Fakultät für Biologie, Chemie und Geowissenschaften

"Ökosystem Grünland":

Digitale Kompetenzen und Nachhaltigkeitskonzepte der Sekundarstufe-1

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Inhalt

1. Summary

Climate change and its consequences have an increasing impact on our everyday lives. Nevertheless, there seems to be a discrepancy between the preservation of one's lifestyle and the perception of the negative effects of the same. Education for Sustainable Development (ESD) attempts to close this gap by focusing on interconnectedness and multi-perspectivity regarding social, economic, and environmental dimensions of sustainability issues. Addressing such topics in a student-friendly manner requires educational and methodological consideration. Before the pandemic, specialized centers provided ideal learning environments for student-oriented ESD learning [1,2]. This well-established cooperation between schools and extracurricular institutions had to be suspended for the past two years. This raises the question whether such ESD experiences can be substituted appropriately in online distance learning.

Study A dealt with the conceptualization and implementation of a newly developed ESD unit. In the Bavarian curriculum, "Ecosystem Pasture" addresses ESD issues in grade five [3]. The learning content addresses biodiversity of domestic flora and its connection to intensive and extensive agricultural techniques. Scientific working methods are to be trained in the form of plant identification exercises. The new ESD unit implemented these contents with digital teaching methods. Empirical data from a pilot group at an out-of-school learning site showed significant learning gains and consistent environmental protection preferences. In the context of pandemic-related school closures, the question arose to what extent process-oriented competencies can be promoted via digital, asynchronous forms of instruction.

A detailed review of the knowledge gains was presented in study B. Data from an intervention study that had to be conducted in distance learning were compared with the pilot group from Study A. Both groups showed significant learning gains, but surprisingly no significant difference among each other. Potential explanations for these results were discussed. Additionally, two semantic differentials were collected to investigate the concepts *sustainability* and *environmental protection* [4,5]. Although both terms were rated similarly, they represented different factors.

Study C analyzed the relationship of digital preferences, motivational tendencies and learning progress in the ESD learning module. Previous studies showed a correlation between environmental knowledge, attitudes, and behavior [6]. The consensus is that affective aspects, in addition to cognitive components, promote the transition from conventional to more sustainable lifestyles. Accordingly, methodological and content-related preferences of the students were investigated in addition to knowledge gains.

The *Digital Nativity Assessment Scale* was used to assess students' digital preferences [7]. The concept of digital generations is highly debated [8,9]. On the one hand, skill levels among age cohorts are recognized, on the other hand, considerable variations within these groups are reported [10,11]. In addition to further insights regarding preferences of *multitasking*, *real-time communication*, *use of digital devices*, and *graphical representation* among fifth graders, the influence of digital nativity on knowledge gains in a digital learning environment was examined. Recommendations for digital instruction in secondary education were derived.

The *Fascination with Biology* scale was used to assess motivational preferences [12]. The relationship between motivational components and ESD has already been surveyed in other studies [13–15]. Additionally, digital preferences were compared with interest in biological content. The extent to which pandemic distance learning and the resulting increased screen time have a positive or negative influence on this value was discussed. In a structural model, it was shown that both digital nativity and fascination had a positive influence on knowledge gains.

In addition to study B, qualitative data on the distinction between *sustainability* and *environmental protection* were collected for study D. Students' preconcepts are of special interest for phenomenon-oriented subjects [16,17]. They are not only relevant for effective ESD teaching but used in problem-oriented STEM teaching as well [18,19]. As indicated by other studies, most items were assigned to the ecological dimension [20]. Thus, more attention should be paid to economic and social aspects of sustainable actions, for example through cross-curricular teaching in schools.

The present research project has shown that although students are confronted with the term *sustainability* in everyday life, basic ESD knowledge in the areas of economy and social issues is lacking. These gaps need addressing by the schools themselves or in cooperation with specialized ESD centers. Significant learning gains within the teaching unit "Ecosystem Pasture" showed that effective ESD teaching can rely on digital teaching methods and online courses. It must be ensured, however, that learners have the necessary digital skills, as this does not seem to be inherent prerequisite. High individual interest in biological topics among German fifth graders can be instrumentalized as motivational boost for other ESD topics. The extent to which methodological and content-related preferences change with adolescence and whether typical subject-related working methods, such as plant identification techniques, can be adequately promoted in distance learning, however, remains to be seen.

2. Zusammenfassung

Der allgegenwärtige Klimawandel und daraus resultierende Umweltkatastrophen wirken sich zunehmend auf unseren Lebensalltag aus. Dennoch scheint es eine Diskrepanz zwischen der Wahrung des eigenen Lebensstils und der Wahrnehmung der negativen ökologisch-ökonomischen Auswirkungen ebendieses zu geben. Bildung für nachhaltige Entwicklung (BNE) versucht diese Wahrnehmungslücke zu schließen, indem auf die Verschränkung komplexer Fachinhalte und Multiperspektivität in Bezug auf soziale, wirtschaftliche und umweltbewusste Dimensionen von Nachhaltigkeitsthemen gesetzt wird. Um solche Themengebiete schülergerecht aufzubereiten, bedarf es Lernumgebungen mit besonderer didaktisch-methodischer Aufbereitung, welche vor der pandemischen Lage vor allem in spezialisierten BNE-Zentren angeboten wurden [1,2]. Diese eingespielte Kooperation zwischen Schule und außerschulischem Lernort musste aus bekannten Gründen in den letzten zwei Jahren ausgesetzt werden. Daraus ergibt sich die Frage, ob solche BNE-Module auch im Distanzunterricht ihre Wirkung entfalten.

Teilarbeit A behandelte die Konzeption und Implementierung einer neu entwickelten BNE-Unterrichtseinheit. Im bayerischen LehrplanPLUS ist BNE in den fächerübergreifenden Bildungszielen verankert und fachinhaltlich in jeder Jahrgangstufe vertreten [3]. In der fünften Jahrgangsstufe der Gymnasien wurde das Thema „Ökosystem Grünland" im Natur-und-Technik-Unterricht im Umfang von fünf Unterrichtsstunden eingeführt. Zentraler Aspekt des Lehrplaninhaltes ist die Biodiversität einheimischer Flora und deren Zusammenhang mit intensiven und extensiven Bewirtschaftungsmethoden. Neben kognitiven Fähigkeiten sollen naturwissenschaftliche Arbeitsweisen geschult werden. Die neu konzipierte BNE-Einheit setzte diese Fachinhalte und prozessorientierte Kompetenzen mit digitalen Unterrichtsmethoden um. Empirische Daten einer Pilotierungsgruppe am außerschulischen Lernort zeigten signifikanten Lernzuwachs und stabile Umweltschutzpräferenzen. Im Kontext der pandemischen Lage stellte sich die Frage, inwiefern solche Kompetenzen über digitale, asynchrone Unterrichtsformen gefördert werden können.

Eine ausführliche Überprüfung des kognitiven Lernens wurde in Teilarbeit B dargelegt. Die Daten einer Interventionsstudie, die im Distanzunterricht durchgeführt werden musste, wurden mit der Pilotierungsgruppe verglichen. Beide Gruppen zeigten signifikanten Lernzuwachs, überraschenderweise jedoch keinen signifikanten Unterschied untereinander. Mögliche Gründe hierfür wurden diskutiert. Ergänzend wurden zwei semantische Differentiale erhoben, um die Verwendung der Begriffe *Nachhaltigkeit* und *Umweltschutz* zu untersuchen [4,5]. Obwohl die Begriffe ähnliche Werte erzielten, wurden sie als unterschiedliche Faktoren abgebildet.

Teilarbeit C analysierte den Zusammenhang digitaler Präferenzen, motivationaler Tendenzen und Lernfortschritt im Lernmodul zu „Ökosystem Grünland". Frühere Studien zeigten einen Zusammenhang zwischen Umweltwissen, Einstellungen und Verhalten [6]. Dabei besteht Konsens darüber, dass neben kognitiven Komponenten auch affektive Aspekte den Übergang von herkömmlichen zu nachhaltigeren Lebensstilen begünstigen. Entsprechend wurden methodische und inhaltliche Präferenzen der Schüler:innen untersucht.

Mittels der *Digital Nativity Assessment Scale* wurden digitale Präferenzen erhoben [7]. Das Konzept digitaler Generationen gilt als umstritten [8,9,21]. Einerseits sind gewisse Durchschnittswerte für Alterskohorten bekannt, andererseits sind berichtete Schwankungen innerhalb dieser Kohorten enorm [10,11]. Neben Erkenntnissen zu den Bereichen *Multitasking*, *Echtzeitkommunikation*, *Nutzung digitaler Endgeräte* und *grafische Darstellung* von Fünftklässler:innen, wurde der Einfluss auf den Wissenszuwachs in einer digitalen Lernumgebung überprüft. Daraus wurden Empfehlungen für digitalen Unterricht in der Sekundarstufe abgeleitet.

Zur Erfassung motivationaler Präferenzen für Biologie wurde *Fascination with Biology* eingesetzt [12]. Der Zusammenhang zwischen motivationalen Komponenten und BNE wurde bereits in anderen Studien erhoben [13–15]. Im Rahmen des vorliegenden Projektes wird zusätzlich untersucht, ob digitale Präferenzen im Kontrast zu Interesse für biologische Inhalte stehen. Eine mit omnipräsenter Technologie aufgewachsene Generation, so die These, könnte das Interesse an originaler Interaktion mit Pflanzen und Tieren verloren haben. Inwiefern der forcierte Distanzunterricht und die dadurch erhöhte Bildschirmzeit einen positiven oder negativen Einfluss auf diesen Wert haben, wurde diskutiert. In einem Strukturmodell konnte gezeigt werden, dass sowohl digitale Nativität als auch Faszination einen positiven Einfluss auf den Wissenszuwachs hatten.

Um den Forschungsansatz zu *Nachhaltigkeit* und *Umweltschutz* aus Teilarbeit B weiterzuführen, wurden für Teilarbeit D qualitative Daten in Form von Schüler:innen-Vorstellungen erhoben. Diese werden auch als Alltagsvorstellungen oder Präkonzepte bezeichnet und sind vorrangig in Phänomen-orientierten Unterrichtsfächern von Bedeutung [16,17]. Sie werden nicht nur im BNE-Bereich, sondern in allen MINT-Fächern erhoben und als Grundlage problemorientierter Unterrichtskonzepte verwendet [18,19]. Wie durch andere Studien angedeutet, bezogen sich die meisten Items auf ökologische Aspekte von Nachhaltigkeit [20]. Daraus wurde für zukünftigen BNE abgeleitet, dass ökonomische und soziale Aspekte stärker herausgearbeitet werden müssen, beispielsweise durch fächerübergreifenden Unterricht.

Im Rahmen der vorliegenden Forschungsarbeit konnte gezeigt werden, dass es Wissenslücken in den Bereichen Ökonomie und Soziales gibt, obwohl Schüler:innen mit dem

Begriff *Nachhaltigkeit* im Alltag konfrontiert werden. Diese Lücken müssen seitens der Schulen oder in Kooperation mit BNE-Zentren aufgearbeitet werden. Signifikanter Lernzuwachs in der Unterrichtseinheit „Ökosystem Grünland" zeigte, dass dies auch mit digitalen Unterrichtsmethoden oder im Distanzunterricht erfolgreich umgesetzt werden kann. Dabei muss darauf geachtet werden, dass Lernende nötige digitale Fertigkeiten besitzen, da diese nicht intuitiv vorhanden zu sein scheinen. Hohes individuelles Interesse für biologische Themen kann als Anknüpfpunkt für ökologische und gesellschaftliche Thematiken instrumentalisiert werden. Inwiefern sich methodische und inhaltliche Präferenzen mit dem Heranwachsen verändern, und ob fachtypische Arbeitsweisen, wie beispielsweise Bestimmungsmethoden, im Distanzunterricht adäquat gefördert werden können, bleibt indes offen.

3. Synopsis

Die *Agenda 2030* der Vereinten Nationen (UN) umfasst 17 Ziele für nachhaltige Entwicklung (engl. *Sustainable Devlopment Goals*, im Folgenden mit *SDGs* abgekürzt). Diese sollen globale Probleme, wie den Klimawandel, Armut und Ungleichheit, adressieren. Die SDGs (siehe Abbildung 1) können auf politischer und individueller Ebene umgesetzt werden. Erstere wird beispielsweise durch den SDG-Index gefördert [22]. Dabei werden Länder und Städte anhand der 17 SDGs analysiert und bewertet, inwiefern sie bis 2030 diese erreichen bzw. in welchen Bereichen dafür nachgebessert werden sollte.

Abbildung 1: 17 Ziele für nachhaltige Entwicklung (*SDGs*) der UN, bereitgestellt von https://www.unesco.de/bildung/agenda-bildung-2030/bildung-und-die-sdgs

Laut SDG-Index sollte in Deutschland vor allem an den Zielen 12 (Nachhaltiger Konsum und Produktion) und 13 (Klimaschutz und Anpassung) gearbeitet werden [23]. Beide Bereiche können durch gesetzliche Vorgaben verbessert werden. Zudem können Bürger:innen auf individueller Basis Einfluss nehmen. So hat sich gezeigt, dass Konsument:innen im Bereich Fleischersatzprodukte den Lebensmittelmarkt beeinflusst haben [24,25]. Ähnliche Trends sind im Bereich Wohnen und Mobilität zu beobachten [26,27]. Auch beim Klimaschutz sind Maßnahmen seitens der Regierung und Bürger:inneninitiativen umgesetzt worden [28,29]. Top-down-Maßnahmen, also solche, die seitens der Regierung initiiert wurden, werden in der Bevölkerung jedoch negativ wahrgenommen, wenn den Bürger:innen Informationen zu Umweltschutzeffekten dieser Maßnahmen fehlen [30,31]. Beispielsweise wird der Ausbau erneuerbarer Energien in Deutschlang politisch vorangetrieben, jedoch stehen Bürger:innen der erfolgreichen Implementierung skeptisch gegenüber [32]. Bei bottom-up-Initiativen, also von den Bürger:innen angestoßenen Vorhaben, hat mangelndes Umweltschutzwissen keinen solchen Effekt [33].

Dies zeigte sich bei der Initiative „Rettet die Bienen" von 2019, welche lokal initiiert und schließlich auf landespolitischer Ebene umgesetzt wurde. Verbesserung im Bereich Bildung für nachhaltige Entwicklung könnten sowohl die Akzeptanz für politische Vorgaben und als auch die Bildung weiterer Bürger:inneninitiativen unterstützen.

Deshalb wird Bildung für nachhaltige Entwicklung (BNE) als ein wirksames Instrument zur Erreichung der SDGs angesehen [34]. Mit der UN-Dekade "Bildung für nachhaltige Entwicklung" von 2005 – 2015 sollte unter anderem auf die Implementierung von BNE in internationalen Curricula aufmerksam gemacht werden. Der Abschlussbericht von 2017 weist jedoch auf Mängel im deutschen Bildungsraum hin. Um die Ziele bis 2030 zu erreichen, müssen Lehrpläne weiter angepasst und BNE-Institutionen ausgebaut werden [35]. In diesem Sinne wurde das deutsche Schulsystem bzw. die länderspezifischen Lehrpläne auf BNE-Elemente untersucht [36]. Die Ergebnisse sind in Einklang mit dem Befund der UN, welcher stärkere Anstrengungen zur Erreichung der SDGs seitens der deutschen Bildungslandschaft fordert. Zudem wurde festgestellt, dass es große Unterschiede bei der Implementierung von BNE in den Lehrplänen zwischen Schularten und Bundesländern gab. Der neue bayerische LehrplanPLUS implementierte im Vergleich mit anderen Bundesländern die meisten BNE-Konzepte. Bezüglich der tatsächlichen Umsetzung im Schulalltag liegen noch keine Befunde vor.

Viele BNE-Initiativen sind Kooperationen zwischen spezialisierten Umweltzentren und Schulen. Während der pandemischen Lage gestaltete sich die Zusammenarbeit mit solchen Zentren als schwierig, da Exkursionen nicht stattfinden konnten und digitaler Unterricht sich anfangs schwierig gestaltete. Daher ist damit zu rechnen, dass BNE in den vergangenen zwei Jahren wenige Fortschritte machen konnte und das Erfüllen der Ziele für *Agenda 2030* in den kommenden Jahren weiter an Bedeutung gewinnen wird, um diese Rückschläge ausgleichen zu können. In Hinblick auf die infektionstechnisch weiterhin angespannte Lage (Stand Frühjahr 2022) gewinnen digitale bzw. durch Fernunterricht umsetzbare BNE-Initiativen an Bedeutung.

Die vorliegende Arbeit analysiert digitale Bildung für Nachhaltige Entwicklung und mögliche Einflussgrößen darauf. Zunächst wird eine digitale BNE-Unterrichtseinheit, die passend zum Bayerischen Lehrplan für diese Interventionsstudie konzipiert wurde, vorgestellt. Anschließend wird der Lernfortschritt gymnasialer Fünftklässler:innen innerhalb der Interventionsstudie analysiert. Kognitive Aspekte werden in Kontext konnotativer Präferenzen, welche in Form semantischer Differentiale erhoben wurden, gesetzt [37]. Anschließend wird der Zusammenhang digitaler und inhaltlicher Präferenzen der Schüler:innen untereinander bzw. mit Wissenszuwachs dargestellt. Ergänzend zu den quantitativen Elementen der Forschungsarbeit werden qualitative Daten zu

Schüler:innenvorstellungen zu Nachhaltigkeit und nachhaltigem Verhalten vorgestellt und didaktisch-methodische Implikationen erläutert.

3.1. Theoretischer Hintergrund

Die UN definiert Nachhaltigkeit als "Befriedigung der Bedürfnisse der Gegenwart, ohne die Fähigkeit künftiger Generationen zu gefährden, ihre eigenen Bedürfnisse zu befriedigen" [38] S. 4]. Diese eher anthropozentrische Definition wurde später dahingehend abgeändert, dass sie wirtschaftliche, ökologische und soziale Aspekte umfasst [39]. Das britische *Department for Environment, Transport and Regions* (DETR) definiert vier Schlüsselelemente der nachhaltigen Entwicklung [40]:

1) sozialer Fortschritt, der die Bedürfnisse aller Menschen berücksichtigt
2) wirksamer Schutz der Umwelt
3) umsichtige Nutzung der natürlichen Ressourcen
4) Aufrechterhaltung eines hohen und stabilen Niveaus von Wirtschaftswachstum und Beschäftigung

Folglich ist Nachhaltigkeit und nachhaltiges Handeln ein komplexes, interdisziplinäres und auf die Schule bezogen fächerübergreifendes Konzept [41]. BNE wird definiert als "Befähigung der Lernenden, sich selbst und die Gesellschaft, in der sie leben, zu verändern, indem sie Wissen, Fähigkeiten, Einstellungen, Kompetenzen und Werte" anwenden ([42] S. 7). Die UN hebt dabei die Verflechtung von Themen wie Weltbürgertum, Klimawandel und Verlust der Artenvielfalt hervor. Die Verknüpfung wird deutlich durch die drei Säulen, auf denen BNE beruht: Ökologie, Ökonomie und Soziales (siehe Abbildung 2).

Abbildung 2: Die drei Säulen Nachhaltiger Entwicklung nach Pufé [41]

Beispielsweise kann das Thema *Konsum* aus verschiedenen Blickwinkeln betrachtet werden: die ökologische Dimension in Form vom ökologischen Fußabdruck seitens der Konsument:innen, die ökonomische Dimension als Produktverantwortlichkeit seitens der Hersteller:innen, und die soziale Dimension als Gleichstellung der Geschlechter in gesetzlichen Vorgaben für Arbeitgeber:innen [43]. Solche Themen und ihre Auswirkungen vollständig zu verstehen, ist eine Herausforderung, insbesondere für junge Lernende. Es empfiehlt sich ein Spiralcurriculum, das stufenübergreifend und aufeinander aufbauend konzipiert ist. BNE-Unterricht in der Primar- und Sekundarstufe sollte zunächst eine solide Basis an Wissen über Nachhaltigkeit schaffen, bevor zu komplexen Zusammenhängen übergeleitet wird. Bei jungen Zielgruppen beispielsweise wird der Begriff *nachhaltig* meist synonym mit *umweltfreundlich* verwendet [44]. Hier sollte der Fokus folglich darauf liegen, zunächst auf ökonomische und soziale Aspekte einzugehen, bevor man nachhaltige Handlungsfelder multiperspektivisch erörtern kann. Dieses Vorgehen wird im Folgenden anhand des Spiralcurriculums demonstriert (siehe Tabelle 1).

Tabelle 1: Beispiele für BNE-Inhalte im LehrplanPLUS [3]

Schulform	**Lernbereich**	**Kompetenzerwartung**
Grundschule	HSU 3/4 3.3 Luft, Wasser, Wetter	erläutern die Gefährdung von Wasser sowie die Bedeutung von Schutzmaßnahmen und zeigen eine verantwortungsbewusste Haltung.
Gymnasium	Natur und Technik 5 2.5 Ökosystem Grünland	vergleichen verschiedene Bewirtschaftungsmethoden an einfachen Beispielen im Hinblick auf ökonomische und ökologische Aspekte, u. a. Biodiversität, nachhaltige Entwicklung.
Gymnasium	Biologie 9 6 Ökosystem Boden	beurteilen die Bedeutung des Bodens für eine nachhaltige Produktion von Lebensmitteln, charakterisieren Gefahren für dieses Ökosystem durch die komplexe Verkettung menschlicher Einflüsse und sind sich dabei der Folgen für die Menschen bewusst.
Gymnasium	Englisch 9 2 Interkulturelle Kompetenzen	hinterfragen ihre eigenen Wertvorstellungen und Verhaltensweisen im Vergleich mit denen englischsprachiger Jugendlicher kritisch, auch im Hinblick auf Konsumverhalten und Nachhaltigkeit, lassen eigene Sichtweisen erkennen und zeigen Bewusstsein für die kulturelle und historische Prägung bestimmter Werte und Normen
Gymnasium	Deutsch 9 2.3 Pragmatische Texte	untersuchen, ggf. vergleichend, informierende und argumentierende Texte, indem sie insbesondere Kernaussagen, Struktur und ggf. Hypertextstruktur, Argumentationsweise, Adressatenbezug, Intention und sprachliche Gestaltung herausarbeiten.

Im Grundschulbereich wird im *Heimat- und Sachunterricht* ein abiotischer Faktor, beispielsweise Wasser, untersucht und nachhaltiger Umgang damit erörtert. In der Sekundarstufe werden in *Natur und Technik* bzw. *Biologie* ausgewählte Ökosysteme durch ihre

biotischen und abiotischen Faktoren charakterisiert. Zudem werden anthropogene Wechselwirkungen mit ebendiesem Ökosystem hervorgehoben. An dieser Stelle könnte man ökonomische und gesellschaftliche Nachhaltigkeitsaspekte einfließen lassen. Fachübergreifender BNE kann in Kombination mit gesellschaftswissenschaftlichen Fächern umgesetzt werden. Beispielsweise könnten soziale Aspekte im Rahmen des Themas „interkulturelle Kompetenz" durch den Vergleich deutscher Nachhaltigkeitsinitiativen mit denen in anderen Ländern aufgegriffen werden. Bei der Analyse pragmatischer Texte im Deutschunterricht könnte auf wissenschaftliche Texte zu Nachhaltigkeitsproblematiken zurückgegriffen werden. Die in den Lernzielen angedeutete zunehmende Reflektionskompetenz deutet an, dass Fachwissen allein nachhaltige Lebensstile nur unzureichend begünstigt.

Studien haben gezeigt, dass umweltfreundliche Lebensstile von drei wesentlichen Faktoren abhängen: Wissen, Einstellungen und Verhalten [45–47]. Bei Kindern und Jugendlichen konzentriert sich die Forschung auf die ersten beiden Bereiche. Dies bezieht effektive Wissensvermittlung adressatengerechter Themen ein. Umweltwissen wirkt sich wiederum positiv auf umweltfreundliche Einstellungen sowie Verhaltensweisen aus [6,48]. Demnach sollte fundiertes Wissen über Nachhaltigkeit die Lernenden implizit dazu motivieren innerhalb ihres Handlungsspielraums einen nachhaltigen Lebensstil zu führen. Es scheint eine Diskrepanz zwischen den bekannten Auswirkungen von umweltfreundlichen Handlungen und den potenziell negativeren Auswirkungen von umweltschädlichem Verhalten zu geben [49]. Das bedeutet, Menschen verfügen meistens über grundlegende Kenntnisse, beispielsweise über negative Auswirkungen der weltweit sinkenden Artenvielfalt. Eine Verhaltensänderung zeigt sich jedoch erst, wenn eine konkrete Bedrohung des eigenen Lebensstils aufkommt, wie z. B. Preissteigerungen bei Lebensmitteln als Folge von Missernten durch Wetterphänomene und Schädlinge. Es hat sich gezeigt, dass die meisten Lernenden genau wissen, was nachhaltiges Verhalten bedeutet, aber binäre Wahrnehmungen von nachhaltigen Lebensstilen haben [50]. So sind ihnen beispielsweise Problematiken von Einwegplastikprodukten bekannt, sie kaufen dennoch Soft- oder Heißgetränke in ebensolchen Verpackungen, anstatt auf wiederverwendbare Alternativen zu setzen. Um derartige Diskrepanzen zu vermeiden, sollte BNE zunächst auf adressatengerechte Alltagsthemen eingehen und anschließend globale Problematiken und Lösungsansätze erläutern.

3.1.1 Bildung für Nachhaltige Entwicklung im LehrplanPLUS

Im naturwissenschaftlichen Forschungsfeld besteht schon länger Konsens darüber, dass Klimawandel zum einen hauptsächlich anthropogenen Ursprungs ist und zum anderen in naher Zukunft verheerende Auswirkungen haben wird bzw. bereits hat [51]. Mittlerweile sind sowohl der Klima-Diskurs als auch die durch die Erderwärmung verursachten

Problematiken im öffentlichen Raum angekommen [52]. Umweltfreundliche Produkte, ökologische Fußabdrücke und die Verschmutzung der Umwelt sind Gegenstand einer lebhaften öffentlichen Diskussion. Junge Menschen haben in einer weltweiten Bewegung gezeigt, dass sie sich trotz heftiger Kritik an ihren mangelnden Kenntnissen auf diesem Gebiet, insbesondere bei der Bewertung der menschlichen Auswirkungen auf die Erdsysteme, für Nachhaltigkeit interessieren und engagieren [53]. Um zukünftige Generationen für die Komplexität dieses Themengebietes zu sensibilisieren, wurde BNE im Bayerischen LehrplanPLUS in den fächerübergreifenden Bildungszielen verankert und in jeder Jahrgangstufe mindestens ein BNE-Thema aufgenommen [3]. Die neuen BNE-Lernziele gehen Hand in Hand mit der „Global EverGreening Alliance" der UN, dem „Green Deal" der EU und der Initiative „From Farm To Fork" [54,55]. In der fünften Jahrgangsstufe der Gymnasien wurde das Thema „Ökosystem Grünland" eingeführt.

„Ökosystem Grünland" führt in der fünften Klasse in die Konzepte der Nachhaltigkeit und des nachhaltigen Handelns am Beispiel von Landwirtschaft ein (siehe Abbildung 3). Dabei werden vorrangig ökonomische und ökologische Aspekte behandelt. Es knüpft an Lehrplaninhalte aus dem Bereich Botanik an, wobei ideale Wachstumsbedingungen von Pflanzen vertieft und in Kontext landwirtschaftlicher Methoden gesetzt werden. Die Auswirkungen verschiedener landwirtschaftlicher Methoden auf die Artenvielfalt werden gegenübergestellt. „Traditionelle" Anbaumethoden sind gekennzeichnet durch den Einsatz von Düngemittel, Insektiziden und Großmaschinen ökonomischer. Ökologische Landwirtschaft schont die einheimische Flora und Fauna, indem die natürliche Fruchtbarkeit des Bodens und das lokale Klima berücksichtigt werden. Letztere gilt als umweltfreundlich, jedoch muss der geringere Ertrag bezüglich des SDG 2 („kein Hunger") berücksichtigt werden.

NT5 2.5 Ökosystem Grünland

Inhalte zu den Kompetenzen:

- ausgewählte einheimische Pflanzenarten des Grünlands
- Grundbegriffe zu einem Ökosystem: Lebensraum, Lebensgemeinschaft
- intensiv und extensiv bewirtschaftetes Grünland, Bewirtschaftungsmethoden

Abbildung 3: Auszug aus dem LehrplanPLUS, Jahrgangsstufe 5, Natur und Technik

Botanik bietet durch das Auseinandersetzen mit Biodiversität, der einheimischen Flora und ihrer tragenden Rolle in Ökosystemen einen idealen Anknüpfpunkt für BNE-Themen. Es können Beziehungen zwischen abiotischen Faktoren, wie Wasserversorgung oder Lichtintensität, und biotischen Faktoren, wie Pflanzenwachstum oder Abhängigkeiten zwischen Arten, veranschaulicht werden. Studien haben den Mehrwert von Schulgärten und dem Erkunden der Flora des Schulgeländes untersucht [56,57]. Es wurden unterschiedliche Ansätze verglichen, wie die Gegenüberstellung von experimentellen und

traditionellen Unterrichtsstilen [58] oder die Ausweitung auf sozioökonomische Einflüsse [59]. Die Ergebnisse stimmen darin überein, dass Unterricht in und um Schulgärten positive Auswirkungen auf emotionale und kognitive Werte von Schüler:innen haben [60–62]. Im LehrplanPLUS wird die Originalbegegnung mit einheimischer Flora in Form eines Schulgartens oder „naturnahen Schulumfeldes" verlangt [63]. Es wird auf die Expertise und Unterstützung seitens außerschulischer Einrichtungen verwiesen, wie z.B. botanische Gärten oder Wildparks. Aus wissenschaftlicher Perspektive gibt es einen direkten Zusammenhang zwischen dem Erwerb von ökologischem Wissen und der Nähe des untersuchten Ökosystems zum eigenen "natürlichen" Umfeld der Schüler:innen [64]. Dies bedeutet, dass Themen wie Biodiversität besser im Kontext lokaler Ökosysteme wie Weiden oder Wälder unterrichtet werden können, statt anhand exotischer Beispiele wie Regenwälder oder Wüsten. Daher sollte sich BNE-Unterricht zunächst auf den Einfluss des Menschen auf lokale Ökosysteme konzentrieren, um anschließend auf die globale Ebene überzugehen.

Das übergeordnete Ziel des Lernmoduls „Ökosystem Grünland" ist es, Visionen von Nachhaltigkeit im Kontext der Landwirtschaft zu entwickeln. Bio-Landwirte wenden andere Anbaumethoden an, u.a. um nachhaltigere Lebensstile zu fördern [65,66]. Die Hauptunterschiede zwischen ökologischen und konventionellen Anbaumethoden sind der Einsatz von synthetisch hergestelltem Düngemittel und Pestiziden [67]. Schüler:innen sollen für verschiedene Anbaumethoden und deren Auswirkungen auf lokale Ökosysteme sensibilisiert werden. Des Weiteren werden eigene Handlungsfelder diskutiert und bewertet. Eine Kombination mit fachtypischen Arbeitsweisen rundet die authentische und schüler:innenorientierte Lerneinheit ab.

3.1.2 Inhaltlicher und methodischer Hintergrund von „Ökosystem Grünland"

Im „Ökosystem Grünland" sollen Inhalte zu Biodiversität, Ökosystemen und Bewirtschaftungsmethoden vermittelt und gleichzeitig fachtypische Arbeitsweisen und -techniken eingeübt werden. Als *Ökosystem* wird „die Gesamtheit an interagierenden abiotischen und biotischen Komponenten in einem abgegrenzten Gebiet" (68, S. 746). Unter *Grünland* werden landwirtschaftlich oder kulturell genutzte Flächen zusammengefasst, wie z.B. Ackerland, Weiden, Obstplantagen und Fußballrasen. Im Lehrplan wird die Gegenüberstellung natürlicher Lebensräume mit landwirtschaftlich genutzten gefordert. In Deutschland gibt es durch die sukzessive Umwandlung von Naturlandschaften in Kulturlandschaften jedoch keine naturbelassenen Lebensräume [69]. Intensive Landwirtschaft wird durch den Einsatz von Düngemitteln, Pestiziden und automatisierter maschineller Arbeit charakterisiert. Dadurch haben sich eutraphente Arten, die ertragsreich aber störungsempfindlich beispielsweise gegenüber Pathogenen oder Temperatureinbrüchen sind, durchgesetzt [70]. Neben der Umgestaltung von Lebensräumen und der

Verbreitung invasiver Arten, werden zudem große Landflächen in Form von Siedlungen und Verkehrsflächen dauerhaft versiegelt [71,72]. Diese Entwicklungen führen nicht nur zu biologischer Verarmung und Bodenverlust, sondern auch zu atmosphärischen Veränderungen [68]. Um den Nahrungsmittelbedarf der wachsenden Weltbevölkerung zu decken und gleichzeitig das Gleichgewicht innerhalb der Biozönose wiederherzustellen, bedarf es nachhaltiger landwirtschaftlicher und kultureller Methoden. Essenziell ist dabei der Zusammenhang von Ökosystemfunktion und Biodiversität innerhalb des entsprechenden Ökosystems.

