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Plastic Detectives

The Search For Plastic

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ABSTRACT

Microplastic pollution is an environmental threat with substantial effects on ecosystems. Persistence and ubiquity are the central causes of the problems microplastics generate, especially throughout water-based food webs. To limit microplastic pollution, accountability of individuals is needed, which requires reliable information for an individual to act accordingly. Knowledge about sources, contamination, fate, and effects of microplastic in the environment may be an essential element in enhancing students' motivation and sense of responsibility. Our module "Plastic Detectives – The Search for Plastic" offers consciousness-raising tasks that involve students in hands-on learning activities. Within student-centered activities, different tasks on sources in everyday life, sinks in aquatic ecosystems, effects on marine animals, and prevention strategies for microplastics are in focus. With an appropriate overview, students may be sufficiently enabled to ponder their purchase decisions and potentially limit microplastic pollution in everyday life.

Key Words: microplastic pollution; environmental behavior; hands-on lesson; primary education.

○ Introduction

Plastic is everywhere. The increasing use of plastic at every occasion is a universal phenomenon. Around the globe, plastic finds practical application in diverse segments of the economy (e.g., automotive, packaging, and construction; PlasticsEurope, 2019). Consequently, it comes as no surprise that supermarkets, households, transport, and even schools are unthinkable without plastic. Therefore, students can hardly avoid it. They start their day by brushing their teeth with a plastic toothbrush, using a plastic toothpaste tube, pouring breakfast cereals from plastic packaging, putting on synthetic clothes, and taking the bus to school, where almost any school material includes at least some plastic. After short- or long-term use, all of those plastic items will inevitably become garbage. Such plastic debris, which intentionally or unintentionally enters every ecosystem on Earth, is considered the most common source of plastic in the environment (Duis & Coors, 2016).

Next to this obvious, visible plastic debris, microplastics (i.e., particles smaller than 5 mm; GESAMP, 2016) are an ever-growing environmental concern because of their presence in marine, freshwater, and terrestrial ecosystems (Rochman, 2018). In the household, microplastic enters the environment as microbeads from rinse-off products ("primary microplastic"; e.g., in shampoo, shower gel, hand washing gel, or exfoliating cream; Fendall & Sewell, 2009) and through the release of fibers from synthetic textiles during washing ("secondary microplastic"; Browne et al., 2011; Browne, 2015; Napper & Thompson, 2016). Another source of microplastics is large plastic items that disintegrate, through degradation processes, into smaller pieces, ending up as secondary microplastic. The small size of microplastic makes it an even more serious threat than large pieces of plastic (Xanthos & Walker, 2017). Small particles are more difficult to perceive visually; are more easily available to a variety of organisms (Browne et al., 2007; Cole et al., 2011); and possess a high surface-to-volume ratio; therefore, pollutants sorb to microplastic more readily (Duis & Coors, 2016). Once microplastic is in the environment, it is transported over long distances, accumulates (for example, in the Great Pacific Garbage Patch; Goldstein et al., 2012), cannot be removed, and is therefore ubiquitous (Barnes et al., 2009).

Because of the far-reaching consequences of microplastics, the topic is a subject of lively discussion – driven by a constant flow of new scientific findings – in society, media, and politics (Hartley et al., 2015). Recently, for example, Wetherbee et al. (2019) showed that plastic particles present in the Rocky Mountains entered the ecosystem by incorporation into raindrops. Reports like these offer food for thought in considering societal changes to deal with this pollution, such as bans on single-use plastic items like straws, plates, and wrappers. Unlike many countries, the United States still lacks restrictions on the use of plastic bags (Xanthos & Walker, 2017). On the other hand, after several states prohibited products containing microbeads, the federal Microbead-Free Waters Act of 2015 banned the production and distribution of microbead rinse-off cosmetics and nonprescription drugs nationwide (United States, 2015). However, the problem of microbeads in makeup and other personal-care products remains.

Therefore, individual responsibility is all the more crucial. Students often lack knowledge of the ingredients in cosmetic products, the composition of textiles, or eco-friendly alternatives to plastics and microplastics. This circumstance may lead to poor purchase decisions. Insights of students into the ecological problem of microplastics and the contribution of purchased products are the basis for a sense of responsibility. Students need reliable information about the current state of knowledge on sources, contamination, fate, and effects of microplastic. Our module “Plastic Detectives – The Search for Plastic” starts on this proposition and aims to enlighten and sensitize young students to this environmental concern.

