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Article

Hands-On Activity Illustrating the Sorting Process of Recycled Waste and Its Role in Promoting Sustainable Solutions

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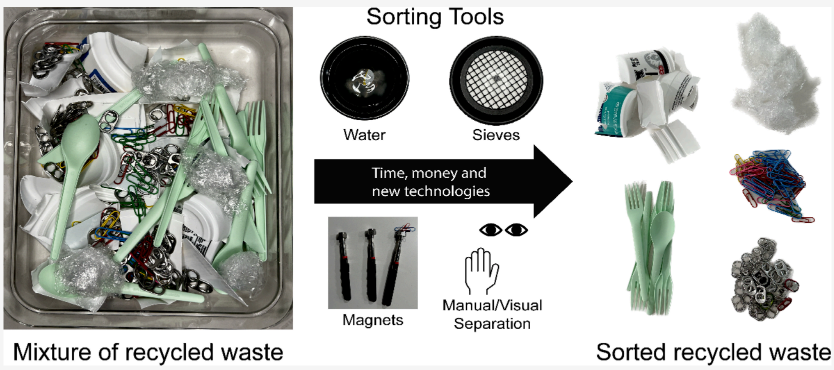

ABSTRACT: Effective recycling is not merely a matter of collecting waste; it also requires meticulous categorization to maximize the potential for reusing material and minimizing waste sent to landfills. Education and awareness of the sorting and recycling process bottlenecks need to be emphasized and extended beyond higher educational contexts (e.g., in multiple stages of educational pathways, such as middle or high school). Hence, this project introduces a hands-on plastic sorting activity where students use recycled waste to be sorted based on their physical properties. Several tools were provided to perform the separation, such as water, sieves, magnets, and manual/visual separation while considering the time and cost associated with each tool. The activity was evaluated by pre- and post-evaluations based on Likert-scale and open-ended questions grouped in several categories related to the sorting process. In several categories, we observed that the activity enhanced student knowledge (e.g., general sorting understanding), while in other categories, there was no growth. From open-ended questions, students expressed an understanding of how to sort recycled waste and an appreciation for the trade-offs in developing sorting solutions. This activity effectively enhanced students' awareness of the sorting process of recycled waste. It lays the foundation for future inquiry and outreach project design.

KEYWORDS: *Plastic Sorting, Recycling, K-12 Activity*

■ INTRODUCTION

As the global population continues to grow and the Earth's resources become increasingly strained, finding innovative solutions to address the challenges of waste management and environmental sustainability has become imperative.[1] By 2050, it is estimated that the accumulation of plastic waste in landfills and water bodies will reach a staggering 12 000 Mt, with only 9% recycled and the rest incinerated or landfilled.[2] The widespread and long-lasting existence of plastic waste, especially disposable plastic products, in aquatic ecosystems signifies that plastic is emerging as a substantial environmental contaminant on a considerable magnitude.[3,4] Recycling plays a crucial role in this endeavor, offering a viable means to conserve resources, reduce pollution, and minimize the strain on our planet. However, effective recycling is not merely a matter of collecting waste; it also requires meticulous categorization to maximize the potential for reusing material and minimizing waste sent to landfills.[5,6]

Sorting plastics is a critical step in the recycling process, serving as the foundation for the efficient and sustainable utilization of resources. Most plastics are immiscible with one another and, if not sorted, the mixed waste exhibits inferior properties that prohibit its use in applications. By separating different types of plastics, recycling facilities can yield fairly pure recycled streams with greater performance and ensure that each material stream undergoes the appropriate treatment

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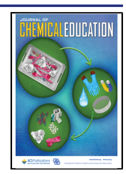

