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Increasing Approval of Novel Recycling Technologies with Education: A Case Study of Multi-Material Plastic

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Abstract: Plastic recycling is an important but complicated issue. Some plastics are currently readily recyclable with existing technologies, whereas others are not. However, the general public often does not appreciate the benefits and costs associated with hard-to-recycle (e.g., multi-material) plastics, potentially causing confusion and, in some cases, backlash. While some methods of relaying information to the public have been previously studied (e.g., infographics, descriptive labeling), educational videos have not. We created an educational video on the properties and functions of single- and multi-material plastic. Participants who viewed the educational video were more knowledgeable about multi-material plastic recycling and had higher intentions to use and be satisfied with a hypothetical recycling company that intends to begin recycling multi-material plastic. Our data suggest that education interventions have the potential to inform and empower the public while protecting common values.

Keywords: plastic recycling; education; framing nudge; choice architecture

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1. Introduction

Can a short educational video impact consumers' views about multi-material plastics and associated potential novel recycling technologies? We provide evidence that it might. We report experimental evidence that a well-constructed educational video about multi-material plastics can increase consumers' knowledge about these materials and influence satisfaction with a hypothetical company that recycles them. Additionally, we find that educational interventions can influence intentions about recycling multi-material plastics, improve trust in recycling companies, and change perceptions of fairness of companies that recycle multi-material plastics.

1.1. Multi-Material Plastic

Multi-material plastics are plastics that are composed of more than one material (e.g., more than one kind of polymer, rather than containers made of a single type of plastic, or single polymer, referred to as single-layer or single-material plastic from here; see Figure 1) [1]. There are many benefits of multi-material plastics that single-layer plastics do not possess. Multi-material plastics are often used to keep products fresh, like meats, cheeses, fruits, and vegetables, and used for bags that contain frozen products, chips, and snacks. Because multi-material plastic often requires less overall material to achieve

comparable performance (compared to single-layer plastic), it is usually more lightweight than single-layer plastic containers. Consequently, the production of new multi-material plastic often has a lower carbon footprint compared to the creation of identically functional alternative products (e.g., one multi-material plastic bottle can have a lower carbon footprint than a rigid single plastic alternative) [2].

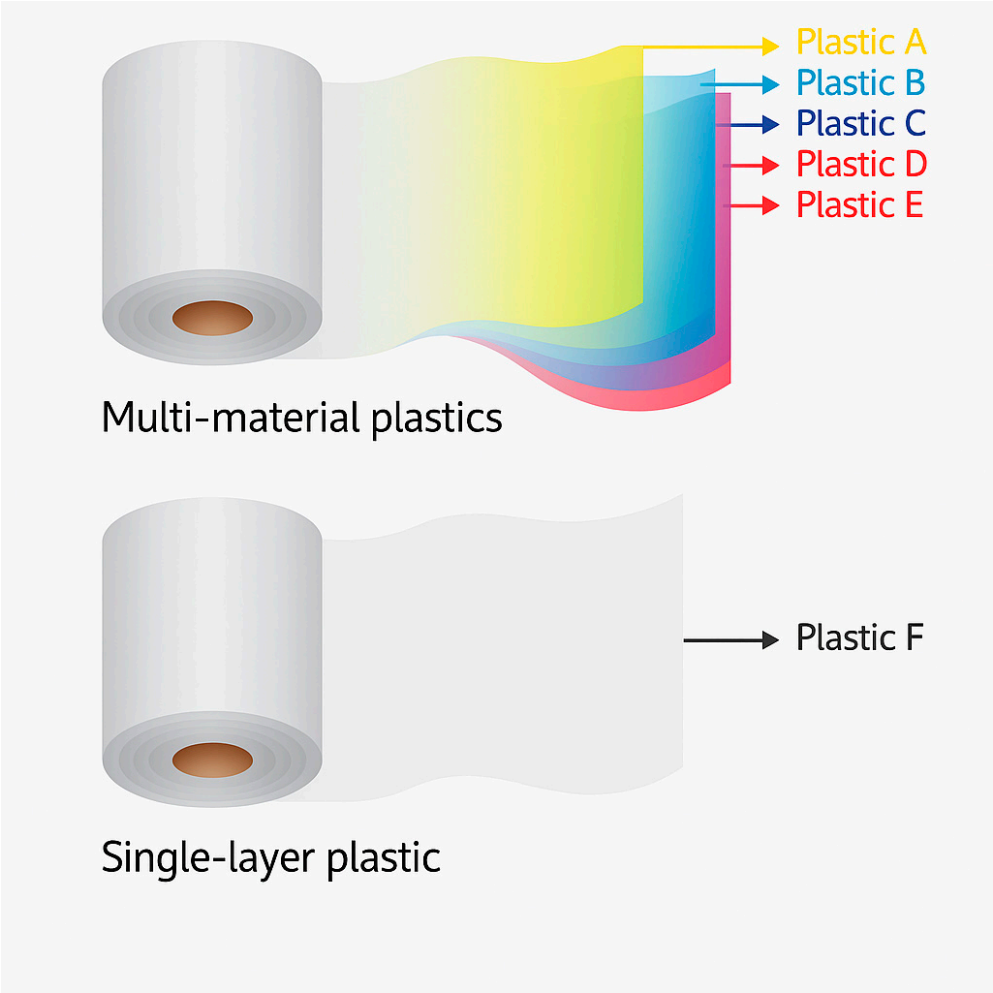

Figure 1. Single- and multi-material plastic.

However, multi-material plastics can have substantial disadvantages over some kinds of alternative materials (e.g., other kinds of single-layer plastic, cardboard, or glass) [1,3,4]. One of the major disadvantages of multi-material plastics is that currently there is no widely accessible, cost-effective way to recycle them [1]. While it is currently *possible* to recycle multi-material plastics (e.g., on small scales, in laboratories, or with a very pure, specific source of film waste next to a production facility), the costs that would be involved often prohibit wide-scale adoption. The reasons why multi-material plastics are difficult to recycle are diverse, but chief among them is the lack of cost-effective recycling technologies. To illustrate, single-layer plastics (made of a single type of material) are often shredded and melted, resulting in a homogeneous mixture that can then be used to create new products of that same type (material) of single-layer plastic. This process, often called mechanical recycling, ideally minimizes the alteration of the material. For multi-material plastic, because it is composed of multiple layers of different polymers that have very different properties, melting in a similar way would result in a heterogeneous mixture [5]. This heterogeneous mixture is not usually beneficial (e.g., able to construct new types of

multi-material plastic or valuable compounds). Hence, nearly all multi-material plastic that is currently discarded ends up in a landfill or is incinerated.

Because the end-of-life of most multi-material plastic is often not perceived to be environmentally friendly, there has been substantial backlash surrounding the use of multi-material plastics. These attitudes can then spill over to other types of recyclable plastic [6,7]. One often cited element involved in public reactions to multi-material plastic use is what people believe about multi-material plastics. The *knowledge deficit model* suggests that one reason people feel the way they do, largely negatively, about an issue is that they do not know enough about a topic to form an accurate view [8–10]. Without having a good understanding of the complexities, costs, and benefits of multi-material plastic, it may be easy to bias or otherwise manipulate individuals into endorsing some views about multi-material plastics [11]. In this light, some people may not know much about the advantages of multi-material plastics but may know some of the disadvantages, thereby giving them a non-representative understanding of multi-material plastic use and recycling—an understanding that might contribute to overly harsh attitudes about the use of multi-material plastics. Previous research suggests that types of objective knowledge about plastic recycling are related to important recycling-related outcome variables [12].