○ Learning Objectives

Our module focuses on microplastics’ sources, sinks in aquatic ecosystems, effects on marine animals, and prevention strategies. The objectives for students are sevenfold:

- (1) to receive an overview of the topic;
- (2) to understand the term *microplastic*;
- (3) to identify drugstore items and textiles containing microplastic;
- (4) to gain an understanding of possible ways that microplastic enters the environment;
- (5) to come to realize the adverse effects of microplastic on marine animals;
- (6) to discover the advantages and disadvantages of single-use, multiple-use, and alternative products; and

- (7) to develop awareness of how to reduce an individual’s release of plastic and microplastic into the environment.

Initially, the module was designed for fourth-graders; however, the topic of microplastic and the comprised thematic areas are relevant across grades; the experiments of stations 1 and 2, especially, can easily be modified for any grade. The stations apply three-dimensional learning, which was defined by the *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013). A detailed description of the *disciplinary core ideas* is provided in Table 1.

The learning activities contain *science and engineering practices* that address K-ESS3-3 and 5-ESS3-1 (Obtaining, Evaluating, and Communicating Information); 5-LS2-1 (Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena); MS-ESS3-3 (Constructing Explanations and Designing Solutions); and MS-LS2-3 (Developing and Using Models); and different *crosscutting concepts* that address K-ESS3-3 and MS-ESS3-3 (Cause and Effect); 5-ESS3-1 and 5-LS2-1 (Systems and System Models); 5-ESS3-1 and MS-ESS3-3 (Science Addresses Questions about the Natural and Material World); MS-LS2-3 (Scientific Knowledge Assumes an Order and Consistency in Natural Systems); HS-LS2-7 (Stability and Change); and HS-ESS3-4 (Influence of Engineering, Technology, and Science on Society and the Natural World).

○ Learner-Centered Module & Exercises

To enable young students to learn cooperatively, all tasks were carried out in groups of three or four at working stations. In total, the module requires 180 minutes; the introduction, the processing of each station,

Table 1. Alignment of the station learning with the *Next Generation Science Standards* (NGSS Lead States, 2013).

Disciplinary Core Ideas	Student Outcomes
K-ESS3-3. Communicate solutions that will reduce the impact of humans on the land, water, air, and/or other living things in the local environment.	Students understand that their way of life (e.g., use of plastic bottles) influences the environment. Students discuss and collect treatment options to reduce the entry of plastic and microplastic into the environment.
5-ESS3-1. Obtain and combine information about ways individual communities use science ideas to protect the Earth’s resources and environment.	Students understand that their activities in everyday life, especially their use of everyday products and textiles, cause the entry of microplastic into the environment.
5-LS2-1. Develop a model to describe the movement of matter among plants, animals, decomposers, and the environment.	Students create a flowchart of a food web by which they realize that animals and humans are burdened by microplastic due to its indigestibility.
MS-ESS3-3. Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment.	Students discuss the impacts of humans on the environment and evaluate solutions to reduce the entry of plastic and microplastic into the environment.
MS-LS2-3. Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.	Students create a flowchart of a food web by which they realize that animals and humans are burdened by microplastic due to its indigestibility.
HS-LS2-7. Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.	Students discuss and collect treatment options to minimize humans’ changes to the environment.
HS-ESS3-4. Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.	Students collect and assess possible solutions to reduce pollution and waste.

and the evaluation take 20 minutes each. This learner-centered module consists of seven learning stations. Figure 1 presents an overview of the learning cycle based on the seven stations. Table 2 gives an overview of pre-activity preparation, teaching phases, activity and learning content, assessment, and required time.

When starting the module, every student received a workbook (see Supplemental Material Appendix A), including all tasks that had to be fulfilled at each station. Further work materials and informational texts were set up at the respective stations (see Supplemental Material Appendix B). Figure 2 shows the setup of the stations in the classroom. The tasks in the workbook and the work

materials were self-explaining. The teacher acted as a supervisor or mentor and intervened only on request or in case of possible danger. After the student groups completed a station, they self-reliantly checked the correctness of their results with the sample solution (see Supplemental Material Appendix C). Thus, the groups worked uninterrupted at their own pace. Figure 3 illustrates an example page of the workbook. Figure 4 shows the related instruction, which is placed at station 1. All other supplemental materials were available at the stations.

