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Development of an objective measure of knowledge of plastic recycling: The outcomes of plastic recycling knowledge scale (OPRKS)☆

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ABSTRACT

We are witnessing exponential trends in the production and use of plastic. This exponential increase can largely be attributed to the benefits certain kinds of plastic have. However, there are harmful consequences of plastic use and disposal. Recycling plastic is one potential way to mitigate the harmful consequences of plastic disposal, yet people in the United States recycle at a low rate (~20–30% of recyclable material). One factor likely related to recycling behaviors is objective knowledge of plastic recycling. No instrument exists to measure objective knowledge of plastic recycling. In three studies, (N = 224, 195, and 246) we developed a 13-item objective measure of knowledge of plastic recycling, the Outcomes of Plastic Recycling Knowledge Scale (OKPRS). The 13-item measure predicted attitudes towards recycling, subjective norms, subjective knowledge, and environmental concern. The OKPRS also uniquely predicted positive recycling behaviors in addition to attitudes towards recycling, subjective norms, subjective knowledge, and environmental concern. Having a measure of objective recycling knowledge fills a void in models predicting plastic recycling and may help us estimate if, and to what extent, educational interventions increase desirable recycling behaviors.

What do people know about plastic recycling? Currently, we do not have a good answer to that question. While attitudes and perceptions of recycling in general have been well explored, relatively little work has been done concerning what people know about plastic recycling. Here, we attempt to help address that gap by developing a short, 13-item measure of objective knowledge regarding plastic recycling, the Outcomes of Plastic Recycling Knowledge Scale (OKPRS). In Studies 1 and 2, we used Item Response Theory to identify 13 items to measure objective knowledge of plastic recycling. Study 3 provides initial evidence that the OKPRS predicts criterion variables (e.g., positive recycling behaviors), is related to similar instruments (e.g., positive attitudes towards recycling, subjective norm, perceived behavioral control, environmental concern), and is unrelated to theoretically unrelated constructs (e.g., extraversion, emotional stability, age, sex). Study 3 also provides evidence that objective knowledge can uniquely predict positive recycling behaviors beyond factors such as environmental concern, positive recycling attitudes, or perceived recycling control. We close by discussing the potential utility of using an objective measure of plastic recycling knowledge (e.g., testing effectiveness of educational interventions).

1. Predictors of plastic recycling

We are currently producing plastic at rates per year that are greater than previous decades worth of plastic production, yet only 9% of the plastic we have ever produced has been recycled (Eco Watch, 2014, April 7; RTS, 2019). Plastic waste can take hundreds of years to decompose, often having a lasting impact on the environment, wildlife, and humans (Cheung, Chow, & So, 2018; Brucker, 2018; Eco Watch, 2014, April 7). Despite these impacts, recycling rates in the United States currently range from 20% to 30% (*Facts on Plastic, 2020*). But why?

Any answer to that question will be complicated and involve many different elements (e.g., availability of recycling in one's community; ease of recycling; having recyclable products). Here, we focus on psychological factors that have been associated with plastic recycling

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behaviors or intentions to recycle plastic (for a review, see Heidbreder, Bablok, Drews, and Menzel (2019)). These psychological factors include awareness of consequences of plastic recycling, general attitudes towards recycling, subjective norms, and perceived control (Dilkes-Hoffman, Pratt, Laycock, Ashworth, & Lant, 2019; Guagnano, Stern, & Dietz, 1995; Kahn, Ahmed, Najmi, & Younus, 2019). In general, those who are more aware of the consequences of not recycling, have positive attitudes towards recycling, believe their friends, family, and neighbors think that they should recycle, feel as though they have the ability to recycle, and perceive desirable external conditions (e.g., have access to curbside recycling) are more likely to recycle plastic or intend to recycle plastic than people lower on those dimensions.

One element that has received relatively less attention is what people know about plastic recycling, even though knowledge has been identified as a major factor for general recycling behaviors (for a review, see Varotto and Spagnolli (2017)). From a theoretical perspective, we expect knowledge to factor into how people interact and behave with recycling practices. To help illustrate, the theoretical framework we are adopting is the Framework for Skilled Decisions (Cokely et al., 2018). On this model (see Fig. 1), skilled decisions (i.e., high quality decisions) about plastic recycling are likely a function of both proximal factors and more distal factors. Consistent with other standard models in decision making, two of those proximal factors are what one knows and attitudes or value one has (see also Baron (2008)). In addition, the model posits that one's confidence and how long and well one deliberates can indirectly influence a skilled decision. More distally, general cognitive abilities (e.g., numeracy, or the ability to understand and use statistics) have been indirectly related to decisions. Finally, decisions are not made in a vacuum and there are several environmental factors the influence decisions. Here, the model posits that education is related to more skilled decisions. To illustrate, it would be surprising if what people know about plastic recycling is not (at least partially) related to the decisions they make. If one does not know that one can recycle #2 plastic, then it is not likely that one will reliably recycle #2 plastic regardless of one's attitudes towards recycling. Consequently, being able to measure each of these factors, including what one knows about recycled plastic, is important to predicting skilled plastic recycling decisions.

Previous research on general recycling and plastic recycling specifically has shown that some kinds of knowledge are correlated with plastic recycling relevant behaviors and attitudes (Heidbreder et al., 2019; Varotto & Spagnolli, 2017). In previous studies, knowledge has mainly been explored with subjective measures. Subjective measures of knowledge ask participants what they think they know about a topic. For example, Afroz, Rahman, Mehedi Masud, and Akhtar (2017) asked participants to indicate whether they were aware of the "no plastic bag campaign," whether they knew harmful consequences of plastic bags such as animal death and human health problems, if they were aware of the motivational factors of using plastic (e.g., cheapness, durability, and availability), and how industries are contributing to the plastic problem (see also Goldsby (1998)). All these questions ask participants to self-report how much they think they know about, or their awareness of,

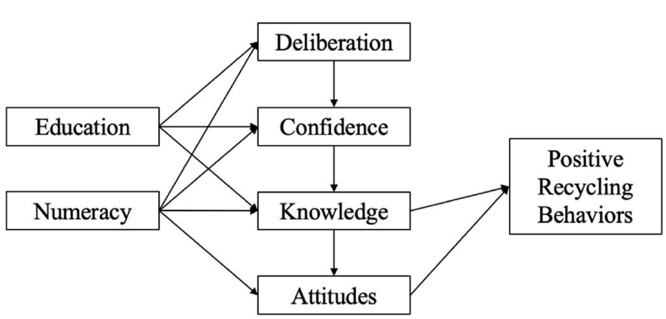

Fig. 1. Framework of skilled decision making.

aspects of plastic recycling. One potential limitation with subjective measures of knowledge is that one could indicate knowledge or awareness of harmful consequences of plastic bags, but perhaps not know the extent of these consequences (e.g., that plastic can end up in our bloodstream). An additional potential limitation is that people may think they know more than they in fact do (e.g., via overconfidence, mistaken self-perceptions, or social desirability).

Objective measures of knowledge focus on whether people understand objective facts about the world rather than on their perceptions of how well they understand those objective facts (Feltz et al., 2022). Some researchers have attempted to understand how much people know about objective facts concerning plastic. For example, Phelan, Ross, Setianto, Fielding, and Pradipta (2020) sought to capture objective knowledge of plastic recycling from individuals in Indonesia using focused interviews. In these interviews, Phelan et al. (2020) asked a series of 14 questions that theoretically had correct and incorrect responses (e.g., "Do fish and other marine animals eat plastic waste?"). However, other questions were not clear objective measures of knowledge (e.g., "What effect does plastic waste have on the environment?" correct answer = negative impact) whereas others were not clearly about plastic recycling ("Organic waste (e.g., food waste, plate litter) thrown on the ground will quickly break down and disappear (become part of the soil)" correct answer = agree). There were also questions that resembled subjective knowledge of plastic recycling (e.g., "Have you ever heard about 'microplastics'—tiny pieces of plastic floating in the ocean" correct answer = 'yes'). So, parts of Phelan's measure incorporate what we call objective knowledge, but those parts were mixed with non-objective and subjective measures. Additionally, all measures were interview based and thereby likely to be resource (e.g., time) intensive.

We set out to build on this previous research to develop a short, non-interview based, objective measure of plastic recycling knowledge and to provide initial evidence for validity of the measure. To foreshadow, Study 1 used Item Response Theory (IRT) to evaluate 51 objective, true/false questions that were developed in consultation with experts on plastic recycling. Study 2 tested a reduced set of items based on the results of Study 1. Study 3 again retested the IRT properties of the items while providing some evidence for construct validity. Study 3 also begins to model recycling behavior including objective knowledge and other factors in line with the Framework for Skilled Decisions.

2. Study 1

Study 1 was designed to test an initial set of items to measure objective knowledge of plastic recycling. The analyses in Study 1 were exploratory and were designed to serve as the basis for subsequent validation studies (i.e., Studies 2 and 3).

2.1. Participants

Two hundred and eighty-seven participants were recruited from Amazon Mechanical Turk and were compensated for their participation in the study ($0.75). Participants recruited from Amazon Mechanical Turk are generally believed to be of acceptable quality for these kinds of survey tasks, especially when compared to typical subject pools (e.g., university undergraduate subject pools; Buhrmester, Kwang, & Gosling, 2011; Buhrmester, Talifar, & Gosling, 2018).

We employed some general data quality checks. Sixty-four participants were excluded for a variety of reasons including incomplete surveys ($N = 29$), missed attention-check questions (e.g., *I have never used a computer*) ($N = 32$), and rapid completion (e.g., under 1 min spent completing survey) ($N = 3$). Two hundred and twenty-three participant responses were retained for further analysis. Due to a coding error, demographic information was not included in the study (but see Studies 2 and 3 for typical demographics for Amazon Mechanical Turk).

2.2. Materials and methods

The 51 recycling knowledge items were created in conjunction with plastic recycling experts (see Appendix A for complete set of items). Participants were randomly presented with the 51 items and could indicate whether they believed the statement was true, false, or they could respond "I don't know." Correct responses were coded as 1, and incorrect or "I don't know" responses were coded as 0.