Biologische Vielfalt, zu der die genetische Vielfalt, die Artenvielfalt und die Vielfalt der Ökosysteme gehören, ist ein Hauptunterschied zwischen natürlichen und anthropogen beeinflussten Lebensräumen [73]. Artenarmes Wirtschaftsgrünland liefert durch Düngung große Heumengen, wobei sich einige Grasarten und wenige krautige Pflanzen durchsetzen. Artenreiches Wirtschaftsgrünland, zu denen auch Parks und Naherholungsanlagen gezählt werden können, ist deutlich weniger eutrophiert und weist folglich eine höhere Biodiversität auf [70]. Für den Schulunterricht bedeutet diese Entwicklung, dass zwar keine natürlichen Lebensräume, jedoch vom Menschen stark beeinflusste Ökosysteme und eher naturbelassene Systeme anhand ihrer Biodiversität charakterisiert und kontrastiert werden können. In „Ökosystem Grünland" wird durch die Begegnung mit einheimischen Pflanzen und die Sensibilisierung für ihre charakteristischen Merkmale vorwiegend Artenvielfalt vermittelt. Genetische Vielfalt und ökologische Vielfalt wird aus Gründen der didaktischen Reduzierung in höheren Jahrgangstufen eingeführt.

Um die Schüler:innen für die Relevanz biologischer Vielfalt zu sensibilisieren, müssen fachliche Grundlagen und Arbeitsmethoden vermittelt werden. Grundlegende Kenntnisse über den Bauplan einheimischer Pflanzen sind beispielsweise Grundvoraussetzung dafür, komplexere BNE-Themen, wie beispielsweise schwindende Fauna aufgrund landwirtschaftlicher Monokulturen, verstehen zu können. Studien haben gezeigt, dass Erwachsene Schwierigkeiten haben, Grundstrukturen von Pflanzen zu benennen [74]. Mögliche Gründe werden im vielfältigen Erscheinungsbild von Blütenpflanzen gesehen [75]. Das auffällige Aussehen der meisten einheimischen Pflanzen ist das Ergebnis von Koevolution. Pflanzen dienen dabei vorwiegend als Lebensraum und Nahrungsquelle, während Insekten und andere Tiere nützlich bei der Pollen- und Diasporenausbreitung sind [68]. Das Anlocken potenzieller Bestäuber durch Nektar führt im Grunde dazu, dass das Insekt die Narbe und das Fruchtblatt berührt und somit Pollen von einer Blüte zur nächsten weitergibt [76]. Für Pflanzen bedeutet dies einen evolutionären Vorteil, da Pollenübertragung durch Insekten effektiver ist als beispielsweise durch Windbestäubung [70]. Somit ergeben sich direkte Abhängigkeiten von Insekten und Pflanzen, und damit weitereichende Auswirkungen für Ökosysteme, in denen die Flora stark reguliert

wird. In „Ökosystem Grünland" soll diese Interdependenz durch die Erfassung der Biodiversität eines Lebensraumes mittels fachtypischer Arbeitsweisen angebahnt werden. Dabei müssen zunächst Aufbau und Fachbegriffe von Pflanzen thematisiert werden. Anschließend wird das neu erworbene Grundwissen in Bestimmungsübungen praktisch angewandt.

Kenn- und Bestimmungsübungen sind ein wichtiger Bestandteil fachtypischer Arbeitsweisen der Biologie. Bestimmungsübungen dienen in erster Linie der Schulung von Arten- und Formenkenntnis [77]. *Artenkenntnis* bezieht sich auf die korrekte Benennung einzelner Organismen durch den (wissenschaftlichen) Namen und einer Einordnung in einen Stammbaum. *Formenkenntnis* beschreibt die Fähigkeit, Organismen anhand der Bestimmung von Charakteristika wie Körperform, Wuchsform oder Blattform zu unterscheiden, sowie diese Formtypen fachgerecht bezeichnen zu können. Kennübungen zielen auf das Wiedererkennen bereits bekannter Arten ab und sollen anhand heimischer Tier- und Pflanzenarten im Spiralcurriculum wiederholt eingesetzt werden. Bei beiden Verfahren soll mit steigender Klassenstufe auch die Komplexität der Merkmale und Organismen zunehmen. Als Grundlage wissenschaftlicher Bestimmungstechniken dient ein dichotom aufgebauter Bestimmungsschlüssel (z.B. 78–80). Die Anwendung eines solchen Bestimmungsschlüssels erfüllt das Prinzip der Wissenschaftlichkeit, erfordert jedoch detaillierte Kenntnis einer Vielzahl von Fachbegriffen und deren korrespondierenden Realformen. Deshalb werden vor allem in den unteren Jahrgangsstufen stark vereinfachte Bestimmungsschlüssel eingesetzt, die zum einen den Fachinhalt durch eine Vorauswahl typischer Pflanzen und Tiere reduzieren und zum anderen statt wissenschaftlicher Fachbegriffe Bezeichnungen aus der Alltagssprache verwenden (z.B. 81–83).

Neben biotischen Faktoren von Ökosystemen werden in „Ökosystem Grünland" auch abiotischen Faktoren adressiert. In der intensiven Landwirtschaft werden Düngemittel eingesetzt, um Nährstoffmangel zu verhindern. Nährstoffanreicherung im landwirtschaftlichen Boden beeinflusst auch den umgebenden Lebensraum [84]. Dadurch wirkt sich die Zufuhr zusätzlicher Nährstoffe wie Stickstoff nicht nur auf die Artenvielfalt und Zusammensetzung der landwirtschaftlich genutzten Fläche aus, sondern hat weitreichende Folgen, insbesondere wenn sie den Grundwasserspiegel erreichen. Nährstoffeintrag verschlechtert die Qualität aquatischer Ökosysteme und angrenzender terrestrischer Ökosysteme erheblich [85]. Dies führt zu einem Verlust an Biodiversität, da Pflanzen, die auf bestimmte Nährstoffdefizite spezialisiert sind, von Arten, die in einem Lebensraum ohne Nährstoffzufuhr nicht überleben könnten, verdrängt werden. Die konkreten Auswirkungen sind noch nicht vollständig abschätzbar, es herrscht jedoch Konsens darüber, dass Biodiversitätsverlust negative Folgen für die Menschheit und für Ökosysteme hat [86–88]. In extensiver Landwirtschaft wird versucht diesem Effekt

entgegenzuwirken, indem weniger und vor allem organischer Dünger verwendet wird. Dieser wird aus einer Mischung verschiedener Arten zersetzten organischen Materials gewonnen, wodurch Überdüngung vorgebeugt werden kann. Dieses Beispiel kann als Anknüpfpunkt für Handlungsfelder seitens der Schüler:innen genutzt werden. So könnte ein Schritt zu einem nachhaltigeren Lebensstil auf individueller Ebene darin bestehen, Küchenabfälle zu kompostieren und als natürlichen Dünger zu verwenden, anstatt industriell hergestellten Dünger zu kaufen.

Das Lehrplanthema „Ökosystem Grünland" macht deutlich, dass BNE-Themen fachlich wie methodisch sehr komplex sind und insbesondere in den unteren Jahrgangsstufen entsprechend aufbereitet werden müssen. Die Komplexität nimmt zu, wenn nicht nur auf ökologische Aspekte, wie hier vorrangig dargelegt, eingegangen wird. Deshalb müssen BNE-Inhalte durch schüler:innengerechten Alltagsbezug und didaktische Vielfalt adressatengerecht und motivierend vermittelt werden. Dafür eignen sich sowohl am außerschulischen Lernort als auch im Regelunterricht digitale Unterrichts- und Arbeitsmethoden.

3.1.3 Digitaler Unterricht und Distanzunterricht

Nachdem Deutschland im Bereich digitaler Bildung bisher keine Führungsposition einnahm, hat die Integration von digitalen und Online-Elementen in Schulen durch die pandemische Lage rasche Fortschritte gemacht [89,90]. Ähnliche Entwicklungen sind im Forschungsfeld digitaler Lehrmethoden zu beobachten [91]. Forschungsergebnisse zu digitalem BNE liegen vorrangig für junge Erwachsene vor [92–94]. Durch die pandemische Lage ist die Primar- und Sekundarstufe in den Fokus gerückt. Forschung zu digitalem MINT-Unterricht umfasst eine Vielzahl von Ansätzen: Vergleich von synchronen und asynchronen Ansätzen, Einbeziehung von VR- und AR-Elementen, mobiles Lernen mit MINT-spezifischen Apps und Spielen [95–97]. Internationale Studien im Grundschulbereich zeigen, dass digitale Elemente regelmäßig eingesetzt werden, jedoch selten im Vorfeld überprüft wird, ob Schüler:innen dieser Altersgruppe sie angemessen nutzen können [98]. Studien im Sekundarschulbereich zeigen, dass Informations- und Kommunikationstechnologie (IKT) nicht implizit unterrichtet werden sollte, sondern ein methodischer Ansatz erforderlich ist, um einen langfristigen Lernerfolg zu gewährleisten [99].

Der durch die Pandemie hervorgerufene „Notfall-Fernunterricht" unterscheidet sich von gut strukturiertem, systematischem Online-Lernen [100]. Kommunikationskanäle zwischen Lehrkräften und Eltern wurden nicht flächendeckenden etabliert, was zu Lernengpässen führte. Kommunikation zwischen Schüler:innen und Lehrkräften fand meist asynchron und sporadisch statt. Synchrone und regelmäßige Kommunikation zwischen Lehrenden und Lernenden ist ein wesentlicher Bestandteil effektiven Online-Lernens

[101]. Jüngste Studien zum Thema "Lockdown Schooling" haben bestätigt, dass sowohl Lehrkräfte als auch Lernende im Umgang mit neuen Technologien und digitalen Werkzeugen vor Ort geschult werden sollten, bevor man in den Distanzunterricht geht [102,103].

Unter normalen Bedingungen haben Studien bereits den Einfluss von digitalen Lernumgebungen auf Biologiewissen oder Umwelteinstellungen untersucht [104]. Charakteristisch für diese Studien ist, dass sie in Schulen durchgeführt und von einer Lehrkraft oder einem Betreuer/ einer Betreuerin überwacht werden. Weitere Studien zu *Blended Learning* und *Flipped-Classroom*-Konzepten verwenden eine Mischung aus asynchroner, digitaler Kommunikation und persönlicher Interaktion vor Ort [105]. Dabei werden einzelne Arbeitsphasen zur eigenständigen Bearbeitung nach Hause ausgelagert, die Lernenden interagieren aber ergänzend mit ihren Lehrer:innen persönlich. Im *Lockdown Schooling* verwendete Methoden haben gemeinsame Charakteristika mit *Homeschooling*, das in Deutschland im Vergleich zu anderen Ländern aus rechtlichen Gründen wenige Schüler:innen betrifft [106]. Im herkömmlichen *Homeschooling* erhalten die Lernenden standardisierte Aufgaben, die sie mithilfe eigener Curricula abarbeiten. Der Lernprozess findet zu Hause und ohne Kontrolle einer professionellen Lehrkraft statt [107]. Im Unterschied dazu können in *Flipped-Classroom*-Ansätzen Lernfortschritte überprüft und inhaltliche wie methodische Probleme rechtzeitig erkannt werden. Im „Notfall-Fernunterricht" hatten sich insbesondere bei digitalen Kompetenzen einige Defizite gezeigt.

Jüngeren Generationen, die in einer digitalisierten Welt aufwachsen, wird häufig unterstellt über inhärente Fähigkeiten verfügen, die bei älteren Generationen nicht oder weniger ausgeprägt sind [108]. Eine solche Theorie ist die der *Digital Nativity* von Prensky [109]. *Digital Natives* („digitale Einheimische") werden als Menschen definiert, die im Cyber-Zeitalter aufgewachsen sind. *Digital Immigrants* („Digitale Einwanderer") sind Menschen, die nicht in das Cyber-Zeitalter hineingeboren wurden oder darin aufgewachsen sind, aber in ihm leben. Nach dieser Theorie führt ein technologisiertes Umfeld dazu, dass man intuitiv wissen sollte, wie man (digitale) Technologie nutzt, über grundlegende digitale Kompetenzen verfügt, mit Multitasking, also dem gleichzeitigen Ausführen verschiedener Aufgaben, vertraut ist, experimentelle und kollaborative Lernmethoden bevorzugt, und in Bildern dargestellte Informationen besser verarbeiten kann als in Textform [110]. Ob es die digitale Nativität gibt, und falls ja, welchen Einfluss sie hat, ist Teil des wissenschaftlichen Diskurses. Einige Wissenschaftler:innen bezweifeln die Existenz digitaler Generationen oder zumindest das Ausmaß der Unterschiede zwischen *Natives* und *Immigrants*, andere unterstützen Prenskys These [7,11,111]. Da digitale Technologie seit Aufkommen der Theorie in den 2000ern alltäglicher und omnipräsenter geworden ist, sollten Unterschiede in digitalen Präferenzen zwischen *Natives* und

Immigrants tendenziell größer und daher messbarer sein. Die pandemische Lage bietet zudem eine einzigartige Gelegenheit, Schüler:innen zu untersuchen, die täglich mit digitalen Unterrichtsmethoden konfrontiert waren. Gleichsam sollte deshalb intensiv erforscht werden, inwiefern deutsche Schüler:innen digital versiert sind. Je mehr digitale Unterrichtsmethoden im Schulalltag eingesetzt werden, desto größer könnten die Nachteile für Schüler:innen sein, die in einem der genannten Bereiche Defizite aufweisen.

3.1.4 Digitale Bildung für Nachhaltige Entwicklung

Nimmt die Digitalisierung des Regelunterrichts zu, sollte auch BNE-Unterricht mithilfe digitaler Elemente modernisiert werden. Problematisch ist dabei, ob für BNE- und MINT-Unterricht charakteristische Unterrichtsmethoden, wie kooperative und kooperative Lernstrategien, im Distanzunterricht umsetzbar sind [112,113]. Auch Problemlösungskompetenzen und Peer-basierte Unterrichtsmethoden sind im Online-Unterricht schwieriger zu vermitteln [114,115]. Da BNE häufig in Kooperation mit außerschulischen Lernorten umgesetzt wurde, lag der Fokus bisher auf entdeckendem Lernen vor Ort und nicht auf digitalen Unterrichtsmethoden [2,62] . Als Folge des Lockdowns haben einige dieser Zentren umfangreiches digitales Informations- und Lernmaterial entwickelt. Aktuell wird untersucht, ob diese Strategie den gleichen Lerneffekt und die gleiche Umweltsensibilisierung bei jungen Lernenden hervorrufen kann, wie ein Besuch eines außerschulischen Lernortes.

Obwohl ein solcher Besuch mit organisatorischem und finanziellem Mehraufwand verbunden ist, wird in der Umweltbildung die Multiperspektivität von außerschulischen Lernorten und deren positiver Einfluss auf die Lernenden betont [116,117]. Um nachhaltige Verhaltensänderungen bei Schüler:innen auszulösen, setzt man sowohl auf kognitive als auch affektive Komponenten. Durch das selbstständige Erkunden und Arbeiten am außerschulischen Lernort werden Selbstregulation und individuelles Kompetenzerleben gefördert, sowie die curriculare Forderung nach handlungsorientiertem BNE erfüllt. Der Einfluss der BNE-Kompetenz der Lehrkräfte muss ebenfalls berücksichtigt werden. Zusätzlich zur Komplexität von BNE-Inhalten sahen sich Lehrkräfte mit den methodischen und technischen Herausforderungen des Notfall-Fernunterrichts konfrontiert [118]. Weitere Studien deuten darauf hin, dass leistungsschwache und marginalisierte Gruppen mehr Probleme mit dem Fernunterricht hatten als leistungsstarke [119,120]. Daher wird in der vorliegenden Studie davon ausgegangen, dass Schüler:innen im Fernunterricht schlechtere Lernfortschritte erzielen als eine Kontrollgruppe am außerschulischen Lernort. Unabhängig vom Distanzunterricht sollen im Rahmen dieser Forschungsarbeit weitere Voraussetzung für erfolgreiches Lernen untersucht werden, wie beispielsweise Präkonzepte.

3.1.5 Schüler:innenvorstellungen im BNE-Unterricht

Gemäß einer konstruktivistischen Auffassung von Lernen strukturieren Schüler:innen Wissen aktiv auf Grundlage individueller Fähigkeiten und Erfahrungen [121]. Lernen ist folglich ein aktiver Prozess, der auf den individuellen Eigenschaften des Lernenden basiert [122]. Die Umsetzung dieser Kernaussage fällt unterschiedlich aus [123].

Forschung zum *Konzeptwechsel* (engl. *conceptual change*) geht davon aus, dass neben physischen und sozialen Voraussetzungen auch Vorerfahrungen und Vorwissen eine große Rolle im Lernprozess spielen [124,125]. Beim Betreten des Klassenzimmers können bei Schüler:innen "naive" Vorstellungen vorliegen, bevor sie dort mit "professionellen" Vorstellungen konfrontiert werden. Dieser Übergang von Alltagsvorstellungen zu wissenschaftlichen Vorstellungen ist der Kern der Conceptual-Change-Forschung [126]. Dabei können naive Schüler:innenvorstellungen die Einbettung neuer Ideen in den bestehenden Wissenskomplex negativ beeinflussen. Bisherige Ergebnisse legen nahe, dass für ein Thema eine Vielzahl von Konzepten koexistieren kann. Auch wenn die Konzepte widersprüchlich sind, können sie nebeneinander bestehen, da sie situationsbedingt vom Lernenden angewandt werden [127,128]. Dies gilt insbesondere für Alltagskonzepte, die Phänomene auf einer oberflächlichen, stark vereinfachten Ebene erklären (siehe Abbildung 4).

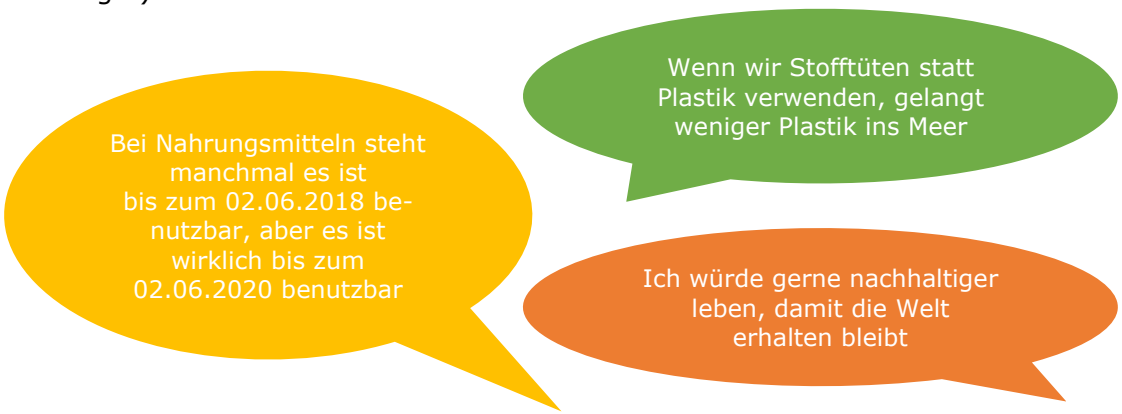

Abbildung 4: Auswahl von Schüler:innenäußerungen zu nachhaltigem Handeln

Solche Vorstellungen können BNE-Bemühungen vor zusätzliche Herausforderungen stellen, da die Lernenden in alltäglichen Kontexten an ihren vorgefassten Meinungen festhalten und wissenschaftlich belegte Konzepte nur in Bildungsumgebungen anwenden. Studien zu Vorstellungen über den Verlust der biologischen Vielfalt haben gezeigt, dass Schüler:innen den Erhalt der biologischen Vielfalt als wichtig anerkennen, sich aber ihrer eigenen schädlichen Handlungen nicht bewusst zu sein scheinen [129]. Dies resultiert in weniger umweltfreundlichen Verhalten [130,131]. Die Conceptual-Change-Theorie bietet Ansätze, um inadäquate Vorstellungen zu eliminieren und adäquate Alltagsvorstellungen als Ankerpunkte für wissenschaftliche Erklärungsansätze zu instrumentalisieren [124]. Die direkte Konfrontation mit alterstypischen Alltagskonzepten spielt eine

zentrale Rolle. Daher ist es für die Bildungsforschung von entscheidender Bedeutung, empirisch zu ermitteln, welche Alltagsvorstellungen in den entsprechenden Alterskohorten vorherrschen. Ein besseres Verständnis der Schüler:innenvorstellungen hilft Lehrkräften im BNE-Unterricht effektiv auf diese einzugehen. Die Identifizierung bestehender Vorstellungen von Schüler:innen in empirischen Studien ist daher eine wesentliche Voraussetzung für effektives Lehren und Lernen.

Bei der Erhebung von Schüler:innenvorstellungen haben sich verschiedene Vorgehensweisen etabliert: Interviews [132,133], offene Fragen [134,135], Concept-Maps [136] oder Multiple-Choice-Fragen [137]. Interviews und geschlossene Fragen bieten sich an, wenn das Thema bereits umfassend erforscht wurde. Beispielsweise liegen zahlreiche Conceptual-Change-Studien zu Evolutionstheorien vor, auf deren Basis man geschlossene Fragebögen erstellen könnte [138–140]. Bisher wurden einzelne Studien zu Vorstellungen von Fünftklässler:innen über Nachhaltigkeit veröffentlicht. Die meisten dieser Studien konzentrierten sich auf andere Altersgruppen und Teilbereiche von *Nachhaltigkeit* wie Energie, Abfallwirtschaft, Biodiversität, Klimawandel und nachhaltige Ernährung [4,133,141,142]. Das primäre Ziel dieser Studie ist es daher, die allgemeinen Vorstellungen der Schüler:innen von *Nachhaltigkeit* zu erforschen, sie mit den professionellen Vorstellungen zu vergleichen und daraus Implikationen für die Unterrichtspraxis abzuleiten.

3.1.6 Einfluss von Motivation und Interesse

Um das Verhalten von Schüler:innen hin zu nachhaltigeren Lebensstilen zu prägen, sollten nicht nur kognitive, sondern auch affektive Komponenten berücksichtigt werden. Entsprechend wird in der Umweltbildung motivationalen Effekten ein großer Einfluss auf umweltfreundliche Verhaltensweisen zugesprochen [2,15]. Im weitesten Sinn kann *Motivation* als sämtliche aktivierende Prozesse bezeichnet werden [143]. Verschiedene motivierende Komponenten – von internen Trieben bis hin zu externen Anreizen – veranlassen Menschen dazu, gewisse Handlungen selbstständig auszuführen. Diese Definition kann um einen durch das Individuum positiv bewertetet Zielzustand, der durch die Handlung erreicht werden soll, ergänzt werden [144]. Dieser Zustand kann sowohl etwas Angestrebtes sein (z.B. Kontakt mit einer interessanten Person), als auch die Vermeidung von etwas Unerwünschtem (z.B. schlechte Noten). Des Weiteren kann auch eine Handlung an sich als motivierend empfunden werden, z.B. Sport oder Freizeitaktivitäten. Motivationspsychologie ist nicht auf den schulischen Sektor beschränkt [145,146], sondern beschäftigt sich mit Antriebs- und Ausrichtungsphänomenen, die generations- und gesellschaftsübergreifend, etwa in der Unternehmensoptimierung oder Werbebranche, erforscht werden [147–149].

Es wird grundlegend zwischen intrinsischer und extrinsischer Motivation unterschieden [150,151]. Ersteres bezieht sich auf die Tätigkeit an sich (z.B. Spaß am Experimentieren), letzteres auf einen durch die Tätigkeit beabsichtigten Effekt (z.B. gute Noten durch Lernen). Im Bereich der Lernmotivation wird intrinsische Motivation als Kompetenzerwerb oder Lernzielorientierung definiert, während extrinsische Motivation als Kompetenzdemonstration oder Performanzorientierung bezeichnet wird [152]. Die beiden Motivationsarten müssen sich dabei nicht ausschließen (siehe Abbildung 5), und sind deshalb nicht eindeutig voneinander abgrenzbar. Möchte ein:e Schüler:in beispielsweise optimal für eine Zimmerpflanze sorgen, sollten die Grundbedürfnisse von Pflanzen recherchiert werden. Dabei gilt das Recherchieren als Tätigkeit an sich nicht als intrinsisch motiviert, der Lerneffekt und das daraus resultierende Kompetenzerleben (= die Pflanze überlebt) jedoch schon. Im pädagogischen Bereich wird deshalb die Autonomie des Lernprozesses betont, um zwischen extrinsischer und intrinsischer Motivation zu unterscheiden. Hätte der/ die Schüler:in sich für eine gute Note in einem Referat über Wachstumsbedingungen von Pflanzen informiert, wäre dies folglich ein extrinsisch motivierter Lernprozess gewesen.

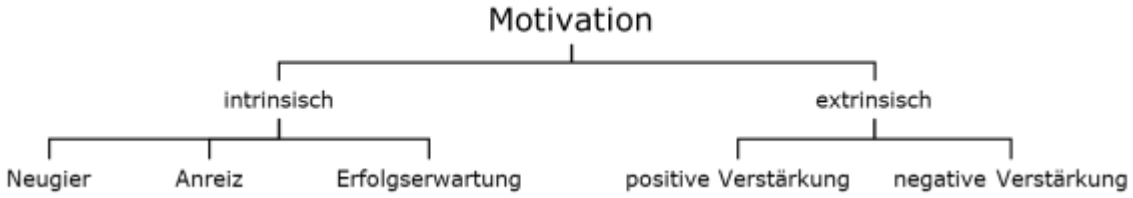

Abbildung 5: Modell extrinsischer und intrinsischer Motivation nach Edelmann [136]

Deci & Ryan [153], Begründer der Selbstbestimmungstheorie, erweiterten die Unterscheidung zwischen intrinsischer und extrinsischer Motivation um drei psychologische Grundbedürfnisse, welche auch in Lernsituationen Anwendung finden: (1) Lernende müssen weitestgehend autonom, also freiwillig, handeln. (2) Beim Lernen in sozialer Eingebundenheit, spielen sowohl der eigene Einfluss auf die Gruppe, also auch deren Einfluss auf das Individuum eine Rolle. (3) Lernende müssen sich selbst als kompetent wahrnehmen, also von der eigenen Handlungsfähigkeit überzeugt sein. Diese Faktoren spielen vor allem beim situationsunabhängigen Interesse eine Rolle. Daran angelehnt werden bei der Unterrichtsplanung vier Grundvoraussetzung zur Förderung intrinsischer Lernmotivation zu berücksichtigt: nachvollziehbare Bedeutung des Lernstoffes, soziale Einbindung, Instruktionsqualität und Autonomieunterstützung [77,154]. Lerninhalte sollten zielgruppenrelevant sein, also altersgerecht und schüler:innenorientiert. Unterricht sollte in verschiedenen Sozialformen durchgeführt werden, auch wenn dadurch effektive Lernzeit reduziert wird. Arbeitsaufträge sollten operationalisiert und transparent sein. In Arbeitsphasen sollte Schüler:innenaktivität im Vordergrund stehen.

Interesse ist eine besondere Form der intrinsischen Motivation, die auf einen bestimmten Gegenstand, Lerninhalt oder eine Person bezogen ist [154]. *Interessiertheit* ist folglich ein fokussierter, emotionaler Zustand, der sich positiv auf Lernzuwachs und Kompetenzerwerb auswirkt. Das Konzept kann situations- und personenbezogen differenziert werden (siehe Abbildung 6, vgl. [155–157]):

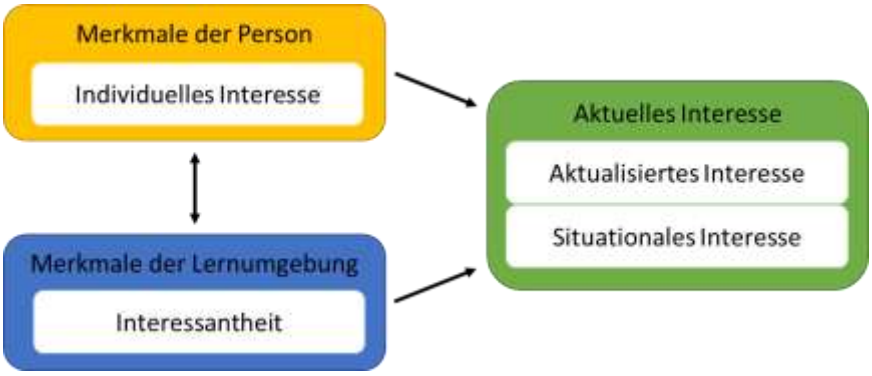

Abbildung 6: Modell zu Interesse & Interessantheit nach Urhahne [151]

- *Individuelles Interesse*: stabiles persönlichkeitsspezifisches Merkmal, das sich als Präferenz gegenüber eines bestimmten Lerngegenstandes äußert
- *Interessantheit*: Eigenschaften des Lerngegenstandes unabhängig von der Lernsituation und den Lernenden
- *Aktuelles Interesse*: situationsspezifischer motivationaler Zustand hervorgerufen durch das Zusammenspiel von Lernenden, Lerngegenstand und Lernsituation
- *Aktualisiertes Interesse*: Interessantheit eines bestimmten Gegenstandes in einer bestimmten Situation
- *Situationales Interesse*: in einer konkreten Situation durch äußere Faktoren hervorgerufen, wie z.B. Interaktion mit Freunden oder Alltagsrelevanz des Lerngegenstandes

Im schulischen Kontext wird angestrebt, durch didaktisch-methodisches Vorgehen situatives Interesse zu konservieren und als individuelles Interesse zu verankern [158]. In der Biologiedidaktik hat sich dazu das Modell der Interessensgenese etabliert [159]. Demnach müssen für eine erfolgreiche Interessensgenese in Anlehnung an die Selbstbestimmungstheorie die Grundbedürfnisse Autonomie, Kompetenz und soziale Eingebundenheit erfüllt sein. Entsprechend ergeben sich für guten Biologieunterricht Handlungsempfehlungen. Im Bereich der Umweltbildung wurde dies in Studien konkretisiert: aus Motivation kann sich die Ausbildung eines umweltfreundlichen Handlungsmotivs entwickeln, woraus sich eine Intention, die Handlungsabsicht, und schließlich Volition, die Konkretisierung der Handlung, ableitet [160]. Inwiefern dies für BNE-Unterricht in der Sekundarstufe instrumentalisiert werden kann, bleibt indes offen.

Im Rahmen dieser Studie wurde Interesse gegenüber dem Lerngegenstand, bei Otto et al. als *Faszination with Science* bezeichnet [12], mit individuellen Präferenzen gegenüber der Methodik, der *digitalen Nativität* nach Teo [7], gegenübergestellt. Beide Variablen wurden in anderen Studien unabhängig voneinander untersucht und ihr Einfluss auf Lernzuwachs wiederholt bestätigt [2,13,161,162]. Da sich Interesse für biologische Inhalte und Präferenzen für digitales Arbeiten deutlich zu unterscheiden scheinen, wird ein negativer Zusammenhang zwischen den beiden Ausprägungen erwartet.

3.2 Ziele und Fragestellungen

Im Kontext der pandemischen Lage und der *Agenda 2030* ergaben sich vor dem dargelegten fachlichen Hintergrund folgende Forschungsfragen:

- Wie können naturwissenschaftliche Arbeitsweisen und digitale Unterrichtsmethoden in der 5. Jahrgangsstufe in einem schülerzentrierten BNE-Modul kombiniert werden? (Teilarbeit A)
- Welche Unterschiede in Bezug auf Wissenszuwachs gibt es zwischen einer herkömmlichen und einer digitalen Unterrichtseinheit zu Bildung für nachhaltige Entwicklung? (Teilarbeit B)
- Inwiefern können Fünftklässler:innen die Begriffe *Nachhaltigkeit* und *Umweltschutz* differenzieren? (Teilarbeit B)
- Welchen Einfluss haben digitale Präferenzen und individuelles Interesse für biologische Thematiken auf den Lernfortschritt in einer digitalen BNE-Unterrichtseinheit? (Teilarbeit C)
- Inwiefern stellen digitale Präferenzen und individuelles Interesse für biologische Thematiken gegensätzliche Ausprägungen dar? (Teilarbeit C)
- Mit welchen Vorstellungen zum Thema *Nachhaltigkeit* kommen bayerische Fünftklässler:innen in die Sekundarstufe I? (Teilarbeit D)
- Welche Unterschiede zwischen den Geschlechtern können in Bezug auf Schüler:innenvorstellungen zum Konzept „Nachhaltigkeit" festgestellt werden?

