency, but without the pretension of a zero environmental and social impact, because that would mean contradicting the Entropy Law [16].

In a recent article, Anastas and Zimmerman [16] discuss the role of GC in promoting sustainability by discussing the field's tools, strategies, and goals. This article, an exception in the group analyzed, considers the part of GC for social welfare and presents categorical objectives that override economic factors. The authors set humanitarian objectives of GC as the proactive pursuit of well-being beyond the mere diagnosis and mitigation of impacts, a chemistry that refuses to produce substances and processes that serve war, death, and either chemical or economical addiction, respecting the free access to genetic information of nature and the individual's control of his own genetic code. Science communication in clear, accessible and true language is advocated as a means of bringing the public closer to chemistry, demystifying the public perception about the field, and attracting the lay-person's trust.

However, the strategies to achieve these goals are not so clear. The authors [16] argue that externalities are considered in cost assessment and that social benefits can be incorporated into the decision process. While denying that this is monetizing social and environmental qualities, the authors understand that this can create value that confer monetary benefits, which sounds paradoxical, especially when the authors themselves agree that "profit is the almighty motivator." The discussion continues to warn of the limitation of metrics in making a complex analysis of multiple variables, many of them qualitative (such as social and environmental), which limits the scope and possibilities for innovation.

5.2. Green Metrics and Social Indicators

Assessing the sustainability of GC practices remains a challenge. The metrics proposed so far focus on the efficiency of processes with respect to mass and energy (E-factor, mass intensity, atom economy); some work with intrinsic risks of chemical products (Green Star, for instance), but the evaluation of sustainability of the processes is more comprehensive, and researchers have suggested the life cycle assessment (LCA) as a viable alternative. Although LCA allows for a more holistic assessment of industrial practices, it is often reduced to economic and environmental aspects because of the lack of clarity of social indicators and effective ways on how to assess them [24–26,37,38,70]. Even the environmental indicators are difficult to measure in the proposed LCA due to lack of available data on the impacts of the production, consumption, and disposal of chemicals [71,72].

Jiménez-González et al. [73] reviews the LCA processes in the pharmaceutical industry but does not report the evaluation of the social dimension. Tabone et al. [74] correlate Green Design Principles to sustainability indicators, ignoring explicit mentions to social sustainability. Kralisch, Ott, and Geriche [71] provide a tutorial-review on LCA in green chemical processes and report only one evaluation strategy of social, economic, and environmental dimensions together—the SocioEcoEfficiency analysis (SEEbalance) developed by BASF [75]. Van Schoubroeck et al. [76] review sustainability indicators in the bio-based economy (an important branch of GC) [3] and found degrees of importance attributed to the dimension: half of the assessments were one-dimensional and related to environmental impacts; 34% were two-dimensional, regarding the environment and the economy; 16% encompassed the environment, the economy and society together, even though it was not done in a dynamic and interlinked way. The aforementioned authors [76] conclude that there is a hierarchy underlying the sustainability dimensions, the environmental one being the most assessed, followed by the economy, and society barely being mentioned.

In April 2019, a paper was published reporting techno-economic analysis along the SLCA. Sadhukhan et al. [77] investigated the avoidance of social impacts when transitioning from an industry based on animal protein, plant sugar, and marine salt into extracting proteins, sugar, and salt from microalgae. Their methodology follows the UNEP/SETAC guidelines, considering as social indicators: "labour rights and decent work; health and safety; human rights; governance; and community infrastructure and underneath twenty-two sub-themes" ([77], p. 2649). These indicators go beyond the impacts on human health, addressing issues of gender and race, social conflicts, infrastructure in the local community and so on [27].

As noted, LCA is focused on the evaluation of processes that are already carried out (an impact assessment), while GC is focused on research and design, in which the processes are generally exploratory and not yet applied on a large scale, which makes it difficult to evaluate by LCA [78]. This may pave the way for important interactions between GC and society if democratic and constructive evaluation processes are proposed, rather than focusing on post facto evaluation. This is the case of constructive technology assessment [79,80], an approach that provides broad social participation in the design process of technologies in which the public contributes to the establishment of a socially committed research agenda and the creation of social indicators relevant to all stakeholders, enabling a more effective technological adherence, representativeness of objectives and plurality of values. This can be an interesting path for GC to tread, expanding its agents and members beyond industrial sectors, government, and academics, including society as a strong partner to promote social transformations and environmental preservation.