The responses were analyzed using Item Response Theory (IRT) (Rizopoulos, 2006). IRT is a latent trait estimator that predicts the probability that individuals with varying degrees of an ability will correctly answer a question (Baker & Kim, 2004). For our purposes, the ability that we were measuring was knowledge of plastic recycling. Estimates of difficulty and discrimination were particularly of interest in Study 1. The difficulty (i.e., the location) parameter gives us a quantitative representation of the knowledge level at which 50% of participants will get a question correct, where 0 indicates average ability. For example, a difficulty value of 2 would indicate a relatively difficult question, whereas a value of −2 would indicate a relatively easy question. The discrimination parameter provides a value quantifying how well an item differentiates individuals based on knowledge level. Higher discrimination values are preferred because they demonstrate that individuals at higher ability levels have a greater probability of getting a particular question correct in comparison to individuals of lower ability levels. A discrimination value of 0 indicates that those of lower ability levels (e.g., those that know less about plastic recycling) have the same chance of getting an item correct compared to individuals of higher ability levels (e.g., those that know more about plastic recycling).

2.3. Results and discussion

Percent correct, difficulty, and discrimination values can be found in Table 1. Our initial assumption was that knowledge of plastic recycling could be modeled as a single factor. Some evidence for the unidimensionality of the 51 items was provided from an exploratory factor analysis that was constrained to 1 factor (Ziegler & Hagemann, 2015). Nearly all of the items had moderate to excellent loading on the one factor (factor loadings >0.4, but see supplemental materials for full unconstrained exploratory factory analyses factors with eigenvalues greater than 1. See also the Discussion section for a discussion of the potential for multiple kinds of plastic recycling knowledge). The internal reliability of the 51 items was excellent *Cronbach's alpha* = .9.

We anticipated that a smaller set of items from the initial set of 51 would be selected for future examination based on item-level properties (e.g., low discrimination) and redundancy (e.g., similar items having the same difficulty, thus providing the same information). We first selected items for future analysis based on discrimination values. We eliminated 14 items from future analysis that had discrimination values of 0.67 or less (typically indicating a range for low discrimination) (Baker & Kim, 2004).

Next, we looked at items with similar difficulty. Questions of similar difficulty are not likely to add additional information to the overall measure and could be removed from the measure without loss of information. For example, Item 6 ("Recycling plastic water bottles takes over 50% less energy than making plastic from raw materials" correct answer = 'true') was correctly answered by 52.49% of participants and had a difficulty parameter of −0.11 and Item 12 ("Recycling creates at least 3 times the jobs landfilling does" correct answer = 'true') was answered correctly by 53.81% of participants and had a difficulty parameter of −0.12. To eliminate redundancy, we visually inspected the data to find items with similar difficulties. Then, for each group that had similar difficulties, we selected the item with the highest discrimination value. In this way, we were able to identify 22 items for elimination resulting in 15 items to be tested in subsequent studies (see Table 1 for the justifications for item selection).

Table 1
Percent correct, difficulty, and discrimination values for objective knowledge questions in Study 1 with inclusion criterion for Study 2.

Item	Difficulty	Discrimination	% Correct	Replaced By
1. Enough plastic is thrown away each year to circle the Earth at least 2 times.[b] (T)	−0.97	1.28	72.77	Q19
2. It costs more to recycle trash than to send it to a landfill.[a] (T)	0.95	0.37	41.52	–
3. Over 50% of disposable water bottles are recycled in the United States.[b] (F)	0.34	0.63	45.09	Q13
4. At least 1,000,000 sea creatures are killed annually due to plastic in the ocean.[b] (T)	−0.62	0.92	62.05	Q21
5. Recycling plastic and burning plastic in an incinerator require the same amount of energy.[a] (F)	0.81	0.57	39.29	–
6. Recycling plastic water bottles takes over 50% less energy than making plastic from raw materials.[b] (T)	−0.12	1.50	54.02	Q14
7. The more compounds used to make a particular type of plastic, the more challenging the plastic is to recycle.[b] (T)	−0.94	0.89	67.41	Q19
8. Plastic decomposes in landfills within 50 years.[b] (F)	−0.7	0.65	60.27	Q26
9. It costs more to recycle a plastic water bottle than to incinerate it.[c] (F)	0.85	0.95	33.48	–
10. Over 50% of plastic produced in the US is recycled.[b] (F)	0.19	0.70	46.88	Q27
11. Americans throw away over 1 million plastic bottles every hour.[a] (T)	−0.04	0.67	59.82	–
12. Recycling creates at least 3 times the jobs that land-filling does.* (T)	−0.36	1.36	58.04	–
13. Recycling creates at least 10 times the jobs that incinerating does.* (T)	0.40	2.01	37.95	–
14. Recycling 1 ton of plastic saves more than 20 cubic yards of landfill space.* (T)	−0.29	2.26	61.16	–
15. Styrofoam decomposes within 100 years.[b] (F)	0.56	0.90	39.29	Q13
16. It takes more than a year for a recycled product to be back on the shelf.* (F)	1.61	0.95	20.98	–
17. At least 4 times more plastic waste is incinerated in the U.S. than is recycled.[b] (T)	−0.08	1.44	52.68	Q14
18. By using reusable drink containers an average person can eliminate the need for over 50 disposable bottles per year.* (T)	−1.42	1.38	81.70	–

(*continued on next page*)

Table 1 (*continued*)

Item	Difficulty	Discrimination	% Correct	Replaced By
19. Over 20% of plastic is used once and then discarded.* (T)	−0.85	1.57	72.77	–
20. Less than 50% of what Americans throw away is recyclable.[b] (F)	0.74	0.77	37.50	Q13
21. Recycling plastic reduces carbon dioxide emissions.* (T)	−0.62	1.11	63.84	–
22. Landfills contribute to soil pollution.[b] (T)	−1.61	1.08	80.80	Q18
23. Most plastics are biodegradable.[a] (F)	−1.53	0.55	68.75	–
24. Recycling a single plastic water bottle saves enough energy to run a 100-W bulb for over 2 h* (T)	0.25	1.67	43.30	–
25. Water quality is not impacted by producing plastic from raw materials.[b] (F)	−0.31	0.84	55.80	Q14
26. Over 1 billion styrofoam coffee cups are thrown away every year by Americans.* (T)	−0.81	1.77	73.21	–
27. Recycling 1 ton of simple plastic saves the energy equivalent of leaving a 100 W lightbulb on for 5 years.* (T)	0.15	2.18	55.98	–
28. Recycling is over a $100 billion industry in the U.S.* (T)	0.12	2.09	47.32	–
29. Over 20% of the plastic ever made has been recycled.[a] (F)	2.73	0.36	27.68	–
30. Less than 500,000 plastic bottles are sold every minute.[b] (F)	0.81	0.85	35.27	Q9
31. More than half of the plastic waste in the world comes from 3 basic types of plastic.[b] (T)	−0.17	1.81	56.25	Q14
32. All types of plastic can be recycled in all communities.[a] (F)	−0.73	0.50	58.48	–
33. Not all plastic can be recycled.[a] (T)	−2.04	0.59	11.16	–
34. Plastic must be clean before it can be recycled.[b] (T)	−0.87	0.72	63.84	Q19
35. Whether plastic can be recycled in your community is dependent on the city government.[b] (T)	−1.00	0.77	66.52	Q19
36. Plastic constitutes less than 50% of trash floating on the ocean's surface.* (F)	0.20	0.84	46.43	–
37. Some chemicals in plastic can be absorbed by the body.[a] (T)	−2.29	0.67	79.46	–
38. Many plastics produced today are made from oil.[b] (T)	−1.88	0.82	48.66	Q18
39. The average American throws away more than 150 pounds of plastic per year.* (T)	−0.50	2.38	67.86	–
40. Adding the incorrect type of plastic to a specific recycling bin does not diminish the value of the final recycled produce.[a] (F)	0.32	0.58	45.54	–
41. Biodegradable plastics produce greenhouse gases when they decompose.[b] (T)	0.65	1.02	36.61	Q13
42. Biodegradable plastics are not more widely used because they cost more.[b] (T)	−0.19	0.75	53.13	Q14
43. Multilayer plastic films require more plastic for packaging meat than more traditional plastic.[a] (F)	29.64	0.07	10.27	–
44. Multilayered plastic films are regularly recycled.[b] (F)	0.11	1.03	47.77	Q36
45. Multilayer films cannot be replaced by single-layer films.[c] (F)	1.36	0.83	26.79	–
46. Multilayer packaging films have several thin sheets of materials (including aluminum, plastics, and paper) that are laminated together and are difficult to separate.[b] (T)	0.22	1.84	44.20	Q27
47. Multilayer plastic packaging can yield shelf lives of up to 1 year in challenging weather conditions (high humidity and large increases/decreases in temperature).[b] (T)	0.27	1.98	42.41	Q24
48. Multilayer plastic packaging may prevent light from reaching the contents inside the packaging, resulting in longer shelf lives for edible products.[b] (T)	−0.15	1.72	55.36	Q14
49. Multilayer plastic packaging is extremely light and does not require a lot of material input in comparison to rigid plastic, metals, or glass.[b] (T)	1.02	0.72	33.93	Q9
50. Multilayer plastic packaging costs significantly more in production and transportation of goods.[a] (F)	4.08	0.43	15.63	–
51. Multilayer plastic packaging is stronger than more traditional plastics.[b] (T)	0.05	1.20	59.11	Q36

Note. *indicates items included in final instrument. [a]indicates item eliminated due to low discrimination. [b]indicates item eliminated due to similar difficulty, but lower discrimination than 'Replaced By' item. [c]indicates item was initially kept for Study 2, but eliminated based on post-test expert review.

3. Study 2

In Study 1, we found 15 items that would likely provide a reasonable estimate of what people know about plastic recycling. While we consulted with experts in plastic recycling to construct the best items we could, the actual process of selecting those items was unavoidably (but anticipated to be) post hoc. As such, there is the risk the items we selected only functioned well for the specific sample. Because of this risk, replication is needed. The goal of Study 2 was to replicate the IRT item-level properties of the 15 items identified in Study 1.