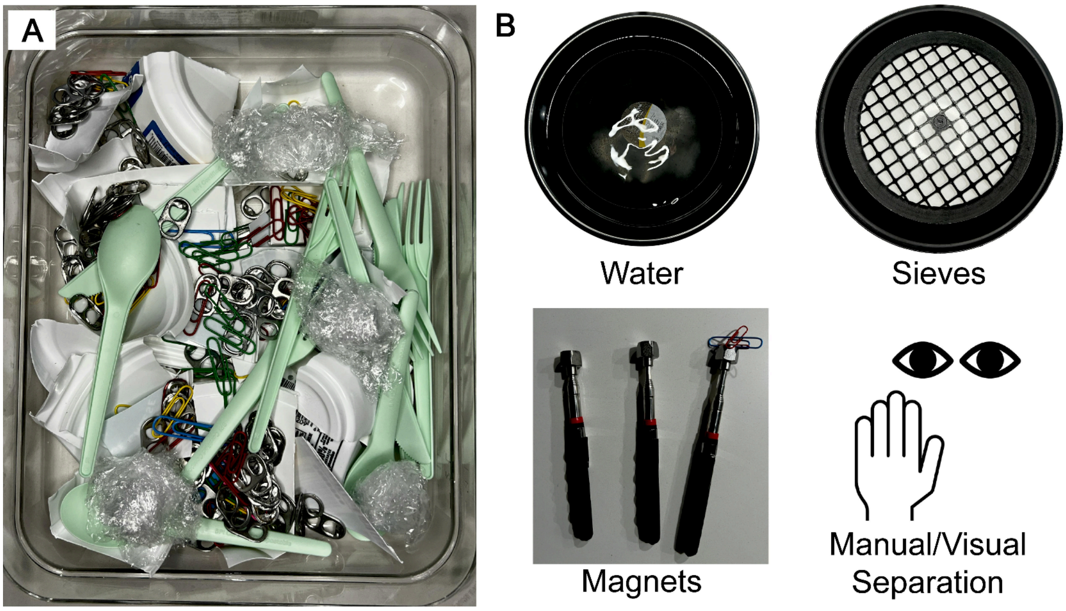

Figure 1. (A) Mixture of recycled waste. (B) Tools (or unit operations) provided in the demonstration.

and transformation.[6] Plastic waste streams follow a sequence of sorting steps based on their size (manual or sieves), elimination of foreign materials (i.e., metals), separating different plastic materials, and, ultimately, the sorted streams are then melt processed and granulated into a plastic recyclate. The key to separating these materials lies in exploiting their physical properties. Some materials can be separated by gravity in airflow (air classifier) or water (sink-float), while magnetic materials can be removed by leveraging their magnetic properties.[7−9] Moreover, technology has greatly improved the efficiency and accuracy of waste sorting. Automated sorting systems employing sensors, optical scanners, and advanced algorithms have revolutionized the recycling industry, enabling high-speed sorting based on various criteria like shape, color, size, and material composition.[10]

The EPA Administrator unveiled the National Recycling Goal in 2020 to elevate the US recycling rate to 50% by 2030. This nationwide objective will serve as a benchmark to assess the effectiveness of collective efforts in enhancing the country's recycling infrastructure.[11] Within these "collective efforts," education and awareness of the sorting and recycling process bottlenecks need to be emphasized and extended beyond higher educational contexts (e.g., in multiple stages of educational pathways, such as middle or high school). Hence, there is a need for K-12 activities or workshops that show the importance of the plastic sorting process to students while following education standards. The NGSS (Next Generation Science Standard) provides the K-12 benchmarks for science education, giving educators the autonomy to craft classroom experiences to spark students' curiosity in science and equip them for higher education, professional pursuits, and responsible citizenship. For Texas-based educators, TEKS (Texas Essential Knowledge and Skills) also provides a set of state standards for what students should know and be able to do.[12,13] Previous hands-on activities have demonstrated commendable effort in showing the process of sorting and recycling plastics within a classroom setting.[14−17] However, there has been a noticeable absence of alignment with current educational standards. This activity was designed with NGSS HS. Human Sustainability standard[18] and TEKS Rule §112.37 Environmental Systems[19] in mind.