Introduction of Module

The module started with a short introductory phase, which had the objective of bringing the students to the same level of knowledge. Ensuring similar pre-knowledge has been shown earlier as essential for sufficient learning success (Scharfenberg & Bogner, 2011, 2013). The students read an explanatory dialogue (see Supplemental Material Appendix D) that addresses the environmental issue of microplastic. In this context, the students were given the lesson's focal problem: How does microplastic get to the beach? The students took the role of plastic detectives, with the goal of solving all tasks in the workbook in the course of the lesson. At the end of the introduction, the students answered questions on their own experiences with plastic, brainstormed about the entry points and whereabouts of plastics and microplastics in the environment, and formulated a standard definition of the term *microplastic* and wrote it down in their workbooks.

Learning Circle

The students were separated into groups to perform the detective work at the stations. Each group started at one station, worked for 20 minutes, and changed stations according to the given order (see Supplemental Material Appendix D). To ensure a smoothly running lesson, each station was set up twice. In their work as plastic detectives, the students had to track microplastic traces in everyday products as well as in textiles. Furthermore, they had to identify possible ways in which microplastics make it into the environment, potential ecological

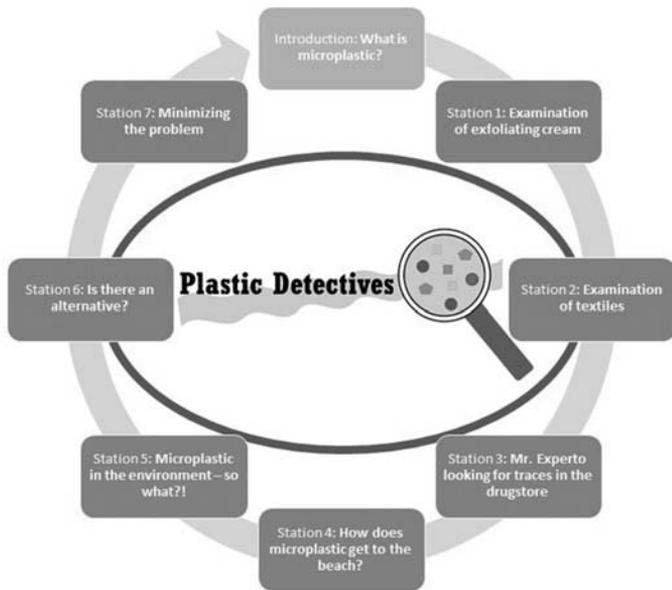


Figure 1. Overview of the module “Plastic Detectives – The Search for Plastic.”

Table 2. Overview of pre-activity preparation, stations, activity and learning content, assessment, and required time.

Pre-activity Preparation			
Printing of workbooks, sample solutions, and instructions (see Supplemental Material Appendices A, B, C)			
When all materials for the experiments are ready (Tables 3–8), the teacher should schedule one hour to prepare the classroom:			
<ul style="list-style-type: none"> • One school desk for each station • Each station is set up twice (12 tables for stations 1–6; station 7 does not require an extra table) • Secure placement of laptops and microscopes • Division of the class in groups of three or four 			
	Activity & Learning Content	Assessment	Time (minutes)
What is microplastic?	<i>Introduction (pre-group phase)</i> Teacher-guided learning & listening of students: <ul style="list-style-type: none"> • Teacher introduces into the issue “microplastic in aquatic ecosystems” • Teacher guides the students through the presentation, motivates and arouses students’ interest • Teacher does not reveal too much yet, so that students are motivated to work out the content themselves • Students contribute and answer open questions in the workbook 	Students independently check the correctness of their solution with the sample solution	20

