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Research article

Providing immediate feedback improves recycling and composting accuracy

Yu Luo[a,*], Ivana Zelenika[b], Jiaying Zhao[a,b]

[a] Department of Psychology, University of British Columbia, Canada
[b] Institute for Resources, Environment and Sustainability, University of British Columbia, Canada

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ABSTRACT

The volume of solid waste has increased significantly in the past century, directly contributing to global environmental problems. Public engagement with waste sorting is crucial to the diversion of solid waste from landfill and the reduction of contamination in waste streams. The current study aims to promote recycling and composting accuracy via a digital sorting game that provides immediate feedback. In this game, participants manually sorted items into four bins (food scraps, recyclable container, paper, and garbage) via a computer interface, and received immediate feedback on their performance after each trial. We found that immediate feedback improved sorting accuracy as measured by correct key presses (Experiment 1) or motion trajectory (Replication 1), even when feedback was no longer provided. This improvement in sorting accuracy remained a week after playing the game (Replication 2). We then implemented this game in residences, and found that after residents played this game, the weight of compost materials increased while the contamination rate decreased (Experiment 2). These findings suggest that providing immediate feedback in a digital sorting game can be an effective tool to engage and educate the public to increase recycling and composting rates.

1. Introduction

Among the multitude of environmental problems facing humanity (Secretariat of the Convention on Biological Diversity, 2014), the volume of solid waste has reached alarming levels, and represents an important issue for our society in the 21st century (United Nations Environment Program, 2015). The amount of global waste has increased ten-fold over the past century with around 3.3 million tons of waste generated per day (United Nations Environment Program, 2015). This volume is expected to double by 2025 (Hoornweg et al., 2013). Global plastics production has increased by four-fold over the past 50 years, and is expected to double again in the next 20 years (World Economic Forum, 2016), causing significant issues for marine and terrestrial ecosystems where a large proportion of plastics has been accumulating (Geyer et al., 2017). In Canada, residential waste has increased by 27% from 2002 to 2012, and each Canadian currently throws out about 700 kg of waste on average every year (Statistics Canada, 2014). In the U.S., solid waste generation per capita has increased by 64% from 1960 to 2013, and each American currently throws out about 800 kg of waste on average each year (Environmental Protection Agency, 2013).

The dramatic increase of global solid waste is especially worrisome since dumping and burning of garbage contribute directly to water, air, and soil pollution (United Nations Environment Program, 2015). The accumulating waste in landfills not only has deleterious effects on human health and ecosystems (Hossain et al., 2011; Schlossberg, 2017), but also contributes to global warming (Humes, 2012; Tammemagi, 1999). Specifically, organic waste which accounts for 33% of landfill materials releases methane during anaerobic decomposition, a gas that is 25 times more potent than carbon dioxide in terms of trapping the sun's heat and thus warming the atmosphere (Intergovernmental Panel on Climate Change, 2007; Statistics Canada, 2013).

Given the urgency of waste problems, many municipalities in the world have set up recycling and composting targets and policies to increase waste diversion from landfills. For example, the City of Vancouver has set a zero waste target in 2020 when the city aims to reduce solid waste going to the landfill or incinerator by 50% from 2008 levels, and to be a zero waste city by 2040 (City of Vancouver, 2016). To reach this target, the city has set up a new policy that bans organic materials from landfills in 2015 (City of Vancouver, 2015). Even with stringent regulations in place and the prevalence of recycling and composting facilities in public and private spaces, the overall recycling rate is still low in North America. Of all the household waste that is produced each year, only 33% is recycled in Canada (Statistics Canada, 2014) and 34% in the U.S. (Environmental Protection Agency, 2013). In fact, a large portion of the waste in landfills can be recycled.

* Corresponding author. Department of Psychology, University of British Columbia, Vancouver, B.C., V6T 1Z4, Canada.
E-mail address: yuluo@psych.ubc.ca (Y. Luo).

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For example, of the 8.3 billion metric tons of virgin plastic that has been produced to date, only 9% is recycled, 12% incinerated, and 79% accumulated in landfills and oceans (Geyer et al., 2017; Jambeck et al., 2015).

There are many reasons for the low recycling rate, including a lack of infrastructure (e.g., the availability of recycling and composting bins), policy backing (e.g., setting up bylaws discouraging food waste in garbage bins), poor environmental attitudes and social norms, or a lack of knowledge about what goes into which bin (Schultz et al., 1995; Thomas and Sharp, 2013). Recent studies in behavioral science have examined strategies to motivate recycling behavior, demonstrating the effectiveness of infrastructure, design, and convenience (DiGiacomo et al., 2017; Duffy and Verges, 2008; Wu et al., 2016), personal environmental values and social norms (Cialdini, 2003; Cialdini et al., 1990; Crociata et al., 2015; Schultz et al., 1995), as well as the role of information and feedback (De Young, 1989; Duprè and Meineri, 2016) in promoting recycling and composting rates.

