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Work In Progress: Investigating AI for Plastic Bag Recycling

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Abstract

The health impact of microplastics has raised growing concerns recently. Plastic has been found in human brains, lungs, placentas, and plaque of clogged arteries. A significant portion of the microplastic issue consists of plastic bags and films. Each year, up to one trillion plastic shopping bags are produced globally, according to an article published by the United Nations Environment Programme in December 2021. Only one-tenth of the 4.20 million tons of plastic bags, sacks, and wraps generated were recycled, according to the Environmental Protection Agency's (EPA) 2018 data. To encourage more people to recycle plastic bags, it is essential to develop technology that helps the public correctly and efficiently identify recyclable bags.

Automating plastic bag recognition is challenging, though. Plastic bags often lack resin identification codes or symbols, such as type 2 (HDPE) or 4 (LDPE), making it difficult to determine if they are recyclable. Visual features, such as shape and color, although necessary for object recognition, are not sufficient to correctly classify plastic bags and films. Bags and films can be transparent and have various shapes. The objects enclosed in transparent bags and films could be recognized instead.

Our goal is to find a low-cost, easily scalable solution to the critical problem of plastic bag and film recycling. In this research, we

- Investigated and compared the capability of two current AI tools, OpenAI API and Gemini API, to recognize plastic bags and wraps from images;
- Designed a new approach for recyclable plastic bag and film recognition, leveraging modern AI's capability to process both image and text inputs;
- Implemented this approach using both OpenAI and Gemini APIs, tested them respectively, and compared the results; and
- Developed a model for academic institutions to partner with community organizations in educating youth through project-based learning, with AI tools to assist in ideation, prototyping, and programming.

Conclusions: Our data show that the Gemini API (gemini-2.5-flash) performed better than the OpenAI API (gpt-4o) across most bag categories we tested, achieving 92.17% overall accuracy vs 71.93%, respectively. Cost-wise, Gemini-2.5-flash offers a free tier of service, making it a better option. Through exploration of fast software prototyping with AI APIs and chatbots, we found that they not only reduced software development time but also enabled us to engage high school students in real-world computing projects and to teach them research and software engineering with minimal resources.

1. Introduction

Research highlighting the negative health effects of microplastics is on the rise. Plastic has been found in human brains[1], lungs[2], placentas [3], and plaque of clogged arteries[4]. Each year, up to one trillion plastic shopping bags are produced globally, according to an article published in December 2021 by the UN Environmental Programme [5]. According to the Environmental Protection Agency (EPA), 4.20 million tons of plastic bags, sacks, and wraps were generated in 2018, while only one tenth of that was recycled [6]. To reduce the amount of plastic bags being produced and circulated, recycling stations have been created to recycle polyethylene bags and films[7]. However, it is difficult for consumers to distinguish among various types of film, especially when they are just beginning to familiarize themselves with recycling. While 77% of Americans are aware of the term' microplastics,' over 70% say they do not know how to mitigate the issue, highlighting the need for an increase in awareness[8]. Thus, for more people to effectively recycle plastic film, it is essential to develop technology that assists the public in identifying recyclable bags efficiently.

In the rest of this section, we examine how plastic bags are recycled, related works in plastic recycling, the educational needs and opportunities with AI, and our contributions through this project.

1.1. How plastic bags are recycled

Plastic bags and films are not typically included in standard governmental commingled recycling systems. In Montgomery County, Maryland, where the authors reside, even though some plastic bags, e.g., grocery bags and bread bags, and some films, e.g., plastic wrapping around paper towels and toilet paper, can be recycled, these items typically can't go in curbside recycling bins. Instead, they need to be taken to specific collection points, such as the Montgomery Recycling Center, grocery stores, Kohl's, and Goodwill. They are then recycled by specialized private recycling companies, such as NexTrex.

The Growing & Giving Club, a non-profit organization, initiated a plastic recycling project in 2023, aiming to reduce plastic film waste and keep it out of the Chesapeake watershed. Composed of middle and high school students passionate about healthy living and environmental protection, this club educates the community about plastic pollution and appropriate recycling, collects plastic film, and advocates for systemic change. So far, it has hosted over 50 outreach events, reached over 7,000 community members, and collected over 4,200 pounds of plastic bags and films. and set up over 25 plastic film recycling bins in school buildings and community centers. The collected plastic is donated to NexTrex, a manufacturer that recycles it into eco-friendly outdoor products.