Table 2. Continued

The search for microplastic in everyday products	<i>Station 1: Examination of exfoliating cream</i> Hands-on learning: • Students filter exfoliating cream (dissolved in water) and extract microbeads • Students identify the plastic type of the microbeads • Students recognize problems of microbeads in sewage		20
The search for microplastic in everyday products	<i>Station 2: Examination of textiles</i> Hands-on learning: • Students wash fleece in soapy water and filter out fibers that detach from it • Students identify the plastic type of the fleece fibers • Students recognize the problems of synthetic fibers in sewage		20
The search for microplastic in everyday products	<i>Station 3: Mr. Experto looking for traces in the drugstore</i> Hands-on learning: • Students check personal-care products and detergents for microplastic		20
Microplastic in the environment	<i>Station 4: How does microplastic get to the beach?</i> Hands-on learning: • Students watch a film about insufficient filter systems in sewage treatment plants • Students create a flowchart on microplastics' path to the beach • Students define primary and secondary microplastics		20
Effects of microplastic	<i>Station 5: Microplastic in the environment – so what?!</i> Hands-on learning: • Students read a text about problems of marine animals caused by plastic • Students answer questions, create a food web, and discuss animals' and humans' burdens		20
Consumption options	<i>Station 6: Is there an alternative?</i> Hands-on learning: • Students play a plastic-memory game: they match related single-use, multiple-use, and alternative products • Students discuss the pros and cons of the products		20
Treatment strategies	<i>Station 7: Minimizing the problem</i> Hands-on learning and discussion of ideas: • Students answer questions of introduction again • Students recapitulate the content of stations and discuss approaches to reduce microplastic input into the environment		20
Evaluation	<i>Evaluation</i> Teacher-guided learning and discussion: • Students summarize and review group results • Students describe, discuss, and improve outcomes • Teacher ensures understanding and consolidates new knowledge	Joint review of the group results to overcome difficulties in comprehension, consolidate new knowledge, and extend students' interest	20

consequences, and prevention strategies. The following description of the stations gives detailed information about procedure and content.

Station 1: Examination of Exfoliating Cream

The students experimented with an exfoliating cream that contained a microplastic (polyethylene) as an exfoliator. Figure 5 shows the

setup of the station in the classroom. After dissolving the exfoliating cream in water and filtering the solution, the students examined the residue under the microscope and described its shape and color (see Figure 6). By studying a plastic list (Ziebarth, 2019) in the workbook, the students identified the plastic type of the residue. The students then edited a fill-in-the-blank text that informed them about



Figure 2. Setup of the stations in the classroom.

Appendix A: Workbook

Plastic Detectives - The Search For Plastic



Station 1: Examination of exfoliating cream



Task 1:

- a) Part A: Carry out the experiment according to the instructions.
- b) Part B: Carry out the experiment according to the instructions. Write down your observations.

Figure 3. Workbook section for station 1. Instruction and necessary materials are set up at station 1. Students filter exfoliating cream and extract microbeads. See Supplemental Material Appendix A.

Appendix B: Work Materials

Plastic Detectives - The Search For Plastic



Station 1: Examination of exfoliating cream



Instruction - Part A

- 1) Carefully pour a drop of exfoliating cream into a beaker. Add 30 ml of water to the beaker with the measuring cylinder.
- 2) Stir the mixture with the teaspoon until the exfoliating cream is completely dissolved.
- 3) Put a filter paper in the funnel and place it in an Erlenmeyer flask.
- 4) Slowly pour the entire exfoliant-water mixture into the filter paper.
- 5) Consider the residue in the filter.

Figure 4. Instructions for station 1. All necessary materials are set up at the station. Students filter exfoliating cream and extract microbeads. See Supplemental Material Appendix B.

insufficient filtration in sewage treatment plants bringing microbeads into waters (see Figure 7). All required materials are listed in Table 3. The material details in Tables 3–8 are based on a group size of four students.

Station 2: Examination of Textiles

The students experimented by imitating the process of washing textiles in a washing machine by using a piece of cloth or blanket (fleece) in soapy water (see Figure 8). After filtering the water, the students examined the residue under the microscope. When closely looking at the shape and color of the residue, the students recognized it as small fibers, which had dissolved from the fleece during the process of washing. The label of the textile informed the students about its composition, namely 100% polyester. A fill-in-the-blank text gave the students a further occupation with the topic of plastic particles in the laundry. Fibers that dissolve from clothes during washing enter sewage treatment plants via wastewater. Insufficient filtration by sewage treatment plants causes the introduction of microplastic fibers into waters. All required materials are listed in Table 3.

Station 3: Mr. Experto Looking for Traces in the Drugstore

The students examined the ingredients of different personal-care products and detergents from a drugstore with the help of the plastic list (Ziebarth, 2019; see Supplemental Material Appendix B). By identifying products containing microplastic, the students were able to assess the eco-friendliness of products. Figure 9 shows the setup of station 3 in the classroom. All required materials are listed in Table 4.

Station 4: How Does Microplastic Get to the Beach?