1.2. Structuring Environments to Increase Recycling

One prominent approach to altering recycling-related behaviors involves intentionally structuring environments in which people make decisions about recycling (i.e., choice architecture) [13–15]. One type of choice architecture is a nudge. Nudges have been defined to be any aspect of choice architecture that alters people's behaviors in a predictable way, typically by designing the physical, social, or psychological environment in which people make decisions, without forbidding any options (i.e., preserving the freedom of choice) or significantly changing their incentives [13,14,16,17]. Nudges are thought to work by taking advantage of people's stable cognitive biases, or decision-making tendencies. For example, people's decisions are influenced by whether information is framed positively (e.g., 80% lean beef) or negatively (20% fat beef) (see [18] for a review of framing effects and potential mechanisms responsible for them). Nudges may be especially helpful for decisions that involve self-control, are complex or difficult, do not provide feedback to learn from previous choices, and are infrequent or unfamiliar [19–23]. The use of nudges like framing has significantly grown over the past 25 years with some governments having consultants recommending their use (e.g., the Behavioral Insights Team, which originated in the U.K.'s government [24]).

There are many types of nudges that have been used to alter environmental decisions. On average, these nudges have met with moderate success (e.g., $d = 0.43$ average effect size) (Ref. [17], but see for potential issues of publication bias [25]). Framing is one common nudge used to encourage pro-environmental behavior. Framing uses different, yet "objectively equivalent" descriptions of the same problem to influence choices [26]. Framing is typically presented as a dichotomy with gain or positive frames (e.g., 30% chance *it will* rain) and loss or negative frames (e.g., 70% chance *it will not* rain). Arguably, those two descriptions of the chances of rain are logically equivalent.

There is evidence that framing can shift pro-environmental attitudes and behaviors. However, it is unclear whether positive or negative frames lead to more behavioral changes [27]. For example, it has been suggested that positive frames may be more effective in relaying more abstract information (e.g., why we should recycle), while negative frames may be more effective in relaying more concrete information (e.g., how to recycle) [27]. Additionally, some have suggested that positive frames may be more effective than negative frames when the choices taken require lower commitment (e.g., changing attitudes rather

than changing behaviors), while negative frames are more promising when attempting to alter intentions or behaviors [26]. At other times, there are no reliable differences resulting from framed messages [27].

Another type of choice architecture is education. On one view, education aims to increase knowledge, or representative understanding (i.e., a minimally sufficient set of relevant, high-quality, factual information to make an informed decision), in individuals, which empowers them to make informed decisions for themselves [14,19,22,28]. Because providing complete information is impractical, if not impossible, representative understanding focuses on the quality (rather than the quantity) of information relayed to individuals [14,29]. A representative understanding can be defined as a sufficiently nuanced and detailed (but not exhaustive) understanding such that additional random bits of information (relevant or irrelevant, accurate or inaccurate) are unlikely to influence inferences made on the basis of that understanding [14,30]. One potential reason that education that provides a representative understanding is effective is that understanding can be directly tied to one's values, emotions, and risk perceptions to make decisions [29].

While nudges and education often target similar positive behaviors (e.g., increasing recycling), the ways in which they operate are different. Traditionally, choice architecture interventions have been evaluated practically based on their ability to encourage or discourage a particular intention or behavior. It is often posited that nudges incur no ethical costs because they always leave open the opportunity for a person to decide something different. Yet these claims are rarely accompanied by evidence. Nudges often target non-rational biases to change behavior. Because nudges target those biases, they do little to change the individual decision maker, make the decision maker better, more informed, or more competent. Education interventions, on the other hand, aim to explicitly change the individual by providing information that the individual can integrate into prior beliefs and values. For this reason, it is possible that nudges may be accompanied by costs that educational interventions do not have (e.g., nudges may not improve decision-making competence like education do or does not change other related, important mental states like trust). Thus, we were interested in evaluating a nudge (framing) against education not only on whether it increased outcome-related targets (e.g., intentions to recycle) but also on other non-target-related outcomes that are more indicative of changes to the individual decision making (e.g., knowledge, trust, and perceptions of justice).

We present evidence from an experiment that a well-constructed educational video that identifies some of the benefits and costs of multi-material plastic is effective at making people more knowledgeable about multi-material plastics compared to a control video. This educational video also shifted people's attitudes, intentions, and perceptions about multi-material plastics toward greater acceptance. In all instances, education was more effective at shifting those variables compared to a framing nudge. All data are available on this project's OSF page: https://osf.io/ndy72/ (accessed on 18 April 2025).

2. Methods

Participants

Four hundred and seventy-three participants were recruited from CloudResearch (Flushing, NY, USA) and were compensated for their participation (USD 1.00). CloudResearch is an online participant recruitment platform where potential participants agree to take part in a study in exchange for compensation (see https://cloudresearch.com (accessed on 18 April 2025) for more details). Research suggests that CloudResearch meets or exceeds standards for the kinds of tasks in our studies (e.g., compared to traditional psychology subject pools [31]). We only allowed participants with an IP address in the United States to participate. Participants ranged from 18 to 74 years old (M = 40.75, SD = 12.14), and 62.56%

were female. Twenty-seven participants did not provide any responses to the survey, so they were excluded. Additionally, participants were excluded if they responded to less than 50% of the items within the survey (N = 14). Thirteen participants were not allowed to continue due to their IP addresses being outside of the United States. Participants (N = 13) were excluded if they did not correctly answer a comprehension check question (a correct response was selecting "false" to "there are 20 days in one week"), resulting in four hundred and six participants retained for analyses. A post-hoc power analysis suggested that this sample size and design would allow us to reliably detect a small overall effect (f = 0.18 with N per group = 67, *power* = 0.8, and *alpha* = 0.05).

3. Materials

We received IRB approval for this experiment and the included materials.

The primary manipulation in this study was whether participants saw an educational video about multi-material plastics or a control video. Public awareness of multi-material plastics is low, at least partially because new research providing new knowledge and best practices in the field can move quickly and the majority of the public is not exposed to these advances [32]. Because of the lack of understanding of multi-material plastics, an educational video could be effective in filling the knowledge gap. Related research suggests that videos are often an effective way to communicate information, especially compared to alternatives like text or infographics [33]. So, we created an educational video after exploring the existing educational media on multi-material plastic. In January 2024, we searched for an educational video and could not find any that (1) were not affiliated with a company or cause (e.g., "ban plastic bags"), thereby potentially creating a conflict of interest; (2) differentiated between the types and recycling processes of different plastics; and (3) provided a nuanced (highlighting both costs and benefits) understanding of plastic. Because technology is still advancing in multi-material plastics, we were not surprised not to find a video satisfying 1–3. Hence, we created a new educational video.