During the plastic bag & film collection, the club found that consumers, particularly those who just started recycling plastic bags and films, are in great need of help with identifying recyclable plastic bags and films efficiently and correctly.

1.2. Related works

There have been efforts to develop software and devices for recognizing recyclable plastics [9], [10]. For example, the Plastic Scanner Project [9], [10] is an initiative to develop a handheld device that uses machine learning to determine if plastic is recyclable. Both the hardware design and the software are open source. However, as the author has recognized, the accuracy (70%) isn't reliable enough for practical use, and the key components of the hardware are difficult to obtain consistently[9]. Besides, we believe the requirement for an additional device creates a financial burden on plastic bag/film consumers and is thus not feasible for widespread household adoption.

There are two major challenges in automating plastic bag recognition: cost and technology. We analyze them below.

The cost challenge. For the recycling behavior to be adopted by as many people as possible, the cost must be minimal. Thus, we aim to explore the possibility of developing a software for cell phones, a device that most plastic consumers already have and use, and a low/free cost API for sustainability. While current AI APIs (Application Programming Interfaces) are accessible, they still carry a cost. Thus, we aim to investigate and compare the feasibility, performance, and affordability of multiple APIs.

The technical challenge. These days, one standard sensor on a cell phone is the camera. However, bags do not always have resin identification code symbols, such as type 2 (HDPE) or 4 (LDPE), to tell whether they are recyclable. While shapes and colors are commonly used in computer vision, they alone are not sufficient for bag recognition. Nor do they determine whether a bag contains the chemical ingredients that make it unrecyclable. Besides, transparent bags enclosing various objects may lead to the object being recognized rather than the bag. Thus, it is challenging to determine whether a bag is unrecyclable solely from visual cues.

1.3. The educational need and opportunity with AI

Recently, AI development, particularly in LLMs, has fundamentally changed the way programming is done. This transformation has presented challenges for recent graduates and computing students. The industries' pursuit of efficiency has led to job cuts and flat recruitment [11]. Companies are requiring employees to use AI to improve efficiency [12], [13] and are seeking 'AI literate' job candidates [14]. Colleges are yet to catch up with the industry in using AI in programming. Departments are wrestling with how to change the curriculum [15] and how to evaluate students differently [16]. This disruptive technology has changed programming [15], [17], and higher education institutions need to acknowledge the "evolving notion of originality" [16] and accelerate AI adoption [18].

Vibe programming and agentic programming significantly reduced the requirement for the programmer's experience, thus providing excellent opportunities to educate youths about research and software engineering at an earlier age. Using AI, students could quickly learn a new topic and leverage existing libraries, APIs, open-source code, and other resources to accelerate ideation and prototyping. AI could increase opportunities for project-based learning, which has proven success but was limited by faculty mentors' availability.

1.4. Our contributions

In this research, we made the following unique contributions:

- To the best of our knowledge, we are the first to investigate and compare the capability of two current AI tools, OpenAI API and Gemini API, to recognize recyclable plastic bags and wraps from images;
- Developed a new software approach for recyclable plastic bag and film recognition, leveraging AI Application Programming Interfaces (APIs);
- Implemented this approach using both OpenAI and Gemini APIs, tested them respectively, and compared results; and
- Developed a model for academic institutions to partner with community organizations in educating youth through project-based learning, with AI tools to assist in ideation, prototyping, and programming.

2. Methodology

This project is a collaboration between two community youth clubs and a higher education institution. One adult leader and one youth are from the aforementioned Growing & Giving Club, and another adult leader and another youth are from Potomac Community 4H Club, a STEM-focused club. One of the authors, a community volunteer who leads the Potomac Community 4H Club, is also a faculty member in Computer Science at the higher education institution, with research interests and expertise in AI and image processing. The two youths, both high school students, brought in years of experience in programming and app development, and plastic bag and film collection, respectively.

Our educational objective is to develop software development skills, research capacity, and AI competency among youth. We educated the youths in software engineering, project management, and scientific inquiry. For project management, we use Notion[19] task board, a free software application with advanced project management templates. Google Drive was used to store and share images, code, and files. The sharing and meeting links are posted in Notion for easy access by the team.