3.3 Methoden

3.3.1 Stichproben und Studiendesigns

Die Eckdaten der Teilarbeiten werden in Tabelle 2 zusammengefasst. Teilarbeit A stellt eine Unterrichtskonzeption dar und wurde mit einer kleinen Pilotgruppe validiert. Teilarbeit B vergleicht den Wissenszuwachs und konzeptuelle Präferenzen zwischen Distanzunterricht und herkömmlichen BNE-Unterricht. Teilarbeit C befasst sich mit den Einflussfaktoren *Digitale Nativität* und *Faszination für Biologie* auf den Wissenszuwachs ebendieser Stichprobe. In Teilarbeit D wurden mittels einer von den Teilarbeiten A-C unabhängigen Stichprobe Schüler:innenvorstellungen erhoben.

Tabelle 2: Informationen zu Stichprobengröße (N), Alter, Geschlecht und Erhebungszeitraum

Teilarbeit	N	M_{Alter} ± *SD*	Geschlecht	Erhebungszeitraum
A	88	10,7 ± 0,34	40% ♀	Juni 2019
B	288	10,8 ± 0,45	41% ♀	Mai-Juni 2020
C				
D	139	10,2 ± 0,28	43% ♀	September-Oktober 2019

Die Daten wurden mittels eines Pre-Post-Testdesigns erhoben. Die Schüler:innen füllten für Teilarbeit A-C pseudonymisierte Fragebögen vor und nach einer Unterrichtseinheit aus. Für Teilarbeit D wurde ein Messzeitpunkt verwendet.

3.3.2 Erhebungsinstrumente

Der kognitive Lernfortschritt wurde mit einem programmspezifischen Messinstrument erhoben. Dafür wurde von einem Expertenteam bestehend aus Lehrer:innen und Didaktiker:innen vor dem Hintergrund der in der Unterrichtseinheit vermittelten Lehrplaninhalte ein Fragenset entwickelt. Die Fragen bezogen sich auf botanische Inhalte, wie Blattstellungen und Blütenformen, auf landwirtschaftliche Bewirtschaftungsmethoden, wie Düngung und Mahdzeitpunkte, sowie BNE-Wissen zu Nachhaltigkeitskonzepten und Biodiversität. Alle Fragen wurden als One-Choice-Option mit drei Distraktoren entwickelt. Das originale Fragenset wurde mit einer Pilotierungsgruppe getestet, wobei 24 Fragen für die Hauptstudie per Schüler:innenfeedback und Faktorenanalyse ausgewählt wurden (siehe Anhang Teilarbeit B: Fragebogen kognitives Wissen).

Semantische Differenzierung (*Semantisches Differential* oder *Differentialsemantik*, im Folgenden mit „SD" abgekürzt) wurde ursprünglich von Osgood, Suci und Tannenbaum [163] in den 1950er Jahren als eine Technik zur Extraktion von Einstellungen gegenüber Objekten oder Konzepten vorgeschlagen. Die Methode wird als universell einsetzbar angesehen, um einen Begriff, ein Objekt, ein Idee, ein Aktivität usw. zu messen [164–166] . SDs wurden verwendet, um die Einstellung zu bestimmten Themen oder Objekten

in einer Vielzahl von Forschungsdisziplinen zu bewerten, z.B. in den Bereichen Sozialwissenschaften, Wirtschaft, Marketing, Geologie und Architektur [167–173]. Es gilt als wirksames psychologisches Instrument zur Messung multidimensionaler Merkmale wie Persönlichkeit, Einstellung oder Kommunikation [174]. Es scheint auch ein vielversprechendes alternatives Instrument für regelmäßige Testungen an Schulen zu sein [175].

Ein semantisches Differential besteht aus bipolaren Adjektivpaaren, die im Idealfall eine antonymische Bedeutung haben, wie beispielsweise *gut – schlecht* (siehe Abbildung 7). Der gesamte Satz von Adjektiven wird anhand einer Likert-Skala bewertet (siehe Anhang Teilarbeit B: Fragebogen Semantisches Differential). Es werden acht bis 12 bipolare Paare mit sieben bis neun Skalenpunkten empfohlen [37].

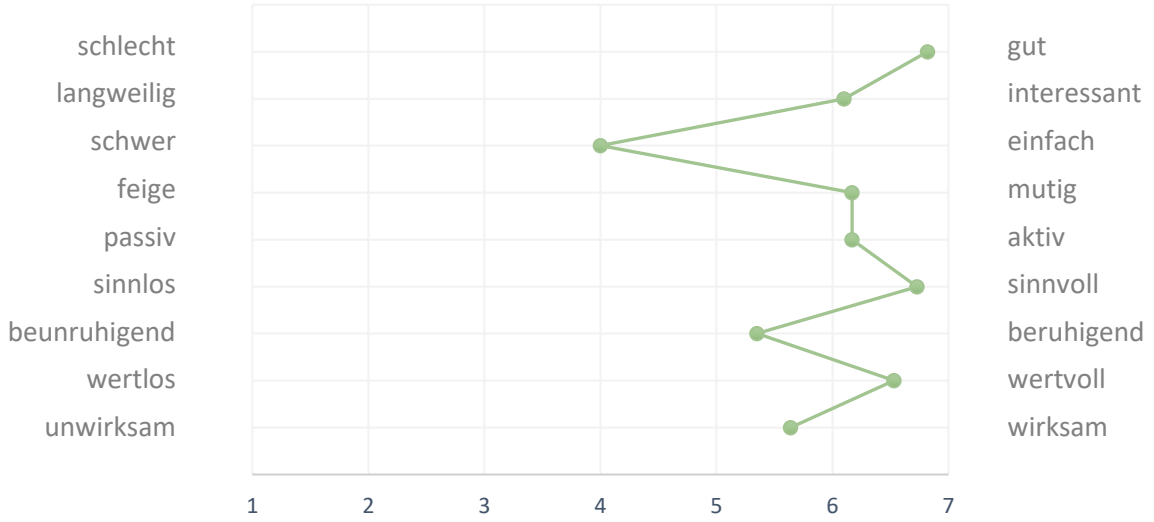

Abbildung 7: Beispiel eines Polaritätsprofils zum Begriff *Umweltschutz*

Semantische Strukturen und Bedeutungen werden auf einer multidimensionalen Ebene in Form einer Korrelationsmatrix dargestellt. Diese Matrix stellt den semantischen Raum dar, der von der Bewertung eines Konzepts eingenommen wird. Jedes Konzept wird durch ein Polaritätsprofil repräsentiert, das mit den Profilen anderer Befragter zu demselben Konzept oder dem Profil desselben Befragten zu anderen Konzepten verglichen werden kann. Zudem können Summenwerte oder Mittelwerte für jedes Konzept verglichen werden. In dieser Studie wurde ein SD mit einer Sieben-Punkte-Skala und neun binären Paaren verwendet. Die mittlere Punktzahl betrug somit 31,5. Wenn der Summenwert unter diesem Wert lag, kann die Einstellung zu dem Konzept im Allgemeinen als negativ zusammengefasst werden, und umgekehrt.

Des Weiteren wurden Messinstrumente eingesetzt, die durch selbst-berichtete Fähigkeiten latente Variablen erfassen (siehe Tabelle 3). Diese Vorgehensweise gilt in vielen Fachbereichen, insbesondere in der Verhaltensforschung, als etabliert und wird regelmäßig angewendet [176–178]. Sie folgt dem Campbell-Paradigma, laut dem eine Einstellung aus selbstberichteten Verhaltensweisen, Emotionen oder affektiven Aussagen

abgeleitet wird [179]. Verhalten liegt zwischen dem individuellen Einstellungsniveau einer Person und der potenziellen Kosten des jeweiligen Verhaltens. Das bedeutet, je schwieriger die Aussagen, denen die Schüler:innen zustimmen, und je aufwändiger die Verhaltensweisen, die sie betreffen, desto höher wird die entsprechende Einstellung bewertet [180]. In der Verhaltensforschung wird auch untersucht, welcher Zusammenhang zwischen den selbst-berichteten und tatsächlichen Fähigkeiten oder Verhalten besteht [181–183]. In diesem Forschungsprojekt wird deshalb eine Mischung aus Tests, wie dem kognitiven Lernfortschritt, und selbst-berichteten Fähigkeiten, wie der Digitalen Nativität und Faszination für Biologie, gewählt.

Tabelle 3: Messinstrumente aus Teilarbeit C

Messinstrument	**Abkürzung**	**Autor**	**Zitation**
Fascination with Biology	FBio	Otto et al.	[12]
Digital Nativity Assessment Scale	DNAS	Timothy Teo	[7]

Um die digitalen Fähigkeiten der Schüler:innen zu messen, wurde die *Digital Nativity Assessment Scale* verwendet [7]. Für die deutsche Übersetzung wurde ein Expert:innenteam sorgfältig ausgewählt. Es wurden einige sprachliche Anpassungen gemacht, indem beispielsweise neue Technologien wie Tablets berücksichtigt werden. Vor dem Einsatz des Fragebogens in dieser Studie wurde ein Pilottest mit 24 Schüler:innen zur Validierung der Übersetzung durchgeführt. Da es gemischte Ergebnisse zur Reproduktion der 4-Faktoren-Struktur von Teo gibt [11,184] wird zunächst die interne Struktur mittels Faktorenanalyse überprüft. Da für diese Zielgruppe nur wenige Daten vorliegen, insbesondere hinsichtlich möglicher Veränderungen der DNAS-Scores über kurze Zeiträume, wurde der Fragebogen pre-post eingesetzt. Die ursprünglich 7-strahlige Likert-Skala ("stimme überhaupt nicht zu" bis "stimme voll und ganz zu") besteht aus vier Unterkategorien mit jeweils fünf oder sechs Fragen. Im Gegensatz zu anderen internationalen Studien [185–187] wurde DNAS in Hinblick auf die Frustrationstoleranz und Fragebogen-Erfahrung der Zielgruppe als 5-Punkte-Skala eingesetzt (siehe Anhang Teilarbeit C: *Fragebogen Digital Nativity Assessment Scale*).

Um individuelles Interesse der Schüler:innen zu erfassen, wurde die *Fascination with Science Scale* verwendet [12]. Sie erfasst Verhalten, Wissen und Emotionen auf einer 5-stufigen Likert-Skala ("stimme überhaupt nicht zu"/"nie" bis "stimme voll zu"/"sehr oft"). Die ursprüngliche Skala besteht aus 84 Items in sieben verschiedenen Themenbereichen: Wissenschaft im Allgemeinen, Biologie, Chemie, Physik, Astronomie, Geologie und Technologie. Jede Subskala besteht aus 12 Items. Bei einer jungen Zielgruppe muss besonders darauf geachtet werden, dass die Schüler:innen nicht mit zu vielen Fragebögen überfordert werden [188]. Daher wurde nur eine der sieben Subskalen

verwendet, und zwar diejenige, die dem Inhalt der Interventionseinheit entspricht (siehe Anhang Teilarbeit C: *Fragebogen Faszination Biologie*). Da keine signifikanten Verhaltensänderungen im individuellen Interessenniveau über den kurzen Zeitraum der Intervention zu erwarten waren, wurde der FBio-Fragebogen einmal eingesetzt [189,190].

Zur Erfassung von Schüler:innenvorstellungen wurden vier offene Fragen eingesetzt (siehe Tabelle 4) und die schriftlichen Äußerungen anhand eines dafür entwickelten Kategoriensystems **Fehler! Verweisquelle konnte nicht gefunden werden.**quantifiziert. Diese Vorgehensweise folgt der qualitativen Inhaltsanalyse nach Bos & Tarnai und Mayring [191,192]. Dabei wurden die Äußerungen der Schüler:innen zunächst im Original transkribiert. Anschließend wurden die Äußerungen in einzelne Items unterteilt und ggfs. umgangssprachliche Formulierungen entsprechend angepasst. Basierend auf bisherigen Forschungsergebnissen wurde ein initiales Kategoriensystem erstellt. Dies wurde in mehrere Iterationen mit jeweils ca. 10% der Items verfeinert, indem nicht verwendete Kategorien gestrichen und induktiv neue hinzugefügt wurden. Das finale Kategoriensystem wurde durch sehr gute Werte der Beobachterübereinstimmung, sowohl zwischen verschiedenen Ratern als auch innerhalb eines Raters im Abstand von drei Monaten, verifiziert.

Tabelle 4: Fragen zur Erfassung von Schüler:innenvorstellungen

Frage	Formulierung
F1	Was stellst du dir unter dem Begriff „Nachhaltigkeit" vor? Nenne mind. 2 Beispiele für nachhaltiges Verhalten.
F2	Ist ein nachhaltiger Lebensstil wichtig? Begründe deine Antwort.
F3	Beschreibe Methoden, die bei nachhaltiger Landwirtschaft eingesetzt werden.
F4	Was würdest du gerne verändern, um einen nachhaltigeren Lebensstil zu führen? Nenne Beispiele aus deinem Alltag.

3.3.3 Datenauswertung

Für statistische Analysen sowie Datenaufbereitung wurden Microsoft® 365 Excel™ Enterprise und IBM® SPSS® Statistics Version 27 (2020) und Version 28 (2021) verwendet. ConQuest™ Version 2.0 wurde für Rasch-Analysen eingesetzt und SPSS® Amos™ Plugin Version 27 bzw. 28 für Strukturmodellberechnungen. Es wurden drei Signifikanzlevel unterschieden: $p \leq 0{,}05$ = *; $p \leq 0{,}01$ = **; $p \leq 0{,}001$ = ***. Weitere Kennzahlen für statistischen Verfahren können den jeweiligen Teilarbeiten entnommen werden.

In Teilarbeit A wurde die Effektivität des konzipierten Lernmoduls mittels einer Pilot-Gruppe überprüft. Dafür wurden Pre-Post-Testungen mittels t-Test verglichen.

In Teilarbeit B wurde zunächst die Validität und Reliabilität des selbst-konzipierten kognitiven Messinstruments ermittelt. Dafür wurden in SPSS Validitäts- und Reliabilitäts-Tests durchgeführt [193,194]. Anschließend wurde die Itemschwierigkeit sowie die Passung der Daten mittels Rasch-Analyse überprüft. Als zweites Instrument wurde das Semantische Differential analysiert, indem Mittelwerte zweier unterschiedlicher Konzepte (*Nachhaltigkeit* und *Umweltschutz*) gegenübergestellt wurden. Mittels explorativer Analyse beider Differentiale wurde ermittelt, ob die beiden Begrifflichkeiten eigene Komponenten darstellen. Anschließend wurde eine weitere Faktoranalyse der einzelnen Differentiale durchgeführt, um die interne Struktur zu bestätigen. Abschließend wurden Korrelationen zwischen Wissenszuwachs und Differential-Leveln überprüft.

In Teilarbeit C wurden zunächst die internen Strukturen für DNAS und FBio, also die Verteilung der Items auf latente Variablen, mittels konfirmatorischer Faktoranalyse bestätigt. Anschließend wurden beide Skalen mittels Spearman-Korrelation und Strukturmodellberechnungen in Relation zum Wissenszuwachs der Schüler:innen gesetzt. Als Vergleichswerte für das Strukturmodell wurden CFI (*Comparative Fit Index*), RMSEA (*Root Mean Square Error of Approximation*), relativer Chi^2 und SRMR (*Standardized Root Mean Square Residual*) herangezogen.

Teilarbeit D beschäftigt sich mit Schüler:innenvorstellungen. Um die einzelnen Äußerungen zu quantifizieren, wurde gemäß der qualitativen Inhaltsanalyse in mehreren Iterationen ein Kategoriensystem erstellt. Ebendieses konnte durch geeignete inter- und intra-rater-Reliabilitäten bestätigt werden. Anschließend wurde die Verteilung der Items auf einzelne Fragengruppen analysiert. Ergänzend wurde die Grundtendenz (positive/ negative Handlungen) sowie Korrelationen zwischen Geschlecht und Antwortschema berechnet.

3.4 Ergebnisse und Diskussion

Im Folgenden werden wesentliche Ergebnisse und Implikationen der Teilarbeiten zusammengefasst. Teilarbeit A bezieht sich auf das Unterrichtskonzept „Ökosystem Grünland". Teilarbeit B und C legen quantitative Daten der Interventionsstudie dar. Teilarbeit D stellt ergänzend qualitative Daten einer unabhängigen Stichprobe vor.

3.4.1 Teilarbeit A: BNE-Modul „Grünland – ein Einstieg in nachhaltiges Handeln"

Biodiversität und *Nachhaltigkeit* sind Schlüsselbegriffe modernen naturwissenschaftlichen Unterrichts. Während die meisten Studien abstrakte Beispiele für den Verlust biologischer Vielfalt verwenden, rückt das BNE-Modul „Ökosystem Grünland" Lebensräume in der Vordergrund, mit denen die Schüler:innen vertraut sind. Zentraler Aspekt der Lerneinheit ist eine problemorientierte und schülerzentrierte Vorgehensweise, um fachliche Inhalte und fachtypische Arbeitsweisen anhand einheimischer Flora und lokaler

Ökosysteme zu vertiefen [3]. Dabei werden moderne Unterrichtsmethoden eingesetzt, wie beispielsweise kollaborative Lernformen und digitale Unterrichtsmethoden.

Die Unterrichtssequenz zum Lehrplaninhalt „Ökosystem Grünland" wurde für die Interventionsstudie zu digitalen Unterrichtsmethoden entwickelt. Daher wurden vor, während und nach der Einheit Phasen zur Erhebung der Schüler:innendaten mittels Fragebogen eingeplant (siehe Anhang Teilarbeit A: Unterrichtssequenz „Ökosystem Grünland"). Die Informationen wurden sowohl vor Ort als auch im Distanzunterricht digital über die Präsentationsplattform *Prezi* bereitgestellt. Zur Umsetzung fachtypischer Arbeitsweisen, wie z.B. Pflanzenbestimmung oder Messung abiotischer Faktoren, wurden vor Ort digitale Methoden eingesetzt. Im Distanzunterricht wurden hierfür Alternativen bereitgestellt

In einer Pilotgruppe (N=88) konnte eine signifikante Zunahme kognitiver Fähigkeiten unter Berücksichtigung der Pre-Post-Tests nachgewiesen werden. Somit kann die Kombination aus originaler Naturbegegnung und digitalen Lehrmethoden als vielversprechender Ansatz bewertet werden, um das Verständnis für ökonomische und ökologische Implikationen von Nachhaltigkeit bei Fünftklässler:innen zu verbessern. Um den Einfluss des außerschulischen Lernortes besser einschätzen zu können, sollten in weiteren Erhebungen zusätzlich Kontrollgruppen im Regelunterricht erfasst werden. Bisherige Studien lieferten gemischte Ergebnisse zum Einfluss des natürlichen Lernumfeldes [57,195,196]. Im Bereich fachtypischer Arbeitsweisen bleibt offen, inwiefern man von Multiple-Choice-Tests auf prozessbezogene Kompetenzen schließen kann. Hier sollte in Folgestudien ein separates Messinstrument zu Kenn- und Bestimmungsübungen eingesetzt werden.

3.4.2 Teilarbeit B: Lerneffekte im BNE-Modul „Grünland"

Untersuchungen haben ergeben, dass sich direkte Interaktionen mit und in natürlichen Umgebungen positiv auf BNE-Wissen und -Einstellungen auswirken [1,197,198]. Pandemiebedingte Schließungen machten Exkursion und Besuche außerschulischer BNE-Zentren jedoch schwer realisierbar. Diese Teilarbeit vergleicht den Lerninhalt „Ökosystem Grünland" im Distanzunterricht mit den Daten aus der Pilotierung am außerschulischen Lernort. Das Lernmodul vermittelt Fachinhalte aus dem Bereich Botanik, wie Pflanzenmerkmale und Pflanzenfamilien, sowie aus dem Bereich Bildung für Nachhaltige Entwicklung, wie ökonomische und ökologische Vor- und Nachteile traditioneller und nachhaltiger Anbaumethoden. Der kognitive Lernprozess und konnotative Präferenzen von 288 Lernenden wurden in einem Pre-Post-Testdesign erfasst.

Der für diese Lerneinheit konzipierte Wissenstest deckte botanischen Inhalte sowie Aspekte nachhaltiger Landwirtschaft ab. Kontrollwerte zur Validität und Reliabilität sowie

die mittels Rasch-Analyse berechnete Itemschwierigkeit lagen innerhalb literaturbasierter Grenzwerte [194,199]. Zusammenfassend ist die Schwierigkeit des Tests als moderat zu beschreiben, wobei selten die volle Punktzahl erreicht wurde. Zur Messung umweltschutzbezogener Präferenzen wurde die Methode des semantischen Differentials verwendet. Die drei Dimensionen *Potenz*, *Valenz* und *Aktivierung* konnten mittels Hauptkomponentenanalyse bestätigt werden [37]. Zwischen den Mittelwerten für *Nachhaltigkeit* und *Umweltschutz* konnte kein signifikanter Unterschied festgestellt werden, sie wurden jedoch in innerhalb einer Komponentenanalyse jeweils als eigene Dimension abgebildet.

Nachdem die verwendeten Testinstrumente als reliabel bestätigt wurden, konnte der Lernfortschritt vor Ort und im Distanzunterricht untersucht werden. Frühere Studien haben festgestellt, dass Outdoor-Aktivitäten Wissenserwerb stärker fördern als herkömmlicher Unterricht [116,200,201]. Die Interventionseinheit „Ökosystem Grünland" führte jedoch in beiden Umsetzungen zu signifikantem Wissenszuwachs. Demzufolge konnten BNE-Inhalte mithilfe schülerzentrierter Unterrichtseinheiten auch im Kontext von Distanzunterricht erfolgreich umgesetzt werden. Die pandemische Lage stellte für Schüler:innen und Lehrkräfte eine Ausnahmesituation dar. Inwiefern die Daten davon beeinflusst wurden bzw. wie repräsentativ sie für den Regelunterricht sind, sollte in eine Folgestudie fortgeführt werden. Das Semantische Differential (SD) scheint besonders für Lehrkräfte und Erzieher:innen großes Potenzial zu haben, da die Verwendung von Adjektivpaaren ein einfaches Testinstrument darstellt. Die Verwendung der SD-Methode bei weiteren Konzepten und Altersgruppen sollte wertvolle Einblicke in dessen universelle Anwendbarkeit geben. Die Ergebnisse der SD-Analyse decken sich mit anderen BNE-Studien, indem sich die Wahrnehmung der Begriffe *nachhaltig* und *umweltfreundlich* weitestgehend deckt [18,202]. Die Faktoranalyse legt jedoch nahe, dass die Konzepte durchaus differenziert betrachtet werden. Diese Diskrepanz bietet Ansatzpunkte für weiteren Studien zur Auffassung der Nachhaltigkeitsdimensionen in dieser Altersgruppe.

Die Ergebnisse dieser Studie machen Hoffnung für die Erfüllung der *Agenda 2030*. Notfall-Distanzunterricht ist nicht mit einem Rückschlag im Bereich BNE gleichzusetzen, sondern vielmehr als wertvolle Ergänzung zu herkömmlichem BNE-Unterricht einzusetzen. So können kollaborative Unterrichtsmethoden vor Ort mit digitalen Elementen auf individueller Ebene verknüpft werden. Allerdings sind weitere Untersuchungen mit einer repräsentativeren Stichprobengröße erforderlich. Andere digitale Lehrmethoden wie *Blended Learning* und kollaborative Module sollten ebenfalls für den Unterricht in der Primar- und Sekundarstufe evaluiert werden.

3.4.3 Teilarbeit C: Digitale Nativität und Faszination mit Biologie

Im Rahmen des pandemie-bedingten Distanzunterrichts wurde der Einfluss digitaler Präferenzen auf den Lernfortschritt untersucht und mit dem Einfluss des Faszinationsgrades verglichen. Eine negative Korrelation zwischen der Zeit, die die Schüler:innen draußen in der Natur verbringen, und der Zeit, die sie drinnen vor einem digitalen Gerät verbringen, ist zu erwarten. 288 Fünftklässler:innen absolvierten die Lerneinheit „Ökosystem Grünland", in der biologischen Themen, wie Pflanzenbestimmung und Umweltfaktoren, sowie zu Themen der Bildung für nachhaltige Entwicklung, wie z.B. Merkmale einer nachhaltigen Landwirtschaft, vermittelt wurden. Vor und nach der Unterrichtseinheit wurden Fragebögen zu kognitiven Kompetenzen, digitaler Nativität und Faszination mit Biologie erhoben.

Die *Digital Nativity Assessment Scale* (DNAS) wurde eingesetzt, um Präferenzen hinsichtlich der Methode der Intervention zu erfassen [7]. Es konnte kein signifikanter Unterschied zwischen Pre- und Post-Testwerten festgestellt werden. Die grundlegende Robustheit der Skala sowie die Subskalen *Technology*, *Multitasking*, *Rewards* und *Graphics* konnten mittels konfirmatorischer Faktoranalyse bestätigt werden. Die Skala *Fascination for Biology* (FBio) wurde verwendet, um die individuelles Interesse das Thema der Intervention zu erfassen [12]. Hier konnte ebenfalls die grundlegende Faktorenstruktur mit drei Subskalen bestätigt werden. Nach separater Analyse beider Instrumente wurde Strukturgleichungsmodellierung angewandt, um die Beziehung zwischen der Faszination für das Thema, der Vertrautheit mit digitalen Lehrmethoden und dem Wissenszuwachs näher zu beleuchten. Das Modell zeigte gute Werte und sowohl DNAS als auch FBio beeinflussten den Wissenszuwachs positiv. Entgegen der Forschungshypothese scheint es jedoch keinen negativen Zusammenhang zwischen DNAS und FBio zu geben.

Die Ergebnisse untermauern die grundsätzliche Struktur des DNAS-Instruments [185,186]. Allerdings deuten die Daten darauf hin, dass einige Items an jüngere Nutzer:innen und moderne Technologien angepasst werden sollten. Die Bedeutung grundlegender Unterschiede zwischen digital kompetenten und nicht kompetenten Menschen nimmt in der modernen Gesellschaft zu. Es bleibt jedoch offen, ob die digitale Nativität lediglich eine Frage des Alters ist, oder ob andere Faktoren wie der soziale Hintergrund oder die Nationalität eine wichtigere Rolle spielen könnten [8,161,203]. Unabhängig davon sollten die digitalen Präferenzen der Schüler:innen ermittelt werden, bevor digitale Lehrmethoden im Unterricht eingesetzt werden [101,183]. Die Ergebnisse zur Faszination bestätigten bisherige Literaturwerte [2,13]. Wie erwartet zeigte sich kein signifikanter Unterschied zwischen Vor- und Nachtest, weder bei der Kontrollgruppe am außerschulischen Lernort noch bei der Gruppe im Distanzunterricht. Individuelles Interesse gilt als stabiles Persönlichkeitsmerkmal und kann über einen so kurzen Zeitraum nicht signifikant modifiziert werden [204]. Der positive Einfluss auf den Wissenszuwachs

lässt vermuten, dass individuelles Interesse instrumentalisiert werden könnte, um komplexe BNE-Inhalte erfolgreich zu vermitteln. Kognitive Überforderung kann bei Schüler:innen zu Frustration führen und sich negativ auf den Lernfortschritt auswirken [205]. Die vorliegenden Analysen deuten an, dass hohe Faszinationswerte diesem Effekt entgegenwirken könnten. Für BNE ist eine hohe Frustrationstoleranz besonders relevant, da die Inhalte multiperspektivisch und dadurch inhärent herausfordernd sind. Um genauere Informationen über den Zusammenhang zwischen Präferenzen der Methode, individuellem Interesse für das Thema und Lernfortschritt zu erhalten, sollten die anderen Subskalen der Faszinationsskala sowohl in Online-Lerneinheiten als auch in der Praxis getestet werden.

Überraschenderweise zeigten *Fascination* und *Digital Nativity* einen geringen, wenn nicht vernachlässigbaren Zusammenhang. Somit konnte die Hypothese, dass „Screen-Time" im Gegensatz zu „Green-Time" steht, nicht bestätigt werden. Für die Schüler:innen sind Interesse für biologische Thematiken und digitale Präferenzen folglich nicht gegensätzlich. Dies birgt Implikationen für modernen Biologie- und BNE-Unterricht. Zum einen könnten Schüler:innen durch den virtuellen Besuch einer natürlichen Lernumgebung für Umweltthemen sensibilisiert werden. Zum anderen könnten digitale Präferenzen genutzt werden, um Inhalte, die für die Lernenden sonst nicht attraktiv wären, durch moderne Unterrichtsmethodik motivierend zu gestalten. Um weitere Implikationen für die Unterrichtskonzeption ableiten zu können, sollten die Ergebnisse im Schulalltag zunächst reproduziert werden.

3.4.4 Teilarbeit D: Schüler:innenvorstellungen zum Begriff „Nachhaltigkeit"

BNE-Programme, die an den Vorstellungen der Schüler:innen anknüpfen, gelten als idealer Ausgangspunkt für effektive Lernfortschritte [178]. Angesichts der zunehmenden Fokussierung auf Nachhaltigkeitskonzepte in den Medien ist es vielversprechend, dieses Thema in einem schüler:innenorientierten Rahmen zu behandeln. Die vorliegende Querschnittsstudie soll durch eine systematische Analyse der Vorstellungen von Schüler:innen den Einblick in jugendliche Präkonzepte von Nachhaltigkeit und nachhaltigem Verhalten erweitern. Außerdem sollen die Daten auf Unterschiede zwischen den Geschlechtern überprüft werden. Nachhaltige Verhaltensweisen werden häufig als feminin dargestellt [206], wobei fraglich ist, ob diese Tendenzen bereits bei Zehnjährigen bemerkbar sind. Die Schüler:innenvorstellungen wurden mithilfe offener Fragen erhoben und anhand eines validierten Kategoriensystem quantifiziert. Diese Studie dient als Ausgangspunkt für weitere Datenerhebungen, zum Beispiel in Form von Interviews. Die Rekrutierung einzelner Schulklassen durch *Convenience Sampling* erlaubt keine verallgemeinernden Aussagen für eine ganze Generation [207].

Der Begriff *nachhaltig* war den meisten Teilnehmer:innen nicht aus der Schule, sondern aus den Medien bekannt. Andere Studien berichteten einen ähnlichen Einfluss der Medienberichterstattung auf Schüler:innenvorstellungen [20,208]. Entsprechend wird erwartet, dass keine differenzierten Definitionen oder komplexe Beispiele aus Lehrplaninhalten von den Schüler:innen angeführt werden. Im Kategoriensystem wurde deshalb grundlegen zwischen Definitionen für Nachhaltigkeit und einfachen Beispielen unterschieden. Dadurch sollte erfasst werden, ob die Schüler:innen Informationen aus ggfs. schulischen Kontexten in Form von Merksätzen wiedergeben, oder einfache Alltagsbeispiele. Im Kategoriensystem wurden folglich vier Hauptkategorien unterschieden: 57% der Items fielen in die *Beispiel*-Kategorie, 17% wurden als *Definition* kategorisiert, 20% der Items wurden als Nonsens verworfen (z.B. „Keine Ahnung") und 6% waren thematisch inadäquat (z.B. „Greta Thunberg" ohne weiteren Kontext). Die meisten Beispiele gehörten zur Unterkategorie *Recycling* und bezogen sich auf wiederverwertbare oder wiederverwendbare Alltagsgegenstände, wie etwa Stofftaschen und Glasflaschen. Weitere Beispiele bezogen sich auf *Fortbewegung*, vor allem mit dem Fahrrad zu fahren, anstatt ein Auto zu nutzen. Diese Aspekte scheinen aus der Alltagswelt der Schüler:innen zu stammen und sind vermutlich unreflektiert. Beispielsweise haben wenige Schüler:innen argumentiert, weshalb Autos nicht nachhaltig oder umweltfreundlich seien. Einige Nennungen von E-Autos könnten auf die in den Medien diskutierte E-Mobilitätswende, die in den letzten Jahren an Bedeutung gewonnen hat, zurückzuführen sein.

Im Gegensatz zu Ergebnissen aus Teilstudie B konnte keine eindeutige Unterscheidung der Begriffe *nachhaltig* und *umweltfreundlich* seitens der Schüler:innen festgestellt werden. Wie in anderen Studien angedeutet, werden ökonomische und soziale Aspekte kaum erwähnt [17,209]. Zudem scheinen sie nicht zu glauben, dass ihre eigenen Handlungen einen spürbaren Einfluss auf die Umwelt haben können. Diese Schlussfolgerung lässt sich aus der Diskrepanz zwischen den Fragen 2 und 4 ziehen. In Frage 2 („Ist ein nachhaltiger Lebensstil wichtig? Begründe deine Antwort.") wird häufig "ja" angegeben, jedoch wird bei Frage 4 ("Was würdest du gerne verändern, um einen nachhaltigeren Lebensstil zu führen? Nenne Beispiele aus deinem Alltag ") häufig mit "nichts" oder synonymen Begriffen beantwortet. Es scheint unrealistisch zu sein, dass viele Schüler:innen bereits so nachhaltig wie möglich leben. Internationale Klimaschutzbewegungen, wie *Fridays-For-Future*, zeigten, dass junge Menschen durchaus Handlungsspielraum ihrerseits sehen [210]. Die hier analysierte Zielgruppe scheint jedoch wenig Möglichkeiten zu kennen, sich selbst aktiv für den Umweltschutz und einen nachhaltigeren Lebensstil einzusetzen. Hier könnte BNE-Unterricht ansetzen, indem altersgemäße Handlungsmöglichkeiten aufgezeigt werden.