Informal learning offers an ideal opportunity to connect learning to students' experiences and identities[20−25] because there is increased instructional flexibility,[26] and the stakes are lower than in a traditional classroom.[27] This work aims to present an interactive activity to sort recycled waste and assess its impact on students' understanding of plastic sorting and recycling. The activity challenged student teams to develop a solution to sort plastics based on their physical properties while considering time and cost constraints. It also extends the discussion on the potential technologies that could be used in the sorting process.

■ SORTING ACTIVITY INFORMATION

Students & Setting

The activity was provided to students who were part of a Summer Residential STEM Academy in the southwest U.S. This program integrates online and offline learning, bringing together young individuals from over 18 countries across the globe.[28] The activity was conducted with 30 students between 15 and 17.5 years old, encompassing both males and females.

Activity Description and Logistics

Activity Introduction to Students. We delivered a short presentation (approximately 15 minutes) to introduce key concepts of the activity to the students. Topics discussed: current recycling numbers in the U.S., the bottleneck for the recycling process, the challenges of sorting recycled waste, the importance of a good sorting process, the economics behind sorting recycled waste, how to exploit the physical properties of the recycled waste to perform the separation, and some current sorting technologies available in the market.

Group Setting. We divided students into smaller groups of 3−4 to maximize participation. We then asked students to create their sorting facility and decide on a company name, CEO (Chief Executive Officer), CFO (Chief Financial Officer), and the Sustainability Engineers and document it in

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Table 1. Pre- and Post-evaluation Results Separated into Several Categories of Importance in the Sorting of Recycled Waste Process[a]

	Question	Category[b]	Pre-evaluation[c]	Post-evaluation[c]
Q1	All recycled waste/plastic have the same sorting process	GS	2 ± 1	1.2 ± 0.4
Q2	I am familiar with the limitations and drawbacks of plastic recycling	GS	3 ± 0.9	4 ± 1
Q3	The sorting process for several types of recycled waste/plastics is not important	GS	1.5 ± 0.6	2 ± 1
Q4	Proper recycled waste/plastic sorting is crucial for ensuring successful recycling outcomes	GS	4.4 ± 0.7	4.4 ± 0.9
Q5	The process of sorting and recycling recycled waste is straightforward	GS	2.7 ± 0.7	2 ± 1
Q6	All the trash I put in my recycling bin will be recycled	GS	2.3 ± 0.8	1.4 ± 0.7
Q7	Recycling plastic is not economically viable	E	2.1 ± 0.8	3 ± 1
Q8	Sorting recycled trash is an expensive process	E	3 ± 1	4.3 ± 0.7
Q9	I believe that there is no market demand for recycled plastics	E	2 ± 1	2 ± 1
Q10	Sorting recycled waste requires a significant amount of energy	EN	3.2 ± 0.8	4.2 ± 0.7
Q11	Plastic recycling is a relatively recent development	T	3 ± 1	4 ± 0.7
Q12	New technologies can improve the sorting process of recycled waste	T	4.6 ± 0.4	4.7 ± 0.8
Q13	Recycled waste can be sorted based on its physical properties	S	3.7 ± 0.7	4.6 ± 0.5
Q14	Recycled waste can only be sorted by hand	S	1.7 ± 0.4	1.4 ± 0.6
Q15	All recycled waste have the same properties	S	1.8 ± 0.7	1.3 ± 0.5

[a]Median ± standard deviation was compared between both evaluations. [b]Questions were separated into several categories: general sorting concepts (GS), sorting economics (E), energy requirement (EN), technology in sorting (T), and science involved in sorting (S). [c]Likert-scale rated responses 5 − Strongly Agree, 4 − Agree, 3 − Neutral, 2 − Disagree, and 1 − Strongly Disagree.

the Students Activity Worksheet (provided in the Supporting Information).

