Technology and Inquiry-Based Outreach Learning

waste to energy—think sustainably!

by Alexandra Stöckert and Franz X. Bogner

Our current lifestyle is inextricably linked to waste production (Bogner & Fremerey, 2017). Everything we consume results in waste of one kind or another, which is why children should learn how to reduce and sustainably handle waste (Hasan, 2004). Sorting waste and bringing it to the respective bin is just a small contribution to effective waste management. Therefore, it is crucial to include important technical and ecological foundations of sustainable waste management in school curricula (Stöckert & Bogner, 2020).

Most students have only limited knowledge of what happens to their waste after having been disposed of in a bin. A scientist and teacher designed an outreach module to address this particular gap in knowledge. This module outlines the treatment of waste, from collection management to incineration plants, providing valuable technical insights for participating students. Inspired by these, students acknowledged the importance of waste separation and reconsidered individual options to reduce the quantity of produced waste (Grodzińska-Jurczak, Bartosiewicz, Twardowska, & Ballan-

Figure 1. A larger group working together at Station 1A.

tyne, 2003). The teacher also differentiated between waste that can be recycled and converted into usable energy and waste that cannot be recycled and requires special treatment using a simple functional model. In the end of this module, students visited an incineration plant, adding firsthand experience to their previously obtained technological and scientific knowledge. This combination constitutes a holistic, interdisciplinary, and integrated learning approach, which encourages students to conceive and critically discuss solution strategies.

Student Objectives and Goals

Since effective waste management entails many scientific and technical processes, students should improve their respective theoretical knowledge to understand the importance of waste avoidance and to communicate its benefits for society (Grodzińska-Jurczak et al., 2003).

The first goal was to make students reconsider their consumption patterns and to encourage a sustainable mindset and lifestyle. This will ultimately contribute to conserving their hometowns', countries', and planet's nature. Therefore, students performed activities focused on reducing, reusing, and recycling of potential waste in the first module. The second goal was to foster their understanding of technological processes relevant to effective waste management, such as the substantial use of modern waste incinerators. They should, hereafter, also be able to explain these processes and confidently apply the respective terminology. Since modern technologies have pervasive effects on all areas of life, students should moreover learn to assess their advantages and drawbacks critically. In this intervention, which is part of a research study to analyze knowledge acquisition (Stöckert & Bogner, 2020), students learned to define different types of energies, discovered how they can be converted or conserved and how they interact with other physical forces. Basic knowledge about energy, theories of matter, and open or closed systems was indispensable. The latter also helped students to design solutions, to create explanations, and to develop models. Hence, this interdisciplinary approach improved students' overall factual knowledge in physics and biology as well as industrial technology. This module provided a basis for in-depth reflections on the beneficial effects of technological developments on environmental protection. It also contributed to students acknowledging the necessity to act sustainably and to think responsibly as a society in order to protect our planet.

Links to Standards

This intervention also considered *Standards for Technological Literacy* (ITEA/ITEEA, 2002/2007/2013) and *Standards for Technological and Engineering Literacy* (ITEEA, 2020). It not only aimed at fostering a basic understanding of the technological processes necessary for an effective waste management, but also tried to raise students' awareness of resource-saving waste treatment. Since our waste still contains valuable raw materials, it must be carefully separated and sorted to later recover those materials in recycling plants. Thus, recyclable materials, like glass, metal, or plastic, will have to be disposed of separately, as they undergo different recycling processes. Building a model to illustrate the relation between structure and function helped students realize that recycling only works if all components are arranged according to their function. To see a large proportion of their waste recycled and reused for industry or everyday objects, students understood the importance of collecting waste from beaches, roadsides, or woods. A visit to industrial companies in their neighborhood provided the respective firsthand experience of how industrial waste can be efficiently reused. In this context, students also critically discussed the effects of technologies on the environment.

In this context, the students discussed the effects of technology on the environment and got a glimpse of industries in their neighborhood. By building a model that only worked if the individual components were arranged correctly according to their function, they also learned about the relationships between structure and function.