We adopted a two-pronged strategy to create the educational video combining top-down and bottom-up approaches. Starting with the bottom-up approach, we first asked ChatGPT (San Francisco, CA, USA) (version 3.5) to provide a 5-min script covering what the average person should know about multi-material plastic recycling. We believed this approach may allow for adequate sampling of the available information and may buffer against a noted pitfall in the educational plastic literature (e.g., information provided by ChatGPT was not necessarily affiliated with a company or cause, or in our case, a grant). We then consulted with experts in chemical engineering to check the script for accuracy (a top-down approach). The experts provided input on the script, which did not significantly alter the content of the script from ChatGPT (see the OSF page for the initial ChatGPT script and the final expert-revised script).

The video started with some basic facts about plastic, detailing how much we rely on plastic, how plastic is classified, and how little plastic is recycled. The video then explained some of the factors impacting the recyclability of plastic, namely (1) the type (i.e., some plastics are easier to recycle because they are composed of one layer made of one material), (2) the ease of separation and purification (i.e., rigid, solid plastic containers are easy to separate and recycle, whereas plastic films can easily become tangled with other products and machinery, making them more difficult to recycle), and (3) the current state of technology (i.e., we currently only have technology to recycle efficiently certain types of plastic, such as PET and HDPE, but not other types of plastic, such as multi-material films). The video then discusses mechanical recycling, which is the process through which most plastic is currently recycled, and how mechanical recycling is unable to recycle multi-material films. Because we wanted to provide a nuanced understanding (i.e., both costs

and benefits), we then highlighted some of the beneficial properties of multi-material films (e.g., extends the shelf life of fresh products, greater durability in changing temperature conditions, less quantity needed). Chemical recycling, one (but not the only) proposed method to recycle multi-material films, was then highlighted, briefly explaining the process as one in which chemical reactions convert plastics into their original compounds or into a different type of compound to facilitate recycling. We focused on only one potential novel technology rather than several (i.e., enzymatic or biological recycling) for two main reasons. First, the length of the video needed to be short to ensure that participants watched the video. Second, we knew of no empirical reason to think that the specific kind of novel technology would make a difference in the outcome variables we measured. We assumed one novel technology would be functionally identical to all novel technologies in the video (although future research could test this). The video concludes by informing viewers that researchers are currently working on energy and cost-efficient ways to carry out chemical recycling and separation processes on a larger scale. The length of the educational video was 5 min and 8 s, and can be viewed here: https://youtu.be/x1zclNe1OD4 (accessed on 1 July 2024).

Procedure

After providing informed consent, participants were randomly assigned to either the education condition, where they watched the video on plastic recycling, or the no-education condition, where they watched a video on the lifecycle of sea turtles (https://youtu.be/xAbAwgWyinQ (San Bruno, CA, USA), accessed on 1 July 2024). The no-education video was selected because it was approximately equal in length to the plastic education video (5:13) and did not contain any content about plastic or plastic recycling. To ensure participants paid attention to the video, they responded to a multiple-choice attention-check item: "The video was about _____." For the control video, the response options were sea turtles, starfish, sharks, or jellyfish. For the education video, the response options were plastic recycling, paper recycling, glass recycling, or aluminum recycling. Anyone answering incorrectly was excluded from analyses.

After viewing one of the two videos, we randomly assigned participants to receive one of three hypothetical scenarios involving a plastic recycling company. We included different versions of the scenario to test *framing nudges*. We included this additional manipulation to explore the comparative effects of the educational video to more traditional choice architecture interventions commonly used in the environmental domain [16]. The framing manipulation systematically changed the description of how much plastic was recycled, while remaining arguably logically equivalent [13,20,34]. While framing nudges are typically presented dichotomously in the literature (e.g., positive/gain vs. negative/loss), we included an additional "neutral" frame to act as a control.

The scenario we used for the positive (underlined), negative (italics), and neutral (normal) font framing nudge conditions, respectively (in brackets), was:

> "Recycling Company A estimates that they [recycle 20–30%/*do not recycle 70–80%*/recycle some] of the plastic they receive. Previously Recycling Company A did not accept certain types of plastic waste, but one day they announce that they will invest in new technologies to recycle plastic waste that they previously did not accept."

Individuals were instructed to read the passage carefully, as they would be asked a series of questions regarding Recycling Company A.

After reading one of the scenarios, participants responded to a set of questions about (1) their knowledge of multi-material plastic (see Table 1); (2) their satisfaction with the company (see Table 2); (3) their intention to use the company (see Table 3); (4) their trust

in the company [35] (see Table 4); and (5) how just they viewed the company [36–38] (see Tables 5–8 for distributive, procedural, interpersonal, and informational justice, respectively).

Table 1. Multi-material plastic knowledge items.

Item	T/F	% Correct
Multi-material plastic films require more plastic for packaging meat than plastic film made of a single type of plastic.	F	19.21
Multi-material packaging films have different layers of materials that are difficult to separate.	T	68.72
Multi-material plastic films are regularly recycled.	F	67.00
Multi-material plastic films can be replaced by films consisting of a single layer without adding weight.	F	20.20
Multi-material plastic packaging can extend the shelf life for fresh products compared to single-material plastic packaging.	T	59.61
Multi-material plastic films can be replaced by films consisting of a single layer without compromising function.	F	29.31
Multi-material plastic has layers that can prevent transfer of oxygen through the film.	T	61.58
Multi-material plastic has layers that can prevent transfer of moisture through the film.	T	64.29
Multi-material plastic has layers that can prevent transfer of light through the film.	T	35.22

Notes. Participants could indicate whether they believed each item was true (T), false (F), or they could select "I don't know". Correct responses were coded as 1, and incorrect responses or "I don't know" were coded as 0. We used the sum of items in all analyses.

Table 2. Satisfaction with a hypothetical recycling company (Recycling Company A) items.

Item	*M*	*SD*
I am satisfied with Recycling Company A.	4.63	1.28
I am satisfied with the types of plastic Recycling Company A accepts.	2.55	1.48
Recycling Company A is doing a good job.	4.84	1.26
I trust Recycling Company A.	4.54	1.19
I know Recycling Company A has a good reason for the certain kinds of plastic they don't accept.	4.91	1.22

Notes. *M* (mean) and *SD* (standard deviation) of the satisfaction items. Participants indicated their level of agreement with each item on a 7-point Likert scale (strongly disagree–strongly agree). The mean response for each participant was calculated for further analysis. Cronbach's $\alpha = 0.89$.

Table 3. Intentions with a hypothetical recycling company (Recycling Company A) items.

Item	*M*	*SD*
I would use Recycling Company A to recycle plastic.	5.06	1.21
I would recommend to others in my community to use Recycling Company A.	4.70	1.36
I would encourage my neighbors who don't currently recycle to use Recycling Company A.	4.83	1.41
I would encourage friends or family that moved to my area to use Recycling Company A.	4.71	1.40
I would use Recycling Company A whenever I could.	4.88	1.30

Notes. *M* (mean) and *SD* (standard deviation) of the intention items. Participants indicated their level of agreement with each item on a 7-point Likert scale (strongly disagree–strongly agree). The mean response for each participant was calculated for further analysis. Cronbach's $\alpha = 0.94$.