Materials. A bowl with five types of recycled waste was provided: paper clips, aluminum pop tabs, PS (polystyrene) plastic wrap, PE (polyethylene) plastic pieces, and PLA (polylactic acid) plastic cutlery Figure 1A. The tools (we called them unit operations) that were used to perform the separation included sieves, a water bath, magnets, and manual/visual separation Figure 1B (a complete list of material sourcing is provided in the Supporting Information)

Challenge. Groups were challenged to sort recycled waste into its pure components while considering that each tool/unit operation had a time and cost associated with its use. The Student Activity Worksheet asked students to provide their companies' business and financial plans. For the business plan, the students were asked to determine the order of the unit operations used for the separation and their observations. They could use each of the unit operations a maximum of once. They could also choose not to use a unit operation. Based on the unit operation order, the designated CFO completed the financial plan with the total time and cost it would take to finish the separation. Finally, we asked the students to propose sorting technologies they would implement in their company.

Scientific Concepts. The sorting fundamentals were based on exploiting the physical properties of the materials. The paper clips were magnetic, while the aluminum pop tabs were not; therefore, magnets could be used to separate the magnetic pieces from the nonmagnetic ones.[7] Size exclusion could be applied to separate recycled waste of assorted sizes using sieves. Plastic could be separated based on density through the floating test, where some material would sink or float.[16,29] The density of water was assumed to be ∼1g/mL, while the approximate densities of PLA, PE, and PS were 1.24, 0.92, and 0.91 g/mL, respectively.[30−32] For that reason, PLA would sink, while PE and PS would float. For materials with similar densities, like PE and PS, a transparency test can be performed. This is accounted as the "manual/visual separation" unit operation, as PS would have higher transparency than PE, hence enabling the separation of these two components.[33]

Outcome. The students were asked to present their findings, including the order of the unit operations, observations, innovative technologies they would implement, time, and cost, and to show that the separation was completed.

■ ACTIVITY EVALUATION METHODS

Permission was provided by program directors to share anonymized results from our hard-copy surveys which used Likert-scale and open-ended questions before and after the activity. The Likert-scale rated responses as 5 − Strongly Agree, 4 − Agree, 3 − Neutral, 2 − Disagree, and 1 − Strongly Disagree. This strategy has been reported to successfully indicate how a program or activity impacted the student's attitude toward certain topics in the short term by participating in a hands-on activity.[34−36] In both evaluations, general questions were asked related to sorting recycled waste, economic feasibility, energy requirement, technology in sorting, and the science behind sorting. Open questions such as "In your own words, why is sorting recycled waste/plastic important? Do you believe that sorting and recycling plastic is economically viable? Why/why not? How did the activity impact your understanding of sorting recycled waste and plastic?" were also asked to better connect Likert-scale results with survey responses. More Likert-scale questions were added to the post-evaluation to understand students' interest in the topic and how the activity changed their perspective on recycled waste sorting.

■ DATA ANALYSIS METHODS

Descriptive statistics were used to summarize and describe the main features of the dataset . For example, we sought to undersand the for each question on the pre- and post- the mean, and mean standard deviation were obtained to compare the pre and post-survey responses and investigate students' understandings of plastic recycling and sorting. The post-evaluation contained 13 additional Likert-scale questions to examine what students thought about the activity and gather feedback for future workshops. In the same way, it was used to connect how the activity impacted the students' understanding of the topic. As generalizability was not the goal of this project,

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J. Chem. Educ. 2024, 101, 1899−1904

we used thematic analysis to shed light on the Likert-scale findings through the development of themes.[37]