The intervention was comprised of the three dimensions of science education. First, "crosscutting concepts" connect all four domains of science and enable students to understand cause and effect of complex scientific phenomena. Second, "combining science and engineering" offers students the chance to act as real researchers and engineers who investigate scientific phenomena using models and experiments designed for their level of proficiency. Third, "inter-disciplinary core ideas" comprise key concepts and structures to connect different realms of science (Achieve, Inc., 2013). Respective examples can be taken from Station 3A – 3C below. In so doing, the module included relevant sustainability benchmarks of *Standards for Technological and Engineering Literacy* (ITEEA, 2020) and *Education for Sustainability* (ESD) (Unesco, 2016, Unesco, 2009) to help the young generation become respectful and responsible citizens.

Costs, Adaption Possibilities and Pitfalls

The lessons were free of charge. Material costs were manageable since, for example, electric motors are already an integral part of physics lessons and can be used as generators in the model. Even if parts of the model must be added, the price per model including LEDs does not exceed $40. If the model's steam station does not generate enough pressure to drive the turbine, blowing into the silicone hose helps instead. The model is also applicable to other lessons about wind, hydro, and thermal power plants since their operating principles are comparable and only differ in minor technical details. Moreover, visiting a power plant is not mandatory. The entire module can be implemented exclusively in the classroom using a multimedia-guided tour through a power plant via AV glasses or film. Thereby, student working groups can vary in size (Figure 1 and Figure 4), but we recommend a group size of 2-3 students.

Before you start

Materials required for a class of 20 students are listed in Table 1.

Module Flow Chart, Content, and Student Activity

The intervention "Waste to Energy—Think Sustainably!" (Table 2) was designed for students aged 10-13 and comprises about three 45-minutes lessons. Knowledge was assessed at three testing times: two weeks prior to the intervention, and then directly, and six weeks thereafter, as described in Stöckert and Bogner (2020). The lessons were formally divided into three phases. In the beginning, teachers explained the course schedule and different stations. Then each student received a workbook (Appendix A) containing tasks for each station and space to write down the respective results. Before students were divided into groups of two or three, with whom they worked for the next hours, an expert in the industry provided a short general introduction to waste incineration plants (e.g., which processes are involved? How much waste arrives there every day? Which catchment area has our neighborhood's incineration plant?). If no expert is available, the teacher can also take on this task.

Doing the *"Waste to Energy—Think Sustainably!"* Module

MODULE 1: REDUCE, REUSE, RECYCLE (3R)

The "3 Rs", Reduce, Reuse, and Recycle, are also an integral part of this module's content-related design. Teachers, therefore, instructed their students to brainstorm possible ways for waste reduction.

Station 1 A) "Does this mountain have to be that high?"

Each student received a small colored paper and the picture of a garbage mountain (Appendix A, Workbook, p. 3) or, alternatively, pictures of full dustbins in their classrooms, to raise awareness for the global problem of waste production. This should encourage students to acknowledge the problem, to critically reflect on their contribution to the problem, and to find feasible solutions to reduce their waste production. Students wrote their respective ideas on the colored paper and matched them with the different "baskets" (reduce, reuse, recycle, recover) on the poster. After this exercise, students

Table 1. Material for the waste to energy unit.

Station	Count	Material
1A)	1	poster with four illustrated rubbish bins
	1 4 10 20	Label with heading: - Reduce - Reuse - Recycle - Recover Marker with different colors Glue Colored papers
1B)	5 20 3-4 2	Puzzle of recyclables in an envelope Sticker of recyclables (Solution) Examples for recyclables; labelled Solution Sheet 1B
2)	5	Information graph 2 / Solution sheet 2
3A)	10 5	Ruler Information sheet 3A / Solution sheet 3A
3B)	5 5	Information sheet 3B / Solution sheet 3B Information graph
3C)	5 20	Set: model of an incineration plant: construction manual 1x backing strip 6 inch (black) 1x shallow ground 2,4 inch V-track left and right 1x shallow ground 0,6x0,6x0, 2 Inch 1x brick, 1,2 Inch (black) 1x gear-wheel (black) 1x generator with LED and shallow ground 6x0,6x0,2 Inch 1x gear-wheel threaded 1x brick 0,6 inch with screw 1x hub retaining nut 2x cantilevered slab 1,2x0,6x0, 2 Inch 1x flexible tube 1x cord cover 1x brass pipe Workbooks