We had mini-lessons on software engineering and defined the roles of the team members. The youth from the Growing & Giving Club served as a customer and human expert in data collection and labeling, and the youth from the Potomac Community 4H Club served as a software developer. Regular meetings were scheduled, and goals, tasks, and deadlines were established and tracked on Notion. Meetings were recorded, transcribed, and summarized by AI. The CS faculty served as the team leader, selected and posted tutorials on flowcharts, software engineering process models, etc., on Notion, assigned tasks to team members, monitored the team's progress, and guided the team in time management, prioritization, and direction. The youths were encouraged to use ChatGPT for self-directed, inquiry-based learning on how to use AI APIs. Figure 1 shows the application's flowchart.

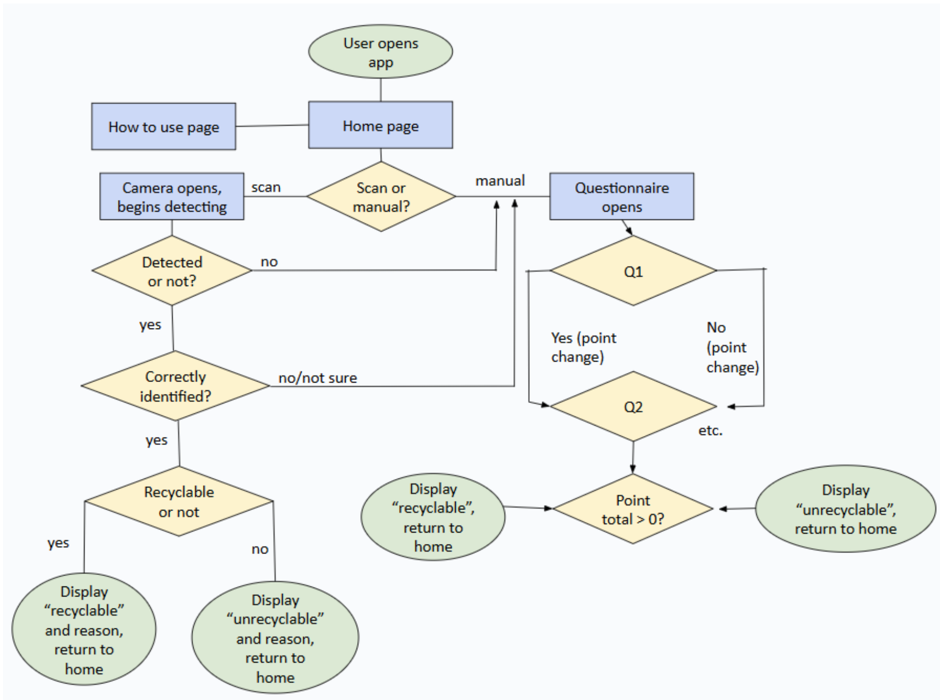


Figure 1. Recyclable Plastic Bag and Film Recognition App Flowchart

We first tested our hypothesis that objects in plastic bags or films affect bag/film recognition accuracy when vision alone is used. Then we tested two popular AI chatbots, ChatGPT and Gemini, on sample images downloaded from NextTrex's website to determine whether they could recognize plastic bags as recyclable or not using context information in the text prompts. Based on our findings, we decided to develop two versions of computer applications, each using one of the two state-of-the-art AI APIs, the OpenAI API and the Gemini API, to investigate their performance on real-world images of various types of plastic bags and films.

We then implemented the flowchart in Python, except for the questionnaire branch, using the OpenAI and Gemini APIs, respectively. The applications integrate computer vision with textual context and thus can focus on recognizing bags rather than their contents or other objects in the same images. These two apps are desktop versions for prototyping and testing.

We then tested the accuracy of these prototypes on images of real-world samples, including transparent bags with contents. We present the results in the next section.