■ RESULTS AND DISCUSSION

Students showed an improvement in their overall understanding of general sorting concepts. For example, Table 1 shows a one-point improvement for 4 of the 6 questions (Q1, Q2, Q5, & Q6). The other 2 questions (Q3 and Q4) showed no change. Results are promising in that in the pre-evaluation, several students described their unfamiliarity with recycling, for example, one student said, ". . . Honestly, I do not know. I know nothing about plastic, but I think maybe it's important because different plastic is used for different things. . ." However, in the post-evaluation, students described that they thought sorting plastics was a bit more important than they had initially thought and demonstrated their newfound knowledge in this area. For example, one student said, "[sorting is important] so that they [plastics] can be used properly, w/o damaging the chemical/physical properties of the plastic." In the post-evaluation, other students described the level of care that might be needed in sorting. For example, another student said, ". . . gives the opportunity for reuse again systematically." This category shows the impact of exposing young learners to topics they may not have been exposed to before. At the end of the activity, they were able to demonstrate growth from saying they did not know anything to at least sharing their immediate understanding of the topic.

In the category of sorting economics, students showed an overall improvement in their understanding of the economic viability of sorting recycled waste. Results showed a one-point improvement for 2 out of the 3 questions (Q7, Q8). Q9 did not show an improvement. Several students demonstrated an understanding of sorting economics in the post-evaluation when compared to pre-evaluation responses. For example, in the pre-evaluation, a student said, ". . .there are plenty of sorting and recycling processes that are cheap." However, in the post-evaluation, students elaborated more on the complexities of sorting economics and some uncertainty. For example, one student said, "...the final result might be good, but the process of sorting can be expensive and unprecise." Another student said, "...it is not economically viable because [it] is an expensive process, and there are machines that have to be bought and persons to play (the person that sorts waste manually)." A third student said, "Sorting is economically viable as it does create a lot of jobs, from the activity, manual sorting is expensive." Student comments enable us to see and point to not only student understanding but also illuminate economics as an area that should be further emphasized in future iterations of the project.

On the sorting energy requirement question, students showed improvement in their understanding of the significant amount of energy needed to sort recycled waste. Several students described the process as simply being "an expensive process" in the pre-evaluation to being able to elaborate on possible contributions to the expenses of recycling in the post-evaluation. For example, in the post-evaluation, one student said, "...this process costs a lot of time and needs a lot of electricity to support it." While another student described, "required a lot of energy, land and sometimes a lot of manpower."

Students also demonstrated some improvement in their understanding of the technology involved in sorting. From the pre-evaluation, students showed some understanding of the use of technology to facilitate sorting and recycling processes. Some students stated, "...I think the development of technology will make sorting and recycling plastic economically viable," and "...some processes require new technology." After the activity (post-evaluations), students showed more appreciation of how technology can be applied to optimize processes: "...I believe that new technologies will improve the efficiency of [the] recycling process as an effort to save the world." Another student went beyond the activity and mentioned their interest in changing the world and contributing to sustainable solutions: "...I might actually join the industry to solve more problems in recycling and improvise current technologies." This category is also an area that could be further explained in future iterations of the activity so that students have a clearer understanding.

Perhaps most importantly, students improved their understanding of the science involved in sorting. This implies that we effectively communicated the scientific concepts of sorting recycled waste to students through the activity. An example of students' demonstrated growth in this category of questions can be seen in the specificity of the post-evaluation responses compared to the pre-evaluation responses. For instance, in the pre-evaluation response, one student described, "[plastic] should be sorted according to the characteristics it has and what it will be used for." However, in the post-evaluation response, one student said, "[sorting is important] so that we can deliver or use it the right way according to its physical properties." Another student said, "All recycled plastic/waste has different physical properties, such as hardness, density, transparency..." This might be an important category in a hands-on activity design in that it will help students connect what they have learned here to concepts they are familiar with from school (e.g., science standards).

Last, in the post-evaluation, we also asked students several unique questions to examine their thoughts about the activity and gather feedback for future delivery. Overall, the activity was well received by students, as shown by the post-evaluation unique questions (Table 2) and supporting open-ended responses.

Students' open-ended responses are represented by two overarching themes: "An appreciation for/fun" and "improved knowledge/understanding." Some representative example quotes are listed on Table 3 as illustrations.

