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]. These 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
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:

RQ1: 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?

RQ2: What relevant teacher characteristics influence pre-service teachers’ diagnostic skills?

RQ3: 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, \(M_{\text{age}} = 24.32\) 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].
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 $\alpha$ 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 $\alpha$ values are common and acceptable in the context of meaningful learning [52].
Table 2. Reliabilities (Cronbach’s $\alpha$) for professional knowledge.

| Scale                          | Number of Items | Cronbach’s $\alpha$ |
|-------------------------------|-----------------|----------------------|
| 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.
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.

![How pre-service teachers interpret students’ verbal expressions](image)

**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.

| Indicator                      | 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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References

1. Leicht, A.; Heiss, J.; Byun, W.J. (Eds.) *Issues and Trends in Education for Sustainable Development*; United Nations Educational, Scientific and Cultural Organization: Paris, France, 2018; ISBN 9231002449.
2. Rieß, W. *Bildung für Nachhaltige Entwicklung. Theoretische Analysen und Empirische Studien*; Waxmann: Münster/München/Berlin, Germany, 2010; ISBN 9783830923114.
3. Rieß, W.; Mischo, C.; Waltner, E.-M. Ziele einer Bildung für nachhaltige Entwicklung in Schule und Hochschule: Auf dem Weg zu empirisch überprüfaren Kompetenzen. *GAIA Ecol. Perspect. Sci. Soc.* 2018, 27, 298–305. [CrossRef]
4. Schuler, S.; Fanta, D.; Rosenkraenzer, F.; Rieß, W. Systems thinking within the scope of education for sustainable development (ESD)—A heuristic competence model as a basis for (science) teacher education. *J. Geogr. High. Educ.* 2017, 42, 192–204. [CrossRef]
5. Fanta, D.; Braeutigam, J.; Rieß, W. Fostering systems thinking in student teachers of biology and geography—An intervention study. *J. Biol. Educ.* 2019, 12, 1–19. [CrossRef]
6. Waltner, E.-M.; Rieß, W.; Mischo, C. Development and Validation of an Instrument for Measuring Student Sustainability Competencies. *Sustainability* 2019, 11, 1717. [CrossRef]
7. Baisch, P. Schülervorstellungen zum Stoffkreislauf. Eine Interventionsstudie im Kontext Einer Bildung für nachhaltige Entwicklung; Verlag Dr. Kováč: Hamburg, Germany, 2009; ISBN 978-3-8300-4720-9.
8. Leach, J.; Driver, R.; Scott, P.; Wood-Robinson, C. Children’s ideas about ecology 2: Ideas found in children aged 5-16 about the cycling of matter. *Int. J. Sci. Educ.* 2008, 18, 19–34. [CrossRef]
9. Opitz, S.T.; Blankenstein, A.; Harms, U. Student conceptions about energy in biological contexts. *J. Biol. Educ.* 2017, 51, 427–440. [CrossRef]
10. Taber, K.S. The nature of student conceptions. In *Science Education: An International Course Companion*; Taber, K.S., Akpan, B., Eds.; Sense Publishers: Rotterdam, The Netherlands; Boston, MA, USA; Taipei, Taiwan, 2017; pp. 119–131. ISBN 9463007482.
11. Rosenkranzer, F.; Kramer, T.; Hörsch, C.; Schuler, S.; Rieß, W. Promoting Student Teachers’ Content Related Knowledge in Teaching Systems Thinking: Measuring Effects of an Intervention through Evaluating a Videotaped Lesson. *HES* 2016, 6, 156. [CrossRef]
12. Larkin, D. Misconceptions about ‘misconceptions’: Preservice secondary science teachers’ views on the value and role of student ideas. *Sci. Ed.* 2012, 96, 927–959. [CrossRef]
13. Kattmann, U. Schüler Besser Verstehen. Alltagsvorstellungen im Biologieunterricht; Aulis-Verlag: Hallbergmoos, Germany, 2015; ISBN 978-3-7614-2941-9.
14. Bransford, J.D. *How People Learn. Brain, Mind, Experience, and School, 3. Print*; National Academy Press: Washington, DC, USA, 2000; ISBN 0309065577.
15. Morrison, J.A.; Lederman, N.G. Science teachers’ diagnosis and understanding of students’ preconceptions. *Sci. Ed.* 2003, 87, 849–867. [CrossRef]
16. Ruiz-Primo, M.A.; Furtak, E.M. Exploring teachers’ informal formative assessment practices and students’ understanding in the context of scientific inquiry. *J. Res. Sci. Teach.* 2007, 44, 57–84. [CrossRef]
17. Loibl, K.; Leuders, T.; Dörfler, T. A Framework for Explaining Teachers’ Diagnostic Judgements by Cognitive Modeling (DiaCoM). *Teach. Teach. Educ.* 2020, 91, 103059. [CrossRef]
20. Heitzmann, N.; Seidel, T.; Hetmanek, A.; Wecker, C.; Fischer, M.; Ufer, S.; Schmidmaier, R.; Neuhaus, B.J.; Siebeck, M.; Stürmer, K.; et al. Facilitating Diagnostic Competences in Simulations in Higher Education: A Framework and a Research Agenda. *Frontline Learn. Res*. 2019, 7, 1–24. [CrossRef]