Table 4. Exploratory factor analysis (EFA) for satisfaction items.

Item	Factor 1
I am satisfied with Recycling Company A.	0.99
I am satisfied with the types of plastic Recycling Company A accepts.	0.86
Recycling Company A is doing a good job.	0.86
I trust Recycling Company A.	0.73
I know Recycling Company A has a good reason for the certain kinds of plastic they don't accept.	0.51

Notes. Number of factors identified based on factor analysis using principal axis factoring estimation and oblique oblimin rotation. $\chi^2(1) = 0.74$, $p = 0.39$. RMSEA = 0.00, 90% CI = 0.00–0.10. 68.4% variance explained.

Table 5. Exploratory factor analysis (EFA) for intention items.

Item	Factor 1
I would use Recycling Company A to recycle plastic.	0.78
I would recommend to others in my community to use Recycling Company A.	0.89
I would encourage my neighbors who don't currently recycle to use Recycling Company A.	0.93
I would encourage friends or family that moved to my area to use Recycling Company A.	0.99
I would use Recycling Company A whenever I could.	0.74

Notes. Number of factors identified based on factor analysis using principal axis factoring estimation and oblique oblimin rotation. $\chi^2(1) = 0.32$, $p = 0.57$. RMSEA = 0.00, 90% CI = 0.00–0.10. 77.4% variance explained.

Table 6. Trust in a hypothetical recycling company (Recycling Company A) items.

Item	*M*	*SD*
I trust that Recycling Company A in the future will provide me with good information about possible problems with plastic recycling.	4.91	1.20
I trust Recycling Company A to manage any risk that may be associated with plastic recycling.	4.84	1.21
I trust Recycling Company A to ensure safe and quality plastic recycling.	4.93	1.14
I can depend on Recycling Company A to provide a good-quality plastic recycling service.	4.79	1.21
I have complete trust in Recycling Company A to provide me with good-quality recycling services.	4.50	1.28
I trust Recycling Company A to ensure the plastic recycling processes are healthy and safe.	4.72	1.19
I have complete trust in Recycling Company A to ensure I have healthy and safe plastic recycling.	4.57	1.22
I have complete trust in any information about plastic recycling given to me by Recycling Company A.	4.45	1.26
I have complete trust in Recycling Company A to manage our plastic waste responsibly.	4.55	1.28

Notes. *M* (mean) and *SD* (standard deviation) of the trust items. Participants indicated their level of agreement with each item on a 7-point Likert scale (strongly disagree–strongly agree). The mean response for each participant was calculated for further analysis. Cronbach's $\alpha = 0.96$.

Table 7. Distributive justice perceptions of a hypothetical recycling company (Recycling Company A) items.

Item	*M*	*SD*
The plastic recycling company provides the amount of service I expect.	4.66	1.35
The plastic recycling company provides the quality of service I expect.	4.62	1.36
Recycling waiting time is reasonable.	4.63	1.16

Notes. *M* (mean) and *SD* (standard deviation) of the distributive justice items. Participants indicated their level of agreement with each item on a 7-point Likert scale (strongly disagree–strongly agree). The mean response for each participant was calculated for further analysis. Cronbach's $\alpha = 0.81$.

Participants were asked nine T/F items about multi-material plastics that had been previously verified as correct by experts in the field (see Table 1). Participants could indicate whether they believed the item was true, false, or they could select "I don't know". We added the number of correct responses for each participant (from 0 to 9) and used the sum for further analysis. We hypothesized that those who viewed the educational video would be more knowledgeable about multi-material plastic and that knowledge would translate to other important outcomes [12]. We anticipated that the effect of the educational video on multi-material knowledge would persist in all framing conditions (i.e., participants would be more knowledgeable if they watched the video than if they had not in all framing

conditions). We did not anticipate that those who did not watch the educational video would be any more knowledgeable about multi-material plastics regardless of the frame they received.

Table 8. Procedural justice perceptions of a hypothetical recycling company (Recycling Company A) items.

Item	*M*	*SD*
The plastic recycling company helps all recyclers get the outcomes they need without favoring any one group.	4.45	1.26
The plastic recycling company produces desired results for all recyclers without bias of any kind.	4.53	1.35
The plastic recycling company delivers good outcomes for all recyclers regardless of who they are.	4.67	1.36

Notes. *M* (mean) and *SD* (standard deviation) of the procedural justice items. Participants indicated their level of agreement with each item on a 7-point Likert scale (strongly disagree–strongly agree). The mean response for each participant was calculated for further analysis. Cronbach's $\alpha = 0.91$.

The rest of the measures participants responded to pertained to Recycling Company A, the hypothetical recycling company introduced in the framing nudge. Participants were asked to indicate their level of agreement with statements assessing each measure on a 7-point Likert scale. We constructed items assessing participants' satisfaction with and intentions to use Recycling Company A (see Tables 2 and 3 for items and descriptives; see Tables 4 and 5 for exploratory factor analyses).

Satisfaction with and intentions to use Recycling Company A were our main targeted outcome variables (i.e., outcomes often targeted with nudges). While satisfaction and intentions are not actual behaviors, they are often positively related to behaviors (e.g., the more satisfied one is with a provider and the more they intend to take part in a behavior, the more likely one is to participate in the behavior with that provider). While behavioral intentions are not the sole predictor of behaviors, they are often related to actual behavioral change [39]. We hypothesized that those who watched the educational video would be more satisfied with and have higher intentions to use Recycling Company A. While we anticipated some effect of the framing nudge, we did not have explicit directional hypotheses (e.g., positive frame more effective than negative frame or vice versa) due to the mixed results in the literature on framing nudges both across and within domains.

The trust measure was adapted from a validated existing measure [35,40]. Trust is not a typical target of nudges since it is not a specific behavioral outcome, but it is nonetheless often taken to be an important element of effective interventions. Participants were asked to rate their level of agreement with nine items assessing their level of trust in Recycling Company A (see Table 6). We hypothesized that individuals who watched the educational video would be more trusting of Recycling Company A due to their increased understanding of why this company had previously rejected certain types of plastic. We did not have any explicit hypotheses for how trust would vary as a function of the framing nudge.

Participants then responded to sixteen items assessing their perceptions of distributive, procedural, interpersonal, and informational justice of Recycling Company A (see Tables 7–10). We measured perceptions of justice using a scale that was adapted and validated from the existing literature (see [36–38,41–48]). We had explicit hypotheses only regarding informational justice, anticipating that individuals who had viewed the educa-

tional video would perceive recycling information as more open, accessible, and tailored to their needs. While we did not have explicit hypotheses pertaining to distributive, procedural, and interpersonal perceptions of justice, we still included these measures, as justice is commonly measured as a multi-factor construct [36,38].

Table 9. Interpersonal justice perceptions of a hypothetical recycling company (Recycling Company A) items.

