Plastic Pollution: Learning Activities from Production to Disposal – From Where Do Plastics Come & Where Do They Go?

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Abstract
Plastic pollution is ubiquitous and there is growing concern about its consequences. Given that current research findings often reach the public insufficiently, the issue should be addressed at school. To create a fruitful learning experience, we propose three associated hands-on, inquiry-based learning activities that require little equipment. Students learn about the origins and properties of plastics, investigate everyday sources, learn about recycling, address and reflect upon the material's (dis)advantages, and are encouraged to consider solutions. All activities align with the Next Generation Science Standards and are primarily designed for the middle school classroom; we further provide modifications for elementary and high school settings.

Key Words: plastic pollution; microplastics; recycling; hands-on; inquiry-based; sustainability.

Introduction
Plastic pollution receives growing media attention but little consideration at school. To prepare students for the multifaceted challenge (e.g., the cost-benefit relationship of plastic applications), we propose activities to provide key information about the origins and production of plastics, to investigate plastic fragmentation and interactions, to address recycling, and to consider solutions to plastic pollution. Supplemental Material adding to the ideas presented in this article are easily accessible online (see Figure 1). Experimental setups and further activities can be conducted with everyday objects; lesson plans delineate suggestions to introduce, elaborate on, secure, and deepen each activity.

Plastic Pollution
Each year, 6–12 million tons of plastics enter the oceans, and plastics have reached the most remote places (Vince & Hardesty, 2017). The synthetic polymers are often derived from crude oil and resistant to degradation; they can accumulate and pose a threat to the (a)biotic environment. Conventional waste management can exacerbate the problem (Alshehrei, 2017); although most plastics could be recycled, their recovery is challenging and not profitable (Subramanian, 2000). Certain plastic waste is mismanaged and enters the ocean through inland waterways (e.g., via landfills). Without infrastructure improvement, Jambeck et al. (2015) estimate a 22% increase in mismanaged plastic waste in the United States by 2025.

There are degradable alternatives, such as polyhydroxyalkanoates, but production costs prevent commercial application (Koller et al., 2010). Degradability itself could even turn into the opposite once xenobiotics or certain additives are involved: compounds like softeners are more likely to leach when plastic becomes fragmented, and microplastics are more difficult to recover from the environment. During biodegradation, materials are completely reintroduced into natural systems; this, however, requires specific parameters, including humidity, that are rarely all prevalent in the natural environment (Wolf et al., 2010), and definitions for terms such as biodegradable vs. bio-based are often unclear (Hermann et al., 2011). Since there is no simple solution to plastic pollution, it demands a multiperspective approach that reflects on both the benefits and the drawbacks of plastics. Students need to learn about plastic distribution, recycling, and implications, and adopt different perspectives (e.g., economic vs. environmental, egoistic vs. biospheric) to use plastics responsibly.

Educational Background
Hands-on Activities
These activities allow learning by doing (e.g., experimenting, modeling) and facilitate engagement with material and understanding of concepts (Scharfenberg & Bogner, 2011). They entail collaborative group work that enables students to exchange ideas, acknowledge different performance levels and learning styles, and provide feedback. Thus, the activities described below embrace group work, offer adjustable degrees of complexity, and address various learning styles.
Inquiry-Based Learning

The American Association for the Advancement of Science and the National Research Council advocate an inquiry-based science approach (Gibson & Chase, 2002). The key element is constructive student engagement. Building on preexisting knowledge, students are encouraged to ask questions, formulate hypotheses, conduct meaningful experiments, interpret data, draw conclusions, estimate limitations (e.g., of the study design), and exercise metacognitive reflection (Keys & Bryan, 2001). There are positive effects of inquiry-based learning on science achievement, cognitive development, science process skills, attitudes toward science, interest in science careers, and deeper learning (Gibson & Chase, 2002). The activities described below aim at such student engagement while increasing the difficulty of tasks in a stepwise manner.

○ Student Objectives

All activities are embedded in the Next Generation Science Standards (NGSS) framework (Table 1) and follow Bloom’s taxonomy. Students will be able to

• define the terms (micro)plastics, polymers, nurdles, microbeads, and marine debris;
• recall basic information about the history and current use of plastics;
• distinguish between primary and secondary microplastics;
• explain one scenario for how microplastics enter the ocean;
• explain two ways in which plastics affect the environment;
• identify relationships between human activities and negative environmental impacts (MS-ESS3-3);
• use a model to explain plastic fragmentation, its implications, and toxin interactions;
• identify the six common types of plastics and their recycling symbol;
• acknowledge the importance of proper recycling as a solution to minimize human impacts on the environment (MS-ESS3-3);
• relate the “six Rs” (refuse, reduce, reuse, recycle, rethink, and redesign) to everyday items; and
• evaluate the necessity of plastics by acknowledging societal needs or desires and environmental effects (MS-ESS3-3).