The issue is complex and extrapolates the field of expertise of (green) chemists. It is necessary that sustainability metrics researchers and sociologists seek together the construction of acceptable and effective social indicators to evaluate the sustainability efficacy of (green) chemistry. It is also important that these indicators emphasize the need to strengthen GC dialogue with the general population and decision-makers. GC needs to expand the role of its members, extrapolating the scope of the academy and provoking social mobilization to generate the popular pressure necessary to put into practice the transformations that it intends. Partnerships with environmental movements and other organized civil groups can help to disseminate GC practices and objectives while enabling GC to rethink and enrich its objectives. Chemistry education, hitherto focused on training highly specialized chemical professionals in environmental matters, must also cover the dissemination of GC for the education of non-specialist citizens in the creation of an environmental culture.

Regarding the relationship between GC and social sustainability, a number of problems may be identified:

- GC has no clear relationship with social sustainability;
- The social dimension is subsumed to the economic dimension;
- GC's technological optimism;
- Lack of broad social participation in GC activities;
- Lack of adequate instruments for assessment.

In the following section, we discuss some contributions of chemistry education to address these problems and pursue sustainability.

6. The Social Dimension in Chemistry Education

The problem with today's chemistry teaching is that there is too much focus on presenting chemistry substantively (what we know and how we can explain it) and too little effort in teaching chemistry as a creative activity (how we think and what we can do with this form of reasoning) [81]. Within the modernist (or positivist) atmosphere [82], chemistry has developed the image of a set of purely conceptual descriptions (of an ideal form) of reality and has lost its character as a transforming agent [58]; its technological nature [6] was suppressed and its social responsibility was only recently recovered [59].

Educating a responsible citizen is not the same as educating a well-informed individual because it requires more than being able to explain a phenomenon. It is necessary to eliminate the artificial separation between chemistry as content, chemistry as process (research and design), and chemistry as a social agent [81] so that systems thinking is more than thinking about the concepts and processes of chemistry throughout the production chain, but it is also about reflecting on society and its goals, facing chemistry *within* culture and *as* culture [57,82].

Chemical thinking is complex and involves several dimensions that need to be developed together if it is to have an effective and transformative practice. For Sevian et al. [83], chemical thinking involves the knowledge, reasoning, and practices that characterize chemical activity, geared towards the development and application of chemical knowledge for analysis, synthesis, and transformation of matter for practical purposes; for Mocellin [84], the chemical style of reasoning has to do with synthesis, control, and transformation. These are the ontological and technological dimensions of chemistry on which Sjöström [6,82] highlights the epistemological and ethical dimensions. Thus, systems thinking in chemistry may be said to involve four interconnected dimensions (see Figure 1):

- Ontological: chemical theories of description and explanation of reality;
- Technological: procedures of transformation and synthesis-intervention in reality;
- Epistemological: philosophical and sociological perspectives on the production of the chemical knowledge of reality; and
- Ethical: the role of chemistry in society.

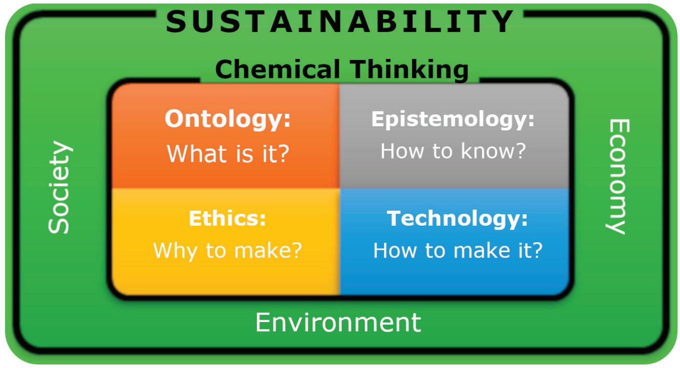

Figure 1. Dimensions of chemistry systems thinking inside the context of sustainability.