Item	*M*	*SD*
The plastic recycling company is polite.	4.65	1.03
The plastic recycling company is respectful.	4.72	1.03
The plastic recycling company treats recyclers with dignity.	4.70	1.00
The plastic recycling company is courteous.	4.70	1.02
The plastic recycling company is friendly.	4.69	1.00

Notes. *M* (mean) and *SD* (standard deviation) of the interpersonal justice items. Participants indicated their level of agreement with each item on a 7-point Likert scale (strongly disagree–strongly agree). The mean response for each participant was calculated for further analysis. Cronbach's $\alpha = 0.95$.

Table 10. Informational justice perceptions of a hypothetical recycling company (Recycling Company A) items.

Item	*M*	*SD*
The plastic recycling company gives timely and specific explanations.	4.68	1.14
The plastic recycling company gives thorough explanations.	4.49	1.25
The plastic recycling company provides reasonable explanations.	4.66	1.24
The plastic recycling company tailors their explanations to meet recycler needs.	4.49	1.17
The plastic recycling company gives open communication with customers.	4.72	1.14

Notes. *M* (mean) and *SD* (standard deviation) of the informational justice items. Participants indicated their level of agreement with each item on a 7-point Likert scale (strongly disagree–strongly agree). The mean response for each participant was calculated for further analysis. Cronbach's $\alpha = 0.93$.

Finally, participants filled out demographic information and were thanked for participating in the study.

4. Results

For all relevant outcome variables (i.e., multi-material plastic knowledge, satisfaction, intentions, trust, and justice perceptions), we conducted 2 × 3 ANOVAs. Test statistics and effect sizes for the educational video and the framing nudge can be found in Table 11. Figures 2–9 illustrate post-hoc comparisons for each analysis.

Table 11. 2 (education vs. no education) × 3 (positive vs. neutral vs. negative nudge) ANOVA for each outcome variable.

Outcome		df	*F*	*p*	η^2
Multi-Material Knowledge	Education	1	202.68	<0.001	0.34
	Framing Nudge	2	0.12	0.81	0.00
	Education × Framing Nudge	2	0.88	0.42	0.00
Satisfaction	Education	1	33.20	<0.001	0.07
	Framing Nudge	2	26.93	<0.001	0.11
	Education × Framing Nudge	2	2.18	0.11	0.01
Intentions	Education	1	16.21	<0.001	0.04
	Framing Nudge	2	24.98	<0.001	0.11
	Education × Framing Nudge	2	0.26	0.77	0.00
Trust	Education	1	9.27	<0.01	0.02
	Framing Nudge	2	7.18	<0.001	0.03
	Education × Framing Nudge	2	0.40	0.67	0.00
Distributive Justice	Education	1	19.48	<0.001	0.04
	Framing Nudge	2	14.84	<0.001	0.07
	Education × Framing Nudge	2	0.27	0.76	0.00
Procedural Justice	Education	1	4.12	<0.05	0.01
	Framing Nudge	2	12.36	<0.001	0.06
	Education × Framing Nudge	2	0.82	0.44	0.00
Interpersonal Justice	Education	1	9.52	<0.01	0.02
	Framing Nudge	2	3.86	<0.05	0.02
	Education × Framing Nudge	2	0.28	0.75	0.00
Informational Justice	Education	1	24.26	<0.001	0.06
	Framing Nudge	2	7.11	<0.001	0.03
	Education × Framing Nudge	2	0.24	0.79	0.00

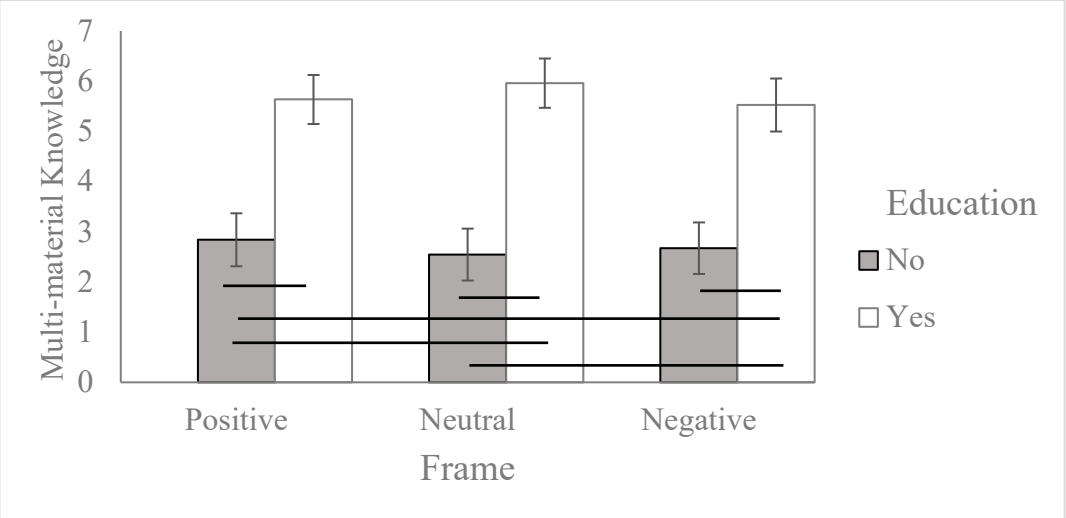

Figure 2. Multi-material knowledge 2 (education vs. no education) × 3 (positive vs. neutral vs. negative nudge) ANOVA. Notes. Marginal means for each condition with 95% CIs. Solid lines indicate post-hoc comparisons, $p_{tukey} < 0.001$.

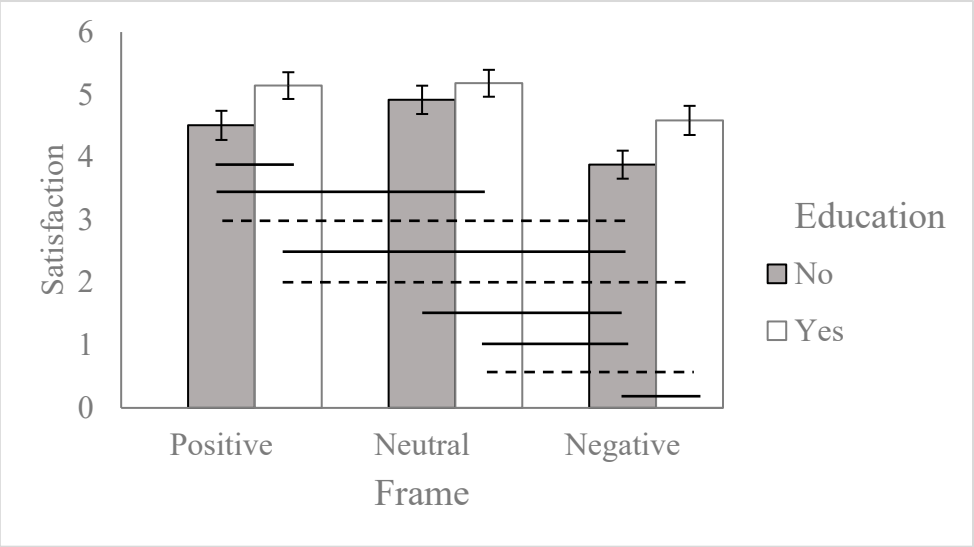

Figure 3. Satisfaction 2 (education vs. no education) × 3 (positive vs. neutral vs. negative nudge) ANOVA. Notes. Marginal means for each condition with 95% CIs. Solid lines indicate post-hoc tests $p_{tukey} < 0.001$. Dashed lines indicate post-hoc tests $p_{tukey} < 0.01$.