21. Hammann, M.; Asshoff, R. Schülervorstellungen im Biologieunterricht. Ursachen für Lernschwierigkeiten, 2. Aufl.; Klett Kallmeyer: Seezle, Germany, 2015; ISBN 978-3-7800-4908-7.

22. Ausubel, D.P. *Educational Psychology. A Cognitive View*; Holt Rinehart and Winston: New York, NY, USA, 1968; ISBN 0030696402.

23. Taber, K.S. Alternative Conceptions/Frameworks/Misconceptions. In *Encyclopedia of Science Education*; Gunstone, R., Ed.; Springer: Berlin/Heidelberg, Germany, 2015; pp. 37–41.

24. Lucariello, J. How Do I Get M Students Over Their Alternative Conceptions (Misconceptions) for Learning? Available online: https://www.apa.org/education/k12/misconceptions (accessed on 4 March 2020).

25. Carpenter, T.P.; Fennema, E.; Peterson, P.L.; Chiang, C.-P.; Loef, M. Using Knowledge of Children’s Mathematics Thinking in Classroom Teaching: An Experimental Study. *Am. Educ. Res. J*. 2016, 26, 499–531. [CrossRef]

26. Decristan, J.; Hondrich, A.L.; Büttner, G.; Hertel, S.; Klieme, E.; Kunter, M.; Lühken, A.; Adl-Amini, K.; Djakovic, S.-K.; Mannel, S.; et al. Impact of Additional Guidance in Science Education on Primary Students’ Conceptual Understanding. *J. Educ. Res*. 2015, 108, 358–370. [CrossRef]

27. Furtak, E.M.; Kiemer, K.; Circi, R.K.; Swanson, R.; de León, V.; Morrison, D.; Heredia, S.C. Teachers’ formative assessment abilities and their relationship to student learning: Findings from a four-year intervention study. *Instr. Sci.* 2016, 44, 267–291. [CrossRef]

28. Biologie unterrichten mit Alltagsvorstellungen. *Didaktische Rekonstruktion in Unterrichtseinheiten*; Kattmann, U., Ed.; 1. Auflage; Klett/Kallmeyer: Seezle, Germany, 2017; ISBN 9783772710681.

29. Gropengießer, H.; Marohn, A. Schülervorstellungen und Conceptual Change. In *Theorien in der Naturwissenschaftsdidaktischen Forschung*; Krüger, D., Parchmann, I., Schecker, H., Eds.; Springer: Berlin/Heidelberg, Germany, 2018; pp. 49–66. ISBN 9783662563205.