3.1. Participants

Two hundred and forty-nine participants were recruited from Amazon Mechanical Turk and were compensated for their participation in the study ($0.75). Participants ranged from 20 to 73 years old (M = 40.59, SD = 12.64) and 50.39% were female. We used some data screening procedures recommended for Amazon Mechanical Turk samples (Arndt, Ford, Babin, & Luong, 2022; Buchanan & Scofield, 2018; Leiner, 2016). We included two attention-check questions (e.g., "*I have never used an electronic device", "humans eat food*"). We excluded participants if they responded anything other than *false* and *true* respectively, eliminating 50 participants. We then checked for straight-lining using the Ten Item Personality Inventory which is a brief measure of the Big Five personality model (Gosling, Rentfrow, & Swann, 2003). For each of the five personality traits, there are two items, in which one is reverse coded (e.g., for extraversion, participants are asked to indicate the extent to which the qualities "extraverted, enthusiastic" and "reserved, quiet" applies to them, where responses for "reserved, quiet" are reverse scored). Because one of the item pairs is reverse scored but measures the same trait, it would be counterintuitive for participants to rate that they are both highly extraverted and enthusiastic as well as highly reserved and quiet (e.g., '7' on both pairs). We checked for straight-lining by calculating the standard deviation of their responses to these ten personality items. Participants with a standard deviation of 0 on the ten items in the Ten Item Personality Inventory were considered to have straight-lined the survey, eliminating another 2 participants. Two participants did not complete the survey. We retained a total of 195 participants.

3.2. Materials

Participants received the 15 items identified in Study 1 in random order with two modifications. We again consulted with experts in plastic recycling to ensure that the items that were selected had face validity. Upon this review, two of the questions (9 and 45) were identified as not having a clear correct answer (or, a correct answer depends on details that were not provided as part of the question). For this reason, those items were excluded from further analyses. The final 13-item Outcomes of Plastic Recycling Knowledge Scale (OPRKS) is presented in Appendix B.

3.3. Results and discussion

Item difficulty, discrimination, and percent correct are in Table 2. Given the replication of item-level properties of the 13 items, we fit the responses to the OPRKS to three different IRT models (Rizopoulos, 2006). First, we fit our data to a one parameter constrained model where discrimination values are set to 1 for each item and difficulty values are free to vary (log likelihood = −1649.10; AIC = 3324.20; BIC = 3368.49). Next, we fit our data to a one parameter unconstrained model where discrimination is set to the average discrimination of all items (log likelihood = −1646.26; AIC = 3320.52; BIC = 3320.52). We then ran an ANOVA to compare the fits of the constrained and unconstrained models. The unconstrained model fit the data better (LRT = 5.67, $p <$ 0.05). We then fit a two-parameter model to the data where discrimination is free to vary by item (log likelihood = −1600.94; AIC = 3253.89; BIC = 3342.47). The two-parameter model had better fit (LRT = 90.64, $p <$ 0.001) than the one-parameter unconstrained model. Hence, the rest of the IRT analyses were performed on a two-parameter model.

Table 2
Difficulty, Discrimination, and Percent Correct for 13 items in Studies 2 and 3.

Item	Study	Difficulty	Discrimination	% Correct
1. (12) Recycling creates at least 3 times the jobs that land-filling does. (T)	2 3	−0.43 −0.50	1.11 1.32	59.64 51.22
2. (13) Recycling creates at least 10 times the jobs that incinerating does. (T)	2 3	0.24 0.58	1.41 0.90	43.95 39.02
3. (14) Recycling 1 ton of plastic saves more than 20 cubic yards of landfill space. (T)	2 3	−0.60 −0.54	2.52 2.21	69.51 66.67
4. (16) It takes more than a year for a recycled product to be back on the shelf. (F)	2 3	2.72 2.56	0.41 0.42	25.56 26.42
5. (18) By using reusable drink containers an average person can eliminate the need for over 50 disposable bottles per year. (T)	2 3	−1.60 −2.18	1.12 1.05	81.17 87.40
6. (19) Over 20% of plastic is used once and then discarded. (T)	2 3	−1.45 −1.89	0.87 0.83	74.89 80.08
7. (21) Recycling plastic reduces carbon dioxide emissions.	2 3	−0.43 −0.97	1.71 0.78	62.33 66.26
8. (24) Recycling a single plastic water bottle saves enough energy to run a 100-W bulb for over 2 h. (T)	2 3	−0.03 0.07	1.97 1.59	51.12 47.97
9. (26) Over 1 billion Styrofoam coffee cups are thrown away every year by Americans. (T)	2 3	−1.21 −1.18	1.26 1.42	76.68 77.64
10. (27) Recycling 1 ton of simple plastic saves the energy equivalent of leaving a 100 W lightbulb on for 5 years. (T)	2 3	0.06 −0.13	2.82 1.84	47.98 53.66
11. (28) Recycling is over a $100 billion industry in the U.S. (T)	2 3	−0.30 −0.71	1.18 0.91	56.95 63.42
12. (36) Plastic constitutes less than 50% of trash floating on the ocean's surface. (F)	2 3	5.50 −1.30	0.05 0.23	43.05 57.32
13. (39) The average American throws away more than 150 pounds of plastic per year. (T)	2 3	−1.09 −1.69	1.63 1.40	77.58 85.77

Note. Numbers in parentheses in item column represent item number in Study 1. Study 2 Cronbach's α = 0.76. Study 3 Cronbach's α = 0.70.

Largely, the item-level properties of the 2-parameter model identified in Study 1 were replicated in Study 2 (see Table 2). While Item 12 had low discrimination, it was also a difficult item. It is not uncommon for very difficult items to have low discrimination because few people (except those very knowledgeable) answer the question correctly. Fig. 2 shows the item characteristic curves for the individual items and Fig. 3 represents the test information function.

Finally, we estimated whether the two-parameter model was an acceptable fit to the data. To do so, we analyzed the Chi-squared residuals. No item pairs had Chi-squared residual values greater than 3.5 (a standardly acceptable level (Baker, 2017)), indicating that the two-parameter model was an acceptable fit to the data. We also conducted a unidimensionality test. The eigenvalue in the observed data

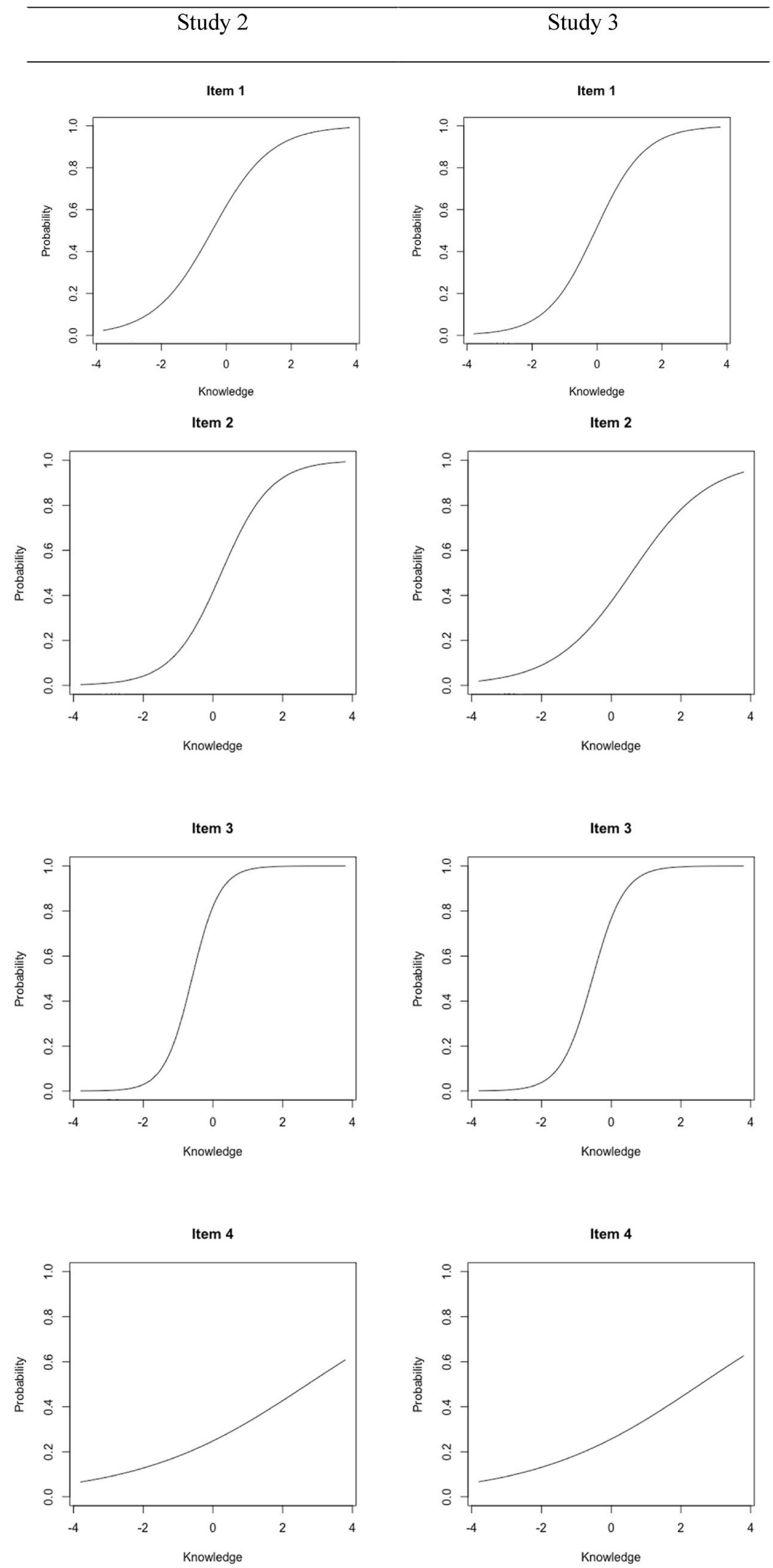

Fig. 2. Item Characteristic Curve for Each of the 13 Items in Study 2 and 3

Note. Each graph is an item characteristic curve for each item in the OPRKS. The x-axis represents ability level (i.e., knowledge). The difficulty parameter is determined by where 50% of participants answer correctly. The y-axis represents the probability that an individual at a particular ability level will get the item correct. Discrimination can be observed by the slope of the curve, where a steeper slope means greater discrimination.