Bemerkenswert ist, dass etwa ¼ der gesammelten Items nicht verwertbar war oder keinen Bezug zum Thema hatte. Dies zeigt, dass ¾ der Schüler:innen sinnvolle

Assoziationen zum Begriff *Nachhaltigkeit* angeben konnten. Nur wenige Aussagen waren definitionsartig und keine bezog sich auf alle drei Dimensionen. Im LehrplanPLUS werden BNE-Themen im Grundschulkurrikulum eingeführt [3]. Bei der hier analysierten Stichprobe konnten jedoch keine multiperspektivischen Nachhaltigkeitskonzepte identifiziert werden. Sofern andere Ansätze bei den Schüler:innen vorhanden sein sollten, konnten sie möglicherweise durch die Erhebung mittels offener Fragen nicht provoziert werden. Mangelnde kommunikative Kompetenzen könnten zudem dafür verantwortlich sein, dass Schülerinnen signifikant mehr themenbezogene Antworten gaben. Durch umfassende Vergleichsstudien wurde auf internationaler Ebene nachgewiesen, dass Mädchen in der Primarstufe einen deutlichen Vorsprung im Bereich Lese-Rechtschreib-Kompetenzen haben [211,212]. Dies könnte das Antwortschema bei offenen Fragen beeinflussen. Im Umfang dieser Forschungsarbeit konnte auf die Erhebung dieser Fähigkeiten nicht eingegangen werden. In Folgestudien sollte deshalb ergänzend mit Interviews gearbeitet werden, um zum einen multiperspektivische Vorstellungen extrahieren zu können, und zum anderen Störfaktoren wir Lesekompetenz zu umgehen.

In Teilstudie B wird angedeutet, dass die Schüler:innen dem Nachhaltigkeitsbegriff grundsätzlich positiv gegenüberstehen. Innerhalb der Schüler:innenvorstellungen scheint jedoch die vorherrschende Tendenz zu sein, dass nachhaltiges Handeln mit Einschränkungen verbunden ist. Zudem sehen Fünftklässler:innen wenig Verbesserungspunkte und Handlungsspielraum in ihrem Alltag. Hier sollten BNE-Initiativen ansetzen und zeigen, wie man sich als junger Mensch regional für nachhaltige Entwicklung und nachhaltige Lebensstile einsetzen kann. Entsprechend der genannten Kategorien könnten Lehrkräfte beispielsweise auf nachhaltigen Konsum, Recycling oder Engagement in Umweltschutzinitiativen eingehen.

4.5 Schlussfolgerung und Ausblick

Der aktuelle Klimabericht des IPCC (Intergovernmental Panel on Climate Change, 209) macht deutlich, dass nur wenig Spielraum besteht, um die 1,5-Grad-Marke der Erderwärmung nicht zu überschreiten. Es werden verschiedene Handlungsfelder zur Begrenzung von CO_2-Emissionen in die Atmosphäre thematisiert: Regierungen können die Nutzung natürlicher Ressourcen beschränken, wirtschaftliche Unternehmen können Innovationen im Bereich Energiehaushalt und CO_2-Konservierung fördern, und Individuen können beim Konsum und fossilen Fortbewegungsmitteln ihren Beitrag leisten. Dies unterstreicht die Bedeutung von Bildung für nachhaltige Entwicklung, da hier eine Möglichkeit besteht, individuelle Lebensstile zu beeinflussen und den Druck auf Politik und Wirtschaft durch bottom-up Bewegungen zu erhöhen.

Die hier vorgestellte Forschungsarbeit hat innerhalb des Lernkontextes „Ökosystem Grünland" gezeigt, dass effektiver BNE-Unterricht auch in schwierigen Situationen wie

der andauernden pandemischen Lage möglich ist. Anhand der dafür konzipierten Unterrichtseinheit wird angedeutet, dass eine ausgewogene Mischung aus digitalen Elementen und schülerzentrierten Arbeitsweisen sinnvoll ist. Darauf aufbauend können Schulen in Zukunft auf digitalen Unterricht oder digitale Methoden in diesem Bereich setzen. BNE-Zentren haben die Möglichkeit, durch Online-Angebote ein breiteres Publikum anzusprechen. Exkursionen an außerschulische Lernorte können durch Distanzunterricht vor- oder nachentlastet werden. Die vorgestellten Modellrechnungen weisen darauf hin, dass digitalisierte außerschulische Lernorte hohes Potential zu Förderung von Wissenszuwachs haben, indem sie individuelles Interesse und methodische Präferenzen effektiv kombinieren. Um insbesondere affektive Komponenten einzubeziehen und fachtypische Arbeitsweisen schülerzentriert zu fördern, empfiehlt sich die Kombination aus digitaler Methodik und Originalerfahrung in natürlichen Lernumgebungen.

Kognitive Lernfortschritte waren innerhalb dieser Studie am außerschulischen Lernort und im Distanzunterricht vergleichbar. Eine Evaluation der Bestimmungskompetenz, wie sie im Lehrplan angedeutet ist, war allerdings nicht möglich. Dafür wäre eine Intervention vor Ort oder zumindest der Durchführung von Bestimmungstests in den Schulen notwendig gewesen. Vom Staatsministerium konnte aufgrund der angespannten Situation an den Schulen keine Erlaubnis für weitere Erhebungen erteilt werden. Inwiefern der kognitive Lernfortschritt hier übertragen werden kann, bleibt folglich fraglich. Zudem weisen die Ergebnisse auf Entwicklungspotenzial auf bildungspolitischer Ebene hin. Zentral organisierte und standardisierte BNE-Einheiten können durch Distanzunterricht in den Schulalltag integriert werden. Hierdurch könnten Diskrepanzen zwischen Schulen und einzelnen Lehrkräften in Bezug auf BNE-Inhalte entgegenwirkt werden.

Es konnte bestätigt werden, dass motivationale Komponenten einen großen Einfluss auf Wissenserwerb haben. Sowohl der Einfluss von digitalen Präferenzen als auch individuellem Interesse sollte deshalb in der Unterrichtskonzeption berücksichtig werden. Die Faszinationswerte der Stichprobe waren überdurchschnittlich hoch. BNE-Module in der Sekundarstufe könnten hier ansetzen, indem sie mit ökologischen Inhalten beginnen und anschließend die Perspektive auf ökonomische und soziale Aspekte ausweiten. Um diese Vorgehensweise zu untermauern, sollten Faszinationslevel für höhere Jahrgangsstufen erhoben werden. In anderen Studien hatten sich hier Entwicklungen hin zu Extremgruppen angedeutet [13]. Weiterhin wäre es im Sinne des Campbell-Paradigmas interessant zu untersuchen, inwiefern sich berichtetes Verhalten der Schüler:innen von ihrem tatsächlichen Verhalten unterscheidet. Je nach Testinstrument und weiteren Einflussfaktoren wie z.B. sozialer Erwünschtheit, könnte berichtetes Verhalten und daraus abgeleitete Einstellungen von tatsächlichem Verhalten bzw. den entsprechenden Präferenzen abweichen. Insbesondere beim DNAS-Instrument könnte eine Folgestudie den Zusammenhang von DNAS-Level und tatsächlichen digitalen Fähigkeiten näher

beleuchten. Die Idee digitaler Generationen scheint innerhalb dieser Arbeit nicht bestätigt worden zu sein, bedarf jedoch weiterer Studien, um sie als widerlegt betrachten zu können.

Analysen zum Semantischen Differential haben gezeigt, dass die Konzepte *Nachhaltigkeit* und *Umweltschutz* bei Fünftklässlern sehr ähnlich bewertet werden. Die ergänzend erhobenen Schüler:innenvorstellungen untermauerten diese Erkenntnis. Dabei wurden unerwartete Interessensgebiete vor allem im Bereich nachhaltiger Produkte und Recyclingkreisläufe aufgedeckt. Hieraus lassen sich schülergerechte Problemstellungen für den naturwissenschaftlichen Unterricht ableiten. Insbesondere die Entwicklung dieser Interessen über den Verlauf einer schulischen Laufbahn bietet vielversprechende Anknüpfpunkte für weitere Studien. So könnten die gleichen Fragen in der Primarstufe oder am Übergang von Sekundarstufe I zu Sekundarstufe II gestellt und die Itemhäufigkeiten verglichen werden. Dadurch könnte zum einen der Einfluss von Lehrplanthemen auf die Schüler:innenvorstellungen untersucht werden und zum anderen überprüft werden, ob die Lernenden mit zunehmenden Alter auch mehr Handlungspotenzial ihrerseits sehen. Schließlich zielt BNE darauf ab, junge Menschen für die akuten Problematiken zu sensibilisieren und ihren Lebensstil sowie den ihrer Mitmenschen nachhaltig zu verändern.

Eingangs wurde der Zusammenhang zwischen den SDGs, ausbaufähigen Zielen in Deutschland und top-down bzw. bottom-up Initiativen erläutert. Globale Klimastreiks haben gezeigt, dass Nachhaltigkeitsinitiativen nicht nur für Erwachsene relevant sind. Deshalb sollten junge Generationen bei Anpassungen in Bereich 12 und 13 einbezogen werden. Dafür müssen zunächst Wissenslücken über die sozialen und wirtschaftlichen Auswirkungen nachhaltiger Lebensweisen geschlossen werden – idealerweise in Kooperation mit professionellen BNE-Zentren. Ist die eigenständige Handlungsfähigkeit, also die Mündigkeit, der Schüler:innen gestärkt, können sie in bestehende Initiativen aktiv integriert oder dazu angehalten werden, eigene Aktionsbündnisse zu etablieren. Auf all diesen Ebenen können digitale Unterrichts- und Kommunikationsmittel effektiv genutzt werden. Sie stehen nachhaltigen Lebensstilen nicht im Weg, sondern bestärken sie, sofern richtig eingesetzt.

4. Verzeichnisse

Insofern keine detaillierten Literaturverweise angegeben sind, wurden Abbildungen und Tabellen selbst erstellt mithilfe der Informationen aus den entsprechenden Quellen oder auf Basis erhobener Daten.

4.1 Abkürzungsverzeichnis

ausgeschriebenes Wort	**Abkürzung**
Augmented Reality	AR
Bildung für Nachhaltige Entwicklung	BNE
ins Englische übersetzt	engl.
Fascination with Biology/ Faszination für Biologie	FBio
Informations- und Kommunikationstechnologien	IKT
Mathematik, Informatik, Naturwissenschaften, und Technik	MINT
Schüler:innenvorstellungen	SVs
Sustainable Development Goals/ Ziele nachhaltiger Entwicklung	SDGs
Semantische Differentiale	SDs
Virtual Reality	VR

4.2 Abbildungsverzeichnis

4.3 Tabellenverzeichnis

4.4 Literaturverzeichnis

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5. Teilarbeiten

Im Folgenden werden zunächst die Teilarbeiten gelistet. Daraufhin wird der Eigenanteil dargestellt gefolgt von den Manuskripten in ihrer Originalfassung. Teilarbeit C & D sind derzeit bei den genannten Journals eingereicht.

5.1 Publikationen

A. Fiedler, S. T., Heyne, T., & Bogner, F. X. (2020). Explore Your Local Biodiversity – How School Grounds Evoke Visions of Sustainability. *The American Biology Teacher*, *82*(9), 606–613. https://doi.org/10.1525/abt.2020.82.9.606

B. Fiedler, S. T., Heyne, T., & Bogner, F. X. (2021). COVID-19 and Lockdown Schooling: How Digital Learning Environments Influence Semantic Structures and Sustainability Knowledge. *Discover Sustainability*, *2*(1). https://doi.org/10.1007/s43621-021-00041-y

C. Fiedler, S. T., Heyne, T., & Bogner, F. X. (2022). Closing the Gap: Potentials of ESE Distance Teaching. *Sustainability*, 14 (14). https://doi.org/10.3390/su14148330.

D. Fiedler, S. T., Heyne, T., & Bogner, F. X. (2023). 'Sustainable' is Synonymous to 'Eco-friendly': Student Conceptions about Sustainability and Sustainable Behavior.

5.2 Darstellung des Eigenanteils

Das Unterrichtsmodul und alle Teilarbeiten wurden von mir konzipiert, alle Teilarbeiten wurden von mir als Erstautoring verfasst und anschließend in Kooperation mit beiden Co-Autoren modifiziert. Das Kategoriensystem wurde mit Unterstützung studentischer Hilfskräfte validiert. Details zu aus der Literatur entnommenen Skalen können den Teilstudien entnommen werden.

5.3 Teilarbeit A

The American Biology Teacher (2020)

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Explore Your Local Biodiversity – How School Grounds Evoke Visions of Sustainability

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Abstract

Biodiversity and sustainability are key words of modern nature-of-science teaching. While most studies use rather abstract examples for biodiversity loss, we focused on habitats that students are familiar with. Our module was developed to deepen the understanding of domestic botanical ecosystems by having students work with and on designated pasture areas. The economic implications of sustainability were addressed by contrasting intensive and extensive agriculture, as well as by touching upon topics such as organic labels and modern agriculture. By focusing on domestic ecosystems within everyday contexts, combined with digital teaching methods, we successfully increased individual knowledge levels when taking before-and-after participation scores into account. Based on these results, we conclude that our approach to using different forms of pasture on the school grounds is a promising way to improve students' understanding of the economic and ecological implications of sustainability.

Key Words:

biodiversity; sustainability; sustainable agriculture; school garden; digital teaching methods.

Introduction

Environmentally friendly products, ecological footprints, and pollution of the environment are currently subjects of lively public discussion. Visions of sustainability in an environmental as well as social and educational context have long been integrated in school syllabi. Students have recently shown, in a worldwide movement, that they are interested in sustainability despite heavy criticism regarding their lack of knowledge in this field, especially in evaluating human impacts on earth systems (Wahlstro¨m et al., 2019).

Botany might not be students' favorite subject; however, plants and their role in ecosystems offer a smooth transition to the core ideas of "human impacts on earth systems." A school garden, for example, can demonstrate the relationships between abiotic factors (like water supply or light intensity) and biotic factors (such as plant growth or interspecies relations). Several studies have focused on students tending a school yard or investigating a wild backyard area (e.g., Cobb et al., 2003; Passy, 2014). Some have used different approaches, like contrasting experimental and traditional instruction styles (Pogacˆ-nik et al., 2014) or socioeconomic influences (Moon & Spinelli, 2013). Despite employing various designs, all these studies concluded that teaching in school

gardens has positive effects on emotional and cognitive scores (Nyberg, 2014; Ampuero et al., 2015; Wistoft & Dyg, 2017). There is a direct relation between students successfully gaining ecological knowledge and the proximity of the studied ecosystem to their own "natural" environment (Simonneaux & Simonneaux, 2009). This implies that subjects such as biodiversity are taught more effectively in the context of local ecosystems like pastures, instead of using extreme examples like the Amazon rainforest or the Sahara Desert. Hence, we decided to focus on the influence of human impacts on local ecosystems. The combination of plants and animals in their natural habitat and digital methods in our intervention design ensures an authentic yet pupil-based learning environment. We defined intensive agriculture as being focused on the highest yield possible by using fertilizers, insecticides, mechanization of labor, and so on. Extensive agriculture uses techniques in accordance with the natural fertility of the land, local climate, and other factors, which results in less yield per unit but is considered more environmentally friendly.

One main difference between natural habitats and those suffering under human influences is biodiversity, which includes genetic diversity, species diversity, and ecosystem diversity (Jeronen, 2019). Here, we do not focus on the latter, since we are looking at one specific ecosystem. In our latitudes, the typical pasture is manmade through thousands of years of cultivation and deforestation. The cultivation of plants, namely agriculture, was one of the main aspects of human evolution and has affected plant evolution as well. Maize, for example, cannot persist without humans because it is not able to spread its seeds on its own (Campbell et al., 2017). Plant breeding has been used for many generations, from long before people understood how genes and genetic transfer work. Since the latter discoveries, the impact of agriculture on plant biodiversity has been even greater. Widespread use of monocultures, for example, has influenced local biodiversity dramatically, and the cultivation of forage crops has heavily reduced species diversity (Rusch et al., 2017). Older students (ages 16–18) are already aware of ecological and economic aspects of biodiversity loss (Menzel & Bo¨ geholz, 2009). Creating awareness of such complex issues in younger students needs something like a methodical wake-up call.

The first step is to be able to identify different species. We took into account what schools are able to provide in the way of living things that young students are able to work with and decided to use plants for taxonomy exercises. Learning scientific identification techniques and the respective scientific vocabulary is a prerequisite for understanding the important role of flowers in ecosystems. Most plants' eye-catching appearance is a result of coevolution of plants and insects: attracting potential pollinators through nectar makes the insect touch stigma and carpel, hence spreading the pollen from one flower to the next (Occhipinti, 2013). The dependencies of insects and plants,

and their implications for ecosystems, can only be fully grasped if we can identify similarities and differences between plant species. Despite its essential role in pollination and fertilization, most people cannot identify a flower's basic structures (Menzel & Bo¨ geholz, 2009). One reason might be the great variety of the outward appearance of the flower itself (Mader, 2009). Thus, we used a balanced combination of a theoretical framework – namely appropriate vocabulary and how to properly use an identification key – and working in the field with real flowers in their natural habitat.

Besides addressing biotic factors of ecosystems, we also focused on the abiotic ones. In intensive agriculture, farmers use fertilizer to reduce nutrient deficiencies in their plants. By doing so, they manipulate the whole surrounding natural habitat through nutrient enrichment (Hendricks et al., 2019). We want to support the idea of using organic fertilizers, naturally derived from a mix of different types of decomposed organic matter, which prevents overfertilization. Installing a compost maker at home and using its decomposed matter as a natural fertilizer can be one example for a more sustainable lifestyle on an individual level. Adding additional nutrients, such as nitrogen, not only affects the species diversity of the respective habitat but has far-reaching consequences, especially when it reaches the groundwater level. An influx of nutrients critically degrades the quality of aquatic ecosystems and adjoining terrestrial ecosystems (Barszczewski, 2017). This results in a noticeable loss of biodiversity, because plants that are specialized in certain nutrient deficiencies are overrun by less adapted and therefore fewer sensitive species, which would not be able to survive in a habitat without nutrient additions. The impact of diversity loss is not yet fully assessable, but many scientists predict heavy negative outcomes for humankind and for ecosystems in general (Cardinale, 2014; Dempsey, 2015; Roe, 2019; Rosenberg et al., 2019).

The overall aim of our learning module is to create visions of sustainability in the context of agriculture. Organic farmers use different (and sometimes more expensive) farming techniques in order to promote a healthier lifestyle for people and the land (Mader, 2009; Rusch et al., 2017). According to the U.S. Department of Agriculture (USDA), the main differences between organic and conventional farming techniques are that the latter rely on synthetically produced fertilizers, herbicides, and pesticides, whereas the former use "old" farming techniques, which rely on natural nutrition, crop rotation, and sufficient biodiversity to fight pests (see USDA, 2015). Our aim is to deepen students' understanding of different farming techniques and their impact on local ecosystems.

Student Learning Objectives

After completing our learning module, students will have developed a certain sensitivity for flowers and their impact on ecosystems. They can use a taxonomic key for local flowers and are familiar with the importance of biodiversity in general. They can evaluate

intensive and extensive agricultural methods in terms of profit, influence on natural habitats, and sustainability. They have rudimentary knowledge of sustainable and not-quite-as-sustainable everyday activities.

Figure 1: Students use the idfentification app iBlumen in the field.

i Details of the Intervention

Our intervention uses ecosystems that the students are familiar with as a tool to evoke visions of sustainability through connectedness to nature. It was designed to provide an authentic glimpse of different states of pasture, combined with digital teaching methods (Figure 1). There were four separate plots of pasture, *6 m2 in size, simulating "normal" lawn, grazing land for intensive agriculture, grazing land for extensive agriculture, and insect-friendly pasture with a variety of different flowering plants (Figure 2). To create authentic plots, we sought out the help of a plant nursery that provides seeding mixtures for local farmers. We gathered information about our soil (pH value, nutrition saturation, average soil moisture), and the plant nursery created seed mixtures, based on these values, of either agricultural crops or flowers (the latter mix is used in specific areas that are designed to help stabilize pollinator populations; in our setup, this seed mixture was labeled "natural"). The plots then, of course, had to be cultivated – thus introducing the students to garden work. Both intensive and extensive plots were created with the agricultural seed mix and were treated differently: the intensive area was mowed more frequently, which resulted in an overall reduced height of the plants and reduced diversity. The aim of having four plots in close proximity is that they appear to be different at first glance. Thus, when students approach the pasture area, they instantly notice significant differences between the four plots.

Figure 2: Layout of different pasture areas used in the first learning unit.

Our intervention covered two lessons, each lasting two hours. Teachers were required to ensure a certain level of pre-knowledge about flowers as reproductive organs. Each intervention day was designed for two student groups of about 25 pupils each, which completed the two different lessons in reversed order – that is, one group started on the pasture, while the other started in the so-called green classroom (Figure 3). The student groups were guided through the day by a researcher diary, which provided work assignments and space for taking notes and summarizing. The diary automatically divided students into "expert groups" with specific tasks for factor measurement on the pasture and the green classroom unit. An example diary is provided in the Supplemental Material available with the online version of this article.

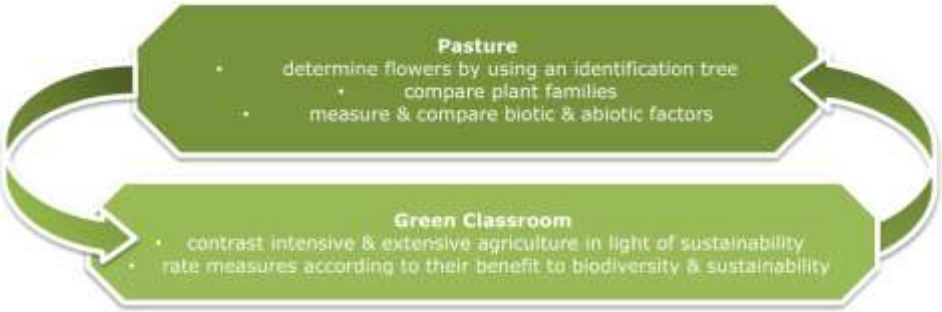


Figure 3: Design of the learning units.

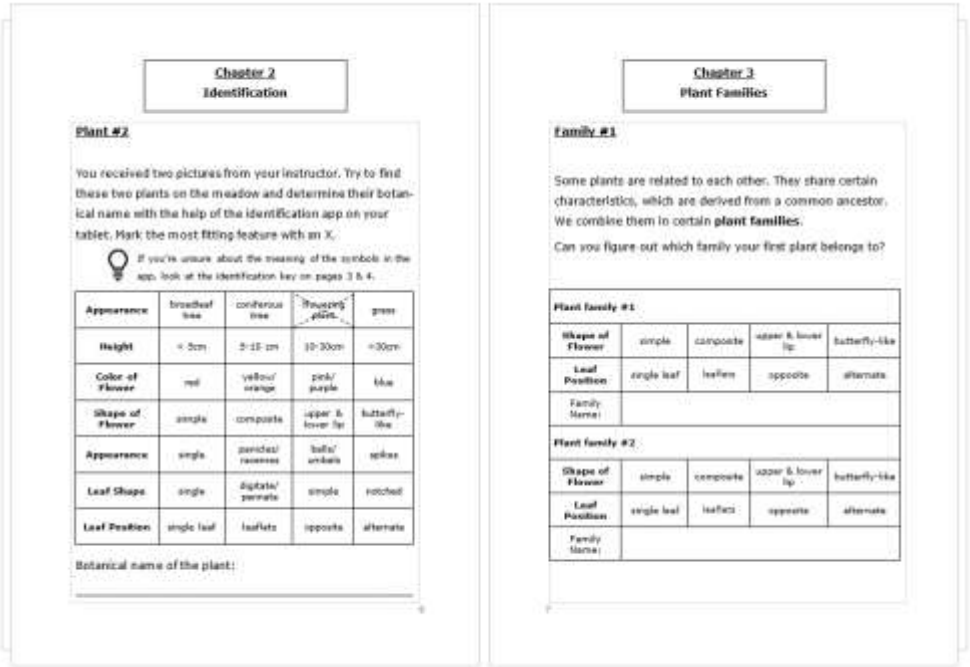
Exploring the Pasture

This module was divided into two major phases: plant taxonomy and ecosystem. Students had to identify different types of plants on the basis of features like size and shape of the leaves. The identification key was provided on tablet computers with the iBlumen app (Figure 4). Students in "bring-your-own-device" classes could bring their own

Figure 4: Screenshots form iBlumen (English version).

tablets, whereas schools that do not have access to such devices were provided with iPads on site. Although the app is intuitively designed, students were paired up during the identification part to make sure that students with little digital knowledge had peer support when facing technical difficulties. The features shape of flower, type of inflorescence, margin of leaves, and arrangement of leaves were established beforehand. In the app, students had to choose one out of six possible values of these plant characteristics. The show button then revealed the possible solutions remaining (ideally only one). In the screenshot (Figure 4), no characteristic is marked, so show is left with all possible solutions – in this case, 1727. We ensured that all "unknown" plants used in our setup were determinable by the iBlumen app.

The students received pictures of two flowers. First, they had to find the respective flowers on the pasture. Second, they had to identify the features to find out their common names. There was a chart in the researcher diary that corresponds with the identification features of the app (Figure 5). Students had to tick the appropriate boxes in the diary after they had determined their plants via the app. This design made it possible to also have non-tablet classes that identified their plants with a book that is commonly used in German schools. They used the same characteristics as in the app. The "unknown" species were chosen by the instructors on a day-to-day basis, because our intervention lasted longer than the flowering time of certain species. After a plenary phase in which students compared their findings with the help of the chart in the diary, they were given a third unknown flower. In this phase, the students had to establish the concept of plant families with similar features. Once again, students had to tick the



Chapter 2
Identification

Plant #2

You received two pictures from your instructor. Try to find these two plants on the meadow and determine their botanical name with the help of the identification app on your tablet. Mark the most fitting feature with an X.

If you're unsure about the meaning of the symbols in the app, look at the identification key on pages 3 & 4.

Appearance	broadleaf tree	coniferous tree	flowering plant	grass
Height	< 5cm	5-10 cm	10-30cm	>30cm
Color of Flower	red	yellow/ orange	pink/ purple	blue
Shape of Flower	simple	composite	upper & lower lip	butterfly-like
Appearance	single	panicles/ racemes	balls/ umbels	spikes
Leaf Shape	single	digitate/ pennate	simple	notched
Leaf Position	single leaf	leaflets	opposite	alternate

Botanical name of the plant:

Chapter 3
Plant Families

Family #1

Some plants are related to each other. They share certain characteristics, which are derived from a common ancestor. We combine them in certain **plant families**.

Can you figure out which family your first plant belongs to?

Plant family #1				
Shape of Flower	simple	composite	upper & lower lip	butterfly-like
Leaf Position	single leaf	leaflets	opposite	alternate
Family Name:				
Plant family #2				
Shape of Flower	simple	composite	upper & lower lip	butterfly-like
Leaf Position	single leaf	leaflets	opposite	alternate
Family Name:				

Figure 5: Excerpt from the researcher diary (taxonomy).

correct boxes and their findings were discussed in plenary and, if necessary, corrected (Figure 5).

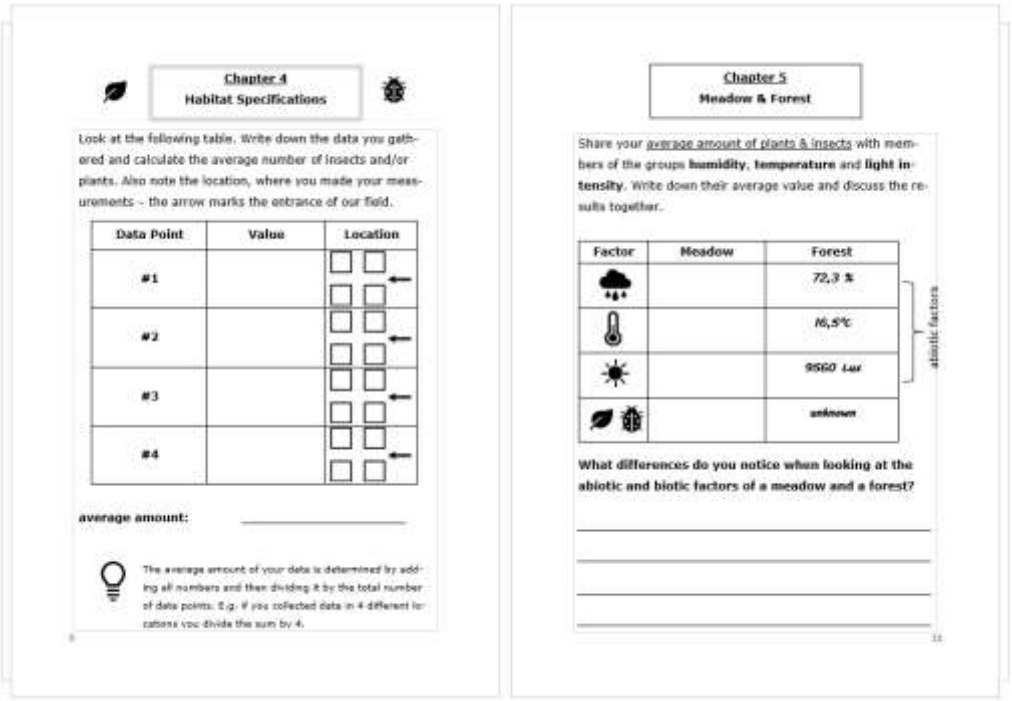


Figure 6: Excerpt from the researcher diary (ecosystem).

Parameters of an Ecosystem

The next part of the pasture module focused on the pasture ecosystem and its unique features. The pupils had to measure and record certain parameters of the ecosystem, like light intensity and soil humidity. Tablet users were able to work on a cloud-based document to save time during the summary phase. The collected data were then compared to given data from the nearby forest in order to emphasize the fact that

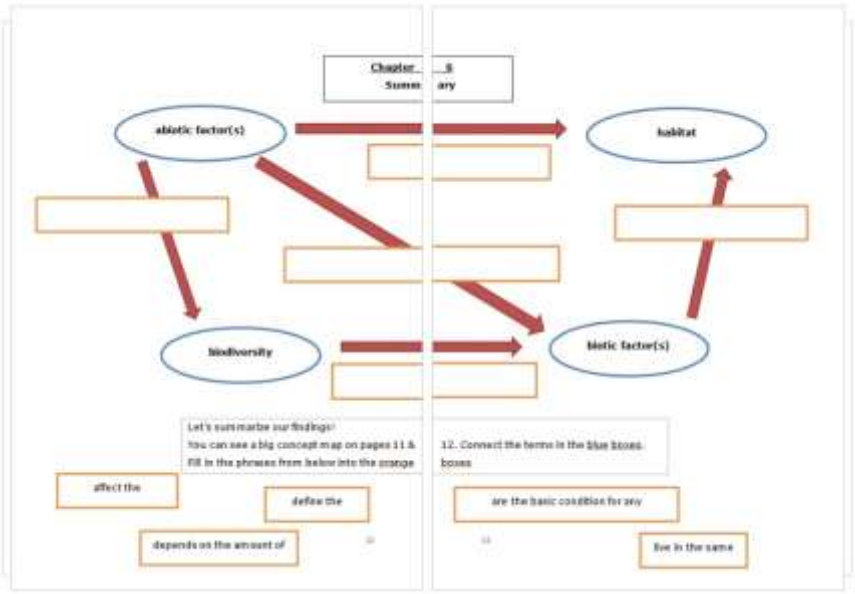


Figure 7: Excerpt from the researcher diary (concept map).

ecosystems are defined by their abiotic and biotic features (Figure 6). To wrap up this lesson, the students completed a concept map (Figure 7).

Getting to Know the Experts

The second (or first) module of the intervention was set in the green classroom. (This part can be realized without practical work on the pasture plots beforehand, but we assume that it would not be as powerful.) In an introductory discussion, different images of the "Fridays For Future" movement were displayed (see https://fridaysforfuture.org). The pictures evoked student reactions related to sustainability and a sustainable lifestyle (e.g., "no plastic," "global warming kills polar bears"). The instructor used these reactions to shift the focus to sustainability on a local level. Standardized questions – like "Is global warming only bad for the polar bears' living space? How about the area where we live?" – in combination with the overall topic "pasture" were used to guide the students toward sustainability in agriculture. The pupils were divided by random selection into four groups. Each group was provided with material linked to the comparison of intensive and extensive agriculture from a certain "expert angle" (see Table 1). Group 1 watched an interview with a "normal" farmer (using intensive methods). After watching the video, the students had to answer certain questions related to the information given in the interview. Group 3 had the same objective, but the farmer used extensive methods. Groups 2 and 4 were provided interactive presentations focused on a local politician and a member of an NGO. For details on the experts, see Table 1, which also provides suggestions for two additional experts (marked in gray) that were designed for more urban areas, where farming might not be as present in the students' perception. The script for the expert interviews as well as the instructions are available in the Supplemental Material. The results of the group work were presented in the form of an

Table 1: Expert angles with core ideas.