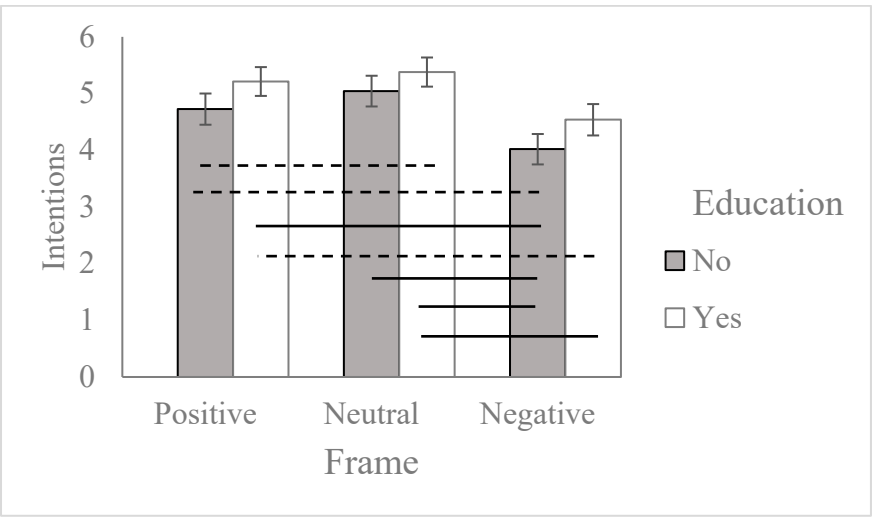

Figure 4. Intentions 2 (education vs. no education) × 3 (positive vs. neutral vs. negative nudge) ANOVA. Notes. Marginal means for each condition with 95% CIs. Solid lines indicate post-hoc tests $p_{tukey} < 0.001$. Dashed lines indicate post-hoc tests $p_{tukey} < 0.01$.

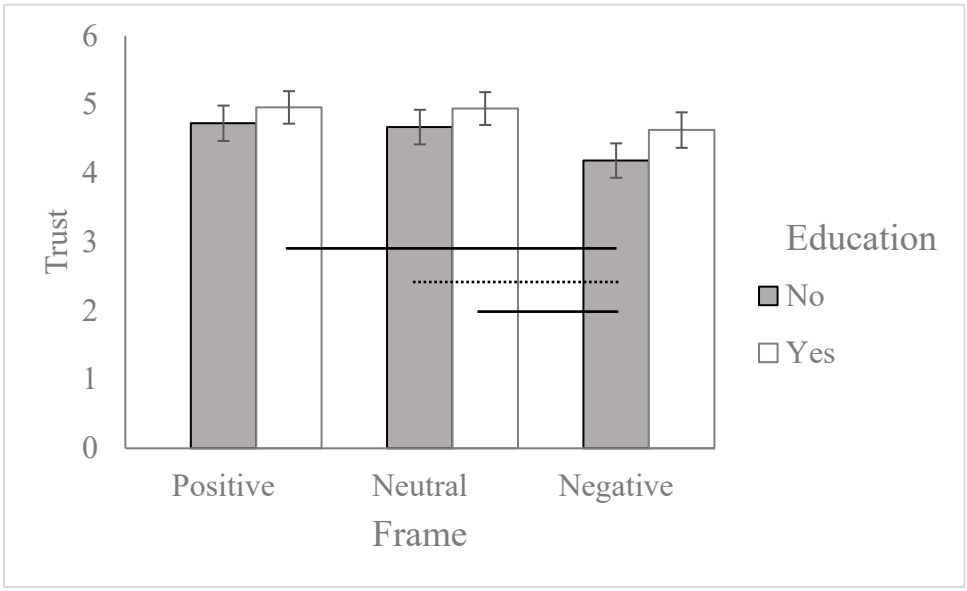

Figure 5. Trust 2 (education vs. no education) × 3 (positive vs. neutral vs. negative nudge) ANOVA. Notes. Marginal means for each condition with 95% CIs. Solid lines indicate post-hoc tests $p_{tukey} < 0.001$. Dotted lines indicate post-hoc tests $p_{tukey} < 0.1$.

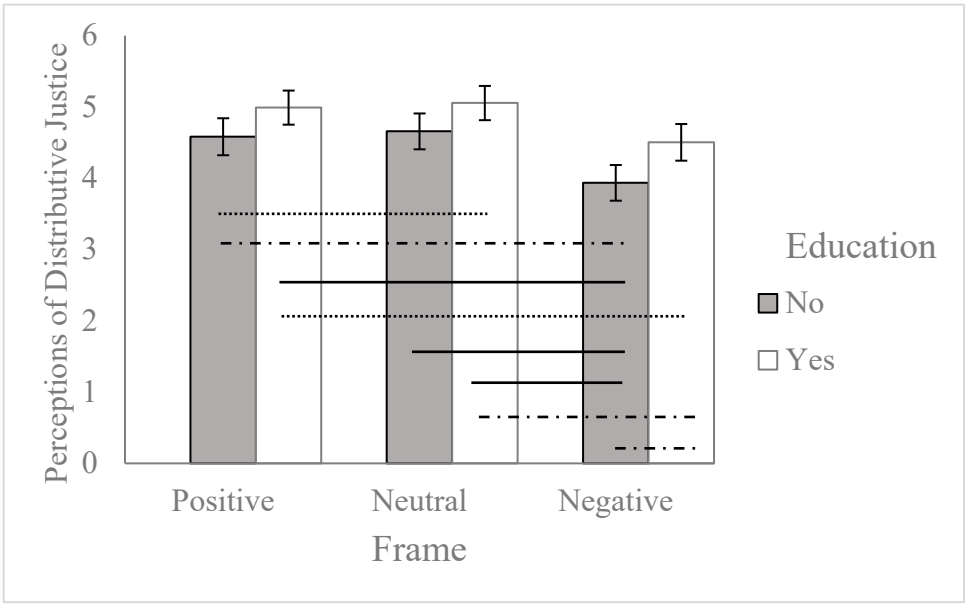

Figure 6. Distributive justice 2 (education vs. no education) × 3 (positive vs. neutral vs. negative nudge) ANOVA. Notes. Marginal means for each condition with 95% CIs. Solid lines indicate post-hoc tests $p_{tukey} < 0.001$. Dash-dotted lines indicate post-hoc tests $p_{tukey} < 0.05$. Dotted lines indicate post-hoc tests $p_{tukey} < 0.1$.