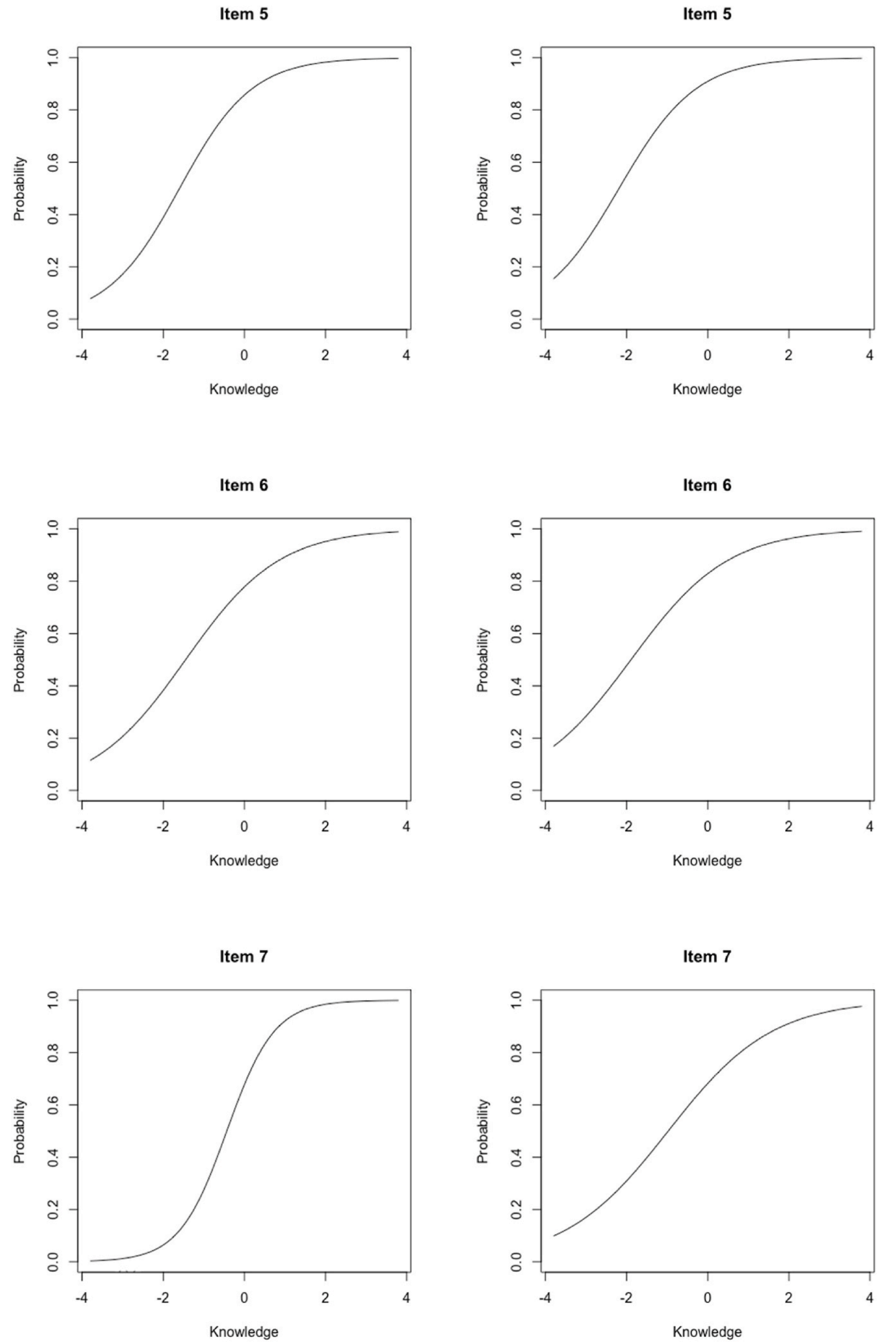

Fig. 2. (*continued*).

was 1.35 while the average of the eigenvalue in Monte Carlo simulation was 1.03 ($p = 0.01$). While this test was significant, which would indicate that our knowledge instrument was not unidimensional, our observed eigenvalue and simulated eigenvalue were both small (i.e., close to 1) so we assumed that our scale was unidimensional. However, to confirm this assumption, a confirmatory factor analysis for binary data was ran to ensure all items loaded onto one factor. The one-factor model with all 13 items displayed acceptable fit (χ^2 (65) = 93.46, p = 0.012, CFI = 0.98, RMSEA = 0.044, RMSEA 90% CI = 0.022–0.064). While the chi-square value is significant, research suggests that when the chi-square value divided by the degrees of freedom is less than 2, it is safe to assume adequate fit (e.g., 93.46/65 = 1.48) (Matsunaga, 2010).

4. Study 3

The goal of Study 3 was to replicate the IRT results of Studies 1 and 2. Also, because we had some confidence that the 13 items would constitute a reasonable set of items measuring knowledge of plastic recycling, we included a set of other variables to begin to help establish elements of construct validity (e.g., convergent, discriminant, and criterion validity) (Cronbach & Meehl, 1955; Messick, 1995). These additional measures included positive attitudes towards recycling, subjective norms about recycling, perceived behavioral control, environmental concern, and subjective knowledge of plastic recycling. Each of these factors has been shown to be related to recycling behaviors or intentions to recycle. Our primary goal was to correlate the OPRKS with these factors. Our secondary goal was to determine if, and to what extent, the OPRKS uniquely predicted positive recycling behaviors.

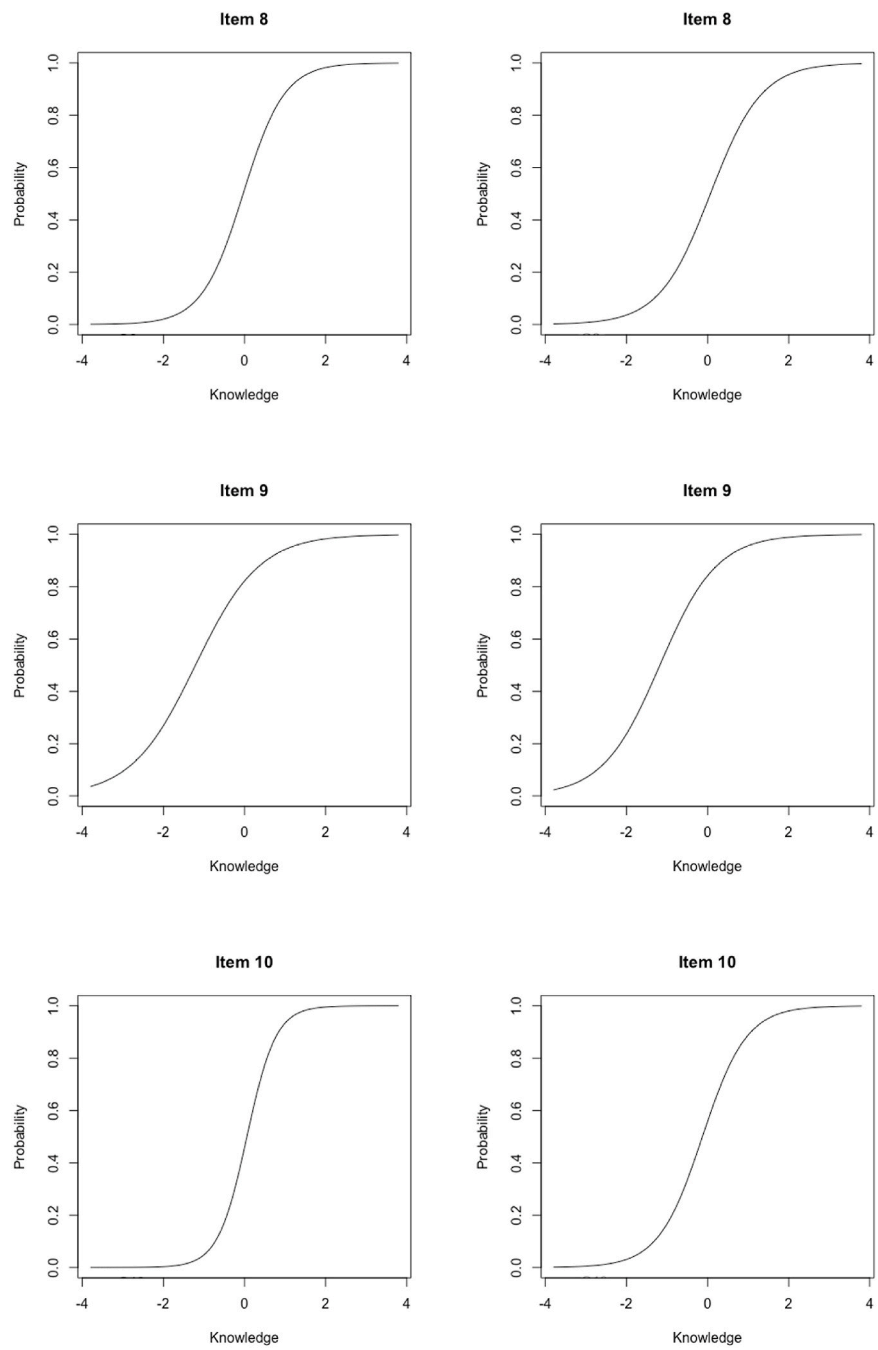

Fig. 2. (*continued*).

4.1. Participants

Two hundred and ninety-two participants were recruited from CloudResearch (cloudresearch.com) and were compensated for their participation in the study ($0.75). CloudResearch is an online participant recruitment platform that uses Amazon Mechanical Turk workers. CloudResearch has propriety lists of approved workers to participate in studies. Evidence suggests that data quality from samples gathered from CloudResearch can be better than using Amazon Mechanical Turk sampling alone (Peer, Rothschild, Gordon, Evernden, & Damer, 2021).