Expert	Core Ideas			
Farmer	More fertilizing, more mowing → less biodiversity	More return (fodder)	Less environmentally friendly → no organic label	"Normal" products are usually underpriced → struggle
Organic Farmer	Less fertilizing, less mowing → more biodiversity	Less return (fodder) → struggle	More environmentally friendly → organic label	Products with organic labels are, on average, more expensive
NGO-Member	What is an ecosystem?	Why is biodiversity important?	How to preserve biodiversity	Visions of sustainability (environment)
Politician	Struggles of local farmers → subsidies	Strict regulations for organic farming	Strict regulations for environmental protection	Visions of sustainability (society)
Engineer (Sewage Plant)	Soil sealing problems in big cities	Nutrient input on groundwater level	Issues caused by heavy rain (drainage system)	Climate change and its effect on cities
Organic Grocery Store Owner	What is an organic label?	Regulations for organic groceries	Organic farming techniques	Sustainable food

expert discussion, in which two pupils from each group usually argued from the point of view of "their" expert. This setup illustrated the ongoing discussion in society.

Visions of Sustainability

In the second phase, the pupils went back into their core groups. They were given a selection of environmentally friendly measures related to agriculture. They were asked to select four out of 12 measures and to design a digital poster on a tablet with Adobe Spark Post (one tablet per group; see Figure 8). The measures that students could select from are available in the Supplemental Material. These posters were then presented to the class via wireless projection. Once again, the students had to argue and justify why they had selected these four measures. In a concluding class discussion, the importance of a sustainable lifestyle was highlighted. The pupils wrote down their "visions of sustainability" in their workbook or tablet.

i Alignment with NGSS

The learning unit was designed to meet several elements of the Next Generation Science Standards (NGSS). It obviously contains Science and Engineering Practices, as the students perform standard taxonomic procedures and interpret data. Crosscutting Concepts are met in Systems and System Models (boundaries of the ecosystem "grassland"), Structure and Function (of reproductive organs of plants), Stability and Change (stability of abiotic and biotic factors of ecosystems determine their overall stability), as well as Cause and Effect (different methods of farming result in changes of the affected ecosystems). Biological Core Ideas are represented in ESS3.C (human impacts on earth systems), LS2.A (interdependent relationships in ecosystems), LS2.C (ecosystem dynamics, functioning, and resilience), and LS4.D (biodiversity and humans). Scientific Method Core Ideas are addressed as mentioned in MSLS2-4 ("Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations") and MS-

Figure 8: Students in a core group discussing different environmentally friendly measures (top) and the digital poster they created (bottom).

LS2-5 ("Evaluate competing design solutions for maintaining biodiversity and ecosystem services").

¡ Conclusion

The learning unit is designed to expand to further issues, such as including digital working methods in "outdoor biology," monitoring students' attitudes toward and perception of environmental issues over a longer period and fostering environmentally friendly thinking in young students. It succeeds in bringing a rather complex vision of a more sustainable lifestyle to the awareness of young students. Therefore, it fills a knowledge gap that has been left open by curricula up until now. Young people call for information about biodiversity, ecosystems, ecology, and sustainable development, which we provide with this program. Botanical knowledge of form and function is also deepened. The contents align with NGSS in multiple dimensions and can be integrated into existing syllabi. Establishing pasture plots according to our outline can also be easily achieved – and even provides more opportunities for biological hands-on learning.

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5.4 Teilarbeit B

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COVID-19 and lockdown schooling: how digital learning environments influence semantic structures and sustainability knowledge

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Abstract

Promoting sustainable lifestyles through Education for Sustainable Development (ESD) is part of the UN's *Agenda 2030*. Earlier empirical studies proved direct interactions with and in natural environments to be effective ESD methods. Pandemic-related lockdowns rendered such courses nearly impossible, which raised concerns about achieving the *Sustainable Development Goals* (SDGs) in general. To evaluate what young learners know about the concept sustainability so far and how it can be taught effectively online, we designed an online learning module tackling sustainability issues and compared it with data from an on-site intervention module for Bavarian 5th graders (~ 10 years old). Cognitive learning as well as attitudinal preferences of 288 learners were monitored in a pretest–posttest design. The learning module comprised two sections: One about botany, plant characteristics, and plant families; the other about the advantages and disadvantages of traditional as well as sustainable farming methods. The customized cognitive test and semantic differentials for sustainability and environmental protection produced three major findings: (1) A digital learning environment successfully and significantly increased sustainability knowledge (2) Learners clearly distinguished the concepts *Sustainability* and *Environmental Protection* (3) There is no direct correlation between semantic differential scores and learning outcome.

Keywords

Education for sustainable development · Digital learning · Lockdown schooling · Sustainability · Semantic differential

Introduction

The United Nations' Agenda 2030 includes 17 Sustainable Development Goals (SDGs) to address global issues such as climate change, poverty, and inequality. Education for Sustainable Development (ESD) is a powerful tool for achieving the SDGs [1]. After the United Nations Decade of Education for Sustainable Development started in 2005, ESD has been implemented in syllabi worldwide. Nevertheless, the Sustainable Development Goals Report 2017, points out that "… the rate of progress in many areas is far slower than needed to meet the targets by 2030" [2, p. 4]. Singer-Brodowski et al. [3] surveyed the German school system at a national level for ESD elements from 2011 to 2016. They came to the same conclusion that efforts to achieve the SDGs should be increased. Most ESD initiatives are collaborations between outreach environmental centers and schools. The latter rarely take on the ESD activities by themselves. Hence, there have been huge differences between individual schools in ESD teaching [3]. Obviously, during lockdown schooling visits to such centers have been impossible. A severe

setback in ESD may therefore be inevitable and thus failing Agenda 2030 is foreseeable, too.

1.1 ESD and sustainability

The United Nations defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" [4, p. 4]. This rather anthropocentric definition was later modified to include economic, ecological, and social implications [5]. Likewise, sustainability knowledge is an interdisciplinary, cross-curricular concept [6]. The UK Department for Environment, Transport and Regions (DETR) defines four key elements of sustainable development: (1) social progress which recognizes the needs of everyone, (2) effective protection of the environment, (3) prudent use of natural resources and (4) maintenance of high and stable levels of economic growth and employment [7]. The UN defines ESD as "empower[ing] learners to transform themselves and the society they live in by developing knowledge, skills, attitudes, competencies and values" [8, p. 7]. They also highlight the interconnectedness of topics such as global citizenship, climate change, and loss of biodiversity. Fully comprehending such topics and their implications is challenging, especially for young learners. Thus, ESD teaching on primary and secondary levels should focus on establishing a solid base of sustainability knowledge before addressing interconnections. The term sustainable itself is mostly depicted as synonymous with environmentally friendly [9]. Without proper ESD in school, 5th graders are likely to have little to no information about economic and social aspects of sustainability. Thus, young learners are not expected to differentiate between these two terms.

H1 5th graders cannot differentiate between the abstract term sustainability and the more tangible concept of environmental protection.

Several studies have demonstrated that environmentally friendly lifestyles depend on three key factors: knowledge, values, and behavior [10–12]. More precisely, high environmental knowledge scores positively influence pro-environmental attitudes and behaviors [13, 14]. Consequently, establishing in-depth sustainability knowledge will motivate learners to live a more sustainable lifestyle. Keselman et al. [15] describe the discrepancy between the known impact of environmentally friendly actions and the potentially more negative effect of environmentally unfriendly behavior. For example, people may have basic knowledge about biodiversity loss, yet do not care about it unless a viable threat to their lifestyle is revealed, such as shortages in their food supply. Kowasch and Lippe [16] argue that most learners know exactly what sustainable behavior means, but manifest binary perceptions of sustainable lifestyles. Thus, ESD knowledge should first concentrate on everyday life issues in addressees' context and then move on to a broader scale to avoid such discrepancies. Since young learners have

little impact on adult behavior such as buying an e-car or shopping for organic groceries, research on this age group should focus on connections between knowledge and attitudes. Generally, a positive correlation between attitudes and knowledge gain is expected.

H2 Positive attitudinal preferences towards sustainability concepts lead to greater learning progress in an ESD module.

To put more emphasis on ESD, the Bavarian Ministry for Education introduced new issues in the curriculum. Ecosystem Pasture introduces concepts of sustainability and sustainable practices in the fifth grade. It tackles both economic and ecological aspects. Learning objectives involve plant growth conditions and the impact of agricultural methods on species diversity by contrasting "traditional" farming methods (which focus on the highest yield possible by using fertilizers, insecticides, mechanization of labor) and "sustainable" agriculture (which considers the natural fertility of the land, local climate, etc.). Sustainable agriculture is considered environmentally friendly. These learning objectives go hand in hand with both the UN's Global EverGreening Alliance, the EU's Green Deal and the From Farm To Fork initiative [17,18]. As regenerative farming is regarded as a good way to start environmental education [19] and fits the target groups' syllabus, it is suitable for this study.

1.2 Digital learning and ESD

Most research on digital ESD has been conducted in higher education [20–22]; however, vast amounts of data are available for online STEM teaching. ESD methodology and STEM teaching share certain similarities: according to Ahel and Lingenau [23] for example both promote problem-solving and cooperative learning strategies to enable learners to tackle future problems. Studies on digital STEM teaching cover a variety of approaches: comparing synchronous and asynchronous approaches, incorporating VR (Virtual Reality) and AR (Augmented Reality) elements, and mobile learning with specific apps and games to name just a few [24–27]. Thompson et al. [28] point out that problem-solving skills are more difficult to train when taught online. Especially during lockdown schooling, online units rarely used collaborative teaching methods, which are essential to ESD [29, 30]. Therefore, less learning progress is expected in an online setting in comparison with a traditional, on-site ESD module.

H3 ESD teaching leads to better learning progress when conducted on-site rather than online.

Hodges et al. [31] describe emergency remote teaching as different from well-structured, systematic online learning. For example, communication with and feedback by teachers has been sporadic and difficult to obtain, although this is an essential part of

effective online learning [32]. Recent studies on lockdown schooling confirmed that teachers as well as learners need training in handling new technologies and digital tools [33, 34]. In normal situations, studies have already investigated the influence of digital learning environments on biology knowledge or environmental attitudes [35]. However, these studies were conducted in schools and monitored by a teacher or supervisor. Apart from asynchronous communication via email, digital teaching as part of blended learning or flipped classroom settings usually relies on personal interaction as well [36]. This means that learners always had some face-to-face time with their teacher besides working on assignments on their own at home. However, lockdown schooling matches elements typical for homeschooling: learners receive standardized input and have specific channels to hand in assignments, but the learning process happens at home without the supervision of a professional educator [37]. As this study was conducted during the first lockdown period, it was designed as asynchronous, with little to no involvement of the teachers.

1.3 Semantic differential as a technique

Semantic Differentiation (Semantic Differential or Differential Semantics) was originally proposed by Osgood, Suci and Tannenbaum [38] in the 1950s as a technique for extracting attitudes toward objects or concepts. The method is now universally applicable to measure any term, object, idea, activity, etc. [39–42]. If, for example, methods such as Likert scales were used in questionnaires, the questions had to fit the respective topic. It is nearly impossible to compare different sets of questions across different topics. It is, however, possible to analyze the semantic structures of different concepts. Thus, Osgood, Suci and Tannenbaum [38] established a universal rating scale based on a standardized set of adjectives. A semantic differential (SD) consists of bipolar adjective pairs, which ideally have an antonymic meaning such as good – bad. Each set of adjectives is rated on a Likert-type scale. Rosenberg and Navarro [42] recommend eight to 12 bipolar pairs with seven to nine scaling points. The SD method allows an analysis of both the affective and cognitive aspects of the selected concept.

SDs have been used to assess attitudes toward certain topics or objects in a variety of research disciplines, such as social studies, economics, marketing, geology, and architecture [43–49]. It is regarded as an effective psychological tool for measuring multidimensional traits such as personality, attitude, or communication [50]. It also appears to be a promising alternative tool for regular monitoring in schools [51].

Semantic structures and meanings are represented at a multidimensional level as a correlation matrix. This matrix represents the semantic space occupied by the rating of a concept. Each concept is represented by a polarity profile (see Fig. 3), which can be compared to profiles of other respondents toward the same concept or the profile of the

same respondent towards other concepts. An initial analysis focuses on the differences between the ratings of binary adjectives. This analysis can also be conducted by comparing the sum scores for each concept. In this study, an SD with a seven-point scale and nine binary pairs was used. Thus, the mean score was 31.5. If a respondent's sum score was below that number, their attitude toward the concept can generally be summarized as negative, and vice versa.

Further analysis via factor scoring determines the distance between the ratings. Osgood, Suci and Tannenbaum [38] claimed that there are three universal dimensions labeled evaluation, potency, and activity. Through these dimensions, each object or concept can be defined and compared using a specific semantic axis. The three dimensions are widely recognized, yet their factor analysis is rather difficult because they consist of several subscales [40, 41, 45]. Furthermore, critics of a universally applicable SD point out that semantics work differently in cultures and languages [41, 52, 53].

1.4 Research questions

Online learning and ESD are essential components of modern teaching scenarios. Thus, this study aims to evaluate the current status of young learners in both fields contemporaneously, thereby gaining valuable insights for educators and teachers.

1. Which learning progress does a online learning environment for botany and sustainable agriculture evoke in comparison with an on-site program?

2. To what extent can 5th graders differentiate between Sustainability and its subcategory Environmental Protection prior to a sustainability module?

3. What correlation can be found between knowledge gain in on-site and online teaching modules and attitudinal preferences measured with a semantic differential?

2 Methods and procedures

2.1 Participants

A total of 288 Bavarian 5th graders (10.8 ± 0.45 years, 41% ♀) were recruited with the help of their teachers and the support of the Bavarian Ministry of Education. Participation was voluntary. They completed online questionnaires before and after and intervention-style unit consisting of two separate modules.

2.2 Intervention design and sample

The intervention took place in 2019 and 2020. Two different methods were used to teach curriculum-related content in botany and sustainable agriculture. The control group (CG, n = 86) completed a one-day on-site intervention, whereas the experimental

group (EG, n = 202) completed an online asynchronous learning module over the course of two weeks. Both groups received a guidebook referred to as researcher diary with tasks either based on information on-site or with links to learning platforms (e.g., Prezi) with customized information.

The first part of the learning unit focused on botanical terms and the categorization of plants. Learners learned to distinguish different plant families for instance by flower shape. Besides characterizing several given plants, they also had to go outside and find an unknown plant on their own. The module continued with prerequisites for ideal plant growth. Learners received input about the location factors humidity, temperature, and sunlight. On-site learners were equipped with different measuring tools. Online learners were instructed to build a DIY (do-it-yourself) rain gauge to monitor the humidity of their backyard. The second part continued with growth factors in the context of species diversity. Learners had to gather information about the three location factors in their area, compare them to a given list of plants and select possible new plants to hypothetically plant in their location. Learners were then confronted with the question of why species diversity is a desirable thing in the first place. Among other sources, three expert videos (traditional farmer, sustainable farmer, local politician) with information about traditional and sustainable agriculture were provided. A concluding DIY task was to create a poster of the pros and cons for more sustainable farming in their area. If possible, these posters were presented in class.

2.3 Test design and instruments

Two Semantic Differentials (SD) with nine bipolar pairs and seven scale points were used to assess learners' attitudes and emotions towards sustainability (see Table 2). The antonyms were partially literature-based and partially expert-selected to suit the target group [42]. See Table 2 for all nine adjective pairs. There was no retest for the SD because previous research has shown that affective dimensions do not change over such a short period [54, 55]. Knowledge levels were monitored through a customized multiple-choice test comprised of 17 items. The items cover botanical knowledge like typical shapes of flowers or the purpose of certain plant organs as well as knowledge about sustainability in agriculture and farming methods (see Table 1). The knowledge test was completed by the learners before they received the learning modules (pretest) and after they completed the last task from the guidebook (posttest). It was not possible to conduct a retention test to assess long-term learning.

Table 1 Example questions for the knowledge test with example answer options for two questions

B12	Here are two pictures of cherry tree flowers. To which plant family does the cherry belong to?	
	❑ Mint family	❑ Bean family
	❑ Rose family	❑ Cabbage family
S11	Which of the following farming techniques are used in traditional agriculture?	
S1	The term "sustainability" is closely related to how we use natural resources. Which of the following statements explains a sustainable use of natural resources the best?	
B9	The flower of labiate plants consists of …	
B11	You want to find the ideal place for a beehive. Which environment holds the ideal source of nutrition for bees?	
	❑ Cornfield	❑ Flower meadow
	❑ Soccer pitch	❑ Deciduous forest

2.4 Statistical Analysis

IBM SPSS 25.0 was used for factor analysis and Quest for Rasch analysis. Level of significance is marked as $p \leq 0.05$ = *; $p \leq 0.01$ = **; $p \leq 0.001$ = ***. For factor analysis values below 0.3 were left out.

3 Results

3.1 Knowledge Levels

The first part of this analysis focuses on changes in learners' cognitive perception of the concept *Sustainability*. A comparison of pretest and posttest scores via Wilcoxon test ($p < 0.01$) showed significant learning progress for both the control group (on-site) and the experimental group (online). Further analysis via Mann–Whitney-U ($p > 0.05$ at 0.565) tested negative for statistical differences in learning progress between CG and EG (see Fig. 1).

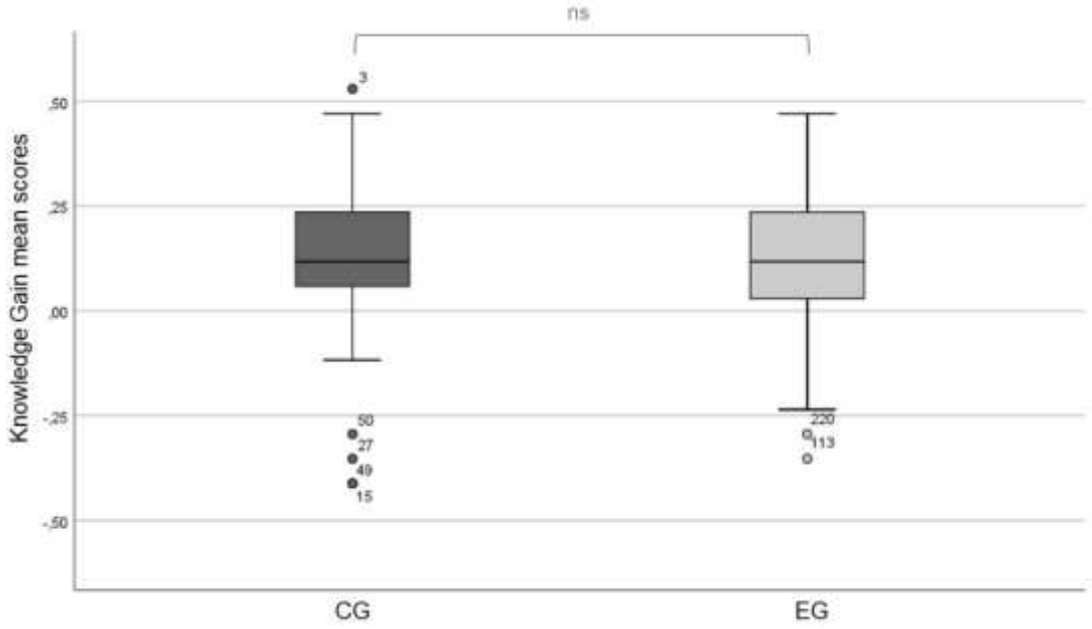

Fig. 1 Comparison of knowledge scores in CG and EG

The test itself was analyzed using Rasch. Cronbach's α assesses internal consistency and was at 0.74 (> 0.7 is *good*, > 0.8 is *very good*, > 0.9 is *not acceptable*; [52, 56]).

The Rasch-model-based reliability showed very good item estimates with Infit MNSQ at 0.99 (± 0.08) and Infit t at 0.13 (± 1.62). Especially MNSQ-values are not sensible to sample size and therefore work for small sample groups, too [57]. Reliability of estimate at 0.98. (± 1.0) is considered *very good* and person reliability of 0.63 (± 0.84) is acceptable and in line with previous analysis that showed the data has no normal distribution. MNSQ for all Item Fits lie between 0.08 and 1.2, which means all items fit the model. Item Estimate Thresholds lie between -3 and + 3 (see Fig. 2). As shown by distribution of the Xs on the left-hand side, cases are spread evenly. The grouping of the questions (Bs and Ss on the right-hand side) indicates that there are no very hard items, many moderate-to-hard items, and one easy item (S10). Therefore, reaching a satisfactory score on the test was easy, but only few learners reached close-to-perfect scores. Several example questions (see Table 1) display a mix of easy, moderate, and hard questions.

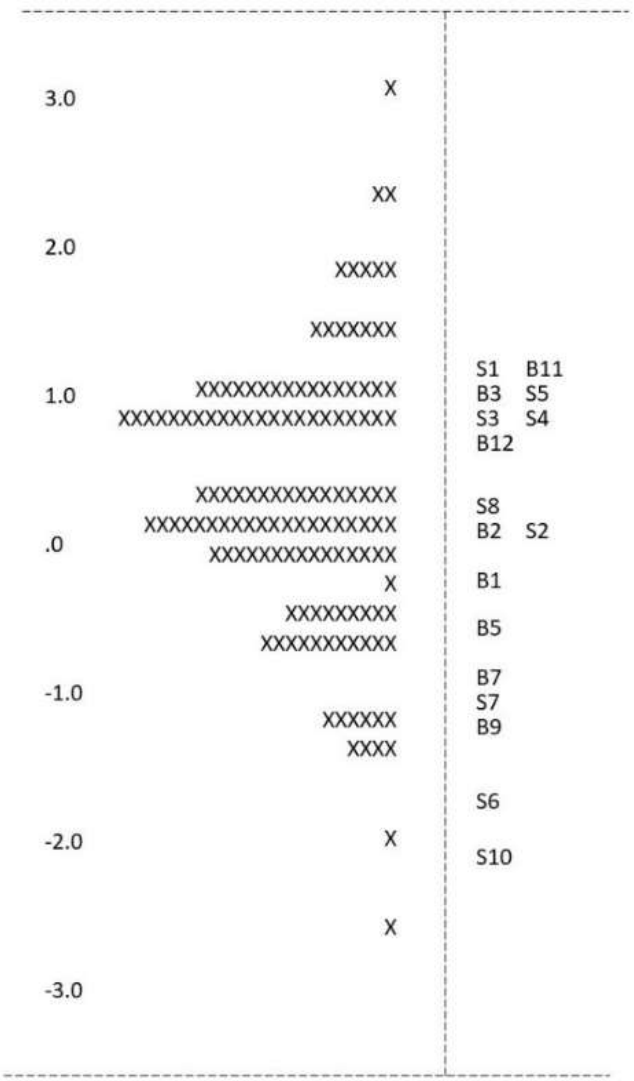

Fig 2. Item estimate threshold for Rasch analysis of knowledge level items. Each X represents 2 learners.

3.2 Semantic differential

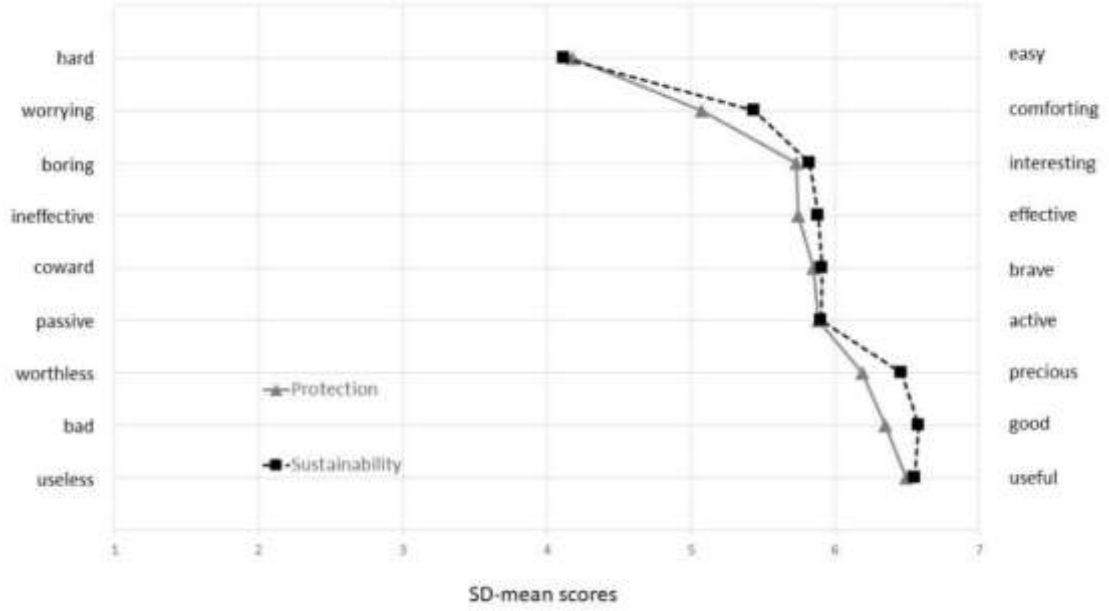

Fig 3. Semantic Differential Scores of PR and SU for all adjective pairs

The second part of this analysis focuses on two semantic differentials, one for Sustainability (SU) and the other one for Environmental Protection (PR). Wilcoxon test at 0.086 showed no significant difference between scores in PR and SU. Mean score for PR was at 5.72 (± 0.67) slightly lower than for SU at 5.85 (± 0.71). The adjective pair hard-easy had the lowest ranking, whereas useless-useful showed the highest ranking (see Fig. 3).

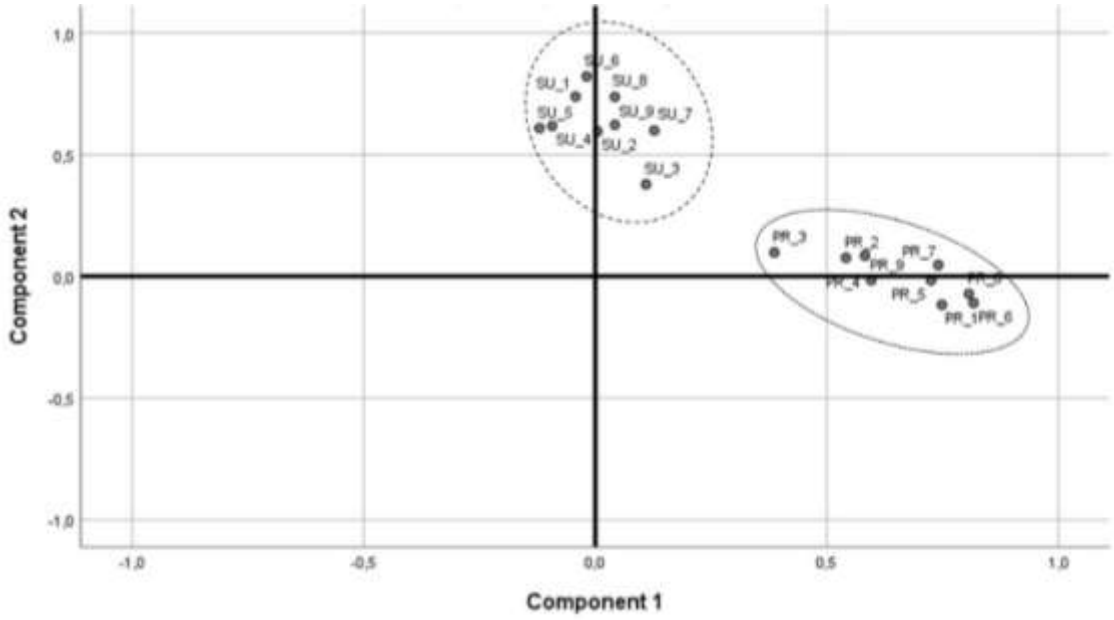

Fig 4. Principal Component Analysis of both Semantic Differentials

The SDs then were analyzed using Principal Component Analysis (PCA) with Oblimin rotation to validate the basic structure proposed by Osgood, Suci and Tannenbaum [38].

KMO for PCA was tested adequate at 0.804. (Kaiser–Meyer–Olkin is considered > 0.7 as intermediate, > 0.8 as good, > 0.9 as very good [58];). Bartlett's test of sphericity ($\chi 2 = 1559.099$, $p < 0.001$) indicated that correlations between items were sufficiently large for PCA. As illustrated by Fig. 4, loading scores of individual adjective pairs showed two principal components: one component consists of all PR-Couples and the other one of all SU-couples. A second PCA with Oblimin rotation was applied on each individual set of bipolar pairs. KMO verified sampling adequacy (KMO = 0.813, $\chi 2 = 671{,}737$, $p < 0.001$). This analysis was conducted to check the data for the three underlying dimensions evaluation, potency, and activity. Three adjective pairs matched each of the dimensions (see Table 2).

Table 2 SD SU factor scores of PCA analysis with Oblimin rotation

Components	Evaluation	Potency	Activity
Bad—good	.908		
Useless—useful	.893		
Worthless—precious	.771		
Hard—easy		.898	
Ineffective—effective		.552	
Worrying—comforting		.522	
Passive—active			.884
Coward—brave			.836
Boring—interesting			.386

After the dimensions had been verified the analysis continued as Heise [59] suggested with calculating the distance between the two concepts for each dimension (e.g., distance for Evaluation $d_E = \sqrt{(E_1\text{-}E_2)^2}$). The results were $d_E = 0.187$, $d_P = 0.15$, $d_A = 0.057$. Higher scores indicate greater dissimilarity between the concepts. None of the distance scores is above 1.0 though, so they can be considered rather close overall. This falls in line with previous Wilcoxon test.

3.3 Correlation between semantic structure and knowledge levels

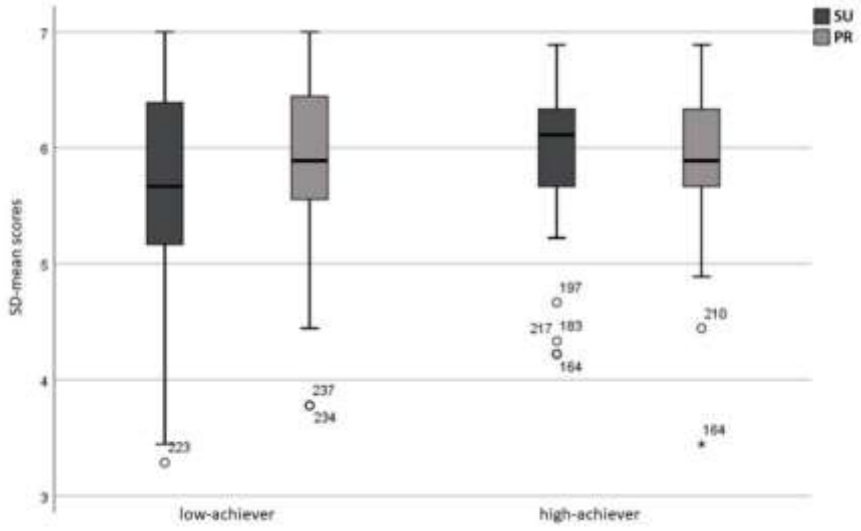

Fig 5. Comparison of knowledge levels (high- and low-achievers) and their mean scores in SD PR & and SD SU

Finally, correlations between posttest knowledge scores and SD scores were calculated. High-achievers (with knowledge scores in the posttest above median) and low-achievers were compared. Spearman-Rho analysis resulted in significant positive correlations between scores in SD-PR and SD-SU (0.598**). Mann–Whitney-U test showed no significant difference between low-achiever or high-achiever mean SD scores (0.13 for SD SU and 0.72 for SD PR). Mean Scores for SD-SU were 5.64 ± 0.86 for low-achievers and 5.91 ± 0.71 for high-achievers. Mean Scores for SD-PR were 5.93 ± 0.71 for low-achievers and 5.87 ± 0.7 for high-achievers (see Fig. 5).

4 Discussion

A major surprise is the same learning outcomes of online and on-site interventions. Previous studies have found that outdoor activities are more effective for sustainability knowledge acquisition [54, 55, 60, 61]. Due to the unique situation caused by COVID-19 lockdown schooling, learners could not engage in outdoor learning activities. It provided an exceptional opportunity to survey children who had not been exposed to didactically prepared natural environments during the study. Contrary to Hypothesis 3, our findings clearly indicate that even a sole digital learning environment significantly alters knowledge levels. This supports studies like Schönfelder and Bogner [62], where no significant difference between on-site and online learning was found. Also [23], point out that asynchronous online learning has some positive practical implications for learners: online content is easily accessible and fits flexibly into learners' daily routines. In an on-site intervention, however, the learning environment is more controlled and more insight, for example, into the learners' motivation is possible. This asynchronous approach was driven by an unprecedented lockdown learning situation. A new approach using blended learning can increase the comparability of on-site and online studies. Other key elements of ESD, such as questioning and re-imagining conventional, non-sustainable lifestyles and empowering learners to adopt more community action [30], could benefit from using more collaborative learning forms.