Table 2. Flow chart of the waste to energy module (from Stöckert & Bogner, 2020)

Waste to Energy—Think Sustainably!		
Module 1: *Reduce, Reuse, Recycle (3R)* Presentation of the problem 1A) Does this mountain have to be that high? Elaboration Phase 1B) Cycle of waste	***Module 2:*** *Recovering Energy* 2) What if recycling is not possible? 3A) Waste in … energy out 3B) The end of waste 3C) Model of an incineration plant 4) Optional Station for higher achieving students	***Module 3:*** *Excursion to an incineration plant* Virtual or onsite

Figure 2. Students write down the requirements of the substances to categorize them according to the 3Rs or recovering energy.

discussed potentially reusable materials and their required substance properties. Teachers also encouraged students to find examples for the aforementioned categories and to put them on the poster (Figure 2).

Educational Background

In addition to professional competencies, this module also fosters social skills like teamwork, effective communication, and self-assessment. The matching exercise, for instance, required students to categorize their ideas and match them with the teacher's four categories. Since students in one group have different ideas and choose different categories, each idea and match is intensely discussed before being put on the poster. Teachers may catalyze reactions and responses from classmates but are generally encouraged to keep a low profile, since the exercise aims at encouraging students to discuss problems within their peer groups. In the end, teachers can address

Figure 3. The cycle of recyclables, students find the solution on their own by comparing it with the natural cycle of matter.

Figure 4. The cycle of recyclables, done by a larger peer group.

Figure 5. Labeled recycling products.

Figure 6. Natural cycle of matter and the recycling cycle.

potential solutions to reduce waste production, like reusing things or buying unpacked food. Students should also realize that the technological progress is ambivalent: it is vital to recycling waste but is also in itself one reason for the waste mountain.

Elaboration Phase

The teachers primarily deployed cooperative and self-explanatory learning methods. These were supported by additional information in workbooks (Appendix A), informational texts, supplemental material, and solution keys. Teachers only observed and supported if necessary. Material required for this phase is listed in Table 1.

Station 1 B) Cycle of Waste

Apart from relevant instructions in the student workbook (Appendix A, p. 5), this station followed an inquiry-based (Bybee, 2007), self-explanatory, and hands-on learning approach.

Short informational text provided an overview of the natural materials cycle, which fostered a basic understanding relevant for the transfer of its general principle to the recycling cycle of waste. Hereafter, students applied their newly acquired knowledge, arranging the recycling cycle of waste (Figure 3, Figure 5) and comparing their proposed solution to the sample solution. They recorded the results in their workbooks.

In the second part of this task, students examined various labels for recyclable products (Figure 6) and retraced their origin. They thereby discovered that these labels comply with recycling processes that the respective recyclable products undergo. Students also learned about relevant material properties of waste in order to qualify for recycling as well as the different materials from which raw materials can be recovered.

Educational Background

This exercise aimed at identifying recyclable products and correctly sorting them prior to disposal. It also fostered students' understanding of issue-specific connections between technology and science. For weaker students, the teacher provided supplementary material to help them understand the recycling cycle. The teachers could thus differentiate between stronger and weaker students on a technical level. In the end, all students should be able to differentiate between recyclable and nonrecyclable materials and sort them according to their material properties in order to recover reusable raw materials. They should also know that recycling processes heavily depend on energy.

MODULE 2: RECOVER AND ENERGY (1R)

Station 2) What if recycling is not possible?

This station (Figure 7) introduced students to the second module. There, students had to find environmentally friendly solutions for waste that cannot be recycled or reused. The teachers only provided the most important information for students in graphs and a brief summary in their workbooks (Appendix A, p. 6). After having completed the exercise, students compared their responses to the suggested solutions. The aim of this exercise was to foster students' understanding of waste incineration and storage. This topic will be intensified at Station 3.