Participants ranged from 20 to 81 years old ($M = 46.44$, $SD = 14.61$) and 61.38% were female. We included one attention-check question (e.g., *humans eat food*) in which participants should have indicated 'true', eliminating 1 participant. We then checked for straight lining using the Big Five personality measure used in Study 2, eliminating 5 participants. There were 40 participants who did not complete the survey. We retained a total of 246 participants for further study.

4.2. Methods and materials

Participants received the following instruments in order.

Subjective Knowledge of Plastic Recycling Subjective knowledge was assessed with one item in which participants indicated how much they believed they knew about plastic recycling on a 7-point Likert scale (e.g., I think that I know a lot about plastic recycling).

Knowledge of Plastic Recycling Participants received the 13-item OPRKS identified in Studies 1 and 2 in a random order.

Positive Attitudes Towards and Subjective Norms About Recycling Positive attitudes towards recycling are thought to assess individuals' positive or negative evaluation of plastic recycling (Goldsby, 1998). We

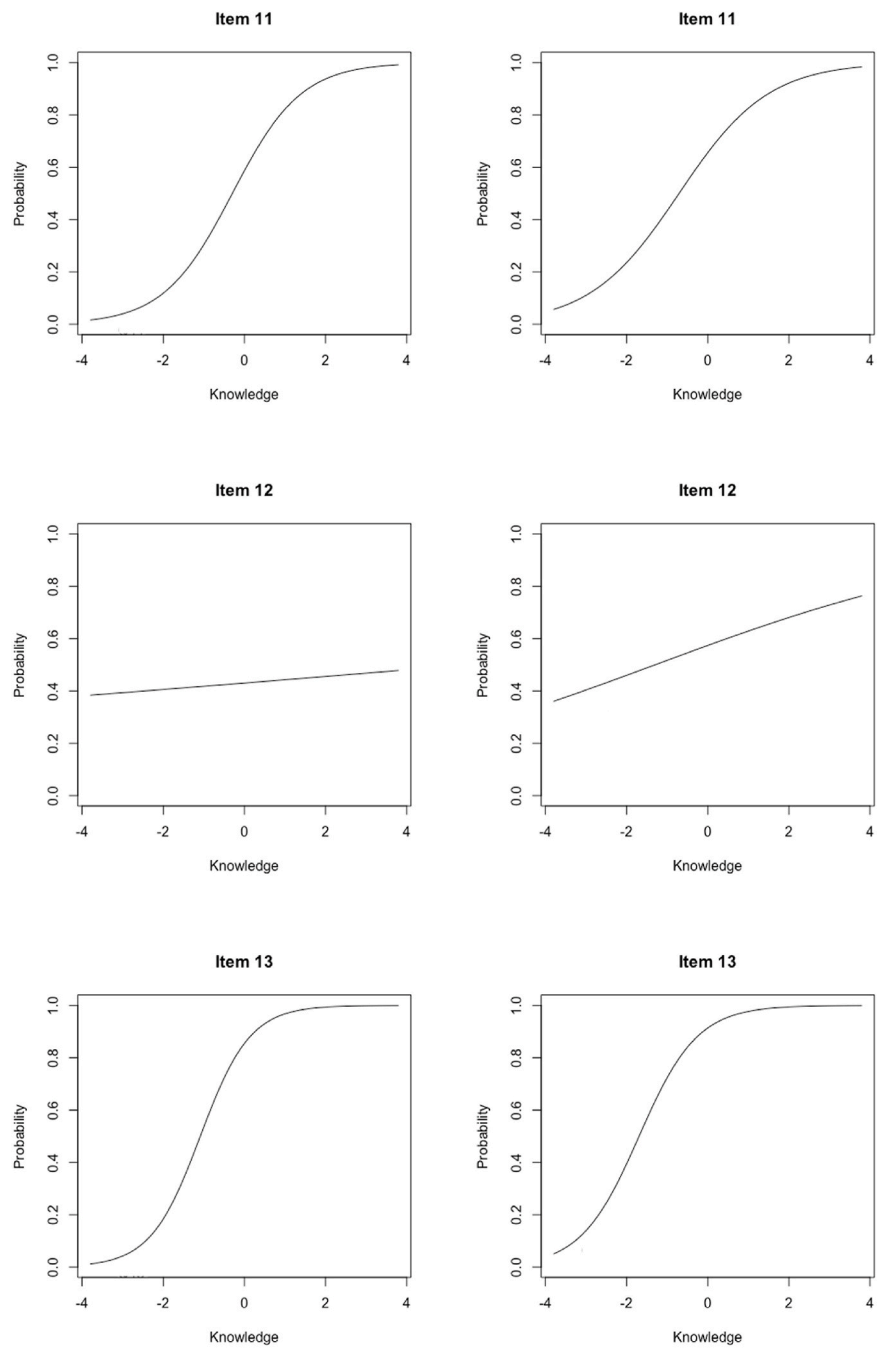

Fig. 2. (*continued*).

adapted items from Goldsby (1998) assessing positive attitudes towards recycling ($\alpha = 0.93$). Participants with a higher score on positive attitudes about recycling are likely to have more positive attitudes about recycling than those with a lower score. Subjective norms are believed to assess individuals' perceptions of societal pressures put on them to perform (or not perform) and support a particular action (Ajzen & Fishbein, 1980). We adapted items from Goldsby (1998) assessing subjective norms ($\alpha = 0.83$). Participants with a higher score on subjective norms about recycling are more likely to perceive stronger endorse cultural norms surrounding recycling than those with a lower score. Previous research has suggested that positive attitudes towards recycling and thinking that recycling is an endorsed cultural norm (i.e., subjective norm) has been positively related to recycling behaviors (Goldsby, 1998) (see Appendix C for full instrument and Table 3 for factor analysis). A mean for positive attitudes and a mean for subjective norms about recycling were used in analyses. We predicted that the OPRKS would be positively related to both positive attitudes and subjective norms about plastic recycling.

Environmental Concern Best and Mayerl (2013) operationalized environmental concern as the range of environmentally related perceptions, emotions, knowledge, values, attitudes, and behaviors. We included a measure from Best and Mayerl (2013) ($\alpha = 0.78$) because concern for the environment typically correlates with pro-environmental actions such as recycling (Best, 2010; Meneses & Patacio, 2005). Participants indicated their agreement with 6 items (e.g., "I would be willing to separate more different kinds of recyclables in the future") on a 7-point Likert-scale. We used a mean of responses to the environmental concern scale in all analyses. We predicted the OPRKS would be positively related to environmental concern.

Positive and Negative Recycling Behaviors We developed a set of

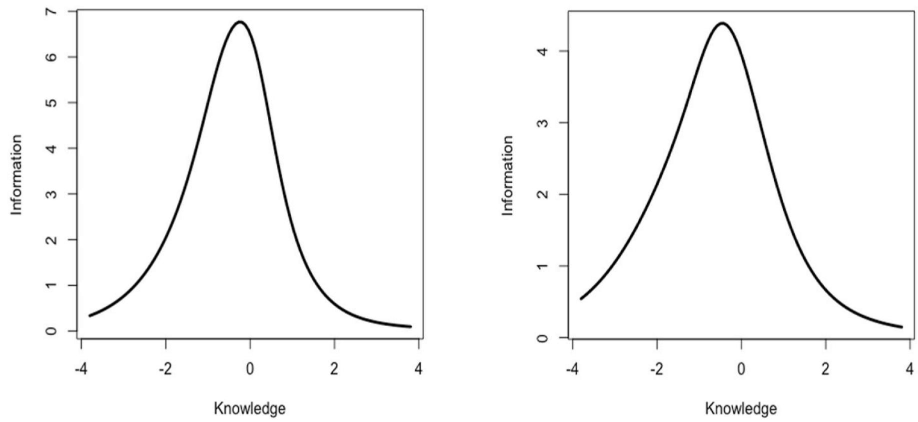

Fig. 3. Test Information Function for the OPRKS in Studies 2 and 3*Note.* On the left is the Test Information Function for Study 2 and on the right is the Test Information Function for Study 3. The Test Information Function represents the range of knowledge that we capture with the OPRKS. The x-axis represents latent trait ability, in our case, recycling knowledge.

Table 3
Exploratory factor loadings of attitudes and norms scale measured in study 3.

Item #	Item	Positive Attitudes	Subjective Norm
1	I feel recycling is …	**0.75**	0.08
2	I feel recycling is …	**0.70**	0.19
3	I feel recycling is …	**0.82**	0.07
4	Recycling plastic waste is a major way to reduce pollution.	**0.77**	−0.08
5	Recycling plastic waste creates a better environment for future generations.	**0.89**	−0.07
6	Recycling plastic is a major way to conserve natural resources.	**0.82**	−0.06
7	My family thinks that I should recycle plastic.	0.19	**0.59**
8	My friends think that I should recycle plastic.	0.22	**0.57**
9	My neighbors think that I should recycle plastic.	0.11	**0.58**
10	I feel that I have the physical ability to recycle plastic effectively.	0.06	**0.70**
11	I feel that I have the knowledge to recycle plastic effectively.	−0.01	**0.72**
12	I feel that I have the resources to recycle plastic effectively.	−0.15	**0.82**
13	Providing better instructions would help me recycle plastic more effectively.	0.30	−0.04
14	Sorting out different kinds of plastic is too much trouble.	−0.08	−0.26
15	New technologies to improve recycling of mixed plastic waste should be developed.	0.35	0.20
16	Waste plastic that is not recycled should be burned for energy.	0.13	−0.08
17	Efforts should be made to eliminate the production and use of plastics that are not currently recyclable.	0.38	0.16

Note. Bolded factor loadings indicate that the item contributed to the factor (e.g., positive attitudes or subjective norms). Items with factor loadings that are not bolded were not included on either factor. There were 6 final items that assessed positive attitudes towards recycling and 6 final items that assess subjective norms towards recycling. Item scores were averaged across each factor, resulting in one positive attitude mean and one subjective norm mean per participant.

behaviors that would be indicative of positive and negative recycling tendencies (see Table 4). We asked participants to fill in the blanks in the statements indicating whether they 'do' or 'do not' engage in each behavior. We calculated a sum for both the positive and negative recycling behaviors where 'do' was coded as 1 and 'do not' was coded as 0 and used that sum in analyses (see Table 4 for results from an exploratory factor analysis). We predicted the OPRKS would be positively related positive behaviors and negatively related to negative behaviors.