While the past approaches have increased participation rates in recycling and composting, it is currently unclear what strategy is effective at reducing contamination in the recycling streams. In other words, convenience or social norms may motivate people to throw items into the recycling or composting bins, but these factors do not necessarily guarantee the *accuracy* of sorting actions. Contamination in waste streams is costly in terms of the time and labor required to correctly re-sort items at a centralized sorting facility or at the pick-up truck (Bohm et al., 2010). In Canada, many cities are struggling to reduce contamination in recycling bins, because contamination can cause tons of recyclable materials to end up in landfills or oceans. It is estimated that every 1% reduction in contamination rates in large cities can lower recycling costs by $600,000 to $1 million per year (Chung, 2018).

To inform people about how to sort, the traditional and the most common approach is to use signage, posters, and flyers to educate the users about the sorting rules. This approach is limited in several ways: First, waste disposal signage is often not standardized even within the same jurisdiction or institution (Andrews et al., 2013), which can lead to confusion and decrease user compliance (Ben-Bassat and Shinar, 2006). Second, there is rarely feedback given to the users as they throw items into the bins, because there is no direct feedback mechanism at most bins. People have to instead rely on passive cues (e.g., the signage on the bins or posters on the wall) to make decisions of which items go to which bins. When feedback is provided to the users (e.g., through notices or fines), the feedback is often delayed from the time of the sorting actions, and the information is often conveyed in general terms, such that people may not remember what they did earlier, or which items were incorrectly sorted. The lack of immediate feedback at the time of sorting could result in persistent errors in recycling behavior and erroneous beliefs about how to sort.

To overcome the problem of feedback, here we propose that providing immediate feedback during sorting can be an effective way to build knowledge and fill in the gaps in people's understanding about sorting rules. We further propose that after people have learned through feedback, sorting performance will remain high even when feedback is no longer provided. Decades of research in cognitive psychology show that feedback facilitates learning and improves task performance by correcting errors (e.g., Anderson et al., 1971; Butler et al., 2007; Kulhavy, 1977; Mory, 2004; Shute, 2008). Past studies have demonstrated that weekly (DeLeon and Fuqua, 1995; Schultz, 1999), biweekly (De Young et al., 1995), or monthly feedback on the quantity of recyclable materials increases recycling rates and the quantity of recyclable materials (Goldenhar and Connell, 1991; Duprè and Meineri, 2016). However, these studies provided delayed feedback, where feedback was only given at least one week later. Immediate feedback may be more beneficial since it has been shown to enhance the retention of course materials (Dihoff et al., 2003), facilitate word learning (Pashler et al., 2005), and promote efficient learning (Corbett and Anderson, 2001). Given the effectiveness of immediate feedback on learning, an unexplored question is whether immediate feedback facilitates the learning of recycling and composting knowledge, and improves sorting accuracy by correcting recycling errors, even when feedback is no longer provided.

To incorporate immediate feedback in sorting behavior, one approach is to ‘gamify’ sorting via a computer interface. The engaging and entertaining elements of games, along with the proliferation of Information and communication technologies, have led to a rise in ‘gamification’ in sustainability development by adding game-like elements (e.g., scoring, rules, and competition) to various activities (Zelenika and Pearce, 2012). Studies have shown that digital tools and gamification can be an effective way to engage people and stimulate learning, since games increase the player's motivation and attention (Connolly et al., 2012; De Freitas, 2006; Mitchell and Savill-Smith, 2004). For example, game technology has been successfully used to positively impact students' learning of mathematics (Shin et al., 2012), geography (Tüzün et al., 2009), sustainable consumption (Huber and Hilty, 2015), and energy related attitudes and behaviours (Knol and DeVries, 2011).

1.1. Current study

The broader goal of the current study is to develop an effective tool to improve sorting accuracy to reduce contamination in recycling streams. Toward this goal, the current study aims to examine the impact of a sorting game that delivers immediate feedback on recycling and composting accuracy. To achieve this goal, we developed and tested a digital sorting game based on the University of British Columbia (UBC) sorting guidelines. We first identified the most problematic items where sorting mistakes occur most often on the UBC campus (pilot study). Targeting these items in particular, we designed the sorting game in the lab where participants manually sorted items into four bins (food scraps, recyclable containers, paper, and garbage) via a computer interface, and received immediate feedback on their performance. Participants sorted the items in two ways: pressing a key on the keyboard to indicate to which bin the item belongs (Experiment 1), or manually dragging the item to the bin so their motion is tracked (Replication 1). We also tested participants one week after playing the game to examine the longevity of the effects of immediate feedback (Replication 2). Finally, we implemented this game in student residences on campus and examined whether the game influenced actual sorting behavior in the residences (Experiment 2).

