ABSTRACT
The terms Anthropocene and Homogenocene are frequently used to describe our current epoch, which is characterized by strong human impacts on the environment. One defining feature of the Anthro- or Homogenocene is biodiversity loss—experts say we are heading for Earth’s sixth mass extinction. A crucial weapon in the battle against threats to biodiversity is education, particularly biodiversity literacy. Raising awareness of the social and environmental value of biodiversity, providing education on the concept of biodiversity, and promoting the ability to act may lead to active and responsible citizenship. We developed a biodiversity education teaching unit to promote biodiversity literacy through formal education. To make the topic of biodiversity tangible for students, our approach involves them in a citizen science project and uses the forest ecosystem to illustrate the relations between economic, ecological, and social aspects of biodiversity.

Key Words: biodiversity education; biodiversity literacy; citizen science; 21st century skills.

Introduction
Today’s students are the decision makers of tomorrow. In the future, they will face individual as well as political decision-making processes. We agree with Grace (2006) that education lays the foundation for the development of active and responsible citizenship. In the case of science education, this has also been referred to as “science for citizenship” (Kolstø, 2001). Future-oriented biology education needs to focus on socio-scientific issues to prepare students for active participation in decision-making processes involving aspects of science. If we equip students with the needed 21st-century learning and thinking skills and the respective knowledge, they will be able to generate and evaluate statements and opinions in debates concerning controversial socio-scientific topics.

We can define 21st-century skills as the set of skills and abilities students will need to make informed decisions and succeed in their future work and life (Dede, 2010; McComas, 2014). We see these skills as a determiner of active and participatory citizenship. Among others, the Partnership for 21st Century Learning (2009) set up a framework to define and support 21st-century skills. At its core are four learning skills, known as the four Cs: creativity, communication, collaboration, and critical thinking. It also provides fundamental subjects and interdisciplinary themes, for example environmental literacy, to be promoted and mastered by students. Here, we present a biodiversity education teaching unit called “FutureForest,” which focuses on promoting the four Cs and biodiversity literacy.

Biodiversity literacy refers to knowledge and understanding of the concept of biodiversity as well as of relevant behaviors that contribute to biodiversity preservation (Moss et al., 2014). We regard biodiversity literacy as a subcategory of scientific literacy and environmental literacy. In the current epoch, referred to as the Anthropocene or Homogenocene, we are headed for Earth’s sixth mass extinction (Samways, 1999; Waters et al., 2016; Ellis, 2018). Biodiversity loss is a threat to nature but also to humans, because our lives rely on several ecosystem services. Over the past two decades, there has been a massive research effort on the impacts of biodiversity loss on ecosystem functioning and provisioning of services. In the words of Cardinale et al. (2012), “There is now unequivocal evidence that biodiversity loss reduces the efficiency by which ecological communities capture biologically essential resources, produce biomass, decompose and recycle biologically essential nutrients.” An investigated example is the influence of soil biodiversity loss on ecosystem functioning. Wagg et al. (2014) found that nutrient availability and plant diversity declined when soil biota diversity was reduced.

Ceballos et al. (2015) cut right to the chase of the matter: “Averting a dramatic decay of biodiversity and the subsequent loss of ecosystem services is still possible through intensified conservation efforts, but that window of opportunity is rapidly closing.” Human activities are known to be primarily responsible for biodiversity change and loss. We therefore consider biodiversity literacy to be of high relevance for the development of environmental sustainability and biodiversity preservation, because students need the knowledge to value biodiversity and the particular skills to contribute to its preservation. The importance of education for the conservation of biodiversity has also been recognized by politics. For example, biodiversity education is
anchored in the Convention on Biological Diversity and is part of its Aichi Biodiversity Targets (Secretariat of the Convention on Biological Diversity, 2014). Here, our focus is also on raising people’s awareness for the value of biodiversity and promoting ways to contribute to biodiversity conservation and sustainability (i.e., biodiversity literacy). Our teaching unit pursues these targets and fosters 21st-century skills such as critical thinking, collaboration, communication, and creativity by exposing students to cooperative learning, discussion, role-play, and innovative teaching methods like computer-mediated learning and a school research collaboration (i.e., a citizen science project). In terms of content, we put the focus on the utilization and preservation of biodiversity, using the example of the forest ecosystem. We think that the forest ecosystem and its ecosystem services provide an example that is in line with students’ reality. The lesson was originally designed for 10th-graders but may also be adapted to suit other age groups.