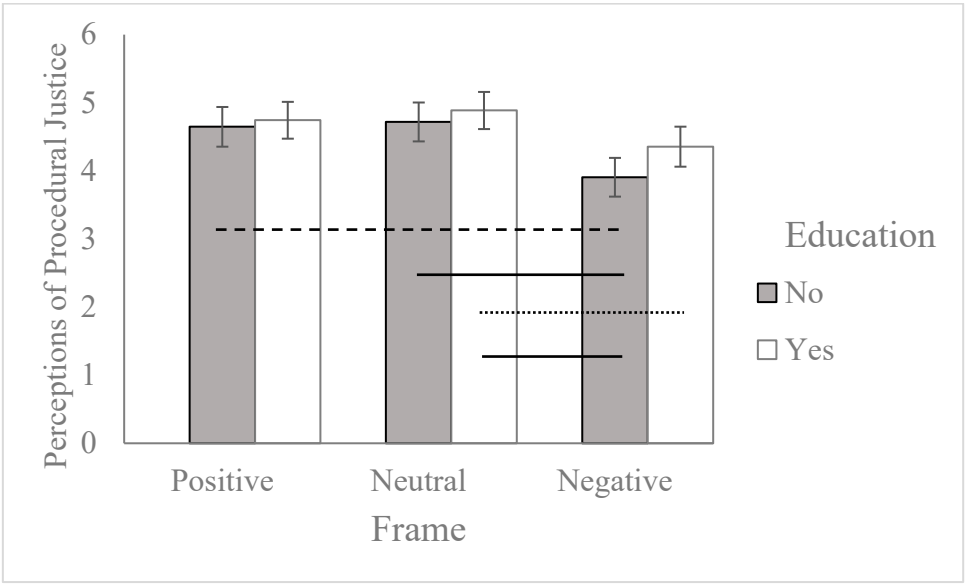

Figure 7. Procedural justice 2 (education vs. no education) × 3 (positive vs. neutral vs. negative nudge) ANOVA. Notes. Marginal means for each condition with 95% CIs. Solid lines indicate post-hoc tests $p_{tukey} < 0.001$. Dashed lines indicate post-hoc tests $p_{tukey} < 0.01$. Dotted lines indicate post-hoc tests $p_{tukey} < 0.1$.

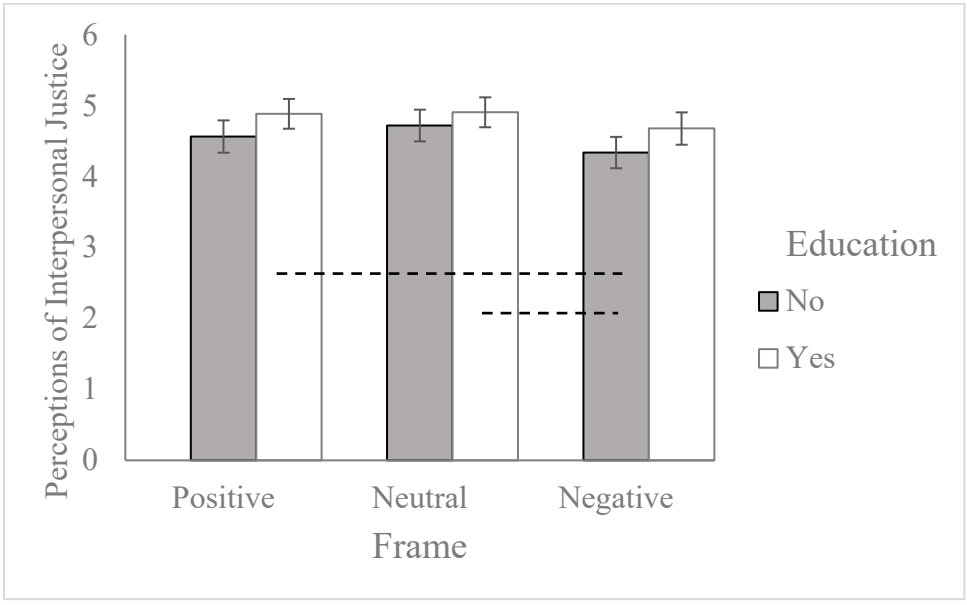

Figure 8. Interpersonal justice 2 (education vs. no education) × 3 (positive vs. neutral vs. negative nudge) ANOVA. Notes. Marginal means for each condition with 95% CIs. Dashed lines indicate post-hoc tests $p_{tukey} < 0.01$.

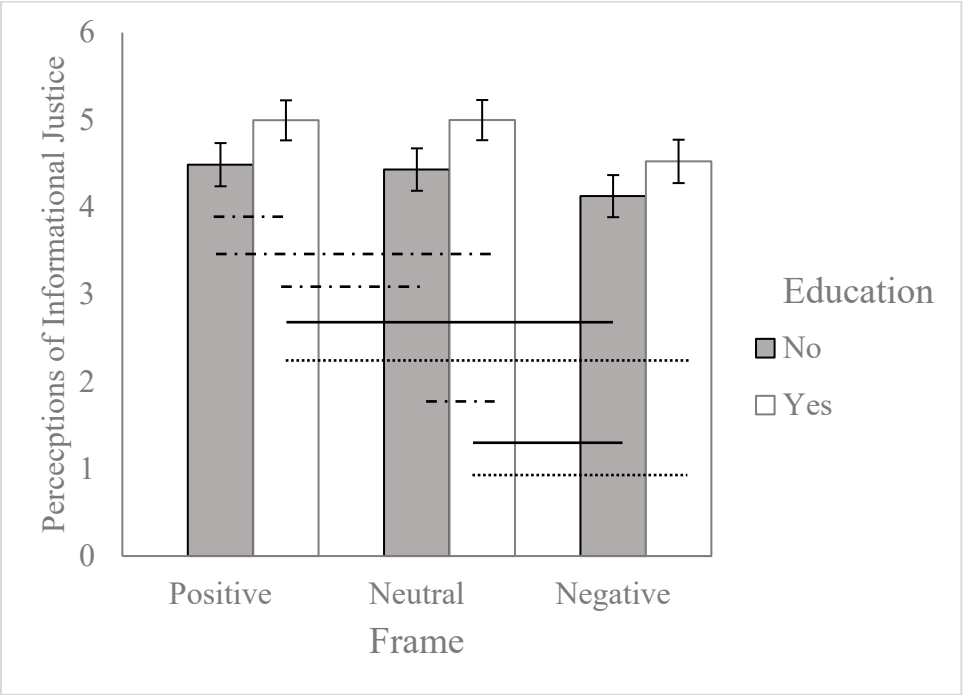

Figure 9. Informational justice 2 (education vs. no education) × 3 (positive vs. neutral vs. negative nudge) ANOVA. Notes. Marginal means for each condition with 95% CIs. Solid lines indicate post-hoc tests $p_{tukey} < 0.001$. Dash-dotted lines indicate post-hoc tests $p_{tukey} < 0.05$. Dotted lines indicate post-hoc tests $p_{tukey} < 0.1$.

There was a significant main effect of education on multi-material knowledge (see Figure 2). As hypothesized, those who viewed the educational video were more knowledgeable about multi-material plastic than those who did not view the educational video in all framing nudge conditions. There was no main effect of the framing nudge, and there was no interaction.