30. Schoenfeld, A.H. Noticing Matters. A Lot. Now What? In *Mathematics Teacher Noticing: Seeing through Teachers’ Eyes*, 1. *Publ*; Sherin, M.G., Ed.; Routledge: London, UK, 2011; pp. 223–238. ISBN 0-415-87863-2.

31. Helldén, G. Environmental Education and Pupils’ Conceptions of Matter. *Environ. Educ. Res.* 1995, 1, 267–277. [CrossRef]

32. Sander, E.; Jelemenská, P.A.; Kattmann, U. Towards a better understanding of ecology. *J. Biol. Educ.* 2006, 40, 119–123. [CrossRef]

33. Schülervorstellungen und fachliche Vorstellungen zu Mikroorganismen und mikrobiellen Prozessen. *Ein Beitrag zur didaktischen Rekonstruktion. Zugl.: Oldenburg, University, Diss.*; Hilge, C., Ed.; Didaktisches Zentrum (DIZ) University Oldenburg: Oldenburg, Germany, 1999; ISBN 3814206851.

34. Smith, E.L.; Anderson, C.W. Plants as producers: A case study of elementary science teaching. *J. Res. Sci. Teach.* 1984, 21, 685–698. [CrossRef]

35. Schecker, H.; Duit, R. Schülervorstellungen und Physiklernen. In *Schülervorstellungen und Physikunterricht*; Schecker, H., Wilhelm, T., Hopf, M., Duit, R., Eds.; Springer: Berlin/Heidelberg, Germany, 2018; pp. 1–21. ISBN 978-3-662-57269-6.

36. Chi, M.T.H.; Siler, S.A.; Jeong, H. Can Tutors Monitor Students’ Understanding Accurately? *Cogn. Instr.* 2004, 22, 363–387. [CrossRef]

37. Shavelson, R.J.; Yin, Y.; Furtak, E.M.; Araceli Ruiz-Primo, M.; Ayala, C.C.; Young, D.B.; Tomita, M.K.; Brandon, P.R.; Pottenger, F.M., III. On the Role and Impact of Formative Assessment on Science Inquiry Teaching and Learning. *Assess. Sci. Learn. Perspect. Res. Pract.* 2019, 68, 1–40. [CrossRef]

38. Chernikova, O.; Heitzmann, N.; Fink, M.C.; Timothy, V.; Seidel, T.; Fischer, F. Facilitating Diagnostic Competences in Higher Education—A Meta-Analysis in Medical and Teacher Education. *Educ. Psychol. Rev.* 2018, 26, 181–193. [CrossRef]

39. Herppich, S.; Praetorius, A.-K.; Förster, N.; Glogger-Frey, I.; Karst, K.; Leutner, D.; Behrmann, L.; Böhmer, M.; Ufer, S.; Klug, J.; et al. Teachers’ assessment competence: Integrating knowledge-, process-, and product-oriented approaches into a competence-oriented conceptual model. *Teach. Teach. Educ.* 2017, 76, 181–193. [CrossRef]

40. Glogger-Frey, I.; Herppich, S.; Seidel, T. Linking teachers’ professional knowledge and teachers’ actions: Judgment processes, judgments and training. *Teach. Teach. Educ.* 2018, 76, 176–180. [CrossRef]
41. Chi, M.T.H.; Siler, S.A.; Jeong, H.; Yamauchi, T.; Hausmann, R.G. Learning from human tutoring. *Cogn. Sci.* 2001, 25, 471–533. [CrossRef]

42. Van de Pol, J.; Volman, M.; Oort, F.; Beishuizen, J. Teacher Scaffolding in Small-Group Work: An Intervention Study. *J. Learn. Sci.* 2014, 23, 600–650. [CrossRef]

43. Glogger-Frey, I.; Herrpich, S. Formative Diagnostik als Teilaspekt diagnostischer Kompetenz. In *Diagnostische Kompetenz von Lehrkräften: Theoretische und methodische Weiterentwicklungen*; Südkamp, A., Praetorius, A.-K., Eds.; Waxmann: Münster, Germany, New York, NY, USA, 2017; pp. 42–45. ISBN 978-3-8309-8596-9.