○ Learning Objectives
In terms of content, we focused on the forest ecosystem and its sustainable utilization and protection. Using the example of the forest ecosystem and forest soil organisms, the anticipated objectives of our lesson were (1) for students to receive an overview of the ecological, economic, and social value of biodiversity; (2) for students to gain an insight into the concept of biodiversity, based on the example of soil fauna; (3) for students to come to realize that the ecological knowledge of species and identification skills form the basis of successful nature, species, and biodiversity preservation; and (4) for students to develop an awareness of the negative impacts of human activity on biodiversity, based on the example of global climate change and the forest ecosystem.

○ Details of Lesson & Exercise
Prior to the Lesson: Collection of Soil Samples
Within our teaching unit, we integrated a citizen science project on DNA barcoding, giving the students the opportunity to actively take part in a real research process. Prior to their participation in the learning module, the students collected forest leaf litter samples, which were extracted and handed over to our campaign partner Barcoding Fauna Bavarica (part of the International Barcode of Life Initiative), which intends to establish a library of DNA barcodes of all Bavarian species. The advantage of this collaborative citizen science project between the participating students and the Bavarian Barcoding Initiative was twofold. On one hand, the barcoding researchers benefitted from receiving soil samples from various Bavarian regions provided by the students. The collection of these various samples would have otherwise required a vast amount of time, great effort, and expense. The students, on the other hand, got the opportunity to be engaged in a real research process and contribute to progress in science research and nature conservation.

Two Learning Modules in the Classroom
To expose students to learner-centered, authentic, and cooperative learning, learning at stations was the method of choice. Based on two modules including four learning stations, the lesson required 180 minutes. Figure 1 illustrates the learning cycle and Table 1 provides an overview on the learning activities.

In the course of the assignments, the students worked independently in small groups of four. All necessary materials (e.g., info texts) were displayed at the stations, and a workbook provided the tasks to be solved (see Supplemental Material Appendix A). At the beginning of every station, a short introductory text outlined the learning content and the problem the students had to solve or the challenge they had to face (see Figure 2).

These texts were meant to grab the students’ attention for the topic, promote their questioning attitude, and foster their situational awareness. Having completed a learning station, the students had to check their results independently with the help of an answer book. In such a learner-centered approach, the teacher takes on the role of an advisor rather than a mediator of knowledge. They answer students’ questions but do not further intervene in the learning process.

**Figure 1.** Overview of the learning module “FutureForest” – biodiversity education using the example of the forest ecosystem.
<table>
<thead>
<tr>
<th>Phase of Teaching</th>
<th>Learning Content</th>
<th>Students Activity</th>
<th>Time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>Introduction to the concept of biodiversity (including all three dimensions) and basic ecological ideas</td>
<td>Hands-on learning</td>
<td>20</td>
</tr>
<tr>
<td>Module 1 (e-learning)</td>
<td>Station 1: “Providers of Well-being”</td>
<td>Forest ecosystem services providing human well-being; relation to biodiversity; personal behaviors contributing to forest preservation</td>
<td>Hands-on learning with an interactive website</td>
</tr>
<tr>
<td></td>
<td>Station 2: “Every Species Counts!”</td>
<td>DNA barcoding and its applications for biodiversity preservation (e.g., biodiversity monitoring)</td>
<td>Hands-on learning with an interactive presentation</td>
</tr>
<tr>
<td>Short break</td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>Module 2</td>
<td>Station 3: “Hidden Diversity”</td>
<td>Identification of soil fauna; relation of species identification and preservation</td>
<td>Examine samples under the microscope; using a dichotomous identification key</td>
</tr>
<tr>
<td></td>
<td>Station 4: “Forest with a Future”</td>
<td>Human activities influencing ecosystems and their services (here: monoculture vs. species-rich forests)</td>
<td>Conducting a role play</td>
</tr>
<tr>
<td>Evaluation</td>
<td>Review, summary, and evaluation of the group results</td>
<td>Asking questions, describing results, complementing or improving results</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 2.** Workbook section for station 2. A short introductory text outlines the learning content.
**Introductory Phase**

At the beginning, a short introductory phase ensured similar pre-knowledge about basic ecological terms (species, ecosystem, etc.) and the three dimensions of biodiversity: species, ecosystem, and genetic diversity. Every group received an envelope containing 21 pictures of different ecosystems (a desert, a river, a coral reef, etc.), various forest animals, and several different-looking squirrels. The students were asked to arrange the pictures in a meaningful way. Afterward, several groups described their result, without any confirmation or rejection by the teacher. Then each group got four different short texts about biodiversity and its three dimensions. Each student was asked to read one text and to share the information provided with the group. Based on the exchange of information, the groups were able to revise and rearrange the order of their pictures. The intended solution was to arrange the pictures into three categories representing the three dimensions of biodiversity. We wanted the students to realize that biodiversity includes not only species diversity (e.g., the different forest animal species) but also the diversity of genes that determine the different-looking squirrels and the diversity of ecosystems. Next, the different outcomes were discussed in plenary. At the end, the students were asked to formulate a definition of biodiversity and write it in their workbooks.