There was a significant main effect for both education and the framing nudge for the satisfaction and intentions outcome variables (see Figures 3 and 4). The interaction was not significant. Those who viewed the educational video were always just as, if not significantly more, satisfied and had similar or significantly higher intentions to use Recycling Company A than those who did not watch the educational video. Interestingly, there were no significant differences in satisfaction and intentions between those who read the positively framed message compared to the neutral message, unless they were educated. In that case, participants were significantly more satisfied and had significantly higher intentions. Rather, the main effect of the framing nudge is evident in those who received the negatively framed message, expressing significantly lower satisfaction and intentions to use Recycling Company A compared to those who received the positively and neutrally framed messages.

When trust was the outcome variable, there were main effects of the education intervention and the framing nudge, with no significant interaction (see Figure 5). Post-hoc comparisons revealed that those who did not watch the educational video and received the negatively framed message had significantly lower trust than those in other conditions.

Finally, there were main effects for each of the justice factors for both education and framing nudge, with no interaction (see Figures 6–9). In line with our hypothesis, those who viewed the educational video viewed Recycling Company A as more informationally just in all framing conditions except the negative frame. There were no differences in perceptions of informational justice between those who viewed the positive and neutrally

framed messages unless they had been educated, in which case they had significantly higher perceptions of informational justice. Again, it was those who received the negatively framed message that had significantly lower justice perceptions. Though we did not have any explicit hypotheses for the rest of the justice factors (i.e., distributive, procedural, and interpersonal), there was a similar pattern of results where those who watched the educational video had greater perceptions of justice than those who did not, and those who received the negatively framed message had lower perceptions of justice than those who received the positively or neutrally framed messages.

The results from the post hoc comparisons for each analysis (see Tables 1–8 on OSF) suggest that overall, those who were educated were never 'worse off' (e.g., less knowledgeable, less favorable views) than those who were not educated, but sometimes they were better. The same cannot be said for nudges. Participants in the neutral (control) nudge condition were consistently similar to those who received the positive nudge. Participants who received the negative nudge appear to have consistently less favorable views towards the hypothetical company. Our results suggest that rather than the positive nudge increasing favorability, the negative nudge may decrease favorability (compared to the control or 'doing nothing').

5. Discussion

Our results suggest that a five-minute educational video can provide individuals with a better understanding of multi-material plastics. Additionally, those who viewed the video were more likely to have higher intentions to use and be satisfied with a hypothetical recycling company that plans to begin recycling multi-material plastic. Participants were also more likely to trust and perceive the hypothetical recycling company as more just if they had viewed the educational video. We also detected an effect of framing nudges. However, those framing nudges did not alter what participants knew and never performed better than education. Our data suggest that in some cases, framing nudges (i.e., negative frames) performed substantially worse than education.

These results may be important because they provide evidence that well-designed educational interventions can help positively influence knowledge and other important outcome variables about novel technologies like those involved in multi-material plastic recycling. The literature on plastic recycling and educational interventions is mixed, with some evidence suggesting that educational interventions can work and some suggesting that there are no effects. This trend holds for studies examining previous research both in the United States and beyond (e.g., UK, Germany, Hong Kong) [49]. However, it is important to note that not all education interventions try to provide a representative understanding (e.g., an informative poster by a recycling can attempts to quickly relay information to recyclers rather than impart a representative understanding). Our data suggest three potential explanations for the moderate to large effects for education in our studies. First, previous studies have primarily focused on subjective knowledge of plastic recycling, awareness of the consequences of plastic waste along with campaigns to mitigate it, or a combination of subjective and objective questions (e.g., "how much do you think you know about plastic recycling") [50–52]. Our knowledge measure was an objective measure, making it less likely that one overestimates what one knows compared to subjective measures. Second, to our knowledge, this is the first experiment that has attempted to impart a nuanced understanding of (1) challenges to recycling different kinds of plastics, (2) kinds of recycling processes, (3) benefits of multi-material plastics, and (4) novel approaches to recycling multi-material plastics. Finally, our two-pronged strategy may have sampled more representative information compared to other, more top-down approaches, though it is important to note that the population of information

sampled by ChatGPT is unknown. Future research could explore which, which combination, or what other factors might have been responsible for the relatively large effects of the education video.

It is also worth mentioning that our data suggest that the deployment of framing nudges comes with some potential risks. In our study, framing did not make participants any more knowledgeable about multi-material plastic recycling. However, importantly, the positive frame only caused more favorable attitudes and intentions compared to the negative frame. This is traditionally how framing nudges are tested (i.e., positive vs. negative frames, but see [11]). If one were only to look at those two data points, one might think that positive frames might be a viable, effective option to improve plastic recycling attitudes. However, this conclusion might be somewhat misleading. While it is true that positive frames performed significantly better than negative frames, the positive frame never performed better than the neutral frame (i.e., no frame, indicating participants were not nudged) that described the company as recycling "some" plastic. This pattern of results is consistent with the view that positive frames do not increase favorable attitudes, but rather negative frames decrease favorable attitudes. As such, one might be cautious about deploying framing to increase acceptance of plastic recycling, as our data suggest we should not use framing nudges to increase plastic recycling.

Apart from the effectiveness of framing nudges, the value of successfully imparting knowledge to individuals may extend to other important considerations when designing and implementing choice architecture interventions. There is mounting evidence that education interventions tend to protect ethical and legal values (e.g., autonomy, beneficence, trust, justice) while performing as well as, or better than, some common types of choice architecture (e.g., framing, defaults) [14,33,35,37,53–55]. Our study is consistent with these general results concerning education and other types of choice architecture.

There are limitations worth considering. First, we only conducted one study with hypothetical stimulus materials, a noted limitation for pro-environmental choices [26]. While there is some relation between hypothetical cases and actual behaviors, the relation is not perfect [33,39]. Second, we only collected responses from participants who had U.S. IP addresses. For that reason, it may be risky to generalize to other populations that may have different plastic recycling infrastructure, experiences, and knowledge. Third, we did not measure which elements (or combination of elements) in the educational video contributed to changes in knowledge and related attitudes about plastic recycling. It could be that some elements of the video were more important than others. Additionally, there are many other aspects of plastic recycling that the video did not cover. As such, one might be able to construct a shorter video or a video with different content that has bigger effects than the video that we used. Finally, as research on and policies about plastic recycling can rapidly develop, educational interventions are likely to require maintenance and updating.

6. Conclusions

Our results suggest that a brief informative video that provides a representative understanding of multi-material plastic recycling can make individuals more knowledgeable, more satisfied, and more likely to use a recycling company that plans to begin recycling multi-material plastics. That company is also seen as more trustworthy and just. The framing nudge, however, seemed only to reduce those same variables. These results may help inform campaigns aimed at increasing recycling, especially recycling that involves novel technologies or aims to increase recycling of currently unrecyclable materials. Moreover, changes in knowledge, trust, and justice are likely to help constitute more enduring changes compared to situation-specific nudges. These changes are likely to translate to greater stakeholder buy-in and support for new and current recycling initiatives.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The coded original data presented in the study are openly available in Open Science Framework at https://osf.io/ndy72/.

Conflicts of Interest: The authors declare no conflict of interest.

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