Big 5 Personality Inventory Finally, participants were given a brief version of the Big 5 personality inventory (Gosling et al., 2003). This brief version asks participants to rate (on a 1–7 scale) the extent to which each pair of adjectives describe them. There were 10 total adjectives, two for each of the Big 5 personality traits (extraversion, emotional stability, agreeableness, conscientiousness, and openness to experiences). Each pair of adjectives, once appropriately scored, was then averaged for a composite value for each personality trait. For example, to measure extraversion, participants were asked to indicate how much the following two adjectives describe them: (1) extraverted, enthusiastic, and (2) reserved, quiet, where (2) was reverse scored. A higher averaged value (e.g., the participant rated themselves very extraverted and enthusiastic and not at all reserved and quiet) indicated greater extraversion. This measure was included to offer additional covariates (i.e., convergent validity) as well as evidence of divergent validity. Previous research has established relationships between pro-environmental attitudes and a number of personality traits (Hopwood, Lenhausen, Stahlmann, & Bleidorn, 2022; Markowitz, Goldberg, Ashton, & Lee, 2012; Pavalache-Ilie & Cazan, 2018). For example, conscientiousness has been linked to both pro-environmental attitudes and actions across studies (Markowitz et al., 2012; Pavalache-Ilie et al., 2018). These relations make theoretical sense in that it's likely one who is conscientious is more likely to be careful of their impact on the environment. However, there is no evidence of reliable relationships between extraversion, for example, and pro-environmental attitudes. We expected conscientiousness to be positively related to the OPRKS. Based on previous research, we thought we might see a positive relationship between agreeableness and openness to experiences and the OPRKS as well. We did not expect extraversion or emotional stability to be related to the OPRKS.

4.3. Results and discussion

The item-level IRT analysis of the OPRKS items in Study 3 suggested that most of the items had acceptable item-level properties. All the discrimination levels were greater than 0.68, except for items 4 and 12 (see Table 2). Item 4 was a difficult item in both Study 2 and Study 3. Item 12 was difficult for participants in Study 2, but easier (than average) for participants in Study 3. Item characteristic curves for the items can be found in Fig. 2. The test information function is represented in Fig. 3.

Similar to Study 2, we fit the responses to the OPRKS to three different models. First, we fit the data to a one parameter constrained model (log likelihood = −1793.83; AIC = 3613.65; BIC = 3659.22). Next, we fit the data to a one parameter unconstrained model, (log

Table 4
Positive and negative behavioral items exploratory factor analysis.

Item	Statement	Behavior (±)	Positive Behavior	Negative Behavior
1	I ___ place plastic bottles (such as 2-L bottles or milk jugs) in the recycling bin without rinsing and drying them first.	–	−0.17	**0.74**
2	I ___ check the number in the recycling arrow symbol on plastic containers before disposing of them.	+	**0.75**	−0.27
3	I ___ recycle plastic waste that still has a bit of food or liquid on it.	–	−0.23	**0.66**
4	I ___ bring my own reusable bags to grocery stores to carry my groceries in.	+	0.52	−0.10
5	I ___ place compostable materials in the recycling bin.	–	0.21	0.45
6	I ___ crush down recyclables such as plastic bottles, aluminum cans, and plastic jugs before placing them in the recycling bin.	+	**0.48**	0.22
7	I ___ crush down non-recyclable containers before disposing of them.	+	0.41	–
8	I ___ recycle pizza boxes, even if there is grease on them.	–	–	**0.52**
9	I ___ check to see if both the lid and the container are recyclable before placing them in the recycling bin.	+	**0.82**	−0.12
10	I ___ put plastic bags (such as grocery bags) in the recycling bin.	–	–	**0.68**
11	I ___ place items that I'm not sure are recyclable in the trash bin.	+	−0.13	0.15
12	I ___ place items that I'm not sure are recyclable in the recycling bin.	–	−0.16	**0.62**
13	I ___ place small items (smaller than a credit card) in the recycling bin.	–	0.20	0.44
14	I ___ know how to check if something is recyclable.	+	0.50	−0.17
15	I ___ try to be mindful of the amount of waste my household produces.	+	**0.64**	–
16	I ___ place my recyclables in grocery bags before placing the bag of recyclables into the recycling bin.	–	0.20	**0.61**
17	I ___ intentionally buy groceries packaged in recyclable materials.	+	**0.73**	0.26
18	I ___ intentionally buy groceries packaged in material that has already been recycled.	+	**0.73**	0.16
19	I ___ double check items in my recycling bin before placing my bin at the end of my driveway or taking it to a drop-off center.	+	**0.66**	–
20	I ___ recycle plastic water bottles with their lids on.	+	–	0.60
21	I ___ place all items that have the recycling arrow symbol on them in the recycling bin.	–	0.58	0.46
22	I ___ buy groceries packaged in single use plastic.	–	–	0.15
23	I ___ flatten cardboard boxes before placing them in the recycling bin.	+	0.58	–

Note. Bolded factor loadings indicate that the item contributed to the factor. Items that are not bolded were not used for further analysis.

likelihood = −1793.72; AIC = 3615.44; BIC = 3664.52). We then ran an ANOVA to compare the fits of the constrained and unconstrained models. The unconstrained model did not fit the data better (LRT = 0.21, p = 0.65). We then fit a two-parameter model to the data (log likelihood = −1765.63; AIC = 3583.25; BIC = 3674.39). The two-parameter model had better fit than both the constrained and unconstrained models, respectively (LRT = 56.40, $p < 0.001$; LRT = 56.19, $p < 0.001$).

We performed a fit on the margins test to see if the 2-paramter model fit the data. Only two pairs of items had a Chi-squared residual greater than 3.5, Item 4 and Item 13 = 3.85 ($\chi^2 = 5.70$, $p = 0.61$ and $\chi^2 = 5.68$, $p = 0.85$, respectively) and Item 1 and Item 2 = 5.94 ($\chi^2 = 14.82$, $p = 0.19$ and $\chi^2 = 7.60$, $p = 0.71$, respectively). While the Chi-squared residual was significant, the raw value of the residual was not very high and only two pairs of items had a significant value suggesting that the two-parameter model was an acceptable fit to the data. We ran a test for unidimensionality of the scale where the eigenvalue in the observed data was 1.41 while the average of the eigenvalue in Monte Carlo simulation was 0.99 ($p = 0.01$). While this test was significant, which would indicate that our test is not unidimensional, our observed eigenvalue and simulated eigenvalue were small, so we assumed that the OPRKS was unidimensional. However, to confirm this assumption, we again ran a confirmatory factor analysis for binary items to ensure all items loaded onto one factor. The one-factor model with all 13 items displayed acceptable fit ($\chi^2(65) = 118.16$, p < 0.001, CFI = 0.85, RMSEA = 0.060, RMSEA 90% CI = 0.043–0.076). While the chi-square value is significant, research suggests that when the chi-square value divided by the degrees of freedom is less than 2, it is safe to assume adequate fit (e.g., 118.16/65 = 1.82) (Matsunaga, 2010).

We factor analyzed our attitudes and norms scale adapted from Goldsby (1998). The items loaded onto the two predicted factors (α = 0.89), positive attitudes towards recycling (α = 0.89, minimum = 3.22, maximum = 7) and subjective norms about recycling (α = 0.85, minimum = 1.50, maximum = 7). For item-level factor loadings, see Table 3.

Next, we factor analyzed the positive and negative behavioral items (see Table 4). We coded all responses for these items where a score of 0 indicates the participant does not engage in the behavior and a score of 1 indicates the participant does engage in the designated behavior, and then ran an exploratory factor analysis for binary data. All but two items loaded on the expected factor (e.g., either positive or negative). We expected Item 20 to be a positive behavior, but Item 20 loaded on the negative behavior factor. We expected Item 21 to be a negative behavior, but Item 21 loaded on the positive behavior factor. We dropped these two items from further analysis. We also dropped all items that did not load onto either factor. Positive behavioral scores were calculated by adding the number of times a participant indicated they engage in a positive behavior (α = 0.72), and negative behavioral scores were calculated by adding the number of times a participant indicated they engage in a negative behavior (α = 0.67). Participants could receive a score between 0 and 7 for positive behaviors, and a score between 0 and 6 for negative behaviors, and those scores were used in future analyses. Positive recycling behaviors were our primary factor of interest when it came to subsequent modeling, but negative behaviors were included in the scale in attempt to display a negative correlation between objective knowledge and negative recycling behaviors.

The OPRKS was related to positive attitudes towards recycling, subjective norms, subjective knowledge, and environmental concern in the predicted direction, thereby providing some evidence for convergent validity. The OPRKS was also positively related to positive recycling behaviors, thereby providing some evidence of criterion validity. The OPRKS was not significantly correlated with age, sex, extraversion, emotional stability, conscientiousness, and openness to experiences, thereby providing some evidence of discriminant validity. There was a significant correlation between the OPRKS and agreeableness, however, due to the weak nature of the correlation (in comparison to the strength of correlations between the OPRKS and positive attitudes, subjective norms, etc.) we didn't investigate this relationship further. Extraversion and emotional stability were two Big Five personality traits selected for evidence of discriminate validity that should not be related to knowledge of plastic recycling (whereas conscientiousness, for example, may be). The OPRKS was not reliably related to negative behaviors, contrary to our prediction (although, of note, the subjective measure of knowledge was reliably and *positively* related to negative behaviors) (see Table 5 for complete correlation table). Additionally, negative behaviors were largely uncorrelated with other factors commonly associated with recycling behaviors or intentions. These results suggest caution interpreting the results involving the measure of negative behaviors (see Table 6).