The fourth station focused on the entry of microplastic into the environment and possible pathways to the beach. A short video (see explainitychannel, <https://www.youtube.com/watch?v=49OJoTsZY00>) gave information about insufficient filter systems in sewage treatment plants, which release small microplastic particles into rivers, lakes, and finally the sea. After watching the video, the students sorted images that illustrate the microplastics' path to the sea into a flowchart (see Figures 10 and 11). Moreover, they developed ideas about how plastic products break down into smaller parts and eventually become microplastic. Thereby, the students learned the terms *primary* and *secondary microplastics*. All required materials are listed in Table 5.

Station 5: Microplastic in the Environment – So What?!

The students read a text named “Conference of Animals in the Sea” (for required materials, see Table 6 and Supplemental Material Appendix B). Students took on the roles of animals talking about diverse problems caused by plastic (see Figure 12). Thus, students learned that animals both small and large suffer from plastic in the sea. Small animals like plankton inadvertently ingest microplastic when filtering their food items, which has further negative impacts within the food web (e.g., because plankton is food for herrings and whales). Furthermore, other animals such as birds confuse plastic or microplastic with food or eat it by mistake. The indigestibility of plastic can lead to serious health effects for the affected animals, which can even result in death by starvation. Moreover, some animals, like turtles, get injured by bigger plastic when they get caught in it. With the knowledge gained from the text, the students answered questions on the topic in their workbook. Moreover, the students created a food web and discussed the probability of animals and humans being burdened by microplastic.

Table 3. All required materials for stations 1 and 2, including quantity and estimated cost.

	Item	Quantity	Cost
Stations 1 and 2	Plastic measuring cylinder (50 mL)	1	\$4.25 ^a
	Plastic wash bottle (250 mL)	1	\$4.95 ^a
	Plastic beaker (100 mL)	1	\$3.00 ^a
	Plastic funnel	1	\$1.70 ^a
	Erlenmeyer flask (250 mL)	1	\$4.50 ^a
	Plastic tray/slide minimum size for use with filter: 10 × 10 cm; minimum size for use without filter: microplastic particles can be transferred to a microscope slide	1	\$12.95 ^a (144/pack)
	Microscope for kids	1	\$39.95 ^a
	Coffee filter (pore size 20 µm)	1	
	Teaspoon	1	
	Workbooks (Supplemental Material Appendix A)	1 per student	
Station 1	Sample solution (Supplemental Material Appendix C)	4	
	Laminated instructions "Part A & B" and laminated info-cards "Cosmetics" & "Exfoliating cream" (Supplemental Material Appendix B)	4	
Station 2	Exfoliating cream containing microplastic	1	
	Laminated instructions "Part A & B" and laminated info-cards "Textiles" & "Polyester" (Supplemental Material Appendix B)	4	
	Piece of fleece blanket + label	1	
	Liquid soap	1	
	Teaspoon	1	

Note: If possible, the use of plastic equipment is preferable to other materials.

^aA possible source of supply: <https://labsuppliesusa.com/>.



Figure 5. Setup of station 1 in the classroom.

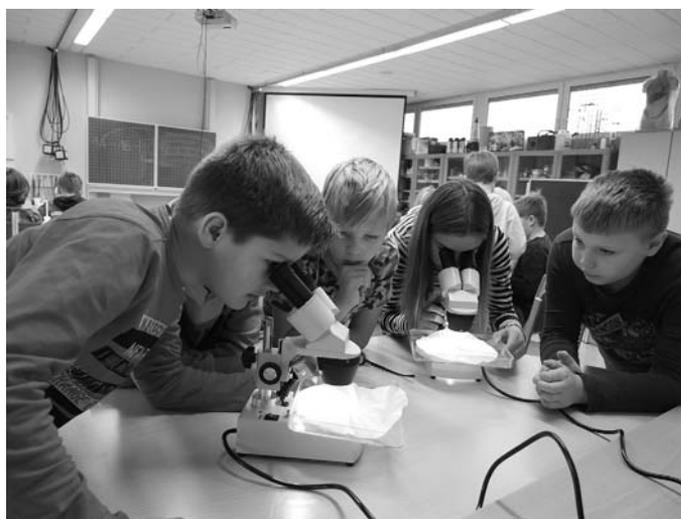


Figure 6. Students examine microbeads under the microscope (station 1).