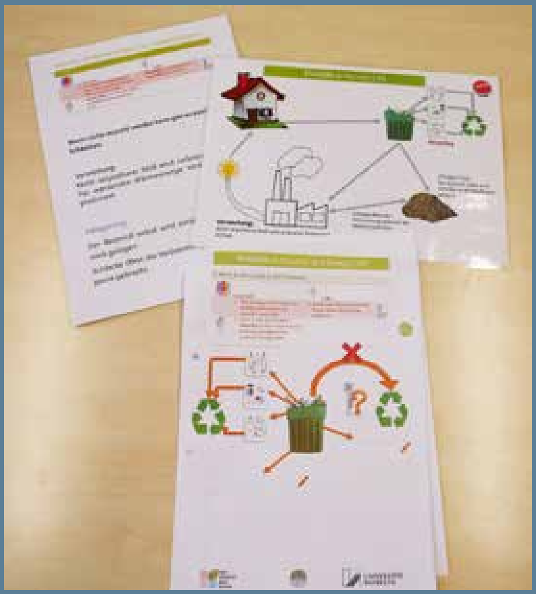

Figure 7. Worksheets containing "What if recycling is not possible?"

Figure 8. Worksheet about the technical terms and their meaning.

Station 3 A) Waste in ... Energy out

This station focused on technical terminology and its meaning (Figure 8). Thereby, students had access to an informational text with technical terminology. Explanations for every technical term were hidden, and students had to use their newly acquired knowledge to match the technical terms with a corresponding example in the workbook (Appendix A, p. 7). To check their results, the teachers provided students with a solution sheet.

Station 3 B) The end of waste

The students read an informational text about the individual technical sections in an incineration plant and drew a functional diagram of a waste power plant (Figure 9).

Figure 9. Worksheets explaining the sections in an incineration plant.

Figure 10. Model of an incineration plant.

Educational Background

Students correctly used and applied the required technical terminology. They could describe the schematic structure of an incineration plant and explain the most important steps of energy conversion and conservation. These steps were categorized using different colors to help students recognize, apply, and transfer them to the model in the next station.

Station 3 C) Model of an incineration plant

Students received a construction kit with components they could assemble independently (Figure 10). The overall aim was to make the LED light shine. As already mentioned, an electric motor with low initial resistance was required as a generator, which could easily be borrowed from the physics department. The model also comprised a steam station. If it is not possible to build one in the classroom, air also possesses the relevant kinetic energy to drive the turbine (Figure 11).

A steam station is, however, quite easy to rebuild. Teachers generate heat with a hotplate, which makes water in a pot boil. (Attention: Steam can cause injuries to the skin!) The steam will then be passed to a silicone hose attached to a machine comparable to a turbine. A brass tube, narrowing the cross section, limits energy losses resulting from the transfer of steam to gear. The gear is connected to a generator, which converts the steam's kinetic energy into electrical energy, illuminating an LED light attached to the generator (Figure 11, Figure 12).

In order to understand how the individual components work and interact, students matched the appropriate technical terms with the respective components and described the entire process in full sentences, Figure 12 (Workbook, Appendix A, p. 11).

Educational Background

This station aimed at fostering independent learning in a social peer group. Students taught themselves how incineration plants operate and deepened their knowledge gained in Stations 3A and 3B. They understood the beneficial impact of modern technologies on effective waste management and critically discussed advantages and disadvantages of waste incineration. Possible effects of energy recovery from recyclable waste on the environment have been realized, and students roughly know how power technologies create electrical energy. This station also promoted cognitive, affective, and psychomotor skills.

Station 4) Ready?

The students were invited to write down their individual opinions about the importance and necessity of waste separation.

Educational Background

An optional fourth module was available for more adept students where they holistically assessed the entire intervention's content by noting their ideas about waste separation (Workbook, Appendix A, p. 12). This station aimed at deepening the information students have obtained at previous stations and enabled them to differentiate between recycling and reusing of products.

MODULE 3: EXPLORING A WASTE-TO-ENERGY PLANT

The third phase entailed a visit to a real waste-to-energy plant. This firsthand experience enabled students to transfer their knowledge obtained from building the model to the machines on-site. An expert guided the students through the waste-to-energy plant and answered questions when needed (Figures 13 and 14). Alternatively, teachers can also show a film or video about waste incineration to students if a field trip to an incineration plant is not feasible.