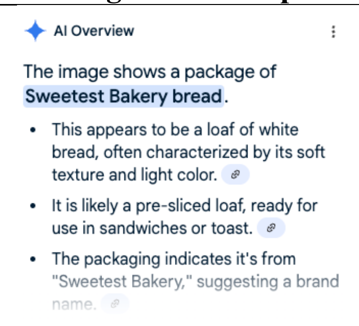
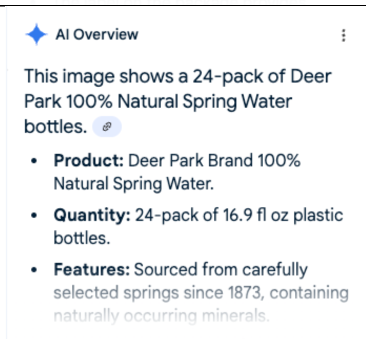
3. Experiment Results

In this section, we show the results of the following experiments: 1) Google Lens on transparent bags with contents; 2) Gemini and ChatGPT on NexTrex sample images; 3) accuracy of prototypes with Gemini API and ChatGPT API; and 4) prototype accuracies on images of transparent bags with contents.

Experiment 1. Google Lens on transparent bags with contents

We first investigated Google Lens's ability to recognize plastic bags and wraps from images without a text prompt. We tested it on pictures of fourteen sample recyclable plastic bags and wraps downloaded from the NexTrex website without text input. Some of the bags and wraps contain objects. It achieved only 50% accuracy. All the images it missed contained transparent plastic bags or films wrapped around objects. Example results are shown in Table 1. It shows that objects in transparent plastic bags present challenges for classification when only video data is used.

Table 1. Sample Items that Google Lens Missed

<table>
<tr><th></th><th>Input</th><th>Google Lens Output</th></tr>
<tr><td>Bread bag</td><td>
</td><td>
</td></tr>
<tr><td>Case overwrap</td><td></td><td>
</td></tr>
</table>

Experiment 2. Gemini and ChatGPT on NexTrek Sample Images

To see whether additional context meets the challenge shown in Experiment 1, we tested both Gemini by Google and ChatGPT by OpenAI with and without text prompts and compared their performance. We tested them on the same sample images on the NexTrex website with a prompt, “list whether in each image there is a plastic bag or a wrap.” The results are shown in Table 2. We can see that both have a perfect success rate in this small set of sample images. Then we used the prompt “which ones can be accepted by NexTrex?” and both again received 100% accuracy. This result, compared with Experiment 1, illustrates the advantage of using both text and images.

Table 2. Comparing Gemini and ChatGPT on NexTrek sample images

Bag Type	**Plastic bag or film?**		**Recyclable by NexTrex?**	
	Gemini	**ChatGPT**	**Gemini**	**ChatGPT**
Pallet wrap and stretch film	Yes	Yes	Yes	Yes
Grocery bags	Yes	Yes	Yes	Yes
Bread bags	Yes	Yes	Yes	Yes
Case overwrap	Yes	Yes	Yes	Yes
Dry cleaning bags	Yes	Yes	Yes	Yes
Newspaper sleeves	Yes	Yes	Yes	Yes
Ziploc® and other resealable food storage bags	Yes	Yes	Yes	Yes
Produce bags	Yes	Yes	Yes	Yes
Product wrap	Yes	Yes	Yes	Yes
Retail bags	Yes	Yes	Yes	Yes
Air pillows	Yes	Yes	Yes	Yes
Bubble wrap	Yes	Yes	Yes	Yes
Plastic shipping envelopes	Yes	Yes	Yes	Yes
Electronics wrap	Yes	Yes	Yes	Yes
Accuracy	100%	100%	100%	100%

Experiment 3. Accuracy of prototypes developed with two different APIs

We tested the Gemini (Gemini-2.5-flash) and OpenAI APIs’ (Gpt-4o) accuracy with the same Python script, except for the API model used. Our prompt for interacting with the APIs is in the Appendix. Our code downsized the test images to 25% on each dimension to be cost-efficient. We created an OpenAI account and a Gemini account to access their API services. We chose Gemini-2.5-flash because it is free, and Gpt-4o because it is less expensive than GPT-5.