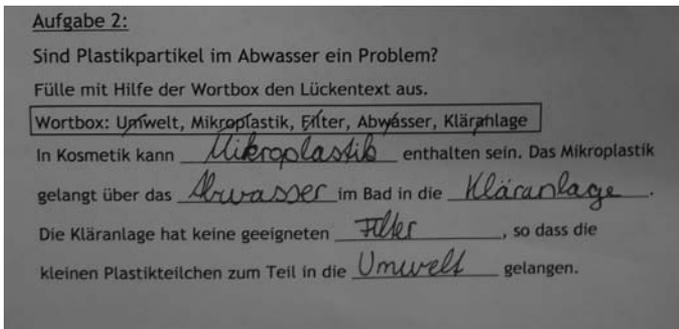


Figure 7. Exemplary solution of the fill-in-the-blank text at station 1. Translation: “Cosmetics may contain microplastics. Via wastewater, microplastics are transferred to the sewage treatment plant. The sewage treatment plant does not have appropriate filters, so some small plastic particles get into the environment.” For sample solution, see Supplemental Material Appendix C.



Figure 8. Students measure water for washing a piece of fleece (station 2).



Figure 9. Setup of station 3 in the classroom.

Table 4. All required materials for station 3.

Item	Quantity
Laminated list “The most common plastics in cosmetics and their abbreviations” (Supplemental Material Appendix B)	4
Diverse drugstore articles with and without microplastic (e.g., toothpaste, bar of soap, detergent, shower gel, cream, sunscreen, exfoliating cream)	
Workbooks (Supplemental Material Appendix A)	1 per student
Sample solution (Supplemental Material Appendix C)	4

Table 5. All required materials for station 4, including URL of informational video.

Item	Quantity
Laminated pictures for placement game (Supplemental Material Appendix B)	1
Sample solutions for gluing in the workbook (Supplemental Material Appendix B)	1 per student
Laptop to show video: https://www.youtube.com/watch?v=49OJoTsZY00	1
Glue sticks	4
Workbooks (Supplemental Material Appendix A)	1 per student
Sample solution (Supplemental Material Appendix C)	4

Station 6: Is There an Alternative?

The students played a memory game in which they matched related single-use, multiple-use, and alternative products (Supplemental Material Appendix B). During this activity, they discussed advantages and disadvantages concerning price, weight, durability, amount of garbage, and the possibility of multiple uses. All required materials are listed in Table 7.

Station 7: Minimizing the Problem

The last station was edited at the end of the learning-circle activity after all students had finished stations 1–6. It aimed to recapitulate the content of the other stations and to explore possibilities for reducing the entry of microplastics and plastics into the environment. First, the students answered the questions of the introduction again and compared their answers with their initial ones. Then they collected ideas for reducing their personal microplastic and plastic use and wrote them down on leaflets (see Figures 13–15). Thus, all students could bring in their own ideas and solutions. Suggestions were communicated within the whole class and the best action strategies were



Figure 10. Students watch an informational video about the entry of microplastic into the environment (station 4).



Figure 11. Students create a flowchart of microplastics' path to the sea (station 4).

discussed. As a conclusion, the leaflets were stuck to a poster in the classroom. All required materials are listed in Table 8.

Evaluation

At the end of the module, the teacher recapitulated the content of every station with the whole class. A joint discussion of the results enabled the teacher to test the students' comprehensive understanding and helped the students consolidate newly gained knowledge.

○ Experiences from the Classroom

The module "Plastic Detectives – The Search for Plastic" was implemented with approximately 450 fourth-graders. The participating students and their teachers confirmed the suitability of the chosen methods to convey information on sources, contamination, fate, effects, and alternatives to microplastics and plastics. Students' independent work at the learning stations and in the workbook gave them



Figure 12. Students read the text "Conference of Animals in the Sea" (station 5).