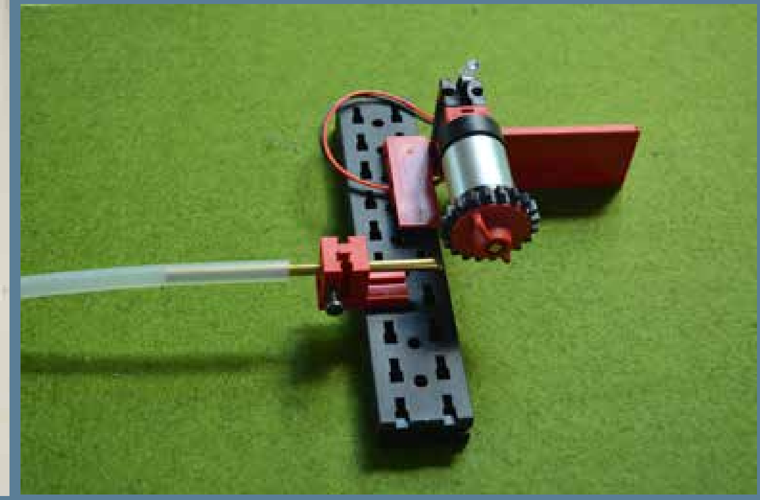

Figure 11. Students combining technical terms with the individual components of the model.

The field trip, however, provided students with firsthand experience about the sheer dimensions of waste disposal operations and demonstrated the logistical efforts involved to optimize these processes. It also addressed students' different sensory channels. In the waste bunker, for instance, students saw, smelled, and heard the incoming waste dropping to the ground. This waste was then transferred to the incineration hall where it was burned. Students were able to feel the resulting heat used to boil water and to create steam for the turbines in the turbine chamber. Literally seeing and feeling thermal energy being transformed into kinetic energy helped them understand the underlying physical processes. In the generator hall, students learned that emerging electrical energy was directly transferred to regional power suppliers. A final, all-encompassing overview of the processes was provided in the control room, where students also discovered how much electricity the incineration plant produced and how by-products, like pollutants and other contaminants, were removed from water and steam before being released into nature.

Figure 12. Students matched the appropriate technical terms with the respective components and described the entire process in full sentences.

Educational Background

Seeing the waste piled up in the waste collection bunker, students realized the impact an individual's handling of waste has on waste production. This experience also raised their awareness of effective waste management as well as of a sustainable and resource-saving consumer behavior. Knowledge about the underlying technical processes of waste recycling and energy production clearly displayed the interrelation between the needs of society and technological progress. Students could, moreover, transfer their knowledge obtained from building the model of the incineration plant to the processes observed on-site. It helped them realize the dimensions of waste disposal operations and demonstrated the logistical efforts involved to optimize these processes.

Figure 13. Students visiting the waste bunker in front of the incineration chamber.

Figure 14. Students visiting the control room of a waste-to-energy plant.

Conclusion

The intervention combined classroom hands-on and peer-guided activities with an out-of-class practical experience, considering *Standards for Technological and Engineering Literacy* and *Next Generation Science Standards*. The out-of-class practical experience at an incineration plant is optional, since teachers could also show a video about waste incineration to students if a field trip is not feasible. The rest of the modules' activities are fit for classroom teaching.

To reconsider the impact of their own consumer behavior and waste-production habits on the environment, students obtained technological, physical, and biological knowledge about effective waste management. The time-consuming processes involved in recycling waste helped students understand how important sorting waste is for energy production and the recovery of essential resources. The visit to the incineration plant also transferred their theoretical knowledge into more tangible firsthand experience. Students, thereby, encountered practical and technical challenges that the waste recycling industry faces on a daily basis due to the sheer amount of waste produced. The entire module aimed at promoting sustainable attitudes as well as resource-saving consumer behavior. It was designed to be compelling and accessible to students at all different ability levels. We consider our module suitable for successfully changing individual consuming and littering behavior.

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Appendices

A. Workbook
B. Workbook Solution
C. Informational Material

NOTE: Appendices are posted online at: www.iteea.org/TETDec20StockertWorkbook.aspx

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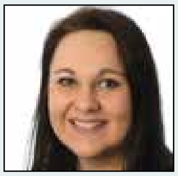

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