44. Klieme, E.; Warwas, J. Konzepte der Individuellen Förderung. *Zeitschrift für Pädagogik* 2011, 57, 805–818.

45. Heritage, M. Formative Assessment: What Do Teachers Need to Know and Do? *Phi Delta Kappan* 2007, 89, 140–145. [CrossRef]

46. Blomberg, G.; Stürmer, K.; Seidel, T. How pre-service teachers observe teaching on video: Effects of viewers’ teaching subjects and the subject of the video. *Teach. Teach. Educ.* 2011, 27, 1131–1140. [CrossRef]

47. Blömeke, S.; Gustafsson, J.-E.; Shavelson, R.J. Beyond Dichotomies. *Zeitschrift für Psychologie* 2015, 223, 3–13. [CrossRef]

48. Piwowar, V.; Barth, V.L.; Ophardt, D.; Thiel, F. Evidence-based scripted videos on handling student misbehavior: The development and evaluation of video cases for teacher education. *Prof. Dev. Educ.* 2017, 10, 1–16. [CrossRef]

49. Helldén, G. What will happen to the leaves on the ground? In *Lehren fürs Leben: Didaktische Rekonstruktion in der Biologie*; Ulrich Kattmann zur Verabschiedung aus dem Dienst der Carl-von-Ossietzky-Universität Oldenburg; Gropengießer, H., Kattmann, U., Eds.; Aulis-Verl. Deubner: Köln, Germany, 2004; pp. 96–108. ISBN 3-7614-2565-1.

50. Rath, V. *Diagnostische Kompetenz von angehenden Physiklehrkräften*. Dissertation; Universität Paderborn: Paderborn, Germany, 2017.

51. Lindmeier, A.M. Video-vignettenbasierte standardisierte Erhebung von Lehrerkognitionen. In *Videobasierte Kompetenzforschung in den Fachdidaktiken*; Riegel, U., Macha, K., Eds.; Waxmann: Münster, Germany, 2013; pp. 45–62. ISBN 9783830928805.

52. Schmitt, N. Uses and abuses of coefficient alpha. *Psychol. Assess.* 1996, 8, 350–353. [CrossRef]

53. Mayring, P. *Qualitative Inhaltsanalyse. Grundlagen und Techniken, Online-Ausg*; Beltz: Weinheim, Germany; Basel, Switzerland, 2015; ISBN 978-3-407-29393-0.

54. Schneider, J.; Bohl, T.; Kleinkecht, M.; Rehm, M.; Kuntze, S.; Syring, M. Unterricht analysieren und reflektieren mit unterschiedlichen Fallmedien: Ist Video wirklich besser als Text? *Unterrichtswissenschaft* 2016, 44, 474–490.

55. Furtak, E.M.; Thompson, J.; van Es, E.A. Formative Assessment and Noticing. Toward a Synthesized Framework for Attending and Responding During Instruction. In Proceedings of the Annual Meeting of the American Educational Research Association, Washington, DC, USA, 8–12 April 2016.

56. Fleiss, J.L.; Cohen, J. The Equivalence of Weighted Kappa and the Intraclass Correlation Coefficient as Measures of Reliability. *Educ. Psychol. Meas.* 2016, 33, 613–619. [CrossRef]

57. Schrenk, M.; Gropengießer, H.; Groß, J.; Hammann, M.; Weitzel, H.; Zabel, J. Schülervorstellungen im Biologieunterricht. In *Biologiedidaktische Forschung: Erträge für die Praxis*; Groß, J., Hammann, M., Schniemann, P., Zabel, J., Eds.; Springer: Berlin/Heidelberg, Germany, 2019; pp. 3–20. ISBN 978-3-662-58442-2.