Tests were conducted on various types of collected bag samples, from both acceptable and unacceptable categories. A total of 99 sample bags, including 50 acceptable shopping bags and 49 unacceptable produce bags, were used. The samples were collected from a NexTrex collection bin stationed in a Maryland church, grocery stores, and the authors’ homes to ensure a wide variety of bags and films. The pictures were taken under various lighting conditions, such as grocery stores, homes, public places, and plastic bag recycling collection stations, the places that everyday people would have used the app on their phones to determine whether a plastic bag is recyclable. One of our team members, with multiple years of experience examining plastic bags for acceptability, labeled the bags as acceptable or not. These labels served as our ground truth.

When the application cannot decide and returns “please use the diagnostic test for confirmation”, the result is counted as a miss in terms of classification accuracy. The results were from a single run. The results are shown in Table 3.

Table 3. Comparing Google AI Studio and OpenAI’s APIs on images of collected bags/films

Downsized images	**Recyclable ?**	**# of samples**	**Gemini-2.5-flash Accuracy**	**Gpt-4o Accuracy**
Shopping bags	Yes	23	100%	82.6%
Mailing Envelopes	Yes	12	100%	8.3%
Resealable Bags	Yes	8	87.5%	87.5%
Case overwrap	Yes	17	94.1%	58.8%
Produce Bags with holes	No	21	71.4%	90.4%
Frozen Food	No	18	100%	100%
Overall Accuracy			92.17%	71.93%

We can see that Gemini-2.5-flash outperforms Gpt-4o in all the above categories except for one. We examine some of these results below.

- **Mailing envelopes:** Gemini-2.5-flash achieved 100% classification accuracy, while GPT-4o achieved only 8.3%. Five of the eleven samples that Gpt-4o missed were correctly identified as shipping envelopes but misclassified as not recyclable. On the NexTrek website, the acceptable items list includes “plastic mailing envelope.” It seems that Gpt-4o does not have that knowledge, nor is it using the information from the website during the decision-making. The prompt in the Python code mentions NextTrek, but does not include the link to NextTrek's acceptable items. We conclude that the knowledge in these two models is different.
- **Case overwrap:** Gemini-2.5-flash did well while Gpt-4o could not make a decision for two out of the seventeen samples and labeled eight others as not recyclable based on “composed of non-polyethylene plastics” or “contains materials/layers incompatible with Trex recycling machines.” We hypothesize that it mistook the contents labeled on the wraps as the items to be decided on, rather than the wraps themselves.
- **Resealable bags:** both Gemini-2.5-flash and Gpt-4o accuracies are the 87.5%, missing only one of the bags tested (not the same one). OpenAI correctly misclassified a resealable food storage bag as “No”, even though it recognized the bag correctly, and the prompt included “Ziploc and other resealable food storage bags” in “Yes.”
- **Produce bags with holes:** Even though NexTrek listed produce bags as recyclable, not all produce bags can be recycled, for example, the ones with holes. The produce bag samples we got at the collection station were not recyclable because they had holes. So we removed “produce bag” from the “Yes” list and added “produce bags with holes” to the “No” list. With the updated prompt, Gemini-2.5-flash achieves 71.4% accuracy, mislabeling six images, while GPT-4o achieves 90.4% accuracy.

The holes are hard to see in the pictures, since these bags are transparent and the photos were taken against a background. For the six images Gemini-2.5-flash failed to identify correctly, Gpt-4o recognized two, 163547 and 160811, correctly as produce bags with holes, but was unable to decide on two others, 155750 and 154738, and recommended diagnostic tests. For the remaining two images that Gemini-2.5-flash misclassified, Gpt-4o classified them correctly, but for questionable reasons. For example, it classified an image "No, because it appears to be labeled as biodegradable, which is incompatible with NexTrex recycling machines," even though the bag is not labeled as biodegradable. In conclusion, Gpt-4o does a slightly better job of detecting holes in bags. Image 155750 was mislabeled by Gemini-2.5-flash as having a recycling symbol "4," whereas it is actually "5." Both models missed four bags with holes.

Experiment 4. Images of transparent bags with contents

The test images in Experiment 3 are taken of the already-collected bags, which, unlike those at a consumer's home, may contain contents when the picture is taken. In Experiment 4, we test both Gemini-2.5-flash and Gpt-4o on ten images of transparent bags with contents. In both versions of our programs, all images were correctly recognized as bags or films and classified according to their recyclability. Both programs identified a mesh bag and bags with holes from the pictures and determined that they were not recyclable.