○ Learning Unit

Although the activities build on each other, each can be implemented independently to focus on key aspects. Some materials such as dice and voting cards link the activities. The students use dice for playful revision and as a model to visualize the process and effects of fragmentation; they use the voting cards to respond to questions and quizzes or to signal to the teacher that a task has been completed (placing the green card on their table) or that help is needed (red card). This is a time-efficient, subtle way to check on the students. A workbook (WB) and PowerPoint presentation

Table 1. Links to the NGSS for the middle school classroom.

| NGSS            | Title                                      | Code   | Disciplinary Core Ideas                  | Focus               | Crosscutting Concepts                               | Science and Engineering Practices                      |
|-----------------|--------------------------------------------|--------|------------------------------------------|---------------------|-----------------------------------------------------|--------------------------------------------------------|
| Primary Topics  |                                            |        |                                          |                     |                                                     |                                                        |
| EARTH AND HUMAN ACTIVITY: HUMAN IMPACTS (ES) |                                            |        |                                          |                     |                                                     |                                                        |
| MS-ESS3-3       | Human Impacts on Earth                     |        | Plastic Pollution                        | Cause and Effect    | Influence of Science, Engineering, and Technology on Society and the Natural World | Constructing Explanations and Designing Solutions |
| MS-ESS3-4       |                                            |        |                                          |                     |                                                     |                                                        |
| MS-LS2-5        | Evaluating Solutions                       |        | Recycling                                |                     |                                                     | Engaging in Argument from Evidence                     |
| Additional Topics|                                            |        |                                          |                     |                                                     |                                                        |
| ECO SYSTEM: INTERACTIONS, ENERGY, AND DYNAMICS (LS) |                                            |        |                                          |                     |                                                     |                                                        |
| MS-ESS3-1       | Natural Resources                          |        | Fossil Fuels, Pollution                  | Cause and Effect; Influence of Science, Engineering, and Technology on Society and the Natural World | Constructing Explanations and Designing Solutions |
| MS-LS2-3        | Energy Transfer and Food Webs              |        | Marine Ecosystem                         |                     |                                                     |                                                        |
| MS-LS2-4        | Ecosystem Dynamics, Resilience             |        | Plastic Accumulation                     |                     | Stability and Change; Scientific Knowledge is Based on Empirical Evidence |                                                        |
| MS-ESS3-3-1     | Natural Resources                          |        | Fossil Fuels, Pollution                  |                     |                                                     |                                                        |
| MS-LS2-3        | Ecosystem Dynamics, Resilience             |        | Plastic Accumulation                     |                     |                                                     |                                                        |

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(PPT) guide the unit. Detailed lesson plans go hand in hand with the presentation and suggest student-teacher interactions (e.g., questions, think-pair-share, flashlight). The students consistently make predictions, which they confirm or refute through experimental investigations or other activities. There is a focus on activating all students with short, playful activities. The incorporation of case studies and everyday objects further facilitates learning and promotes authentic science. See Figure 1 to easily access all Supplemental Material.

**Activity 1: What Are Plastics?**

With newspaper articles about plastic pollution (e.g., “Microplastics are now in the air”), students are led to the question of what plastics actually are. They watch a short video clip to learn about the origins, history, manufacturing, and main applications of plastics, guided by a table with key terms (plastic, polymer, microplastics, microbeads, nurdles, marine debris, PVC, acrylic, and nylon) and questions about its history and current use (WB p. 1). A memory activity helps fill in the table; each student receives one card with either a term, question, definition, or answer. They have to pair up, match the cards on the board, check all matches, and copy the information. Some terms may seem redundant at this point (e.g., nylon), but they help elaborate a feeling for the distribution and variety of plastics. To deepen their knowledge, the students play a game of dice. Allocating a number to each term, in pairs they throw the dice and recap the terms the numbers represent. The game could be played in subsequent lessons for playful revision. Elaborating on plastic distribution, the students extract microbeads and fibers from cosmetics and clothes (see Raab & Bogner, 2020). Or they can use their voting cards for a quiz: the teacher shows everyday items (examples in the PPT), and the students have to raise a green or red card to indicate whether they think the item contains plastics.