These dimensions demonstrate the social character of GC, being embedded in the broad context of sustainability, and are the requirements for a reflexive [6,58] education, a *Bildung* education. *Bildung* is a complex concept [85,86] developed in central and northern Europe since the thirteenth century, acquiring an educational status since the 18th century; it describes the movement of incorporation of the individual into culture. For Sjöström [87], *Bildung* is the awareness of the biases that base the opinions and actions of an individual, contrasted with the social context in which one lives, having to do with the competence for self-determination (autonomy, to follow one's own values), constructive participation in society, and solidarity with people limited in their capacity for self-determination and participation.

As discussed above, GC does not openly discuss its relations with society, and yet it is heavily reliant on the pursuit of technological innovations to solve environmental problems, which has been linked to technological optimism. GC teaching is aimed at the training of qualified professionals to develop and implement green technologies, which shows that GC and its teaching primarily develop its ontological (conceptual) and technological (procedural) dimensions, but it is limited in locating the production of green knowledge in the broad social context (epistemological and ethical); it is a systems thinking reduced to the technological context, a "sub-systemic" thinking. Including the social and cultural system in chemical systems thinking, as discussed above, also requires discussing critically what are the present and future needs of humankind and how to include society in planning research programs and building and evaluating technologies. So far, the societal objective of (green) chemistry is not openly discussed [31], but it has been directed to economic growth [82].

There are several ways to relate science, technology, and society, influencing how to approach science teaching. Sjöström et al. [86] propose three approaches in scientific literacy: (1) conceptual, aimed at discovering the "secrets of nature"; (2) contextual, aimed at solving problems of the productive sector through the understanding of science and its application; and (3) critical, "presenting radical solutions to existing (environmental and social) problems and/or new problems beyond the agenda of the (industrial) establishment" ([82], p. 90), considering education as a means to transform individuals and society. In conceptual and contextual strategies, the social purpose of chemistry is not critically reflected; industrial society and technological innovation are considered as the best solution, but it is neither systematically reflected on what the real problem is nor the limits of technologies. This is made by critical scientific literacy, to think science and technology in terms of a critically defined and socially debated social project, contributing not only to the democratization of social processes but also to the enrichment of the knowledge to be created by scientists. The critical approach is that which relates to the concept of critical-reflexive *Bildung*.

Burmeister, Rauch, and Eilks [88] and later authors [6,89] propose four models for GC integration in chemistry curricula to promote sustainability. Model 1 considers the adoption of sustainable practices in laboratory activities in scientific education, enabling the student to recognize, compare, and reflect on how academia and industries try to minimize the environmental impacts of their activities. Model 2 adds principles of GC and sustainability as topics in theoretical, practical courses, or both, showing the technological advances obtained in the field. In Model 3, controversial questions about sustainability are used for learning *of* science and technology and learning *about* science and technology, making possible the understanding of the arguments involved in the debate and the engagement in the decision-making processes. Model 4 considers the engagement of the whole school and its community in the pursuit of sustainability, extrapolating the scope of teaching activities (teacher-student) and encompassing the role of education within society.

As can be seen, Models 1 and 2 are more related to the conceptual and contextual views of scientific literacy, since they focus on the learning of the ontological and technological dimensions of chemistry. Models 3 and 4 also cover the discussion of the production of chemical knowledge in its broad social context and the need for community engagement to achieve sustainability and, therefore, these models are more adequate for the critical view of scientific literacy and are aligned with the critical-reflexive *Bildung*. Although punctual insertions of GC in chemistry curricula (whether in laboratory practice or on disciplinary topics) are important to disseminate green practices, they are not sufficient to develop effective transformation and education for systems thinking (incorporating ontological, technological, epistemological, and ethical dimensions).