58. Rasch, B.; Friese, M.; Hofmann, W.; Naumann, E. *Quantitative Methoden 2. Einführung in die Statistik für Psychologen und Sozialwissenschaftler, 4, Überarbeitete Auflage*; Springer: Berlin/Heidelberg, Germany, 2014; ISBN 9783662435489.

59. Eid, M.; Gollwitzer, M.; Schmitt, M. *Statistik und Forschungsmethoden. Mit Online-Materialien, 5, Korrigierte Auflage*; Beltz: Weinheim, Germany; Basel, Switzerland, 2017; ISBN 9783621282017.

60. Van Es, E.A. A Framework for Learning to Notice Student Thinking. In *Mathematics Teacher Noticing: Seeing through Teachers’ Eyes*; Sherin, M.G., Ed.; Routledge: London, UK, 2011; pp. 134–151. ISBN 0-415-87863-2.

61. Osternann, A.; Leuders, T.; Philipp, K. Fachbezogene diagnostische Kompetenzen von Lehrkräften-Von Verfahren der Erfassung zu kognitiven Modellen zur Erklärung. In *Pädagogische Professionalität in Mathematik und Naturwissenschaften, 1. Publ*; Leuders, T., Nükle, M., Mielkiskis-Seifert, S., Philipp, K., Eds.; Springer Spektrum: Wiesbaden, Germany, 2019; pp. 93–116. ISBN 9783658086442.

62. Shulman, L.S. Those Who Understand: Knowledge Growth in Teaching. *Educ. Res.* 1984, 15, 4–14. [CrossRef]
63. Loewenberg Ball, D.; Thames, M.H.; Phelps, G. Content Knowledge for Teaching. *J. Teach. Educ.* 2008, 59, 389–407. [CrossRef]

64. Kunter, M.; Gräsel, C. Lehrerexpertise und Lehrerkompetenz. In *Handwörterbuch Pädagogische Psychologie, 5, Überarbeitete und Erweiterte Auflage*; Rost, D.H., Sparfeldt, J.R., Buch, S., Eds.; Beltz: Weinheim, Germany; Basel, Switzerland, 2018; pp. 400–407. ISBN 9783621282970.

65. Ruiz-Primo, M.A. Informal formative assessment: The role of instructional dialogues in assessing students’ learning. *Stud. Educ. Eval.* 2011, 37, 15–24. [CrossRef]

66. Hattie, J.; Yates, G.C.R. *Visible Learning and the Science of How We Learn, 1*. Publ; Routledge: London, UK, 2014; ISBN 9780415704991.

67. Berliner, D.C. Describing the Behavior and Documenting the Accomplishments of Expert Teachers. *Bull. Sci. Technol. Soc.* 2004, 24, 200–212. [CrossRef]

68. Ericsson, K.A. The Influence of Experience and Deliberate Practice on the Development of Superior Expert Performance. In *The Cambridge Handbook of Expertise and Expert Performance*; Ericsson, A., Charness, N., Feltovich, P.J., Hoffman, R.R., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2006; pp. 683–704. ISBN 9780511816796.

69. Todorova, M.; Sunder, C.; Steffensky, M.; Möller, K. Pre-service teachers’ professional vision of instructional support in primary science classes: How content-specific is this skill and which learning opportunities in initial teacher education are relevant for its acquisition? *Teach. Teach. Educ.* 2017, 68, 275–288. [CrossRef]

70. Waltner, E.-M.; Scharenberg, K.; Hörsch, C.; Rieß, W. What Teachers Think and Know about Education for Sustainable Development and How They Implement it in Class. *Sustainability* 2020, 12, 1690. [CrossRef]

71. Rieß, W.; Mischo, C. “Bridging the gap”—Zur Verringerung der Kluft zwischen allgemeinen Lehr-Lernmodellen und konkreter Unterrichtsgestaltung am Beispiel der Förderung dynamischer Problemlösekompetenz in der Biologie. *Zeitschrift für Didaktik der Biologie (ZDB)-Biologie Lehren und Lernen* 2017, 21, 1–22. [CrossRef]

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