Our key criterion variable was positive recycling behaviors. Given the correlations associated with positive recycling behaviors, we estimated whether objective knowledge measured by the OPRKS offered unique prediction above the other variables we collected. To do this, a hierarchical regression was conducted. In the first model, subjective knowledge, positive attitudes towards recycling, subjective norms, and environmental concern were included in Step 1 and positive recycling behaviors was the outcome variable. Model 1 was a significant predictor of positive recycling behaviors. Model 2 included objective knowledge of plastic recycling in Step 2. The inclusion of objective knowledge of plastic recycling significantly increased the predictive ability of the model. These results suggest that knowledge of plastic recycling has unique predictive power beyond those other variables.

To help illustrate some of the possible relations among the variables we gathered, we created a structural model of the data consistent with the Framework for Skilled Decisions. In this model, we included the subjective measure of knowledge of plastic recycling, the OPRKS, and the environmental concern scale (the environmental concern scale is the only previously validated instrument we used). Overall, the model had good fit to the data (X^2 (1, 246) = 0.001, p = 0.97; CFI = 1.00; RMSEA = 0; RMSEA 90% CI = 0.00–0.00; RMSEA p = 0.98) (see Fig. 4).

5. General discussion

Through a series of 3 studies, we refined 51-items measuring objective knowledge of recycling to a 13-item Outcomes of Plastic Recycling Knowledge Scale (OPRKS) using IRT analyses. Study 3 provided some evidence that the OPRKS was positively related to recycling behaviors (predictive validity), was related to attitudes toward recycling, norms, and environmental concern (convergent validity), and was unrelated to age, sex, extraversion, and emotional stability (discriminant validity). Study 3 provided evidence of the unique predictive ability of the OPRKS and supports our claim that objective knowledge is one, but not the only factor influencing positive recycling behaviors. As such, the OPRKS has the potential to serve a valuable role in modeling and predicting recycling behaviors.

In addition to providing unique prediction of recycling behaviors, having a measure of objective knowledge of plastic recycling is likely to help estimate which, when, where, and for whom educational interventions have impacts on recycling behaviors. Educational interventions are one of the most common interventions designed to increase recycling behavior (Heidbreder et al., 2019; Varotto & Spagnolli, 2017). Often, education is equated with providing people information (e.g., a pamphlet, a video) or asking people how much they know. But in many instances, providing information to people will not actually make them more knowledgeable. There are many reasons to think that providing information is not the same as educating. The information may be too complicated (e.g., for novices), not complicated enough (e.g., for experts), or not in a form that people can understand and interpret (e.g., statistical information for those who do not understand statistics well). In each of these cases, providing information will do little to actually increase what one actually knows (Feltz & Feltz, 2019; Feltz & Feltz; Mahmoud-Elhaj, Tanner, Sabatini, & Feltz, 2020; Offer-Westort, Feltz, Bruskotter, & Vucetich, 2020; Tanner & Feltz, 2021). Having an objective measure of plastic recycling knowledge can

Table 5
Study 3 full correlation table.

	M	*SD*	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Objective Knowledge	8.03	2.74	–												
2. Subjective Knowledge	3.92	1.00	0.24***	–											
3. Positive Attitudes	5.88	0.81	0.42***	0.19**	–										
4. Subjective Norm	5.60	1.02	0.35***	0.42***	0.53***	–									
5. Environmental Concern	5.11	1.12	0.25***	0.06	0.61***	0.34***	–								
6. Positive Behaviors	3.28	1.93	0.30***	0.32***	0.31***	0.45***	0.41***	–							
7. Negative Behaviors	1.88	1.68	0.00	0.19**	0.03	0.06	−0.14*	0.00	–						
8. Extraversion	3.70	1.63	0.06	0.05	0.11	0.07	0.13*	0.12	0.07	–					
9. Emotional Stability	4.75	1.57	0.11	0.02	0.03	0.12	−0.07	0.06	0.02	0.16*	–				
10. Agreeableness	5.07	1.42	0.19**	−0.04	0.18**	0.17**	0.17**	0.10	−0.04	0.01	0.53***	–			
11. Conscientiousness	5.32	1.52	0.10	0.02	0.02	0.10	0.03	0.06	−0.02	−0.01	0.57***	0.62***	–		
12. Openness to Experiences	4.80	1.40	0.10	0.02	0.13*	0.14*	0.23***	0.18**	−0.03	0.22***	0.36***	0.41***	0.37***	–	
13. Age	46.44	14.61	0.04	−0.08	0.12	0.06	0.02	0.01	−0.17**	0.11	0.14*	0.15*	0.14*	−0.05	–
14. Sex	–	–	0.06	0.06	−0.06	−0.03	0.21***	0.04	−0.10	0.07	−0.04	0.25***	0.10	0.09	0.12

Note. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. Sex was coded as 1 = male 2 = female. Objective knowledge (OPRKS) scored 0–13. Subjective knowledge, positive attitudes, subjective norm, environmental concern, extraversion, emotional stability, agreeableness, conscientiousness, and openness to experiences scored on 7-point Likert scale. Positive behaviors scored 0–7. Negative behaviors scored 0–6.

Table 6
Study 3 hierarchical regression of positive recycling behaviors.

Model		B	B SE	β	t	p	ΔR^2	$\Delta R^2\ p$
1	Intercept	−2.99	0.81	–	−3.69	<0.001	0.31	<0.001
	Subjective Knowledge	0.36	0.11	0.19	3.16	0.002		
	Positive Attitudes	−0.26	0.18	−0.11	−1.48	0.14		
	Subjective Norm	0.58	0.13	0.31	4.48	<0.001		
	Environmental Concern	0.62	0.12	0.36	5.37	<0.001		
2	Intercept	−2.84	0.81	–	−3.52	<0.001	0.02	0.03
	Subjective Knowledge	0.33	0.11	0.17	2.91	0.004		
	Positive Attitudes	−0.36	0.18	−0.15	−1.99	0.05		
	Subjective Norm	0.55	0.13	0.29	4.25	<0.001		
	Environmental Concern	0.62	0.12	0.36	5.41	<0.001		
	Objective Knowledge (OPRKS)	**0.09**	**0.04**	**0.13**	**2.13**	**0.04**		

Note. Model 1: $F(4, 241) = 27.31$, $p < 0.001$. Model 2: $F(5, 240) = 23.07$, $p < 0.001$. Objective knowledge measured with the OPRKS.

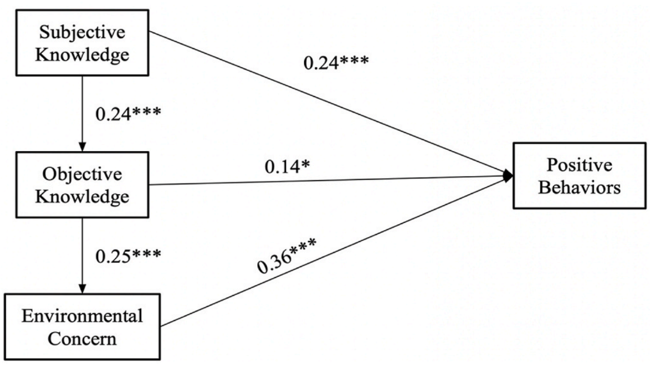

Fig. 4. Structural Equation Model from Study 4 with Environmental Concern Note. *p < 0.05; **p < 0.01; ***p < 0.001. Path coefficients are standardized. Objective knowledge measured with the OPRKS.

help uniquely estimate whether the educational intervention made people more knowledgeable, by how much, and whether that potential increase in knowledge translates to the desired changes the intervention is aimed at.

To illustrate how a measure of objective knowledge can help uniquely estimate the effectiveness of educational interventions, suppose that one only has a subjective measure of plastic recycling knowledge, and one adopts a pre-test post-test design with an educational intervention. It could be that participants over-estimate their subjective knowledge in the pre-test. Then, after the intervention, participants may actually know more than in the pre-test. In the post-test, participants may more accurately assess how much they subjectively know. Consequently, one has more calibrated estimates of what one knows in the post-test. The pre-test, post-test design cannot detect this increase in calibration (since, for example, the pre-test and post-test subjective knowledge scores could be the same). Objective measures of knowledge are not susceptible to these kinds of overconfidence. Either one knows or does not know the answer. Having an objective knowledge measure will allow one to both estimate how overconfident one is while at the same time being able to estimate how much one actually learns from the intervention.

Additionally, the structural model provides some insights into how objective knowledge factors into recycling behaviors. In fitting the structural model, we were more concerned with mapping the proximal features (e.g., confidence/subjective knowledge, knowledge, and attitudes/environmental concern) and their effect on positive recycling behaviors before we start focusing on more distal features (e.g., education and numeracy). First, knowledge is likely to be one of several different potential factors that are involved in decisions to recycle. At a minimum and consistent with standard approaches to decision making, the model suggests that one's values (e.g., environmental concern) should also be considered (Baron, 2008; Weirich, 2004). Although there isn't a strong direct relationship between the OPRKS and positive recycling behaviors, there is a strong mediation where environmental concern mediates the relationship between knowledge and positive behaviors, in line with Skilled Decision Theory. Second, the model suggests that there could be some downstream positive effects of education (see Fig. 1). While the Framework for Skilled Decision Making does not predict a direct effect of education on what one values, there is a hypothesized indirect effect through knowledge. If this model is correct, then educating people could have the impact that people would care more about the environment as a result. Those changes would be related to changes in recycling behaviors. Having a reliable and validated measure of objective knowledge is one important step to estimating those potential indirect, but important, relations. The data gathered for the more proximal features of the model fit how we would expect. Future research will focus on a more complete model in line with the Framework for Skilled Decision Making.