Since the knowledge test had to be customized to fit the intervention's contents, applying Rasch analysis was advisable to assess its model fit. The items tended to be easy, but the cases were spread evenly, and fit indices were within suitable ranges. Internal consistency values were also considered to be good [63, 64]. Therefore, the applied knowledge test did indeed account for botanical and environmental knowledge. Both the experimental group (online) and the control group (on-site) had a significant increase in knowledge. Although items were moderate to easy, there were no perfect scores for either of them. Since knowledge gains were comparable, the age group would seem to have significant influence on this outcome. [65] suggest that 5th graders tend to have high learning motivation in science. Ecosystem pasture is the first unit in the Bavarian

curriculum to target ESD. So, pre-knowledge levels would be rather low compared to other topics. Research indicated that pre-knowledge must be considered if present and that knowledge levels increase more easily from low to moderate scores than moderate to high scores [65, 66].

Our second major finding is that 5th graders can differentiate between the two concepts in question as shown by the PCA of both SD values. Our results point to a distinct differentiation between the abstract concept of Sustainability (SU) and the more tangible concept of Environmental Protection (PR). Most studies focus on the latter while others do not differentiate between ecological, economic, and social aspects [29]. Our semantic structure shows that 10-yearolds can distinguish the complex concept of sustainability from protecting natural environments. Hypothesis 1 thus has to be rejected. To avoid contradictions between sustainability knowledge and actual behavior as suggested by Kowasch and Lippe [16], future research on children's attitudinal preferences towards economic and social aspects of sustainability is recommended. As the UN framework points out, the interconnectedness of ESD-related phenomena is key to promoting more sustainable lifestyles. Learners' knowledge should therefore not be limited to one subject. Our Grade 5 learning units successfully targeted both economic and ecological effects of sustainable and traditional farming. Thus, interdisciplinary topics are suitable for ESD on the secondary levels.

The three-dimensional structure (evaluation, potency, and activity) of semantic differentials has been questioned by a variety of studies [46, 47, 67]. Maclay and Ware [53] point out that semantics work differently in different cultural contexts. According to Chráska and Chrásková [68] this must be considered when using the SD method. Therefore, bipolar adjective pairs need to be standardized for a specific cultural environment [41]. Our adjective pool consists of pairs suggested by previous research as well as additional pairs considered suitable for this age group by experts [40, 42]. The PCA showed all three categories. Hence, our mix of inductive and deductive techniques when choosing appropriate bipolar pairs may be regarded as successful. Consequently, the SD method proved to be an easily applied, convenient method to tackle a variety of research questions – provided that the adjective pairs are representative.

As other statistical tests already showed no significant difference between the affective space of Sustainability and Protection, it was likely that the three subcategories did not differ significantly. A comparison of these findings with the first PCA (see Fig. 3), however, revealed some interesting implications. On the one hand, learners can clearly distinguish between both concepts. On the other hand, they are rated almost the same, although Sustainability is rated slightly higher. Environmental protection is a part of the ecological and economic pillars of sustainability. Acting sustainability-conscious,

therefore, automatically includes actions toward environmental protection. The least-rated item in both SDs was hard-easy. This shows a rather ambivalent kind of thinking within the 5th graders: apparently, they know that acting sustainably is important since good and precious have the highest ranking, but they also evaluate it as a rather difficult task to accomplish. In this context, it would be interesting to track social desirability scores with comparable sample groups [69–71]. Young learners can lack the foresight needed to evaluate the consequences of more sustainable behavior. Prospectively then, SD values could drop once learners were informed about the downsides of sustainable development, such as increased food prices.

Finally, the influence of attitudinal preferences on learning outcomes was analyzed. Since there was no significant difference between the CG and EG, we combined both groups for this analysis. A comparison of high and low achievers, the ones that learned the most and the least during the intervention, showed no statistically significant difference between SD ratings and learning success. This contradicts Hypothesis 2 and previous research [11, 13, 72]. However, Fig. 5 shows a greater standard deviation for SD-SU in low achievers than in high achievers. These findings lead to the possible conclusion that learners, who may have had no idea what the abstract term sustainability meant before the intervention, were simply checking boxes. Hence, some ratings were rather poor, while others were higher as expected. One possible explanation for this increased deviation could be that the term environmental protection is used more commonly and is more self-explanatory. Therefore, learners were much more confident about how to rate this concept. Since the SD was collected before the intervention, sustainability had not yet appeared in the official syllabus. Therefore, they had either no pre-knowledge about it or possibly biased sources, such as their parents or social media. This is especially interesting for educators in ESD. Sammalisto et al. [22] point out, specific courses on sustainability can influence university learners' perceived environmentally friendly behavior. Our findings, however, indicate that educators in younger grades should ensure that there is a certain common ground of sustainability knowledge to build upon before commencing with detailed knowledge. Middle school teachers can assume that there is no common knowledge basis in their classes. Thus, before tackling popular issues such as plastic waste or conducting field courses, learners should first establish an adequate theoretical background about sustainability. In a blended learning scenario, this basic knowledge should be taught through asynchronous online activities, whereas synchronous learning units should be used for direct interaction with and in natural environments.

4.1 Conclusion

Surprisingly, our ESD module led to similar learning progress online and on-site. Contrary to studies in environmental education, attitudinal preferences measured before the learning module had no significant impact on knowledge gains. Gathering more information about social desirability in this age group could shed more light on their attitudinal preferences toward sustainability concepts in general. The semantic differential method was used to measure these preferences. This is especially valuable for teachers and educators, as using adjective pairs is a rather easy design for a test instrument and offers a short but effective monitoring tool. Based on the convenience of the SD tool, it should find its way to regular classroom practice. However, testing the SD method for other concepts and different age groups could provide further insight into its universal application.

Since sustainable agriculture touches many everyday issues even for learners, such as choice of food or production method, it is a suitable starting point for ESD. The topic is not limited to ecologic aspects but provides a variety of possible expansions toward other SDGs, such as political agendas or economic implications. As shown by our analysis of online distance learning, lockdown schooling did not necessarily cause a setback to the SDGs. However, further research with a more representative sample size is required. Other digital teaching methods such as blended learning and collaborative modules should also be evaluated for primary and secondary level teaching.

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Data availability: Data cannot be shared publicly because of the Bavarian Ministry for Education's guidelines regarding data of underaged participants. Data are available for researchers who meet the criteria for access to confidential data. Access must be confirmed by the Ethics Committee of the University of Bayreuth/ ZMNU. Contact the corresponding author for further information.

Code availability: Not applicable.

Declarations

Ethics approval and consent to participate: The research project labelled "Ecosystem Pasture—an introduction to sustainable behavior" was approved by the Ministry authorities. All data privacy laws were respected. Gender, age and study status of participants were recorded pseudo-anonymously. Since our target group were underage students, parents had to give their permission. Participation was voluntary and meant no disadvantages in the school routine.

Competing interests: The authors declare no competing interests.

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Closing the Gap: Potentials of ESE Distance Teaching

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Abstract

Environmental and sustainability education (ESE) traditionally relies on green teaching environments and active participation. Thus, during the lockdown phase, a gap between curricular goals and learning outcomes appeared. This study investigates the impact of ESE distance teaching on 288 Bavarian fifth-graders and learning factors that could bridge this gap. The influence of digital preferences on learning progress is examined and compared with the influence of fascination levels. A negative correlation between spending time outside in nature and spending time inside in front of a digital device is expected. A control group completed a learning unit about biological topics such as plant identification and environmental factors, as well as ESE topics such as characteristics of sustainable agriculture, at an out-of-school ESE center. The experimental group completed the same learning unit in distance teaching. Fascination with Biology (FBio) and Digital Nativity Assessment Scale (DNAS) were applied in addition to a customized knowledge test. Both values seem to have a positive impact on learning outcomes. There were no significant differences between the control and experimental group. Surprisingly, Fascination and Digital Nativity show a low, if not negligible, relationship. Implications for digital ESE, especially between outdoor learning centers and schools, are discussed.

Keywords: Distance Learning – Sustainability Teaching – Digital Nativity – Fascination with Biology

1. Introduction

The United Nations (UN) 2030 Agenda includes 17 Sustainable Development Goals (SDGs). These are intended to address global problems such as climate change, poverty, and inequality. SDGs can be implemented at the political and individual level. The former is encouraged, for example, by the SDG Index [1]. The index evaluates countries and cities based on the SDGs and assesses the extent to which they will achieve them by 2030 or in which areas they need to make improvements. According to the SDG Index, Germany should primarily work on Goals 12 (Sustainable Consumption and Production) and 13 (Climate Protection and Adaptation) [2]. Both areas can be improved through political guidelines. Additionally, citizens can exert influence on an individual basis. For example, the food market recently underwent changes regarding meat substitutes due to consumer demand [3,4]. Similar trends can be observed in housing and mobility [5,6]. Measures regarding climate protection have been pushed forward by both the government and citizen initiatives [7,8]. However, top-down measures, i.e., those initiated by the government, are perceived negatively by the population if citizens lack information on the environmental effects of these measures [9,10]. For example, the expansion of renewable energies in Germany is politically promoted, but citizens are

skeptical about the successful implementation [11]. In bottom-up initiatives, i.e., projects initiated by citizens, a lack of environmental protection knowledge does not result in citizens questioning the effectiveness of the measures [12]. This suggests that poor scientific expertise, which is necessary to understand interconnections in the ecosystem, has a negative impact on citizens' perceptions only in the case of top-down measures. Consequently, sustainable education should, on the one hand, focus on knowledge transfer, and on the other hand, promote sustainable measures that have been proposed by citizens. A project that has made the leap from bottom-up to top-down, was the "Save the Bees" initiative of 2019, which was initiated locally and eventually implemented at the state policy level. Education for Sustainable Development (ESD) should support both the acceptance of political guidelines and the foundation of further citizens' initiatives [13].

ESD should build a bridge between citizens, policy makers, and scientists by communicating the latest research results in a comprehensible way and by taking into account and promoting affective aspects such as connectedness to nature. To draw attention this, the UN Decade of Education for Sustainable Development was initiated. However, the final report of 2017 points out significant shortcomings at the curricular level. To achieve the goals by 2030, curricula need to be further adapted and ESD institutions need to be expanded [14]. In this context, the German school system and regional curricula were analyzed for ESD elements [15]. The results are in line with the findings of the UN, which calls for stronger efforts to achieve the SDGs on the part of the German educational landscape. Furthermore, it was found that there were large differences in the implementation of ESD in the curricula between school types within one federal state and between the same school type in different federal states. The German school system does not offer different learning levels within one high school. After the fourth grade, students choose a type of school that is appropriately designed for stronger or weaker students or has a special focus on content. The new Bavarian LehrplanPLUS implemented the most ESD concepts compared to other federal states.

Although ESD covers a wide range of learning approaches, the term environmental and sustainability education (ESE) is considered more appropriate. It entails not only ESD, which is a relatively new term in environmental education, but refers to traditional approaches such as nature-based learning, outdoor education, or eco-justice education as well. ESE is implemented as projects supported or led by external cooperation partners supplemental to regular teaching. Due to the Covid pandemic, cooperation with such ESE centers proved to be difficult, as field trips could not take place and digital lessons were initially problematic. As a result, it is reasonable to assume that ESE has been able to make little progress in the past two years and achieving Agenda 2030 goals will become even more important in the coming years to compensate for these setbacks. As

the pandemic situation remains challenging, digital or distance-learning ESD initiatives are gaining importance.

Research approaches that refer to control groups and experimental groups are viewed critically in educational research [16,17]. In this article, these terms are also used, but the reader is asked to reflect on them at this point. Several aspects could have influenced the participants but were not measurable. First, the data collection took place during an exceptional situation. Pandemic-related distance teaching led to an interesting research approach. However, this resulted in a lack of values from regular classes, as these simply did not exist during that time period. Second, when researching learning scenarios, it is impossible to control all variables satisfactorily as compared to controlled experiments in a laboratory [18]. Students are individuals who hold individual experiences and learning capacities. Learning environments are thus perceived individually, too. The same is true for teachers, yet they play a minor role in this study design. Even if significant learning effects occur, they can never be attributed to a specific variable. The sample size should offer insights into a basic trend, though, which should be confirmed or rejected with appropriate follow-up studies [19].

1.1 Impact of Distance Education on ESE Learning Outcome

ESE often relies on out-of-school settings, as this is a suitable way to implement multiperspectivity. Even though visiting these places requires additional organizational, temporal, and financial effort, teaching programs at out-of-school learning places are seen as worthwhile, as they can be conducive to linking knowledge, increasing motivation, and fulfilling curricular anchored cognitive as well as affective learning goals [20,21]. Actively engaging students in the out-of-school learning space fosters both affective and cognitive progress [22,23,24]. Curricular requirements such as the imitation of research procedures, action orientation, and applicability are met [25]. Finally, the high level of self-regulation and practicality should enable deeper learning and contribute to environmental awareness, which in turn can be intensified through cross-curricular arrangements and increase intrinsic motivation: A creative, authentic approach to the learning object should promote positive experience via multisensory experiences and explorations. Based on these findings, the intervention unit was designed to be problem-oriented and student-centered. However, the positive effects of an out-of-school learning site and certain aspects of discovery learning are difficult to replicate in distance education. This problem was encountered by many out-of-school learning curricula: even when they offered a digital fallback for processing at home, it was questionable what advantages would accrue from this facility. In addition to the complexity of ESE content, teachers also faced the methodological and technical challenges of emergency distance teaching [26]. Other studies indicate that low-achievers and marginalized groups had more problems with distance learning than high-achievers [27,28]. Thus, the present

study assumes that students in distance learning will perform worse in terms of learning progress than the control group.

1.2 Impact of Digital Preferences on ESE Learning Outcome

Besides contextual challenges of ESE, students as well as teachers were confronted with additional methodological challenges due to spontaneous distance learning. It is implied that younger generations, by growing up in a digitized world, have inherent skills that are not developed, or at least, less developed in older generations [29]. One such theory is about digital nativity by Prensky. Digital natives are defined as people who were raised during the cyber age [30]. Digital immigrants are people who were not born into the cyber age but live in it. According to this theory, being surrounded by technology leads to intuitively knowing how to use (digital) technology, having a basic digital literacy, being comfortable with multitasking (performing different tasks at the same time), preferring experimental and collaborative learning methods, and perceiving information presented in images easier than in text [31]. According to these skills, students should be more comfortable in digital teaching environments than teachers. If this is not the case, digital ESE should take special care not to overburden learners, both methodologically and content-wise.

Whether digital nativity exists—and if so, what influence it has—is still debated. Some scientists doubt the existence of digital generations, or at least the scope of the differences between natives and immigrants [32,33]. Others have developed measurement instruments for digital nativity [34]. Because the presence of technology in everyday life has evolved even more dramatically since the 2000s, when the theory was first proposed, the differences in digital literacy should be much greater and therefore easier to measure today. In addition, the pandemic resulted in a period of thorough digitalization of the school system and therefore provided a unique opportunity to study students who had to work with digital tools daily.

Even before the pandemic, various studies had been able to establish a link between digital skills and increased cognitive performance and knowledge gains [35,36]. Educational environments are becoming increasingly digitalized, just like working environments. Basic digital skills are therefore a prerequisite for success in and out of school. Digital nativity deals with the extent to which skills such as the ones proposed by Prensky are inherent, or whether they have to be established before digital teaching methods can be implemented in a meaningful way. Compared to Information and Communication Technology (ICT) measurement tools, nativity scales go beyond skills and include personal preferences, such as sources of information and media use. In educational contexts, differences between natives and immigrants should be considered when conceptualizing digital as well as nondigital learning environments.

The Digital Nativity Assessment Scale (DNAS) was applied to track digital nativity levels for secondary-level students [37]. It was originally developed to assess self-reported competences such as multitasking and information processing in digital immigrants. The scale comprises four subcategories with a total of 21 items: Grow up with technology (5 items), Comfortable with multitasking (6 items), Reliant on graphics for communication (5 items) and Thrive on instant gratifications and rewards (5 items). DNAS was used successfully in other studies; however, the target groups have only been adults so far [38,39,40]. Students with high DNAS scores are considered to be generally comfortable with digital learning tools. Those with low scores are more likely to have difficulty navigating digital learning environments. The target group of fifth-graders at the beginning of the school year is particularly interesting because ICT has not yet been taught as a compulsory part of the German curriculum.

Previous studies are associated with tests focusing on ICT skills [41,42,43]. Most of them distinguish fundamentally between the use of digital methods inside and outside of school, i.e., in the context of digitalized lessons or for leisure activities. Before pandemic-related distance teaching, fifth-graders faced digital elements solely in the classroom. Therefore, such a distinction is not useful in this context. The DNAS focuses less on usage times of digital devices and ICT skills and captures more general tendencies and preferences of students. These underlying trends may also be valuable for nondigitized or only partially digitized schools. Another key factor in the selection of the measurement instrument was its user-friendliness. DNAS, with its 21 Likert-type questions, is easy for fifth-graders to use and for teachers to evaluate. Therefore, it is an instrument that could also be used in the classroom.

1.3 Impact of Interest on ESE Learning Outcome

Another aspect monitored in this study is Interest as a key factor for successful long-term learning e.g., [44,45]. Interest is a particular form of intrinsic motivation related to a specific object, learning content, or person [46]. Consequently, being interested is a focused, emotional state that has a positive effect on learning growth and competence acquisition. The concept can be differentiated according to situation and person. Situational interest is caused in a specific situation by external factors, such as the everyday relevance of the learning object or the interestingness of the learning environment. Individual interest is a stable personality-specific characteristic that expresses itself as a preference towards a certain learning object. For long-term learning effects, educators try to preserve situational interest through didactic-methodical procedures and to anchor it as individual interest [47]. In the context of this study, interest towards the learning object is assessed as fascination [48].

To track individual interest in biology, the Fascination with Biology scale (FBio) was applied. This standardized instrument has been used successfully in various on-site studies [49,50]. FBio is a subcategory of the Fascination with Science scale by Otto et al. [48], which tests affective, cognitive, and behavioral dimensions. Fascination is a latent construct that cannot be measured directly but indirectly through these three categories. The affective dimension measures positive feelings and emotions towards science. The cognitive dimension tests skills, knowledge, and willingness to solve complex scientific problems. The behavioral dimension tracks activities that students perform regularly in their spare time or as a hobby. The test consists of several statements which participants are asked to rate. The authors propose that when effortful actions are suggested in the test (e.g., going somewhere special or using technical devices), then if a participant agrees to make many of those efforts, that is evidence of deep fascination, whereas a person with low fascination will not agree to as many of the suggested actions. Thus, a person with deep fascination will agree to more statements from the test than a person with low fascination. For the target group of this study, it is particularly relevant that 10-year-olds have so far had very high scores in interest in science. In the intervention, this should primarily have the effect that the students stay engaged even in the case of difficulties with digital methodology due to their high individual interest in the topic.

A link has been established between declining individual interest and the decrease in STEM freshman enrollment in the United States [51]. This decline is most evident during high school. Therefore, fifth-graders have an excellent opportunity to build on and maintain high STEM interest. Other studies suggest that individual interest can be fostered primarily in informal learning environments within social learning scenarios, e.g., at an out-of-school learning site [52]. Distance learning can also be informal, but it takes more effort to maintain social learning opportunities. Thus, the developments of the last two years may pose an additional problem for STEM interest. It is therefore expected that fascination levels in this study will be rather low compared to other studies with high school students.

1.4 Importance of the Study and Research Goals

The main research focus of this study is to analyze the potential of digital ESE. Digital teaching methods have become the focus of educational research due to the recent exceptional pandemic situation. Distance learning forced ESE to be conducted remotely. To what extent this lack of nature-based learning experiences has created an educational gap that needs to be bridged remains open. The study will analyze the influence of students' preferences in regard to content and learning process on their cognitive learning progress. The Digital Nativity Assessment Scale (DNAS) measures whether students are comfortable with digital learning environments. However, it was initially

designed for adults and thus needs validation with students first. The DNAS instrument may be suitable for school use due to its conciseness and comprehensibility. If it performs well in this age group, it may then be adopted for general use. The Fascination with Biology (FBio) Scale is used to measure individual interest levels. An initial validation regarding the target group will also be applied here. Both tools are analyzed regarding their robustness in an online ESE learning unit. Finally, results on the connection between digital teaching method, taught content, and ESE learning progress are explored. Accordingly, the following research questions are addressed:

1. How do fifth-graders perform in the German version of the DNAS?
2. To what extent can the internal structure of the FBio scale be identified in German students?
3. Which influences learning progress more: student fascination as measured on the FBio scale or Digital Nativity as measured on the DNAS scale? How do topic and method influence each other?

2. Materials & Methods

2.1 Participants and Intervention Design

The study was conducted in June 2019 and 2020 with 288 participants from eleven different classes form five urban high schools (10.8 ± 0.45 years, 41% ♀). Participation was voluntary. Students completed questionnaires before and after an intervention-style unit. The learning unit was designed with emphasis on an action-oriented approach to teaching central scientific working methods. Problem-based instruction and student activity are characteristics of good teaching in normal school settings. In distance learning, problem-based approaches have shown higher motivation and better learning effect [53]. The unit was not explicitly designed to change Nativity or Fascination Levels, but to relate them to knowledge gains. The results presented here are quantitative in nature as three validated instruments are further explored. However, there are also qualitative elements to the overall project that have been presented in other articles [54,55].

Two different approaches were used to teach curriculum-related content in botany and sustainable agriculture. The control group completed a conventional, one-day on-site intervention, whereas the experimental group completed an online asynchronous learning unit over the course of two weeks (See Table 1). Both groups received an electronic guidebook with tasks either based on information on-site or with links to learning platforms (e.g., Prezi). In both settings, teachers were instructed to not provide any additional learning material. Any ambiguities on the part of the students were passed on to the team of tutors consisting of university students, who in turn were instructed as to what extent they were allowed to help in terms of content. Said tutors worked with both the control and the experimental group.

Table 2: Timeline of the intervention

Teaching Content	Control Group	Exp. Group
introduction "Save the Bees" plant characteristics plant identification biotic factors abiotic factors	9 a.m.–12 p.m.	Week 1
characteristics of pastures term "sustainability" sustainable dimensions of agriculture traditional vs. sustainable agriculture sustainable actions	1 p.m.–3 p.m.	Week 2

The first part of the learning unit covered botanical subjects such as characteristic features of plant families and how to determine plants by these features. Students learned, for instance, the botanical terms for flower shapes, leaf shapes, and growth forms. They also had to complete tasks such as determining known as well as unknown plants. The second part of the learning unit continued with prerequisites for ideal plant growth by contrasting different location factors. In order to achieve a comparable action orientation on-site and online, the experimental group was additionally given various DIY tasks such as building and implementing a rain gauge to track precipitation. Based on their findings, students had to choose the most suitable plants for their specific location from a given list with growth prerequisites. This task paved the way for the overall topic of species diversity in rural and urban areas. Students gained deeper insight into pros and cons of traditional and sustainable agriculture through three expert videos. To conclude, students were asked to select from a list of sustainable actions some that they thought would be meaningful for their community or hometown. If the students wanted to, they could present their selection of measures in the form of a poster digitally or on site.

In general, the learning unit was designed to let students work independently. They could, for example, make use of graded learning aids, or in case of the online version, contact tutors, which is recommended for hybrid or distance learning [56]. Another central point of the learning unit was the direct connection with the personal living environment of the students [57,58]. The relevance for the students themselves and their living environment was explicitly established in order to elicit as much personal initiative as possible. The student-centered focus was enhanced through DIY projects. In addition, the students' opinions on sustainable actions were included to show that they can make a difference themselves. According to Table 1, the working period in the online version may seem much more extensive. This design was chosen to meet the needs of the teachers. Instead of participating in a one-day field trip, teachers needed to be able to integrate the lessons into their regular schedules. All schools were in distance learning at the time of the study, meaning synchronous contact with teachers occurred only via

video communication. Students in both groups worked with identical research notebooks, information materials, and work assignments, except for the DIY projects. The biggest difference may be the natural environment and the use of living specimens. For the study, suitable pasture sections were created and plants that could be easily identified were planted. The experimental group had to rely on pictures, videos, or plants in the home garden for plant identification. The intervention unit aligns with the Next Generation Science Standards (NGSS). It contains Science and Engineering Practices, for example, taxonomic procedures and measuring abiotic factors. Crosscutting Concepts are met in Systems and System Models (boundaries of the ecosystem "pasture"), Structure and Function (of reproductive organs of plants), Stability and Change (stability of abiotic and biotic factors of ecosystems determine their overall stability), as well as Cause and Effect (different methods of farming result in changes of the affected ecosystems). Biological Core Ideas are represented in ESS3.C (human impacts on earth systems), LS2.A (interdependent relationships in ecosystems), LS2.C (ecosystem dynamics, functioning, and resilience), and LS4.D (biodiversity and humans). Scientific Method Core Ideas are addressed, specifically MS-LS2-4 ("construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations") and MS-LS2-5 ("evaluate competing design solutions for maintaining biodiversity and ecosystem services").

2.2 Instruments and Data Collection

To measure the students' digital capabilities, the Digital Nativity Assessment Scale (DNAS) by Teo [37] was used. A team of experts was carefully selected for the German translation. Some language adjustments were made specifically for that age group, as well as incorporating new technologies that have emerged since the conceptualization of the DNAS. Before the questionnaire was used in this study, a pilot test with 24 students, who did not participate in the study later on, was conducted. Since there are generally mixed results for the reproduction of Teo's 4-factor structure [33,34] and in addition to translation into German further linguistic adjustments were made, the internal structure was first assessed by means of factor analysis. Since few data are available for this target group, especially regarding possible changes in DNAS scores over short periods of time, the questionnaire was completed before and after the intervention. The Likert-type scale ("strongly disagree" to "strongly agree") consists of four subcategories with five or six questions each. Unlike other international studies [38,39,40], a 5-point scale was used due to the age of the target group. Since the factor loadings of item M1 were not good in other samples [38], the subscale was reduced to five items.

Secondly, a subscale of the Fascination with Science Scale by Otto et al. [48] was applied. It covers behavior, cognition, and affection on a 5-point Likert-type scale ("strongly disagree"/"never" to "strongly agree"/"very often"). The original scale is

comprised of 84 items in seven different topics: science in general, biology, chemistry, physics, astronomy, geology, and technology. Each subscale consists of 12 items. In this study, items measuring attitudinal preferences towards biology (FBio) were used. With such a young target group, particular care must be taken not to overwhelm the students with too many question items. As the Fascination scale is quite extensive, only one of the seven subscales was used—specifically, the one in line with the content of the intervention unit. Because no significant changes occurred in other fascination studies, the FBio questionnaire was applied once [59,60]. For both DNAS and FBio some items were reversed (=reworded for the opposite meaning) for data collection and then reversed again for data analysis. This was intended to eliminate students who only ticked maxima and to prevent the potential influence of positive phrasing on students.

A single-choice test specifically designed for this study was used to measure knowledge gains [55]. The items cover botanical knowledge such as typical shapes of plant families' flowers or the purpose of certain plant organs as well as knowledge about sustainability in agriculture and farming methods. The knowledge test was completed by the students before they started the learning unit (pretest) and after they completed the last tasks from the guidebook (posttest). Due to pandemic-related issues it was not possible to conduct a retention test to assess long-term learning. DIY projects and suggestions for sustainable actions were not considered.

2.3 Data Analysis

IBM SPSS 26.0 was used for factor analysis and its AMOS plugin for structural equation modeling (SEM). Level of significance is marked as $p \leq 0.05$ = *; $p \leq 0.01$ = **; $p \leq 0.001$ = ***. For factor analysis, values below 0.25 were left out. Sample size was adequate for behavioral research [61]. Samples larger than 30 ensure enough participants per subcategory, whereas a sample of more than 500 negatively influences sample error of standard deviation.

First, a Confirmatory Factor Analysis (PCA) of the Digital Nativity Assessment Scale (DNAS) was performed to validate the basic structure proposed by Teo [37] and Huang et al. [38]. The two points of measurement for DNAS were combined since t-test showed no significant differences from pretest to posttest ($p > 0.05$). Students who filled out DNAS twice were only regarded once, namely the first score.

Another CFA via AMOS was calculated to establish relationships among the latent variables. Finally, structural equation modeling (SEM) with maximum likelihood estimation was conducted to investigate the relationship between knowledge scores, FBio and DNAS. SEM is a commonly used method to analyze interrelationships between variables. Measured variables are drawn as squares; latent ones as ovals. Path values are standardized regression coefficients β. The larger the β value, the stronger the influence. R2

values are the proportion of variance that can be explained by the independent variable. R2 values—also called effect sizes—below 0.3 are considered weak and above 0.7 strong [62]. Model fit for both CFA and SEM was evaluated with the following conventionally used indices: relative Chi-square (χ2/df), comparative fit index (CFI), root-mean-square error of approximation (RMSEA) and standardized root-mean-square residual (SRMR). For good model fit χ2/df should be <3 and CFI > 0.95. CFI is dependent on sample size; thus, we expect it to be lower than 0.9 [63]. RMSEA > 0.08 or SRMR > 0.08 indicate poor fit [64].

3. Results

The findings are organized in two parts. First, DNAS and Fbio tools are analyzed separately. DNAS is designed for adults and thus needs analysis regarding the current target group. Fbio is one of several subscales and thus needs analysis regarding its internal structure. Secondly, structural equation modeling is applied with DNAS, Fbio, and knowledge gains.

3.1 Digital Nativity Assessment Scale

Following Teo's approach, CFA with Varimax rotation was applied on all DNAS items (Teo, 2013, see Table 2). KMO verified sampling adequacy at 0.802, χ2 =1330.575 and Bartlett p < 0.001 (for KMO 0.70 to 0.79 = middling, 0.80 to 0.89 = meritorious, 0.90 to 1.00 = marvelous according to Kaiser [65]). Cronbach's α was at 0.826 (is considered > 0.7 as good, >0.8 as very good, >0.9 not acceptable; see [66,67]). Internal consistency (Cronbach's α) was assessed for each subcategory: Technology 0.844, Graphics 0.721, Multitasking 0.678, and Rewards 0.674. The overall mean score was at 2.76 (SD = 0.65). Mean scores for each subcategory were: Technology 3.24 (SD = 1.1), Graphics 2.93 (SD = 0.88), Multitasking 1.8 (SD = 0.81) and Rewards 3.06 (SD = 0.95).

Table 2: Factor Analysis with Varimax rotation of Digital Nativity Assessment Scale

	Factor			
	1 = Tech	2 = Graphics	3 = Multi	4 = Rewards
T2	.815			
T1	.787			
T4	.705			
T5	.660	.253		
T3	.509			
G4		.724		
G2		.684		
G5		.679	.271	
G3		.616		
G1		.253		
M4			.767	
M6			.596	
M2			.467	
M3			.422	
M5			.410	
R5			-.257	.204
R2				.695
R3				.682
R4				.586
R1				.385

To assess influences between latent variables Technology, Multitasking, Rewards, and Graphics, another CFA of DNAS via Amos was conducted (see Figure 1). It showed good fit indices with χ2/df at 1.938, RMSEA at 0.068 (<0.08), CFI at 0.883 (>0.9) and SRMR at 0.069 (<0.08). Item R5 was eliminated due to ambivalent results in the CFA prior.