After the introduction, half of the groups started with module 1 while the others began with module 2. Each learning station required 25 minutes. Following a 10-minute break, the students switched modules.

**Brief Summary of Module 1**

**Station 1**

At the first computer-mediated learning station, “Providers of Well-being,” the students worked with an e-learning website (https://www.waldmitzukunft.de) that we had developed and set up specifically for this purpose. The students had to solve two different tasks to complete this learning station. At first, the students worked with an interactive image of a forest (Figure 3). By clicking on different image regions, they were provided with information on all kinds of ecosystem services. Ecosystem services are defined as goods and services that are provided by ecosystems and contribute to human well-being. There are four categories of ecosystem services: provisioning services (e.g., foods such as game meat or raw materials like wood), regulating services (e.g., erosion prevention or pollination), cultural services (e.g., nonmaterial goods such as aesthetic or recreational values), and supporting services, which form the basis of all ecosystem services (e.g., primary production or nutrient cycle). All these goods and services are directly linked to human well-being. Through the learning station “Providers of Well-being,” the students got to know the four categories of ecosystem services and learned how biodiversity relates to ecosystem functioning and consequently determines the provision of ecosystem services and human well-being. If students clicked on the image of a person walking, for example, a text on the recreational value of forests, a cultural ecosystem service, was displayed. Our aim was for the students to recognize the value of the forest ecosystem. In this example, the students should realize the social value of the forest as a place for recreation and nature experience. The overall task for the students was to create a mind-map, which would illustrate the four categories of forest ecosystem services in a reasonable way. After they got to know the services provided by forests, the students were asked to make a list of environmentally friendly behaviors contributing to the protection of the forest ecosystem – behaviors like using recycled paper or buying certified wood and paper products. A solution page enabled the students to check their answers and correct or extend their lists if necessary.
Station 2
At the second e-learning station, “Every Species Counts,” the students worked with an interactive PowerPoint presentation. The presentation gave the students an insight into the systematic recording of biodiversity through DNA barcoding, a new method for species identification via DNA analysis. The information sheet contained instructions on how to work with the interactive presentation. The students had to click through the slides and read the information provided. At some points, the students had to solve problems or answer questions.

The aims of this station were threefold. First, we wanted the students to understand the method of DNA barcoding (i.e., the genetic principles that determine the approach). The students learned that DNA barcoding relies on the identification and comparison of a species-specific gene, the so-called DNA barcode. They learned that DNA barcodes enable the identification of species or larvae that are hardly distinguishable morphologically. Second, we wanted the students to recognize the benefits of DNA barcoding, particularly with regard to nature conservation efforts. For example, the students learned that DNA barcoding requires only small amounts of DNA (e.g., parts of an insect wing). This facilitates environmental monitoring because researchers can quickly examine water or soil samples for their species occurrence and composition. Third, we wanted the students to realize their personal contribution to biodiversity conservation by collecting soil samples for the citizen science project.

○ Brief Summary of Module 2

Station 3
The third learning station gave the students a deeper insight into the species diversity of forest soil organisms. We wanted the students to get to know the “hidden diversity” underground and the important role of these organisms in the ecosystem. Earthworms may be widely known, but most students may not be aware of the huge diversity of soil organisms. We wanted them to realize that the variety of species is necessary to ensure the degradation and transformation of organic matter (e.g., dead plants or leaves) and that a reduction in soil organism biodiversity would result in a decline in nutrient availability and plant diversity.

For time and organizational reasons, we collected forest litter prior to the lesson. The organisms were extracted from the soil using a Berlese funnel (also known as a Tullgren funnel). Because the extraction takes 14 days, we decided, for organizational reasons, to provide the students with already extracted and presorted samples. We gave the students eight different test tubes containing already extracted soil organisms. This way, we could also make sure that each group was given the same predefined organisms that were part of our simplified identification key. After they had read a short instruction sheet on how to proceed with the identification, the students identified specimens with a microscope and a simplified dichotomous identification key (see Figure 4 and Supplemental Material Appendix B). They narrowed the organisms down to the family, genus, or species level. Every student group had to identify all eight forest soil organisms.