Future work could potentially explore the existence and importance of different kinds of plastic recycling. Not surprisingly, different kinds of domain specific knowledge have been shown to be related to different outcome variables. For example, knowledge of animals used as food has been shown to be related to a reduction in the consumption of animal products (Feltz & Feltz, 2019; Feltz & Feltz). However, knowledge of animals used as food is not related to supporting protective measures for animals (e.g., banning gestation crates for pigs). A different kind of knowledge—knowledge of factory framing—was related to supporting protective measures but was itself not related to reduction in consuming animal products (Feltz et al., 2022). Something similar may happen with plastic recycling. While we took out measure to be a unidimensional general measure of plastic recycling, it is possible (and perhaps likely) that different kinds of knowledge of plastic recycling exist and could be differentially related to outcomes. To illustrate, our initial set of items included items about multi-layer plastic that did not pass our exclusion criteria. There could be a reason for that. Knowledge of multi-layer plastic may constitute a unique kind of knowledge that our measure does not capture. There is likely to be value in exploring those potentially different kinds of knowledge.

The findings of this series of studies do not come without limitations. First, rather than using self-report behaviors, it would be better to measure actual recycling behaviors as a criterion variable. It is possible that participants could have responded based on behaviors they *think* they should or should not engage in, rather than responding based on their true behaviors. We assumed these behaviors were primarily rooted in a concern for the environment, but it's possible there are other motivators such as incentives or penalties (Moons & De Pelsmacker, 2012). Second, our instrument was fielded on a U.S.-based, computer literate sample. We have no evidence how our instrument would perform on different samples, and there is some reason to think that the items may differentially function in different populations (Phelan et al., 2020). Third, more needs to be done to estimate the predictive power of objective knowledge with respect to recycling behaviors and to identify the nomological network in which objective knowledge relates to recycling behaviors. Fourth, intervention research should be done to estimate whether, and by how much, educational interventions can increase objective knowledge about plastic recycling and how much that potential change translates to changes in behaviors. Finally, the state of the science for plastic recycling is constantly changing with new breakthroughs happening frequently. These changes may change some of the facts of plastic recycling. Continued efforts will be made to keep the OPRKS current with scientific advancements (e.g., annual review of reliability and validity). Additionally, it could be that some bits of information are more stable than others (e.g., some items remain true for a longer period of time than others). If this is true, it would be beneficial to keep and/or create items that are more stable to the changing environment of plastic recycling. This possibility will be explored upon the annual review of reliability and validity (see plasticrecyclingIQ.org for yearly updates).

Even with these limitations, our studies provide evidence for an important, if somewhat neglected, factor predicting plastic recycling. Having and using a measure of objective knowledge of plastic recycling holds the promise of being able to create, tailor, and evaluate educational interventions to help people make high quality plastic recycling decisions for themselves.

Author statement

Jenna Holt: Conceptualization, Formal Analysis, data curation, Writing- Original Draft, Visualization. Dai-Phat Bui, Han Chau, Kathy Wang, Luis Trevisi, Ana Carolina Roncoli-Jerdy: Methodology, Validation. Lance Lobban, Steven Crossley: Methodology, Validation, Writing-Reviewing and Editing, Funding Acquisition. Adam Feltz: Conceptualization, Writing- Reviewing & Editing, Supervision, Project administration, Funding Acquisition.

Appendix A

Full 51 Question Pool

Question	Correct Answer
1. Enough plastic is thrown away each year to circle the Earth at least 2 times.	**T**
2. It costs more to recycle trash than to send it to a landfill.	**T**
3. Over 50% of disposable water bottles are recycled in the United States.	**F**
4. At least 1,000,000 sea creatures are killed annually due to plastic in the ocean.	**T**
5. Recycling plastic and burning plastic in an incinerator require the same amount of energy.	**F**
6. Recycling plastic water bottles takes over 50% less energy than making plastic from raw materials.	**T**
7. The more compounds used to make a particular type of plastic, the more challenging the plastic is to recycle.	**T**
8. Plastic decomposes in landfills within 50 years.	**F**
9. It costs more to recycle a plastic water bottle than to incinerate it.	**F**
10. Over 50% of plastic produced in the US is recycled.	**F**
11. Americans throw away over 1 million plastic bottles every hour.	**T**
12. Recycling creates at least 3 times the jobs that land-filling does.	**T**
13. Recycling creates at least 10 times the jobs that incinerating does.	**T**
14. Recycling 1 ton of plastic saves more than 20 cubic yards of landfill space.	**T**
15. Styrofoam decomposes within 100 years.	**F**
16. It takes more than a year for a recycled product to be back on the shelf.	**F**
17. At least 4 times more plastic waste is incinerated in the U.S. than is recycled.	**T**
18. By using reusable drink containers an average person can eliminate the need for over 50 disposable bottles per year.	**T**
19. Over 20% of plastic is used once and then discarded.	**T**
20. Less than 50% of what Americans throw away is recyclable.	**F**
21. Recycling plastic reduces carbon dioxide emissions.	**T**
22. Landfills contribute to soil pollution.	**T**
23. Most plastics are biodegradable.	**F**
24. Recycling a single plastic water bottle saves enough energy to run a 100-W bulb for over 2 h.	**T**
25. Water quality is not impacted by producing plastic from raw materials.	**F**
26. Over 1 billion styrofoam coffee cups are thrown away every year by Americans.	**T**
27. Recycling 1 ton of simple plastic saves the energy equivalent of leaving a 100 W lightbulb on for 5 years.	**T**
28. Recycling is over a $100 billion industry in the U.S.	**T**
29. Over 20% of the plastic ever made has been recycled.	**F**
30. Less than 500,000 plastic bottles are sold every minute.	**F**
31. More than half of the plastic waste in the world comes from 3 basic types of plastic.	**T**
32. All types of plastic can be recycled in all communities.	**F**
33. Not all plastic can be recycled.	**T**
34. Plastic must be clean before it can be recycled.	**T**
35. Whether plastic can be recycled in your community is dependent on the city government.	**T**
36. Plastic constitutes less than 50% of trash floating on the ocean's surface.	**F**
37. Some chemicals in plastic can be absorbed by the body.	**T**
38. Many plastics produced today are made from oil.	**T**
39. The average American throws away more than 150 pounds of plastic per year.	**T**
40. Adding the incorrect type of plastic to a specific recycling bin does not diminish the value of the final recycled produce.	**F**
41. Biodegradable plastics produce greenhouse gases when they decompose.	**T**
42. Biodegradable plastics are not more widely used because they cost more.	**T**
43. Multilayer plastic films require more plastic for packaging meat than more traditional plastic.	**F**
44. Multilayered plastic films are regularly recycled.	**F**
45. Multilayer films cannot be replaced by single-layer films.	**F**
46. Multilayer packaging films have several thin sheets of materials (including aluminum, plastics, and paper) that are laminated together and are difficult to separate.	**T**

(*continued on next page*)

(*continued*)

Question	Correct Answer
47. Multilayer plastic packaging can yield shelf lives of up to 1 year in challenging weather conditions (high humidity and large increases/decreases in temperature).	**T**
48. Multilayer plastic packaging may prevent light from reaching the contents inside the packaging, resulting in longer shelf lives for edible products.	**T**
49. Multilayer plastic packaging is extremely light and does not require a lot of material input in comparison to rigid plastic, metals, or glass.	**T**
50. Multilayer plastic packaging costs significantly more in production and transportation of goods.	**F**
51. Multilayer plastic packaging is stronger than more traditional plastics.	**T**

Appendix B

Final 13 Outcomes of Plastic Recycling Knowledge Scale (OPRKS)

Question	Correct Answer
1. Recycling creates at least 3 times the jobs that land-filling does.	T
2. Recycling creates at least 10 times the jobs that incinerating does.	T
3. Recycling 1 ton of plastic saves more than 20 cubic yards of landfill space.	T
4. It takes more than a year for a recycled product to be back on the shelf.	F
5. By using reusable drink containers an average person can eliminate the need for over 50 disposable bottles per year.	T
6. Over 20% of plastic is used once and then discarded.	T
7. Recycling plastic reduces carbon dioxide emissions.	T
8. Recycling a single plastic water bottle saves enough energy to run a 100-W bulb for over 2 h.	T
9. Over 1 billion Styrofoam coffee cups are thrown away every year by Americans.	T
10. Recycling 1 ton of simple plastic saves the energy equivalent of leaving a 100 W lightbulb on for 5 years.	T
11. Recycling is over a $100 billion industry in the U.S.	T
12. Plastic constitutes less than 50% of trash floating on the ocean's surface.	F
13. The average American throws away more than 150 pounds of plastic per year.	T

Appendix C

Recycling Attitudes Scale

Measurement Item	Scale Type
1. I feel recycling is …	7-point (Harmful/Beneficial)
2. I feel recycling is …	7-point (Wrong/Right)
3. I feel recycling is …	7-point (Worthless/Valuable)
4. Recycling plastic waste is a major way to reduce pollution.	7-point Likert (Disagree/Agree)
5. Recycling plastic waste creates a better environment for future generations.	7-point Likert (Disagree/Agree)
6. Recycling plastic is a major way to conserve natural resources.	7-point Likert (Disagree/Agree)
7. My family thinks that I should recycle plastic.	7-point Likert (Disagree/Agree)
8. My friends think that I should recycle plastic.	7-point Likert (Disagree/Agree)
9. My neighbors think that I should recycle plastic.	7-point Likert (Disagree/Agree)
10. I feel that I have the physical ability to recycle plastic effectively.	7-point Likert (Disagree/Agree)
11. I feel that I have the knowledge to recycle plastic effectively.	7-point Likert (Disagree/Agree)
12. I feel that I have the resources to recycle plastic effectively.	7-point Likert (Disagree/Agree)
13. Providing better instructions would help me recycle plastic more effectively.	7-point Likert (Disagree/Agree)
14. Sorting out different kinds of plastic is too much trouble.	7-point Likert (Disagree/Agree)
15. New technologies to improve recycling of mixed plastic waste should be developed.	7-point Likert (Disagree/Agree)
16. Waste plastic that is not recycled should be burned for energy.	7-point Likert (Disagree/Agree)
17. Efforts should be made to eliminate the production and use of plastics that are not currently recyclable.	7-point Likert (Disagree/Agree)

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