4. Education Results

Our learning outcomes have been achieved – our high school students develop software development skills, research capacity, and AI competency. They successfully played their respective roles and collaborated in the software development and research.

The programmer, with no prior API experience, is now competent in using AI APIs for programming, thanks to a step-by-step guide generated by ChatGPT. The other high school student designed the application flowchart after reading tutorials on flowcharts provided by the team leader and collected data samples for testing, following the experiment design. Both went through the phases of software development and research in this project and demonstrated their understanding and developed skills by completing their tasks.

We did not develop instruments to survey their experience, since this project was not intended to be education research. However, we consider investigating students' experiences a future topic of educational research.

It took the high school students a total of ~50 hours over two months to design, implement, and test the software with minimal supervision. This result demonstrated the effectiveness and efficiency of using AI APIs and chatbots for fast ideation and software development to engage high school students in computing. Our project approach serves as a model for academic institutions to partner with community organizations to engage youth in computing through project-based learning and AI tools.

5. Conclusion and Discussions

Gemini-2.5-flash outperforms Gpt-4o in all above categories except for the produce bags with holes. But because bags with holes are easy for consumers to recognize and exclude from recycling, Gemini-2.5-flash stands out with its free-tier access and better overall performance in the other categories.

We noticed that even with the same code applied to the same images, the individual classification and, consequently, the overall classification accuracy may differ across runs. Sometimes, even if the result is the same, the explanation is different. Also, the result can be correct, but for the wrong reason.

In terms of education, we explored fast software prototyping with AI APIs and chatbots. We found that they not only reduced software development time but also enabled high school students to engage in project-based computing and research, and to learn software engineering with minimal experience and resource requirements.

6. Future Work

In the future, we will 1) further test both at scale and on various types of bags and films and average the results across multiple runs; 2) optimize the prompt to improve accuracy; 3) implement the diagnostic questionnaire and the mobile version of the app for users to use at home for plastic bag recycling; 4) add an educational component about the adverse health effects of microplastics and various ways to reduce them.

In terms of education, we plan to 1) scale up the project by involving more K-12 youth from the community and first-year college students to crowdsource the project testing and software development; and 2) develop an open-source software community to engage more K-12 students and first-year college students in project-based learning in computing and to encourage more people to recycle plastic bags.

Appendix. Prompt for AI APIs

You are a recycling assistant for the NexTrex polyethylene film recycling program. The user uploads a photo of a plastic item. Your job is to answer whether or not that item is recyclable based on its plastic composition.

Answer "Yes" if the item is any of the following because they are commonly composed of low-density polyethylene (LDPE) and high-density polyethylene (HDPE):

Air pillows

Bread bags

Bubble wrap

Case overwrap (water bottle, drink cases, etc.)

Cereal box liners

Dry cleaning bags

Electronic wrap

Furniture wrap

Grocery bags

Ice bags

Mattress bags

Newspaper sleeves

Pallet wrap and stretch film

Plastic shipping envelopes

Product wrap (wrapping around paper towels, toilet paper, etc.)

Retail bags

Salt bags

Wood pellet bags

Yard signs ("flimsy" plastic film) with wire stands removed

Ziploc® and other resealable food storage bags

Answer "No" if the item is any of the following, because they are either composed of non-polyethylene plastics or contain layers that are incompatible with Trex recycling machines:

Backyard kiddie pools or ice rinks

Bedding or linen packaging

Candy bar wrappers

Chip bags

Degradable/compostable bags or film packaging

Floral wrap

Frozen food bags

Hot dog or meat wrap packaging

Inner tubes

Lamination film

Mulch/dirt/soil bags

Net or mesh produce bags

Pet food bags

Pet waste bags

Pool covers

PPE – gloves, masks, or protective wear

Pre-washed salad mix bags

Resealable food storage bags

Shiny, crinkly films like floral wrap

Silage and hay bags

Six-pack rings

Snack bags

Vinyl shower curtains or tablecloths

Produce bags with holes

Respond only with "Yes" or "No" and a 1 sentence explanation why (e.g., No because they are composed of non-polyethylene plastics.)

If the film is not recognizable as a specific type of plastic bag or wrap, respond with “please use the diagnostic test for confirmation.”

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