- Video: “Plastic Pollution: How Humans Are Turning the World into Plastic” (Kurzgesagt–In a Nutshell, 2018)
- Memory activity
- Dice
- Voting cards

**Activity 2: Are Plastics Harmful?**

This activity is introduced by the question of how microplastics can be harmful if they are hardly visible to the naked eye. After brainstorming (use mind maps; the answers serve as hypotheses to be confirmed or refuted after the activity), the students learn about microplastics and their environmental impact (primary vs. secondary microplastics, process of fragmentation, plastics entering the ocean, toxins leaching, and surface interaction with toxins) through a short informative text (WB p. 2). A model and a soil experiment help visualize those processes (WB p. 3). The model demonstrates the change in surface area once large plastics become fragmented. In groups of four to eight, the students build one large cube with all their dice, which represent macroplastics. They calculate the surface area, pull the cube apart, and calculate the increased surface area; relating it to plastics, they understand that this allows more toxins to leach or attach, while small pieces can accumulate in the environment. Linking this to daily life, they conduct the soil experiment (Figure 2; WB p. 5). They choose common materials to be buried in the soil and develop hypotheses regarding visible impacts after two to three weeks of exposure. Additionally, they produce their own biodegradable “plastic” film, also to be buried or used at home (Figure 3; WB p. 4). The biodegradable film shows typical features of plastics, yet it breaks down more quickly in moist environments. The key message is that there are less harmful, compostable, and easily producible alternatives. The students discuss parallels of the biodegradable vs. conventional plastics.

**Figure 1.** Link to Supplemental Material (PDF and DOC files); the activities are guided by a workbook (WB) and can be embellished by the PowerPoint presentation. Further learning materials provided include the voting, memory, and sorting cards.

**Figure 2.** Stages of the soil experiment. The students choose everyday materials and formulate hypotheses regarding their visible impacts after soil exposure. Then they place the samples in a jar, keep them moist, and analyze the samples to confirm or refute their hypotheses.

**Figure 3.** Three similar biodegradable “plastic” films made of glycerin, starch, and water as alternatives to conventional plastics. Students can use their films at home and investigate their degradation in another experiment (see Figure 2).
conventional film and elaborate on their benefits and drawbacks. At home, they can explore various applications.

- Dice
- Soil experiment
- Biodegradable plastic experiment
- Voting cards

**Activity 3: What about Recycling?**

A few striking figures about the percentage of actually recycled products lead to the six main types of plastics (PET, HDPE, PVC, LDPE, PP, and PS) and their recycling potential (including upcycling and downcycling). To deepen this knowledge, the students participate in the following memory activity. Everyone receives a piece of paper showing jumbled plastic shreds and related information (type of plastic, its abbreviation, recycling symbol and potential, and common things made of it), which they have to cut, match in pairs or groups, and paste into their WB (p. 7). After a TEDx-Talk introduces the “six Rs” (see above; WB p. 8), students receive pictures of common things and match each to one R-category on the board. Subsequently, they discuss alternative allocations (e.g., a thing could be reused instead of recycled). This fosters creativity and engagement in elaborating sustainable ideas. The 3-Day-Challenge at Home further encourages students to reflect on household waste by assigning throwaway items to one “R” (WB p. 9). Finally, a discussion and the soil experiment analysis summarize the topic, identifying relationships between human activities and their environmental impacts.

- Memory activity
- Video: “Microplastics Are Everywhere” (Dudas, 2018)
- Sorting activity
- Voting cards

**Alignment with the NGSS**

We designed the module for middle school students, but it can be adapted for other age groups. The disciplinary core idea is Earth and Human Activity while focusing on Human Impacts on Earth. The topic Natural Resources is subordinate. Therefore, the main cross-cutting concepts are Cause and Effect and Influence of Science, Engineering, and Technology on Society and the Natural World regarding the invention, management, and (irrevocable) effects of plastics. Consequently, Constructing Explanations and Designing Solutions and Engaging in Argument from Evidence are at the heart of the science and engineering practices, since the whole unit’s design is inquiry-based and aims at developing and evaluating solutions (Table 1; NGSS Lead States, 2013).

**Experiences with Students**

The students loved to produce their own biodegradable film and use it at home. Older students formulated hypotheses and varied the amounts of starch, water, and glycerin to generate the best outcome; this could turn into a competition. Teachers embraced the soil experiment to build on the biodegradable “plastic.” Then, the students buried not only common things but their own “plastic,” both relating the topic to everyday life. Two teachers suggested making this an experimental demonstration instead, which would save time and resources. The majority, however, would allow students to conduct the experiment, for it promoted scientific thinking, engagement, and responsibility.

**Summary**

Inquiry-based, hands-on learning links theory to everyday life by placing scientific topics in a broader context and by providing opportunities for constructive engagement. Although designing such activities may require more preparatory work, they are worth their effort, prompting cognitive, affective, social, and deeper learning. As science continually changes, educational programs need to adapt accordingly, faster than the school curriculum can. Scientific expertise about environmental threats needs to reach the younger generation, which is best accomplished at school. Since the NGSS (2013) are open in nature and embrace current global issues, all activities align with the standards and create a coherent learning experience to allow for profound insight into a major environmental issue, plastic pollution.

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