Levinson [90] compared different approaches to science–society relationships in schools, describing the educational purpose of science-technology-engineering–mathematics (STEM) as providing human capital, that of socio-scientific issues (SSI) as development of scientific knowledge needed for socio-scientific reasoning, that of socially acute questions (SAQ) as developing a critical discourse, and that of science and technology education promoting well-being for individuals, societies and environments (STEPWISE) [91,92] as knowledge for action for socio-ecojustice. Besides STEPWISE, other frameworks are also directed to develop socio-ecojustice, like the socio-scientific sustainability reasoning (S^3R) model [93], and different socio-critical and problem-oriented approaches of science–technology–society–environment (STSE) studies [94,95] such as the Latin American science, technology, and society (LASTS) [96,97], for instance. In its more socio-critical version (such as STEPWISE, LASTS), it is more than teaching to choose between two or more contradictory alternatives; it is about overcoming the contradiction, unveiling the values and philosophies that underly them, searching for new socio-technical alternatives, and performing actions [55,96].

To promote a critical-reflexive Bildung education, socio-critical SSIs can be used to enable understanding of decision-making processes in society and to engage in critical issues, whether through role-playing exercises, case studies or to unravel the values and interests behind scientific-technological policies and media texts, for example. Another important factor is the use of non-formal education to extrapolate the limits of the school environment and better include society in a scientific-technological discussion.

Challenges for Social Sustainability and Educational Guidelines

Table 1 presents some problems in the relationship between GC and social sustainability that may hinder the achievement of full sustainability. In the substantive aspect of social sustainability, GC has not a clear social objective, which is subsumed to the economic dimension. Acknowledging the social genesis of (green) chemistry knowledge in education and discussing an acceptable aim to its practice may be a way to address the epistemological and ethical dimensions of chemical thinking. In the procedural aspect, social sustainability is allegedly achieved by technological innovation, what can be criticized by taking into account technological/entropic inefficiency and the social embeddedness of technology, requiring broad social participation and cultural transformations to achieve sustainability. This calls for a socio-critical *Bildung* education, approaching the entire complexity of chemical thinking in its ontological, technological, epistemological, and ethical dimensions, treating chemistry *in* culture and *as* culture, leading chemistry systems thinking beyond the industrial system and into society.

Table 1. Current problems of green chemistry (GC) to address social sustainability (SS) and the respective educational guidelines and chemical thinking (CT) dimensions.

SS Aspects	Current Problems	Educational Guidelines	CT Dimension
Substantive	No clear relationship between GC and SS	Contextualizing chemical practices and concepts in their broad social context	Epistemological
	Social dimension subsumed to the economic dimension	Discussing the social objectives, the values, and ideologies of chemical practices	Ethical
Procedural	Technological optimism of GC	Promoting the critical evaluation of technological innovations	Ontological; Technological; Epistemological; Ethical
	Lack of broad social participation in GC	Pointing out strategies for broad social participation in scientific, technological and political decision-making processes	Ontological; Technological; Epistemological; Ethical

7. Conclusions

The present analysis has shown that the social dimension is reduced and never explicitly elaborated in GC. The few mentions to the social dimension were related to corporate social responsibility, a self-regulatory initiative of the chemical industries that attempts to change society's perception of chemistry itself. Technological optimism guides GC actions and underlies the belief that the environment and the economy are compatible and they can produce direct and indirect benefits to society (which are not explicitly clarified). At the policy level, GC tries to avoid cost increases due to environmental regulations by creating proactive alternatives. This makes it an elite social movement, targeted at experts and policymakers, ignoring the need for support from other social sectors such as NGOs and environmental movements. Finally, few mentions to social indicators are found, even in more specific tools such as the social life cycle assessment.

Only one analyzed article, published in June 2019, places humanitarian goals above economic progress; integrating benign design, cost reduction, and social dimension into systemic chemical thinking; and underscores the need for qualitative metrics to address this complexity. However, the authors do not make clear the means for GC to achieve its humanitarian goals or to evaluate its performance in this regard so that they make important but still incipient notes.

This qualitative research has the limitation of not covering all GC research, which has tens of thousands of articles. However, it points to a set of important texts (either referenced in textbooks or published in the largest and most important journal in the field), so that the results presented may point to weaknesses and potentialities of this growing field. Further research is needed to explore the relationships between GC, sustainability, and the social dimension, whether in industrial or research practices, in assessment or the concept of systems thinking.

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