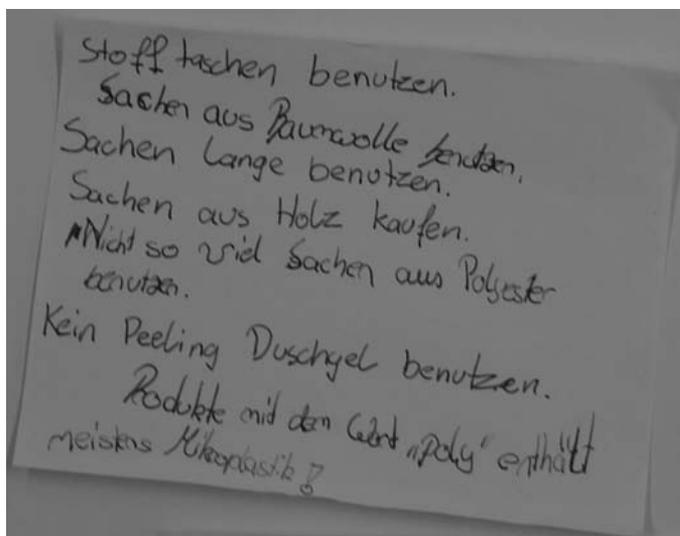


Figure 13. Exemplary leaflet with students' ideas for reducing microplastic and plastic entry into the environment at station 7. Translation: "Use cloth bags. Use cotton things. Use things for a long time. Buy things made of wood. Do not use so many polyester things. Do not use peeling shower gel. Products with the word *poly* mostly contain microplastic."

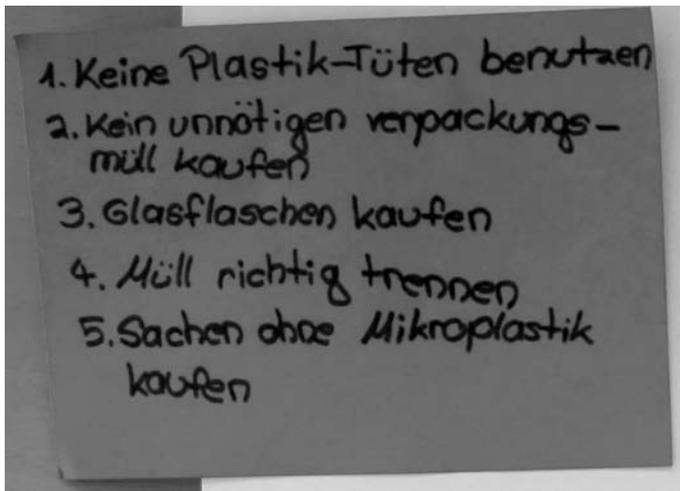


Figure 14. Exemplary leaflet with students' ideas for reducing microplastic and plastic entry into the environment at station 7. Translation: "Do not use plastic bags. Do not buy unnecessary packaging waste. Buy glass bottles. Proper separation of garbage. Buy things without microplastic."



Figure 15. Students collect ideas for how to minimize the problem of plastic and microplastic pollution (station 7).

Table 6. All required materials for station 5.

Item	Quantity
Laminated story "Conference of Animals in the Sea" (Supplemental Material Appendix B)	4
Red pens	4
Workbooks (Supplemental Material Appendix A)	1 per student
Sample solution (Supplemental Material Appendix C)	4

an intensive engagement with the topic. During the module, the students worked swiftly and studiously. Notably, at stations 1 and 2, in which the students experimented with exfoliating cream and textiles, they developed great interest and motivation. At station 3, some

Table 7. All required materials for station 6.

Item	Quantity
Memory for playing (Supplemental Material Appendix B)	1
Memory for gluing in the workbook (Supplemental Material Appendix B)	1 per student
Glue sticks	4
Workbooks (Supplemental Material Appendix A)	1 per student
Sample solution (Supplemental Material Appendix C)	4

Table 8. All required materials for station 7.

Item	Quantity
Poster (Supplemental Material Appendix B)	1
Leaflets	At least 1 per group
Glue sticks	4
Workbooks (Supplemental Material Appendix A)	1 per student
Sample solution (Supplemental Material Appendix C)	4

students voiced difficulties with the identification of cosmetics with microplastic ingredients; however, advice regarding their reading strategy took effect. The summarizing evaluation proved students' understanding of the module's contents.

○ Conclusion

Microplastic is a central environmental threat in the world of today. Plastics and microplastics that enter the environment accumulate and are distributed around the globe. Therefore, it is of high relevance to enlighten students at an early stage of their school career about the consequences of microplastic in our ecosystems. Informing students about the effects of microplastic pollution is one of the main objectives of our module "Plastic Detectives – The Search for Plastic." The module also gives students insights regarding microplastic and plastic sources in daily life, as well as eco-friendly alternatives. The final discussion about potential solutions gives the students food for thought about how to individually minimize the use of plastics and microplastics and to act as models for a sustainable life.

○ Supplemental Material

Appendix A: Workbook
 Appendix B: Work Materials
 Appendix C: Sample Solution
 Appendix D: PowerPoint Presentation

○ Acknowledgments

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