Station 4
Last but not least, at the fourth learning station the students took on roles as different interest groups within a conflict situation about the utilization and protection of forests, in a future scenario of a fictitious municipal forest. The role-play addressed potential future problems of conventionally managed forests (e.g., impacts of climate change and bark beetles on monocultures), and the students considered the advantages and disadvantages of naturally managed forests from different points of view. The students were given a text on the future scenario, short informational texts on four topics, and role cards with hints for each role. These can be found in Supplemental Material Appendix C.

First, the students had to read the fictitious scenario – about a forester in 2050, whose tree monoculture is mostly destroyed as a result of drought, storms, and bark beetle calamities, all caused by climate change – and answer the question of which problems occurred naturally within the fictitious forest and which were due to mistakes or wrong decisions made by the forester. Then each student had to read one of the short texts and share the information in it with the group members. The texts contained information on the topics “dead wood,” “spruces and climate change,” “bark beetles,” and “tree plantations vs. sustainable mixed forests.” After this information exchange, every student had the same knowledge on the topics. Then the students took one role card each and prepared themselves for the role-play, which simulated a town hall meeting in the fictitious Futurecity between the new forester for the Futurecity Forest Service, a member of the Nature Protection Society, a chairperson of the Futurecity Tourism Association, and a chairperson of the Hunting Association of Futurecity. The aim of the meeting was to develop a common concept for a sustainable forest, the “futureforest.”
Alignment with Next Generation Science Standards

The biodiversity education lesson meets several Next Generation Science Standards (NGSS) and involves all three dimensions of the NGSS: crosscutting concepts (Stability and Change; Systems and System Models), disciplinary core ideas (Ecosystem Dynamics, Functioning, and Resilience; Biodiversity and Humans; Developing Possible Solutions), and science and engineering practices (Constructing Explanations and Designing Solutions; Engaging in Argument from Evidence; Planning and Carrying Out Investigations). Specifically, the learning activities meet the following standards (NGSS QUELLE):

- **2-LS4-1 Biological Evolution: Unity and Diversity**
  Make observations of plants and animals to compare the diversity of life in different habitats.

- **3-LS4-4 Biological Evolution: Unity and Diversity**
  Make a claim about the merit of a solution to a problem caused when the environment changes and the types of plants and animals that live there may change.

- **MS-LS2-5 Ecosystems: Interactions, Energy, and Dynamics**
  Evaluate competing design solutions for maintaining biodiversity and ecosystem services.

- **HS-LS2-7 Ecosystems: Interactions, Energy, and Dynamics**
  Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.

Further Research Reading

Our lesson was accompanied by a study concerned with different research questions. First, we focused on students’ conceptions of biodiversity and their attitudes toward its value and protection (Schneiderhan-Opel & Bogner, 2019). We found that most students equate biodiversity with species diversity and that the majority of participants are not aware of the other two dimensions (genetic diversity and ecosystem diversity); 46% of student statements included only one dimension, 97% of which referred to species diversity. Only 2% of student statements referred to two dimensions, and 1% included all dimensions (the remaining statements included no dimension, inadequate answers, or expressions of ignorance).

When students were asked, “Who can benefit from biodiversity? Give reasons for your answer,” 72% of their statements referred to animals, plants, or nature; 52% were concerned with humans; and 43% of their “reasons why” were concerned with ecosystem services. For example, the students mentioned the benefit of forests in the provision of timber and the ecosystem’s function in supplying oxygen and binding carbon dioxide.

Additionally, when students were asked to provide reasons for the protection of biodiversity, 70% of their statements revealed notions of nature preservation, and only 30% of the statements implied notions of nature utilization. Further analysis of research questions on knowledge acquisition, science motivation, and fascination is in progress.

Supplemental Material

The following appendices are available as Supplemental Material with the online version of this article:

- Appendix A: Workbook
- Appendix B: Instruction Sheet and Identification Key for Learning Station 3
- Appendix C: Scenario, Information Cards, and Role Cards for Learning Station 4

Conclusion

To promote biodiversity literacy as well as 21st-century skills, our unit combined real-world problems and future challenges concerning the socio-scientific topic of biodiversity. Our participating students especially enjoyed the student-centered, hands-on learning and seemed to be highly motivated by getting the opportunity to actively take part in a real science research process related to biodiversity preservation. Sustainable development depends on responsible and participative citizens, and we think that biodiversity education units like ours are important for strengthening students’ self-efficacy and sense of responsibility related to socio-scientific issues.

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