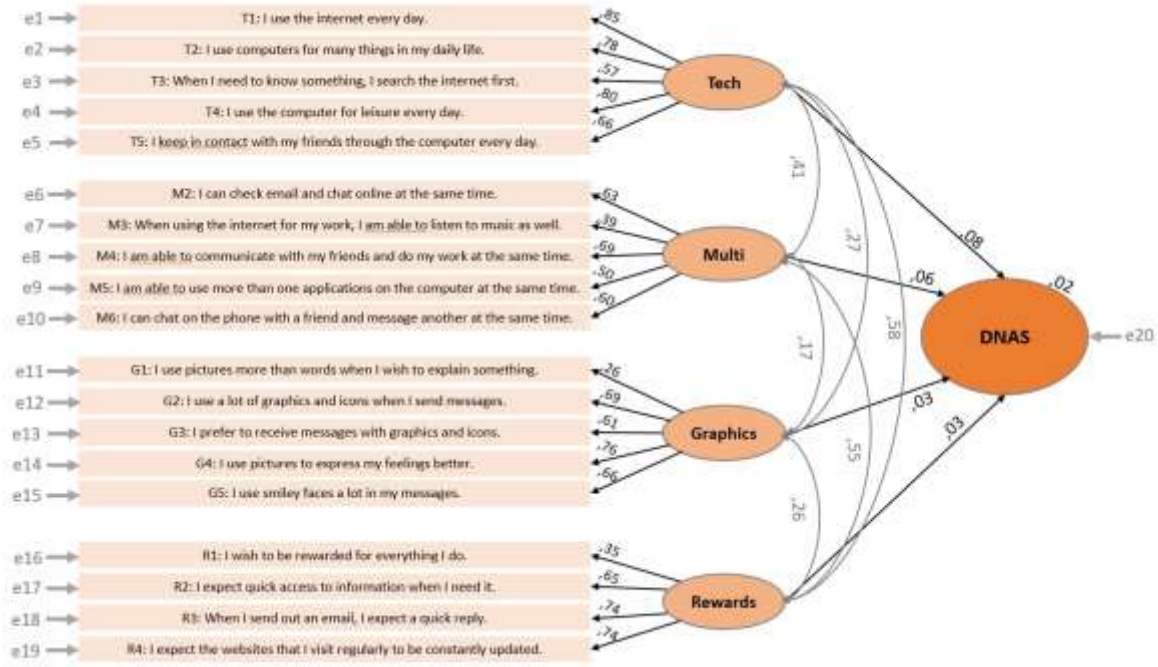

Figure 1: CFA of Digital Nativity Assessment Scale in AMOS

3.2 Fascination with Biology

CFA of the FBio scale (see Figure 2) showed good values with χ2/df at 1.569, RMSEA at 0.053 and CFI at 0.884 and Cronbach's α at 0.831. The overall mean score was at 3.54 (SD = 0.84). Mean scores for each subcategory were: affective 3.684 (SD = 0.75), cognitive 3.41 (SD = 1.08), and behavioral 3.42 (SD = 1.06). An independent t-test showed no significant differences between CG (M = 3.56, SD = 1.02) and EG (M = 3.54, SD = 0.64; t (147) = 0.121, p = 0.904).

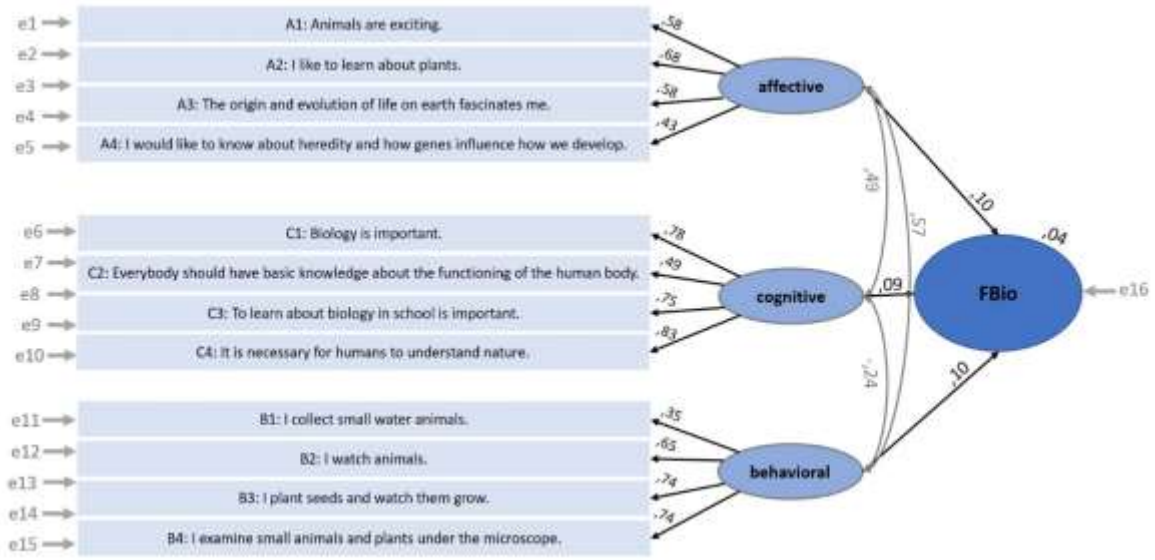

Figure 2: CFA of Fascination with Biology Scale in AMOS

3.3 DNAS, FBio and Knowledge Levels

The knowledge test was previously confirmed a valuable tool via Rasch analysis amongst [55]. A comparison of pretest (M = 15, SD = 3.45) and posttest (M = 19.17, SD = 3.41) via t-test showed significant learning progress due to participation (t (183) = 58.96, p < 0.001; see Figure 3).

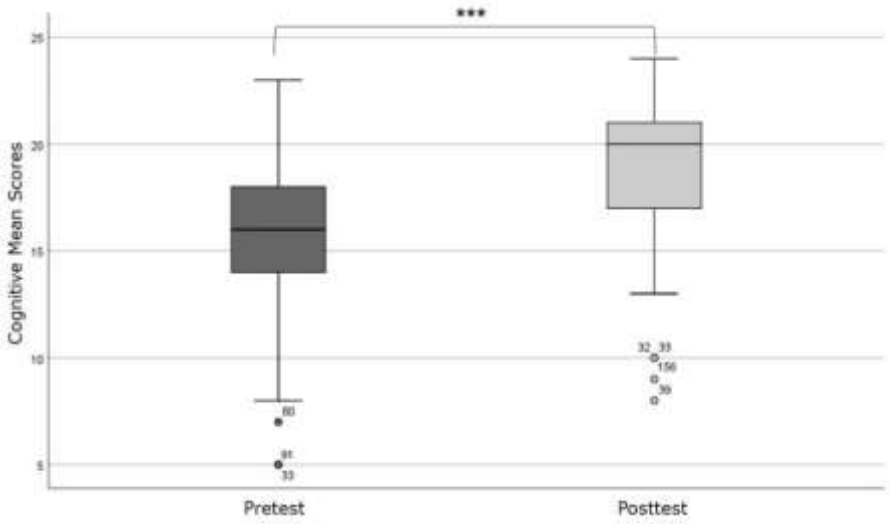

Figure 3: Learning Progress in a digital learning environment

The SEM of DNAS, FBio, and knowledge scores (see Figure 4) showed adequate model fit with RMSEA at 0.06, χ2/df at 1.725, and CFI at 0.78. β coefficients between DNAS and knowledge gain (0.72) as well as FBio and Knowledge Gain (0.56) are high. Influence of FBio on DNAS is poor (0.18). R2 values are indicated above each variable: knowledge gain = 0.98, DNAS = 0.16, and FBio = 0.11.

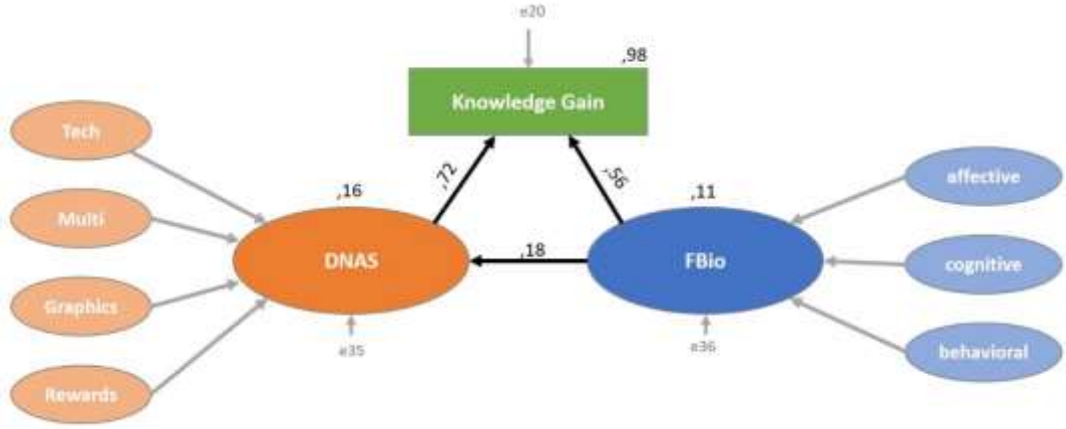

Figure 4: Structural Equation Modeling of DNAS, FBio and Knowledge Gains

4. Discussion

Green issues can be taught effectively through online teaching in distance education, although many outreach and out-of-classroom studies depict natural learning environments as a central prerequisite for their success [49,68,69]. As the intervention took place during lookdown schooling, successfully teaching botanical contents without direct interaction with or in nature seemed doomed to failure. Several studies have shown that engaging with and in natural environments effectively increases individual interest and knowledge levels e.g., [68,70,71]. Yet, our findings have proven otherwise: knowledge levels increased significantly and no significant difference detected between online and on-site was found [55]. By examining the designed ESE unit through a triangulation of learning progress, content preferences (FBio), and methodological preferences (DNAS), it was shown that ESE learning can be similarly effective in on-site and distance learning. In the larger context of the bridge that ESE is meant to build between students, adults, and scientists, these findings provide hope. ESE initiatives can be expanded not by requiring citizens to visit specialized learning sites, but can be reached through online learning opportunities. This allows ESE to reach a broader audience. The integrative nature of the learning unit used in this study should be emphasized. Consequently, such learning programs should rely on action-oriented tasks and content from the target group's life in order to put learners in an active role. Besides effective knowledge integration, this could lay the foundation for bottom-up initiatives by emphasizing the learners' own scope for action.

Although the DNAS tool should be adapted to today's technology, it seems to give a general indication of students' digital condition. Thus, on the one hand, as an analysis tool, it offers possible starting points for methodological workshops with the students. On the other hand, the positive influence of DNAS scores on knowledge gain shows some potential for the school context. For example, subjects that do not generate much intrinsic motivation on the part of the students in terms of content could compensate for this loss of motivation by using digital methods. Surprisingly, no negative correlation between DNAS values and FBio were found. It seems that within the current digital generation "screen-time" is not preferred over "green-time". This provides interesting starting points for modern ESE teaching, which apparently does not necessarily have to take place in natural environments.

4.1 Assessment of DNAS values

The DNAS instrument was used in this study to evaluate its potential in the school context. There are several established scales for ICT skills [42,72]. However, especially for young students, these are not applicable as the questions are too extensive and the skills tested are too specific. In addition, it seems unrealistic for such scales to be evaluated by inexperienced individuals, as this requires experience with statistical analysis. DNAS does not measure skills directly, but self-reported behavior and methodological preferences. Thus, if validated, it has potential to bridge the research gap in digital education at the primary level. An evaluation of DNAS results based on mean values seems to be well realizable for teachers. The extent to which these potential applications can be achieved with the current version of the DNAS will be discussed.

The students reached above average scores for Technology, Graphics, and Rewards. However, Multitasking was at 1.8. This low value could be grounded in the fact that some work processes described in the items are rather atypical for fifth-graders. For example, 10-year-olds do not send emails, but rather text messages. Therefore, items M2 and M4 seem unfitting for this age group. Although other studies point out that age is not a reliable indicator for digital nativity, low scores in the Multitasking category are supported by lower internal consistency scores for the subcategories compared to DNAS studies with older participants [38,40]. In the latter study, participants reached an overall average of 71%; in the former they reached at least 65%. Our sample reached an average score of 54%. This is quite surprising because Wagner's target group averaged between 19 and 29, (Huang: Ø 37,6 years) whereas our target group was between ten and eleven years old. Since the DNAS tool was used on a German sample for the first time, cultural and linguistic differences could explain lower mean scores.

Factor Analysis revealed some items to be problematic. For example, item M3 ("When using the internet for my work, I am able to listen to music as well.") showed low factor

scores (see Figure 1). Possible explanations are cultural differences and social desirability, which is typical for this age group. In the German cultural area, it is unusual for students to listen to music while doing homework. Background noise is generally considered disturbing and distracting. Since the questionnaire measures self-reported behavior, although students were repeatedly assured that neither parents nor teachers would see the results, they may have expressed little agreement on this item—regardless of whether they preferred background music or not. However, to avoid overloading students with too many items, no social desirability or lie questionnaire such as the RCMAS was used in this study [73]. Should the results be refined with a follow-up study, the use of such a questionnaire is advised. The item could also be supplemented by "relaxation music" to exclude distracting noises. In order to tailor the scale to school use, activities that are typical for students should be considered. Additionally, changes in wording of M2, M3, and M4 should also be considered with reference to their β values for DNAS subscales (see Figure 1). Multitasking interacts with both Technology and Rewards. If items were adjusted, this influence would change, too. Graphics generally does not seem to interact greatly with any of the other subcategories. In summary, although modern terms such as cell phone or tablet were already implemented in the German DNAS, the adaptation of some items in relation to young target groups and modern technologies seems appropriate.

Since no significant differences between DNAS pretest and posttest were revealed, the learning unit apparently did not impact the students' digital nativity levels. This supports previous research, where such values are rather stable and thus change only over longer periods of time [29,74]. Research suggests that there are more similarities than differences between digital natives and immigrants [74]. Other studies have found that there actually are more than two generations [75]. Significant differences between first-generation digital natives and later generations are reported [76]. Accordingly, the first generation was the most innovative and excelled at adopting new technology, while the younger generations lagged in ICT skills. This could explain the rather low scores in the study presented here. Consequently, educators cannot assume that students have certain digital skills. Additionally, teachers seem not to be properly skilled to meet their students' needs for digital training [35]. Thus, DNAS could also be valuable for teacher assessment.

4.2 Analysis of FBio values

In order to shape the behavior of students towards more sustainable lifestyles, not only cognitive but also affective components should be considered. Accordingly, in environmental education, motivational effects are considered to have a great influence on environmentally friendly behaviors [49,77]. Students showed high fascination scores with a mean score of 3.5 on a 5-point Likert scale. This is in line with other studies regarding

individual interest levels in ESE [59,78]. It was, however, expected that students who had spent considerable time in distance teaching were detached from nature and thus not as interested in it. Apparently, spending lots of time inside in front of a digital device is not contrary to being interested in ESE topics. The basic structure of FBio was confirmed by factor analysis. As ESE topics are considered interdisciplinary, exploring other subscales of the Fascination with Science questionnaire seems promising.

The data suggest that the students were very interested in the content of the intervention. Fifth grade is regarded a critical turning point for science motivation [46,49]. Primary school students generally tend to score high STEM interest levels, which decline during secondary education. They either lose individual interest or develop very high long-term science motivation. It is also suggested that individual interest is conducive for pro-environmental values and behavior [50]. As addressed in this study, ESE should focus on young target groups to transform situational interest into individual interest to promote sustainable lifestyles. Since fascination scores seem to be independent of the learning site, it seems that ESE can be taught in a motivating way not only at of out-of-school centers, but also at home. However, the action-oriented approach of online learning units should be taken into account.

4.3 Influence of DNAS scores and FBio scores on knowledge gains

When comparing Fascination with Biology and DNAS, surprisingly no significant relation appeared. Spending a lot of time in the great outdoors seems to be in contrast to spending time with tablets or computers. Therefore, a negative correlation was expected. One possible explanation is that mobile devices enable adolescents to combine being outside and online. Game-based research with a combination of outdoor/lab work and digital activities through mobile apps has been conducted in other STEM subjects [79,80]. Game-related interest seems to be a great predicator for cognitive and attitudinal increase. In biology, digital classification tools for plants have become best practice [54]. Other studies suggest a combination of outdoor and on-screen time [81,82]. Since the digital generation grew up with mobile internet, being interested in digital tools and biological subjects does not seem to be contradictory anymore. These findings bare implications for ESE centers to not only focus on nature-based education but also to adopt certain digital tools.

Students scored high on both interest and nativity. The positive influence on learning progress as shown by SEM analysis falls in line with previous research on the relationship between individual interest levels and knowledge acquisition [59,60,78]. The model also shows high correlations between both values and knowledge gains. This suggests that especially in groups that are not interested in biological topics, digital methods should

be used to enable effective knowledge transfer. Thus, digital ESE modules could bridge the gap between less motivated adolescents and sustainability topics.

Studies confirmed that using modern learning settings is a valuable motivation booster [83]. This claim is supported by our SEM, as DNAS levels had an even greater impact on learning progress than fascination levels do. In consequence, future research scenarios should implement an ideal mix of method and subject in order to maximize learning efficiency. Other studies suggest a combination of collaborative settings and gamification elements to increase motivation levels as well as individual learning outcomes [84]. This provides interesting approaches for follow-up studies on fascination. Since FBio is only one subscale, similar teaching methods could be applied to content of other STEM subjects to trace the influence of fascination levels or their development. This has already been well-explored in on-site projects such as teaching–learning labs [85]. However, other STEM subjects are not as popular among students. Thus, educators could use the motivation boost that digital techniques provide. ESE could benefit from findings concerning the connection of being comfortable in digital learning environments and teaching content. We suggest replicating the SEM (Figure 4) with similar teaching techniques in physics, chemistry, and math.

Digital literacy is regarded a key prerequisite for individual learning progress in modern e-learning [86]. As previously discussed, being a digital native does not automatically imply mastery of ICT skills. Studies showed a discrepancy between everyday ICT use (social networking, surfing the internet, participating in online gaming or virtual communities) and skills needed for problem solving and collaborative learning, which are basic elements of STEM learning [87]. Thus, a direct correlation between growing up in a digitized world and better learning outcomes in digital learning environments has not yet been proven. Our findings suggests that in our sample, digital nativity levels have a high influence on knowledge gain. Considering a rather low CFI, other indices very well support the model fit. Low R2 values indicate poor explanation for sample variance; β values still account for the central tendency of the model [88]. It can be concluded that this model gives a first indication but should be refined by a larger sample. As DNAS comprises several subcategories and does not specifically focus on ICT skills, it is rather an indicator of whether students are generally comfortable in digital learning scenarios.

5. Limitations

The abrupt lockdown phase was an exceptional situation and forced educational studies to use distance or hybrid instruction. Therefore, replication under normal circumstances is advisable, although special care was taken to minimize potential differences caused by the learning location. The lesson was designed to be student-centered and action-oriented. In addition to fascination and digital preferences, this could also be a

motivational factor that has a positive effect on knowledge gains. In order to provide further insights into how online instruction should be structured for the digital generations, different e-learning concepts on the same topic need to be compared. To investigate the influence of digitization or the relationship between digital nativity and analogue and digital ways of working, an additional, completely analogue group could have been included. However, since most out-of-school learning locations are by now at least partially digitized, this seemed a rather unrealistic scenario. If the DNAS tool is adapted to this age group and to modern technology, the relationship between DNAS scores and learning growth or improvement of DNAS scores could be continued through certain training programs. In the unit examined in this study, digital skills were taught only passively through use. A unit that explicitly promoted ICT skills might have had a greater impact on DNAS scores. Nevertheless, the relatively low scores in some DNAS categories indicate that the validity of the instrument may be questionable. Here, a study in which different questionnaires on digitality are used and compared should generate further insights.

As FBio scores are expected to drop in high school students and digital skills are refined during that age, repeating the study for an older target group seems appropriate. CFI values of the SEM are rather low. This could be caused by interdependencies between individual factors or a small sample size for structural equation modeling. Thus, repeating the research setup on a larger scale should provide more information for the validity of the model.

6. Conclusions

Modern ESE should rely on both on-site and online teaching methods. Our results indicate that preferences for both teaching method and teaching content have a great influence on learning outcome and thus can be used to strengthen ESE. With digital learning programs, more participants can be reached. We suggest using digital elements to extend collaborations between authentic ESE learning sites and educational institutions. Our study provides additional evidence of the basic robustness of the Digital Nativity Assessment Scale. However, data suggest that some items should be adapted to younger users and state-of-the-art technologies. In addition, to make the scale more attractive for school use, activities from the learning contexts could be included (e.g., "I can take notes and pay attention to a learning video at the same time"). A meta-analysis of all available data from this measurement instrument could help identify problematic items. We generally suggest more comparative studies with digital immigrants and natives. The importance of fundamental differences between digitally proficient and nonproficient people is increasing in modern society. However, it remains to be clarified whether digital nativity is simply a question of age, or whether other factors such as social background or nationality may play a more important role. Structural equation

modeling also confirmed a high influence of fascination levels on learning progress. To provide more accurate information about the relationship between method, subject, and learning progress, the other subscales of the fascination scale should also be tested both in online learning units and in the field.

Author Contributions

Conceptualization, S.T.F. and F.X.B.; Data curation, S.T.F.; Formal analysis, S.T.F.; Funding acquisition, F.X.B.; Investigation, S.T.F.; Methodology, S.T.F.; Project administration, S.T.F. and F.X.B.; Resources, S.T.F., T.H. and F.X.B.; Software, T.H.; Supervision, F.X.B.; Validation, S.T.F. and T.H.; Visualization, S.T.F.; Writing—original draft, S.T.F.; Writing—review & editing, T.H. and F.X.B. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of the Bavarian Ministry for Education (IV.7-BO5106/188/17) on 30 April 2019.

Informed Consent Statement

Written informed consent was obtained from all subjects or legal guardians.

Data Availability Statement

Data cannot be shared publicly because of the Bavarian Ministry for Education's guidelines regarding data of underaged participants.

Conflicts of Interest

The authors have no financial or proprietary interests in any material discussed in this article

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5.6 Teilarbeit D

Studies in Environmental Education

– Under Review –

'Sustainable' is synonymous to 'eco-friendly': Student conceptions about sustainability and sustainable behavior

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1 Abstract

Education for Sustainable Development (ESD) is a designated goal of the UN and by now an integral part of every current curriculum. ESD programs grounded in student conceptions are considered the ideal starting point for effective learning progress. With an increasing focus on sustainability concepts in the media, addressing this issue within a student-oriented framework is the most promising. Our current cross-sectional study is supposed to extend insight into adolescent conceptions on sustainability and sustainable behavior by providing a systematic analysis of students' (*N* = 139, *age* 10.2 ± .28) conceptions. Due to the lack of similar studies within this age group, a suitable category system needed establishment first. On that basis substantial knowledge gaps regarding the three pillars of sustainability were identified: economic and social aspects were rarely addressed. Most students had encountered the term 'sustainable' in the media first. The dominant category was "examples for sustainable behavior". Such examples were mainly related to recyclable or reusable everyday items. The terms sustainable and eco-friendly appear to be used synonymously by the students. Based on conceptual preferences, implications for further research and concepts for student-centered ESD teaching are provided.

Keywords: Sustainability – Student Conceptions – Education for Sustainable Development – STEM Teaching

2 Introduction

The UN's Agenda 2030 addresses global issues such as climate change, poverty, and inequality through 17 *Sustainable Development Goals* (SDGs). *Education for Sustainable Development* (ESD) is regarded a powerful tool to achieve the SDGs [1]. After the United Nations Decade of Education for Sustainable Development started in 2005, ESD has been implemented in syllabi worldwide. Nevertheless, the Sustainable Development Goals Report 2017, describe "the rate of progress in many areas far slower than needed to meet the targets by 2030" (2 p. 4). Analysis of different German school system for ESD elements from 2011 to 2016 reported efforts to achieve the SDGs must increase [3]. At the administrative level, this has taken the form of new curriculum content, for example [4].

2.1 ESD and Sustainability

The United Nations defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" [5 p. 4]. This initial definition later expanded by including economic, ecological, and social

implications [6]. Likewise, sustainability knowledge is an interdisciplinary, cross-curricular concept [7]. A DETR report defined four key elements of sustainable development: (1) social progress, which recognizes the needs of everyone, (2) effective protection of the environment, (3) prudent use of natural resources, and (4) maintenance of high and stable levels of economic growth and employment [8]. ESD is supposed to "empower learners to transform themselves and the society they live in by developing knowledge, skills, attitudes, competencies and values" [9, p.7]. The interconnectedness of topics such as global citizenship, climate change, and loss of biodiversity is highlighted. Nevertheless, comprehension of such topics and their implications is challenging, especially for young learners. To prevent overload, ESD teaching on primary and secondary levels should focus on establishing a solid base of sustainability knowledge before addressing interconnections. The term *sustainable* is often used synonymously with *environmentally friendly* by young students [10–12]. Thus, we expect little conceptions on economic and social aspects of sustainability by 5th graders.

Several studies have demonstrated that environmentally friendly lifestyles depend on three key factors: knowledge, values, and behavior [13–15]. More precisely, high environmental knowledge scores positively influence pro-environmental attitudes and behaviors [16,17]. Likewise, establishing in-depth sustainability knowledge will motivate learners to live a more sustainable lifestyle. A discrepancy between the known impact of environmentally friendly actions and the potentially more negative effects of environmentally unfriendly behavior is described [18]. For example, people may have basic knowledge about biodiversity loss, yet do not care about it unless a viable threat to their lifestyle is revealed, such as shortages in their food supply. Apparently, most learners know what sustainable behavior means, but manifest binary perceptions of sustainable lifestyles [19]. Thus, ESD knowledge should first concentrate on everyday life issues in addressees' context and then move on to a broader scale to avoid revealing such discrepancies. This study aims to uncover students' everyday touchpoints with sustainability issues to find meaningful baselines for effective ESD.

Gender seems to be an important factor affecting environmentally friendly or sustainable behavior [20]. In environmental education, female participants have shown stronger pro-environmental tendencies [21]. Analyses in the field of consumption and advertising have shown that environmentally friendly products, respectively environmentally friendly behavior are associated with femininity [22]. If such associations are conveyed through advertising, such gender differences could already become evident among children and adolescents. Consequently, ESD would have to counteract this gender bias to promote sustainable behavior in all students. Therefore, in this study, sustainability tendencies of fifth graders are assessed using pre-concepts.

2.2 Student Conceptions and Sustainability

Following a constructivist perspective of learning, students are actively structuring their knowledge based on individual skills and experiences [23]. Although a wide variety of constructivist teaching approaches exists, one consensus remains: learning is an active process based on the individual characteristics of the learner [24]. The realization of this core statement varies widely [25]. Scientists agree, however, that besides physical and social prerequisites, pre-experiences and pre-knowledge play a major role in the learning process [26,27]. Prior to entering the classroom, students can hold 'naïve' conceptions before they are confronted with 'professional' conceptions. Naïve student conceptions influence integration of new ideas. Conceptual change research suggests that a variety of concepts can exist for the same topic. However, even if these concepts contradict each other, they do not necessarily need to be replaced, but can co-exist. Several studies have shown that scientific conceptions can coexist with alternative conceptions [28,29]. This is especially true for every-day conceptions that explain phenomena on a superficial, oversimplified level [30]. Such misconceptions can undermine ESD efforts as learners cling to their pre-conceptions in everyday contexts and apply scientifically proven concepts only in educational environments. For example, studies regarding conceptions about biodiversity loss revealed that students acknowledge biodiversity conversation as important, yet do not seem to be aware of their own harmful actions [31]. This results in less pro-environmental behavior [32,33]. The conceptual change theory provides approaches to change nonscientific conceptions into scientific ones [26]. One crucial element of this modification is to target pre-existing concepts directly. Therefore, it is essential for educational research to determine empirically which misconceptions are prevalent. A better understanding of students' conceptions helps teachers effectively address them in ESD teaching. Identifying students' existing conceptions in empirical studies is thus an essential prerequisite for effective teaching and learning.

Student conceptions can be surveyed by different methods: interviews [34,35], open-ended questions [36,37], concept-maps [38], or multiple-choice questions [39]. Interviews and closed-ended questions are appropriate when the topic has been extensively researched. To the best of the authors' knowledge, few studies on students' conceptions of sustainability have been published. Most of these studies focus on specific subareas, such as energy, waste management, biodiversity, climate change and sustainable nutrition [35,40,30,41]. Therefore, the primary aim of this study is to explore students' general conceptions of 'sustainability' to compare them to professional conceptions an derive implications for teaching practice.

2.3 Research Questions

Since the current state of research in this age cohort does not show any categories for student perceptions of sustainability, the first step will be to develop and validate a category system. The resulting category system will be discussed in detail and possible sources of information on the part of the students will be identified. Subsequently, the results will be compared within the sample, i.e., in relation to gender and school. The following research questions guided our analysis:

(1) What student conceptions do 5th graders hold about sustainability and sustainable behavior?

(2) What gender differences can be identified regarding sustainability concepts?

3 Material and Methods

3.1 Sample and data collection

139 Bavarian 5th graders (10.2 ± .28 years, 43% ♀) completed four open-ended questions. The questions shown in Table 1 were validated in a pilot study with 88 students. For this purpose, the test group was divided into two subgroups, which answered a different selection of questions. Subsequently, the questions that provoked the most elaborated answers were selected.

Table 1: Questions for concept-retrieval

Question	Wording
Q1	What does the term "sustainability" mean to you? Give 2 examples for sustainable behavior.
Q2	Is living sustainably important? Give reasons why/ why not.
Q3	What do sustainable farmers do differently?
Q4	What would you change to live a more sustainable lifestyle? Provide examples.

3.2 Development of the Category System

The category system was developed according to qualitative content analysis [39,40]. First, some categories were developed deductively based on literature review. This initial draft of the category system was tested with about 10% of the data set. If items did not fit into any category but their inclusion seemed relevant, new categories were added. This process was repeated three times. A coding guideline with a clear definition of every category and an anchor example for each category was provided. Table 2 displays an excerpt of our coding guidelines.

Table 2: Examples for categories, their definition and anchor examples

Category	**Definition**	**Anchor Example**
Generation	Refers to future generations, their needs etc.	"You should live in a way that your children can live that way, too."
Climate Change	Refers to actions for more climate protection, to stop climate change,	"We need more climate protection."
Locomotion	Refers to any kind of (human) transportation	"We should ride our bicycles more and use the car less."
Recycling	Refers to waste separation as well as reusable materials	"We need good waste separation to protect our oceans."

Three raters who had not previously processed the data set were introduced to the category system through a coding guide. 30% of the data was rated by two independent raters and the entire data set by another rater to determine inter-rater reliability. The latter was repeated two months later to determine intra-rater reliability. Cross-matching of the results was then used to validate the category system. Due to the very good concordance, the validation process was considered complete. Categories that were affected by less than 3% of the data were now grouped together as "others" to simplify the system.

3.3 Reliabilities

To validate our category system, we conducted intra- and inter-rater-reliability tests. One rater rated the whole set of students twice within 2 months (*Cohen's K* = .93). Two other raters rated the same 30% of the dataset. Their results were compared to each other as well as the first rater (*Cohen's K* = .81, .82 and .89). The resulting Cohen's kappa scores in the range of .81–1.00 indicate an 'almost perfect' agreement between the raters [44,45].

4 Results

53.24% of students reported knowing the term sustainability from television or other media. 35.97% stated that they knew it from school. Multiple answers were possible in closed questions. A total of 1001 items was gathered from the open-ended questions.

4.1 Main Categories

The main categories were *Definition*, *Example*, *Other* and *Not Usable*. 57% of the items were coded as *Example*, 17% were classified as *Definition* (see Figure 1). 20% of the items were coded as *not usable*, which includes non-related utterances such as "I don't know". 6% of utterances were defined as 'other', which means they were topic-related but did not fit any of the categories.

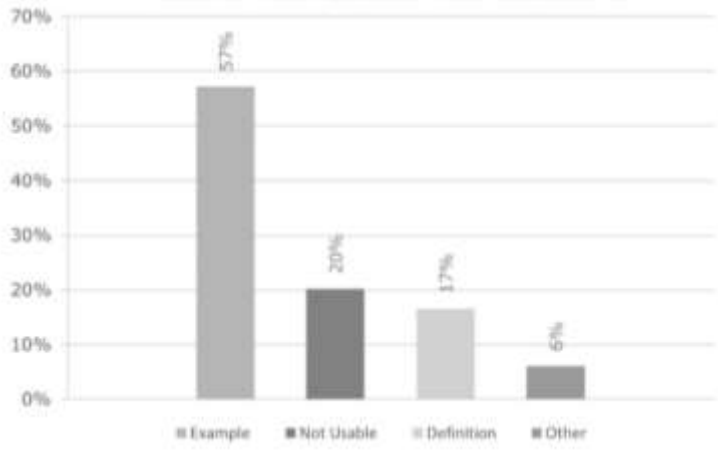

Figure 1: Item count for main categories in %

4.2 'Definition' Category

Item counts for *Definition*-subcategories throughout all 4 questions were *eco-friendly* (48%), *climate change* (27%), *planet-friendly* (19%) and *generation* (7%). Closer analysis of Question #2 shows a general, positive tendency towards sustainable behavior (see Figure 2). Most conceptions fell into the category *eco-friendly* (44%). 14% of the items were classified as '*no/ no answer'*, which means students regarded sustainable lifestyles as not important. 13% concerned the planet-topic, which means students highlighted the fact that there is only one earth to live on and therefore one planet to save for humankind. The original definition of sustainable behavior, namely, to preserve resources etc. for future generations, was mentioned in 3% of the items.

Figure 2: Item count for *Definition*-category in % for Question #2

4.3 'Example' Category

Further analysis of the *example* category throughout all questions showed high item counts for *recycling* (40%) and *environmental protection* (33%, see Figure 3). Most student conceptions addressed using less plastic or reusing plastic waste in packaging or clothing. *Locomotion* (21%) combined items related to means of transport, like taking the bus instead of the car or preferring e-cars to combustion engines. The least rated subcategory, *consumption* (6%), mainly referred to food. Most items were either for buying more organic products or eating less meat in general.