An additional outcome of this work was that open-ended responses pointed to early evidence of how this activity might impact student engineering identity especially as it relates to interest and feelings of competence.[23,38,39] The activity not only points to areas of student growth and areas for improving the activity but also gives us a direct line of inquiry for connecting the work to future engineering identity research. We also plan to further explore, for example, extending the activity to additional students of varying ages and backgrounds as well as extending the activity over multiple days.

This activity can be modified for various age groups (e.g., both younger students and more advanced students). For example, for middle or high school students, we recommend returning to the NGSS and scaffolding the activity deliverables based on the NGSS for that age group. One might also envision modifying the activity for undergraduate students by providing a more in-depth demonstration of other properties that can be exploited to sort recycled waste, along with a hands-on demonstration of cutting-edge technologies currently being used in the space encompassing artificial intelligence

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Table 2. Post-evaluation Unique Questions Measuring the Student's Improvement after the Activity[a]

Question	Post-evaluation[b]
The activity met my level of expectation	4.3 ± 0.7
I am interested in learning more about plastic recycling	4.4 ± 0.7
I enjoyed working on the sorting recycled waste activity	4.6 ± 0.5
I would recommend this activity to my friend	4.5 ± 0.5
The activity was of the right length of time	4.2 ± 0.8
The activity was presented clearly and concisely	4.6 ± 0.4
I enjoyed working in a team to solve the plastic sorting challenge	4.4 ± 0.7
The activity changed my perception of plastic waste's impact on the environment	4.2 ± 0.7
The activity changed my perspective on the importance of reducing plastic consumption alongside recycling efforts	4 ± 1
The activity improved my knowledge about the challenges faced by recycling facilities	4.6 ± 0.5
I now have a better understanding of the journey of waste to the sorting facility and beyond	4.5 ± 0.5
The activity influenced my perception of the energy requirements for sorting/recycling plastic	4.5 ± 0.6
I now have a better understanding of how we can exploit the physical properties of materials for sorting purposes.	4.5 ± 0.5

[a]Mean ± standard deviation was calculated for each question. [b]Likert-scale rated responses 5 − Strongly Agree, 4 − Agree, 3 − Neutral, 2 − Disagree, and 1 − Strongly Disagree.

Table 3. Open-Ended Responses Obtained from the Post-evaluation

Theme	Representative quotes
An appreciation for/fun	• "It was really good"
	• "...I tried to do the demonstration of recycling for the first time, that's fun!"
	• "I appreciate the practical approach of this activity"
	• "I got new information and experiences. It was fun, creative, and informative. Now I know how it works"
Improved knowledge/ Understanding	• "...I learned how to think about recycling effectively..."
	• "This activity help me get a deep understanding of why recycling [is] so expensive"
	• "I was unaware of the recycling process before. Now I am able to understand the different process/time required"
	• "I learned a lot about the steps of sorting and about how recycling works"
	• "I wasn't aware of [separating] waste by density and other properties..."

(AI). Future implementors might also explore potential partnerships with sorting facilities to illustrate a more efficient and authentic process when compared to the small-scale demonstration we presented and teachers or curriculum specialists.

CONCLUSIONS

Through this project, aimed at presenting an interactive activity to sort recycled waste and connected to NGSS and TEKS standards, we enhanced students' understanding of general concepts and the science of sorting recycled waste. Students enjoyed the activity, which is often a first step (e.g., interest) in students' STEM identity development. We propose this activity as an approachable, easy to implement activity that will help build students' competence and awareness of recycling. It lays the foundation for future outreach project design aimed at various aged students and future inquiry designed to understand the impact of outreach on student engagement and learning.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.3c01128.

List of materials (PDF)
List of materials (DOCX)
Notes for instructors (PDF)
Notes for instructors (DOCX)
Pre-evaluation (PDF)
Pre-evaluation (DOCX)
Post-evaluation (PDF)
Post-evaluation (DOCX)
Students Activity Worksheet (PDF)
Students Activity Worksheet (DOCX)

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Notes

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