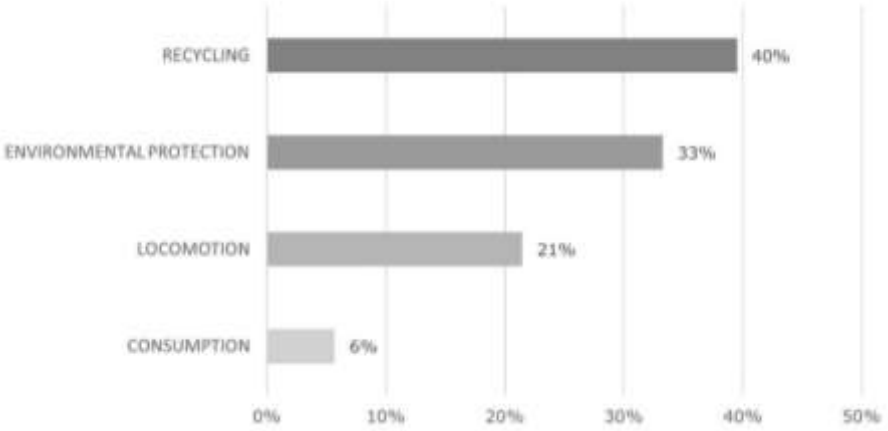

Figure 3: Item count for *Example*-category in % for all questions

4.4 Sustainable lifestyles

Closer analysis of Question #4 confirms a general, positive tendency towards more sustainable behavior (see Figure 4). 13% of the items were classified as "no/ no answer". *Recycling* (37%) and *Locomotion* (28%) were the highest rated categories. *Environmental Protection* (7%) and *Consumption* (5%) the least rated ones.

Figure 4: Item count for *Example*-category in % for Question #4

In a separate analysis items were not categorized regarding their content, but their wording. They were rated as *positive* if they promoted certain behavior like "riding the bike more often" or *negative*, if they opposed certain behavior, like "stop eating meat". Most of the items were rated negative (62%, see Figure 5).

Figure 5: Positive and negative items in % over all questions

4.5 Correlations

Significant correlations appear between response pattern and gender (p=.031). Female students gave an average of 12.83 (±6.9) meaningful responses; male students 10.54 (±5.24).

5 Discussion

5th graders showed a lack of information about the three pillars of sustainable development. Most of the items referred to environmental protection and environmental problems, which means that sustainable is used synonymously to environmentally friendly. This is contradicting to earlier studies where 5th-graders distinguished the term sustainability from environmental protection [46]. The predominance of the ecological dimension in student ideas, however, is in line with the literature [10,12,47]. In our data students seldomly provided definitions of sustainable behavior, and if so, they rarely included intergenerational and interdimensional aspects.

5.1 'Sustainable' is synonymous to 'eco-friendly'

More than two thirds of the analyzed items are related to environmentally friendly or climate friendly behavior. This supports previous studies showing that young students focus on the environmental aspects of sustainability [30,11,41]. 67% of the *definition* category and 77% of the *example* category were distributed among various subcategories covering ecological aspects. This shows a great diversity of student perceptions regarding the ecological dimension. Parts of the *consumption* category can be attributed to the economic aspect of ESD. However, it can be assumed that *organic*

products were mentioned for environmental or animal welfare reasons [40]. The social sector may have appeared in the form of intergenerational aspects of sustainable behavior. Nevertheless, such items account for less than .5% of the total items.

The Sustainable Development Education strategy specifies five fundamental principles of sustainability: living within environmental limits; achieving a sustainable economy; ensuring a strong, healthy, and just society; using sound science responsibility; and promoting good governance [2]. In this study, participants primarily mentioned the first two aspects. It appears that the economic and, above all, social and cultural aspects of sustainability are not yet present among students. The UNs' definition of sustainable development explicitly includes the needs of future generations [9]. However, students rarely voiced the intention preserve resources for future generations, e.g., by using renewable energy sources. Students struggle to make connections between global problems and their own [18]. The ability to assess long-term consequences of behavior develops during adolescence [48]. Initially, there are two parallel concepts of the future: students distinguish between impacts on their own future and on society's [49]. This gap remains to be bridged by clarifying that negative effects for the global community are equivalent to negative effects for the students' lifestyles. The ability to think and act in a future-oriented way can be fostered among adolescents [50]. ESD initiatives should build on this and, in addition to improvements in the content of social and economic aspects, further expand intergenerational issues.

5.2 Influences on student conceptions

More than half of the students indicated that they first encountered the term sustainability in the media. Other studies of student attitudes have reached similar conclusions [51,52]. In consequence, a large proportion of students enters the classroom with pre-concepts about this topic and therefore these pre-concepts need acknowledging in teaching efforts.

Recycling is the highest ranking in the subcategory. It might appear counterintuitive that students would think about which PE group a plastic package belongs to and how it should be reused. However, recycling is a popular issue for elementary and middle school ESD programs [50]. Most students were familiar with the terminology from advertisement and media. In recent years, packaging shifted to highlighting its reusability or recyclability. Consequently, recycling appears so often because it occurs more frequently both in the school context and in everyday life.

Due to high relevance to everyday life, recycling cycles are frequently used as introductory topic for sustainable development courses. Elementary school students have been found to mimic the behavior of their caregivers regarding recycling. The influence

of school lessons is marginal [47]. Students' behavior at this point tends to be unreflective and may not provide insight into environmental attitudes or other pro-environmental behaviors. Nevertheless, a positive trend of student attitudes towards waste separation and recycling can be identified at secondary level [54]. In this age group, recycling behavior seems to be more reflective, but specific knowledge on the complex interrelationships of sustainable development is still lacking. For adults, studies suggest a positive relationship between knowledge of waste management and general environmental attitudes [55]. In the Bavarian curriculum "Ecosystem Forest" is an obligatory topic in 4th grade [4] focusing for instance on tree decline or rainforest deforestation and its consequences. However, a closer look reveals that the students are against forest clearing but cannot give any precise reasons for this. Deforestation and recycling both seem to be popular topics among primary level teachers but seem to be treated superficially. Following a spiral curriculum, the school staff should focus on one topic and address it in recurring projects across subjects and grades. This could on the one hand counteract superficial knowledge transfer and on the other hand help to convey not only ecological aspects of sustainability, but also economic and social ones.

The *consumption*-category was not mentioned as often as expected and does not seem to reflect the behavior of 10-year-olds. For example, a frequently mentioned topic was e-cars. There is no evidence that children can influence the choice of the family car. If they have not had to face this problem themselves, students have likely encountered it in other contexts. Studies have shown that product placements and advertising have a major influence on children's product preferences [56]. Since most students said they were familiar with the terminology from the media, advertising is possible source for student concepts in this case. In Advertisement, environmentally conscious aspects of a product are regarded as the basis for successful positive branding [57]. Other studies report a greater impact on purchase behavior from advertising that does not highlight direct positive effects on buyers, e.g., the special comfort of a car, but the resulting positive impact on the entire community, e.g., e-cars as environmentally friendly alternatives [58]. Brand advertising increasingly focuses on highlighting the sustainable aspects of their products to ensure brand loyalty [59,60]. This concept appeals to young target groups, too [61]. Therefore, it can be assumed that the students have frequently encountered the term *sustainability* in advertising. Typical examples from the German market are smart solutions, e-cars, meat substitutes, or cosmetics with less microplastic and recyclable packaging.

In sustainability contexts, consuming less or no meat is a prevalent topic. Commercials for meat substitutes and organic food have increased in recent years [62]. Even though medical experts emphasize that a vegetarian diet in children may be related to health

deficits, an increase in vegetarians and vegans has been reported [63,62]. Other studies have found that modern vegetarian diets, presumably based on various meat substi-tutes, show little nutritional disadvantage in children. However, no advantages in terms of diseases or fitness could be found either [64]. According to current studies, about 5% of Germans live vegan or vegetarian [65]. However, items related to environmental-friendly food or organic products make up 1% of the data. Thus, students do not seem to see a connection between food consumption and sustainable behavior [66]. Ideal nu-trition and healthy diets are part of the elementary school curriculum in the Bavarian school system. The curriculum does not specify sustainable aspects of food such as CO_2 consumption or transport routes for ideal nutrition. Various components of a healthy diet, such as fruits, could be implemented using mainly local and seasonal examples instead of exotic ones. Thus, healthy choices for students themselves could be linked to clever choices for the society itself. Evidence suggests that vegetarian children have a higher socioeconomic status [67]. It seems as if not the behavior of parents, but very much the parental home determines the eating preferences of children. No data collection on stu-dents' socioeconomic status was approved as part of this study. As part of a follow-up study that further illuminates the categories found here, it would be interesting to collect socio-economic data and compare it with items from the nutrition category.

Discrepancies between item count in the environmental protection category and the data regarding Q4 ("What would you change to live a more sustainable lifestyle?") provided interesting insight into the students' self-perceived influence. When asked about the actions they would take themselves, recycling and locomotion are mentioned most frequently. This was unexpected, as students cannot drive a car yet and it seems unplausible that they can influence what kind of car their parents drive. Although students acknowledge sustainable behavior to be important, they do not seem to attribute power to change to themselves. Thus, they do not think their own actions can have a viable impact on the environment. This conclusion can be drawn from the discrepancy between questions 2 and 4. In question 2 ("Is living sustainably important? Give reasons why/ why not."), 'yes' is frequently stated, but reasons for approval are rarely given. Similarly, question 4 ("What would you change to live a more sustainable lifestyle?") was frequently answered with 'nothing' or synonymous terms. However, it seems questionable that students' daily lives are already as sustainable as possible which leaves room for improvement, such as more sustainable means of transportation. Contrary to participants in climate strikes such as the Fridays-For-Future movement, this target group does not seem to have the opportunity to actively engage in environmental protection and more sustainable lifestyles themselves [68]. This is

where ESD teaching could step in and provide age-appropriate opportunities for improvement.

Studies have shown that women tend to have higher environmental attitudes and environmentally friendly behavior than men [69,70]. Our study supports this conclusion. A correlation between topic-related statements and gender could be revealed. The differences could also stem from gender-specific characteristics of writing ability or response motivation. Different levels of communication skills may be responsible for differences in response quality. Comprehensive meta-studies have shown that at the international level, girls have a clear advantage around reading and spelling skills at primary level [71,72]. This includes the German-speaking education system. Therefore, the response pattern to open-ended questions could be significantly influenced by process-related, rather than content-related, competencies. Within the scope of this research work it was not possible to survey such skills. In follow-up studies, therefore, interviews should be used as a supplement to circumvent such interfering factors. Regardless of literacy skills, further investigation of gender differences in ESD appears promising.

The students' general attitude towards sustainable behavior reveals whether sustainable actions are regarded as something that enriches everyday life or as something that limits it. 62% of the items refer to things they could not do or could no longer do. This is contrasted with positive utterances of how previous actions could be done differently, i.e., instead of "not driving a car" writing "use more public transport". From the point of view of behavioral psychology, changing behavior is related to the individual's basic attitude [12,37,73]. The more positively a person assesses certain behavior, the more willing they are to adapt previous behavior to comply with that very behavior. Finally, any change in behavior needs a certain motivation. Effective ESD and STEM teaching both focus on intrinsic motivation and individual interest [74–76]. Advertising campaigns for sustainable products rely on external motivators such as lower costs due to lower CO_2 taxes. For 10-year-olds, however, these extrinsic factors are not yet motivational boosters. Instead, ESD should focus on fostering students' intrinsic motivation by addressing real-life issues that are relevant to them.

One way of improving sustainability concepts could be more open science communication and its active integration into the classroom. The lack of exchange of new scientific insights with the public is regarded as a major cause for differences between students' conceptions and scientific conceptions [30]. Especially in the digital age, where information is ubiquitous and available through the Internet, science should be more present. Students distinguish between 'school science' and 'real science'. These

expressions are troubling in terms of co-existing ideas. The discrepancy between question #2 ("Is living sustainably important?") and #4 ("What would you change to live a more sustainable lifestyle?") provides evidence that co-conceptions are also present in this sample group. Consequently, school lessons should be aligned as closely as possible with current topics and issues relevant to the everyday life of the students [41]. The Covid-19 pandemic, for example, provides numerous points of reference: Immune response, genetics, recombination of antigens, genetic diversity, biological diversity, to name a few examples. STEM lessons should be inspired by current scientific discourse. Teachers indicate insufficient time and resources are reasons ESD is not based on current issues [12]. To reduce the teachers' workload, regular visits to student laboratories that are closer to scientific research are recommended.

In question #4 the *environmental protection* category drops to 7%. It can be deduced from this that the students do not see any scope for action of their own in the field of environmental protection. However, the Fridays-For-Future movement has shown that young people get involved and try to make a difference [68]. Teachers could act as neutral persons and point out various fields of action or invite representatives of environmental protection organizations into the classroom. In addition to ecologically oriented organizations, economic and social ones should be considered.

5.3 Outlook

First, it should be addressed that approximately ¼ of the items collected were not usable or not related to the topic. On the one hand, this shows that ¾ of the students could relate to the term 'sustainability'. On the other hand, it also shows that a considerable part could not give any meaningful answer. Due to the explorative character of the study, no generalizations can be made, although some indications are apparent. This study serves as a starting point for further data collection, for example in the form of interviews. Recruiting individual school classes through convenience sampling does not allow generalized conclusions for an entire generation [77]. Future research focusing on adolescents from various age cohorts, schools and cities would provide a deeper understanding. The categories found here form the basis for interview guidelines.

The eco-friendly aspects of sustainable behavior seem to act as pronounced triggers among students. The ecological dimension could be used as a starting point to make economic and social sustainability more accessible for students. Students seem to have positive attitudes toward environmental programs. However, they do not see environmental protection in their own scope of action. This is where ESD initiatives should pick up and show how to advocate for sustainable development and environmental protection locally in everyday life, especially as a young person. The prevailing tendency

seems to be that sustainable action implies restrictions on oneself. Here, teachers should avoid reinforcing this negative attitude. Instead, ESD units should not be pointed out which products should no longer be consumed, but rather sensible and realistic alternatives should be addressed. Positive connotations should outweigh negative ones.

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No funds, grants, or other support was received. The authors have no financial or proprietary interests in any material discussed in this article.

Ethics statement

The research project labelled "Ecosystem Pasture – an introduction to sustainable behavior" was approved by the Bavarian Ministry of Education (IV.7-BO5106/188/17). All data privacy laws were respected. Gender, age and study status of participants were recorded pseudo-anonymously. Since our target group were underage students, parents had to give written consent. Participation was voluntary and meant no disadvantages in the school routine.

Data Availability Statement

Data cannot be shared publicly because of the Bavarian Ministry for Education's guidelines regarding data of underaged participants. Data are available for researchers who meet the criteria for access to confidential data. Access must be confirmed by the Ethics Committee of the University of Bayreuth/ ZMNU. Contact the corresponding author for further information.

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Anhang

Teilarbeit A: Unterrichtssequenz „Ökosystem Grünland"

Kapitel 1		
	kognitive/ prozessbezogene Kompetenz	Umsetzung
		Fragebogen
	„Rettet die Bienen"-Initiative	Videosequenz, Vorstellung *Manu*
Kapitel 2		
	naturwiss. Erkenntnisweg	Vermutungen aufstellen (artenarme & artenreiche Wiese)
	Wiederholung (Fachinhalte aus der Grundschule)	Aufbau Blütenpflanze
	fachtypische Arbeitstechniken: Pflanzenbestimmung	ausgewählte Bestimmungsmerkmale, Formenkenntnis
		ausgewählte typische Vertreter, Artenkenntnis
		Schüler:innenaktivität: Pflanzenbestimmung
Kapitel 3		
	Definition *Artenvielfalt*	Videosequenz
	Formen- & Artenkenntnis	Auswahl heimischer Pflanzenfamilien & ihre typischen Merkmale
	biotische Standortfaktoren	Wiesen anhand ihrer pflanzlichen Biodiversität unterscheiden
	naturwiss. Erkenntnisweg	Überprüfung der Hypothesen aus Kapitel 2
	Diagrammkompetenz	Zusammenhang Flora & Fauna (Insekten)
		Fragebogen
	fachtypische Arbeitstechniken: Pflanzenbestimmung	Schüler:innenaktivität: Biodiversität einer Wiese bestimmen
Kapitel 4		
	Definition *Standort/ Lebensraum*	Videosequenz
	abiotische Standortfaktoren (Temperatur, Wasser, Sonnenlicht)	Recherchieren für Würzburg
		Zuordnung ausgewählter Pflanzenarten
	abiotische Faktoren messen	Schüler:innenaktivität: Regenmesser bauen*
Kapitel 5		
	Definition *Nachhaltigkeit*	Videosequenz
	ökonomische, ökologische & gesellschaftliche Dimension	„Expert:innen"videos
	Bewertungskompetenz	Beispiele für nachhaltiges Verhalten auswählen & begründen
	Kommunikationskompetenz	Schüler:innenaktivität: Plakat
		Fragebogen
		Schüler:innenaktivität: Samenbombe

*nur im Distanzunterricht

Teilarbeit B: Fragebogen kognitives Wissen

1. Was versteht man in der Biologie unter dem Begriff "Lebensgemeinschaft"?

- ☐ Gesamtheit aller Lebewesen in einem Lebensraum
- ☐ Gruppenbildung, wie z.B. ein Rudel Wölfe
- ☐ Gruppenbildung bei Verwandten, wie z.B. bei Bienen
- ☐ Gesamtheit aller Jungtiere in einem Lebensraum

2. Einfache Blüten sind gekennzeichnet durch...

- ☐ ...Oberlippe und Unterlippe
- ☐ ...Fahne, Flügel und Schiffchen
- ☐ ...ausschließlich weiße Blüten.
- ☐ ...vier oder fünf Kronblätter

3. Nachhaltigkeit dreht sich um das Thema Ressourcen. Wie würdest du einem Freund/ einer Freundin die Sache erklären? "Nachhaltigkeit bedeutet, dass…

- ☐ ...man ausschließlich vor Ort hergestellte Produkte kaufen sollte, um die Geschäfte zu unterstützen."
- ☐ ...eine Generation alle Ressourcen zur Verfügung haben sollte, die sie für optimales Wachstum benötigt.
- ☐ ...die Erde allen Menschen gehört, und deshalb sollten Ressourcen gleichmäßig aufgeteilt werden."
- ☐ …Ressourcen umweltverträglich verbraucht werden sollten, sodass auch zukünftige Generationen eine geeignete Lebensgrundlage habe

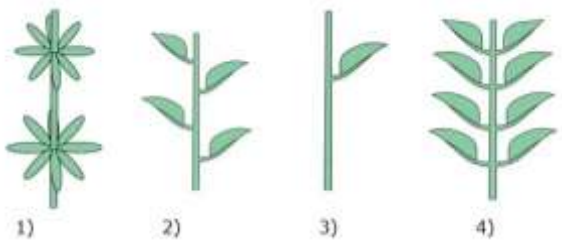
4. Landwirtin Stefanie besitzt einen Bio-Bauernhof, der auf Nachhaltigkeit setzt. Kreuze an, welche Maßnahme auf keinen Fall auf ihren Betrieb zutreffen sollte!

- ☐ 1-2x im Jahr mähen
- ☐ 4-6x im Jahr mähen
- ☐ häufig bewässern
- ☐ selten düngen

5. Ein Lebensraum wird in erster Linie bestimmt durch…

- ☐ ...die Höhe der dort wachsenden Pflanzen
- ☐ ...die Größe der dort vorkommenden Tiere.
- ☐ ...die Anzahl der Lebensgemeinschaften
- ☐ ...seine belebten und unbelebten Faktoren.

6. Welches der folgenden Bilder stellt eine wechselständige Blattstellung dar? Kreuze an



- ☐ 1)
- ☐ 2)
- ☐ 3)
- ☐ 4)

7. Landwirtin Tanja betreibt nachhaltige Landwirtschaft. Welche Maßnahme trifft auf ihren Betrieb zu?

- ☐ 4-6x im Jahr mähen
- ☐ 1-2x im Jahr mähen
- ☐ häufig düngen
- ☐ selten bewässern

8. Du beobachtest einen benachbarten Landwirt beim Düngen. Dir fällt auf, dass er sehr nah am Main entlangfährt. Wo liegt das Problem?

- ☐ Er düngt fremden Boden, da der Uferbereich immer zum Landkreis gehört.
- ☐ Dünger verschmutzt das Gewässer. Er sollte mehr Abstand halten.
- ☐ Der Traktor könnte abrutschen und im Main versinken.
- ☐ Es gibt überhaupt kein Problem

9. Schmetterlingsblüten sind gekennzeichnet durch...

- ☐ ...Oberlippe und Unterlippe
- ☐ ...Fahne, Flügel und Schiffchen
- ☐ ...ausschließlich weiße Blüten.
- ☐ ...vier oder fünf Kronblätter

10. Was kannst du selbst tun, um Artenvielfalt in deinem Garten zu unterstützen?

a) weniger mähen
b) Blumensamen aussähen
c) regelmäßig düngen
d) nur Tulpen anpflanzen

☐ nur d)
☐ a) und b)
☐ b) und c)
☐ a) und c)

Artenvielfalt beschreibt die Anzahl der Tier- und Pflanzenarten in einem Lebensraum.

11. Landwirt Paul möchte von nachhaltiger Landwirtschaft zu traditioneller Landwirtschaft wechseln. Welche der folgenden Maßnahmen würdest du ihm empfehlen?

a) seltener mähen
b) häufig mähen
c) häufig düngen
d) seltener düngen

☐ a) und c)
☐ a) und d)
☐ b) und c)
☐ b) und d)

12. Die Hauptfunktion der Blüte einer Pflanze liegt in der...

☐ …Überwinterung
☐ …Schönheit
☐ …Wasserspeicherung
☐ …Fortpflanzung

13. Artenvielfalt ist...

☐ ...wichtig, weil viele Tiere und Pflanzen vom Menschen genutzt werden können.
☐ ...wichtig, weil sie unsere Ökosysteme im Gleichgewicht halten.
☐ ...nicht so wichtig, weil es mehr als genug Arten gibt.
☐ ...überhaupt nicht wichtig, weil ständig neue Arten entstehen.

14. Welche Aussagen treffen auf nachhaltig bewirtschaftetes Grünland zu?

a) hoher Ertrag
b) niedrige Artenvielfalt
c) wenige Mähzeitpunkte
d) wenig Düngen

☐ a) und c)
☐ b) und c)
☐ c) und d)
☐ a) und b)

15. Hier siehst du zwei Fotos von Wiesensalbei. Nenne die Pflanzenfamilie.


☐ Kreuzblütler
☐ Schmetterlingsblütler
☐ Rosengewächse
☐ Lippenblütler

16. Welche der folgenden Messungen führen Forscher durch, wenn sie die unbelebten Faktoren eines Standortes beschreiben wollen?

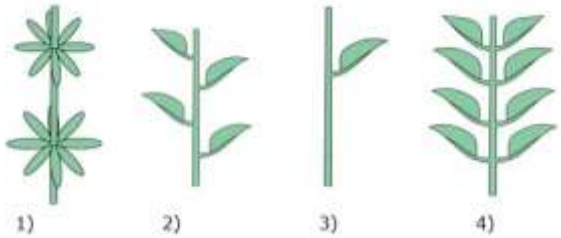
a) Stärke des Lichts
b) Beschaffenheit des Bodens
c) Feuchtigkeit des Bodens
d) Anzahl der Tiere und Pflanzen

☐ a) und b)
☐ a), b), und c)
☐ nur d)
☐ a) und c)

17. Was ist ein Beispiel, für einen belebten Standortfaktor?

- ☐ Stärke des Lichts
- ☐ Beschaffenheit des Bodens
- ☐ Feuchtigkeit des Bodens
- ☐ Anzahl der Tiere und Pflanzen

18. Welches der folgenden Bilder stellt eine Rosetten-Blattstellung dar? Kreuze an!



- ☐ 1)
- ☐ 2)
- ☐ 3)
- ☐ 4)

19. Lippenblütler sind gekennzeichnet durch...

- ☐ ...vier oder fünf Kronblätter.
- ☐ ...eine Oberlippe und eine Unterlippe
- ☐ ...ausschließlich weiße Blüten.
- ☐ ...Fahne, Flügel und Schiffchen.

20. Welche Aussagen treffen auf traditionell bewirtschaftetes Grünland zu?

a) hoher Ertrag
b) niedrige Artenvielfalt
c) wenige Mähzeitpunkte
d) wenig Düngen

- ☐ a) und c)
- ☐ c) und d)
- ☐ b) und c)
- ☐ a) und b)

21. Wozu legt man Grünstreifen mit Wildblumen an?

- ☐ Sie bieten Lebensraum für viele Pflanzen und Tiere
- ☐ Sie können von Kühen und Schafen beweidet werden
- ☐ Sie sehen schön aus und schmecken Kühen besser.
- ☐ Sie grenzen Ackerflächen voneinander ab

22. Nachhaltiger Umgang mit der Natur bedeutet...

- ☐ Alle Ressourcen können voll ausgeschöpft werden
- ☐ Es sollen nur Ressourcen gesammelt werden, die Menschen benötigen.
- ☐ Man sollte nur so viel nehmen, die die Natur ertragen kann
- ☐ Seltene Stoffe sind knapp und deshalb teuer

Ressourcen sind alles, was ein Lebewesen braucht, um zu überleben.

23. Du möchtest ein Bienenvolk halten und suchst einen geeigneten Standort. Damit das Nahrungsangebot ausreichend ist, platzierst du den Bienenstock am Rand...

- ☐ ...einer Kuhweide.
- ☐ ...einer Blumenwiese.
- ☐ ...eines Laubwaldes.
- ☐ ...eines Rapsfeldes.

24. Hier siehst du zwei Fotos eines Ginsters. Nenne die Pflanzenfamilie!

- ☐ Lippenblütler
- ☐ Schmetterlingsblütler
- ☐ Kreuzblütler
- ☐ Rosengewächse

Teilarbeit B: Fragebogen Semantisches Differential

Umweltschutz ist für mich…								
schlecht	☐	☐	☐	☐	☐	☐	☐	gut
langweilig	☐	☐	☐	☐	☐	☐	☐	interessant
schwer	☐	☐	☐	☐	☐	☐	☐	einfach
feige	☐	☐	☐	☐	☐	☐	☐	mutig
passiv	☐	☐	☐	☐	☐	☐	☐	aktiv
sinnlos	☐	☐	☐	☐	☐	☐	☐	sinnvoll
beunruhigend	☐	☐	☐	☐	☐	☐	☐	beruhigend
wertlos	☐	☐	☐	☐	☐	☐	☐	wertvoll
unwirksam	☐	☐	☐	☐	☐	☐	☐	wirksam

Nachhaltigkeit ist für mich…								
schlecht	☐	☐	☐	☐	☐	☐	☐	gut
langweilig	☐	☐	☐	☐	☐	☐	☐	interessant
schwer	☐	☐	☐	☐	☐	☐	☐	einfach
feige	☐	☐	☐	☐	☐	☐	☐	mutig
passiv	☐	☐	☐	☐	☐	☐	☐	aktiv
sinnlos	☐	☐	☐	☐	☐	☐	☐	sinnvoll
beunruhigend	☐	☐	☐	☐	☐	☐	☐	beruhigend
wertlos	☐	☐	☐	☐	☐	☐	☐	wertvoll
unwirksam	☐	☐	☐	☐	☐	☐	☐	wirksam

Teilarbeit C: Fragebogen *Digital Nativity Assessment Scale*

		stimmt überhaupt nicht				stimmt total
1.	Ich bin jeden Tag online.	☐	☐	☐	☐	☐
2.	Ich nutze Computer, Tablets oder Handys für viele verschiedene Dinge im Alltag.	☐	☐	☐	☐	☐
3.	Wenn ich etwas nicht weiß, suche ich zuerst online.	☐	☐	☐	☐	☐
4.	In meiner Freizeit nutze ich Computer/ Tablet/ Handy täglich.	☐	☐	☐	☐	☐
5.	Ich nutze Computer/ Tablet / Handy täglich, um mit Freunden zu schreiben.	☐	☐	☐	☐	☐
6.	Ich chatte oft nebenher, wenn ich andere Sachen am Computer/ Tablet/ Handy mache.	☐	☐	☐	☐	☐
7.	Wenn ich am Computer/ Tablet/ Handy Sachen für die Schule erledige, höre ich dabei oft Musik.	☐	☐	☐	☐	☐
8.	Ich chatte oft mit Freunden, während ich Hausaufgaben am Computer/ Tablet erledige.	☐	☐	☐	☐	☐
9.	Ich habe oft mehrere Apps gleichzeitig offen und in Benutzung.	☐	☐	☐	☐	☐
10.	Wenn ich mit Freunden telefoniere, schreibe ich oft nebenher mit anderen.	☐	☐	☐	☐	☐
11.	Ich schicke lieber ein Bild als eine Nachricht, wenn ich etwas erklären möchte.	☐	☐	☐	☐	☐
12.	Ich verwende generell gerne Smileys oder Gifs.	☐	☐	☐	☐	☐
13.	Ich lese selbst lieber Nachrichten mit Smileys oder Gifs.	☐	☐	☐	☐	☐
14.	Mit Bildern oder Smileys kann ich besser meine Gefühle ausdrücken.	☐	☐	☐	☐	☐
15.	Ich verwende häufig nur Smileys oder Gifs in meinen Nachrichten.	☐	☐	☐	☐	☐
16.	Ich werde gerne für alles gelobt, was ich erledige.	☐	☐	☐	☐	☐
17.	Wenn ich einen Suchbegriff eingebe, erwarte ich sofort eine passende Erklärung.	☐	☐	☐	☐	☐
18.	Wenn ich eine Nachricht verschicke, erwarte ich schnell eine Antwort.	☐	☐	☐	☐	☐
19.	Ich erwarte, dass meine Lieblings-Apps und -Webseiten immer auf dem neuesten Stand sind.	☐	☐	☐	☐	☐
20.	Ich lerne gerne Sachen, die ich gleich anwenden kann.	☐	☐	☐	☐	☐

Teilarbeit C: Fragebogen *Faszination Biologie*

							
		stimmt überhaupt nicht					stimmt total
1.	Tiere sind spannend	☐	☐	☐	☐	☐	
2.	Ich lerne gerne etwas über Pflanzen.	☐	☐	☐	☐	☐	
3.	Der Ursprung und die Evolution des Lebens faszinieren mich.	☐	☐	☐	☐	☐	
4.	Ich würde gerne wissen, wie Vererbung funktioniert und wie Gene unsere Entwicklung beeinflusse	☐	☐	☐	☐	☐	
5.	Ich sammle kleine Wassertiere (z.B. Kaulquappen oder Fische).	☐	☐	☐	☐	☐	
6.	Ich beobachte Tiere.	☐	☐	☐	☐	☐	
7.	Ich pflanze Samen und schaue ihnen beim Wachsen zu.	☐	☐	☐	☐	☐	
8.	Ich untersuche kleine Tiere und Pflanzen unter dem Mikroskop.	☐	☐	☐	☐	☐	
9.	Biologie ist wichtig.	☐	☐	☐	☐	☐	
10.	Alle sollten Grundwissen über die Funktionsweise des menschlichen Körpers haben.	☐	☐	☐	☐	☐	
11.	Es ist wichtig, in der Schule etwas über Biologie zu lernen.	☐	☐	☐	☐	☐	
12.	Es ist für Menschen notwendig, die Natur zu verstehen.	☐	☐	☐	☐	☐	

Teilarbeit D: Fragebogen Schüler:innenvorstellungen

1) Was stellst du dir unter dem Begriff „Nachhaltigkeit“ vor?
   Nenne mind. 2 Beispiele für nachhaltiges Verhalten.

2) Ist ein nachhaltiger Lebensstil wichtig? Begründe deine Antwort!

3) Beschreibe Methoden, die bei nachhaltiger Landwirtschaft eingesetzt werden.

4) Was würdest du gerne verändern, um einen nachhaltigeren Lebensstil zu führen?
   Nenne Beispiele aus deinem Alltag.

(Eidesstattliche) Versicherungen und Erklärungen

(§ 8 Satz 2 Nr. 3 PromO Fakultät)
Hiermit versichere ich eidesstattlich, dass ich die Arbeit selbstständig verfasst und keine anderen als die von mir angegebenen Quellen und Hilfsmittel benutzt habe (vgl. Art. 64 Abs. 1 Satz 6 BayHSchG).

(§ 8 Satz 2 Nr. 3 PromO Fakultät)
Hiermit erkläre ich, dass ich die Dissertation nicht bereits zur Erlangung eines akademischen
Grades eingereicht habe und dass ich nicht bereits diese oder eine
gleichartige Doktorprüfung endgültig nicht bestanden habe.

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Hiermit erkläre ich, dass ich Hilfe von gewerblichen Promotionsberatern bzw. –vermittlern oder ähnlichen Dienstleistern weder bisher in Anspruch genommen habe
noch künftig in Anspruch nehmen werde.

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…… ……

Ort, Datum Unterschrift