2. Pilot study

The goal of the game was to build knowledge and fill in the gaps in people's understanding about sorting rules. To understand the gaps, we first needed to know what the problematic items were for which sorting mistakes occurred most often. In this pilot, we tested people's existing knowledge about sorting without giving them feedback. Specifically, we asked undergraduates on UBC campus to sort 80 common items into four bins (food scraps, recyclable containers, paper, and garbage) via a computer interface and identified items with the lowest accuracy based on UBC sorting guidelines. The goal of this pilot study was to select the most problematic items with the lowest accuracy for the sorting game in the following experiments.

2.1. Participants

Fifty undergraduate students (30 female and 20 male; mean age = 20.1 years, SD = 1.8) from UBC participated for course credit. Participants in all experiments reported normal or corrected-to-normal vision and provided informed consent. All experiments reported here were approved by the UBC Behavioral Research Ethics Board.

2.2. Apparatus

Participants in this pilot study and Experiment 1 were seated 50 cm from a computer monitor (refresh rate = 60 Hz). Stimuli were presented using MATLAB (Mathworks) and Psychophysics Toolbox (http://psychtoolbox.org).

2.3. Stimuli

The stimuli consisted of 80 images of items, 20 in each of the four bins: food scraps (e.g., an apple core), recyclable container (e.g., a beer bottle), paper (e.g., A4 paper) and garbage (e.g., a plastic bag). The item images are listed in Appendix A. Each image (subtending 10.3° of visual angle) was presented at the lower center of the screen against a white background. Four bin signages (each subtending 10.7°) were designed by the UBC Zero Waste Group, and represented the four bins used on the UBC campus (see the signage of the four bins in Section A of Supplementary Materials). The four bin signages were food scraps (R/G/B values: green = 32/138/56), recyclable container (grey = 101/101/101), paper (blue = 32/86/147), and garbage (black = 19/19/19). They were presented from left to right on the top of the computer screen (see Fig. 1a). The order of the four bins followed the standardized bin positions at each waste station on UBC campus.

2.4. Procedure

The pilot study consisted of 80 trials. In each trial, one item appeared on the screen, and participants were instructed to sort the item into one of the four bins, as if they were to throw away the item at a waste station on campus. Participants sorted the item by pressing the "3", "5", "7", or "9" key on the keyboard for food scraps, recyclable container, paper, or garbage bin, respectively. If they did not respond, the item remained on the screen until response. The inter-trial interval was 500 ms. The order of the trials was randomized. There was no feedback given during the sorting task, and their total accuracy score was presented at the end of study. Each participant first received eight trials for practice before starting the sorting task, and received feedback for each practice trial. The items from the practice trials were excluded from the subsequent experiments or analyses. A debriefing session was conducted after the study to clarify the purpose of the study and to answer any questions the participants had about the study.

2.5. Results

Accuracy of each item was analyzed based on UBC composting and recycling guidelines. The mean accuracy of each item in each bin was calculated using the number of participants who correctly sorted the item divided by the total number of participants, because each item was only presented once in the study (see the sorting accuracy for each item in the pilot study in Section B of Supplementary Materials). Overall, the garbage bin had the lowest accuracy (53.7%), followed by the food scraps bin (72.1%), the recyclable containers bin (79.9%), and the paper bin (86.0%). The 10 items with the lowest accuracy in each bin were considered as the most problematic items. In the garbage bin, participants complained about four items (styrofoam bowl, black plastic tray, muffin wraps, and styrofoam tray) as being ambiguous and hard to recognize, so we chose to use the next four items with a low accuracy (straw, hanger, zip lock bag, and bubble wrap). The 40 items were selected as stimuli in the sorting game in subsequent experiments. These items were also verified by the UBC Campus Sustainability Office as common contaminants in the waste streams on campus.

3. Experiment 1

This experiment aimed to examine how immediate feedback in the sorting game influenced sorting performance in the lab.

3.1. Participants and stimuli

A new group of 100 undergraduate students (89 female[1] and 11 male, mean age = 20.5 years, SD = 2.9) from UBC participated in the experiment for course credit. To determine the sample size in this experiment, we conducted a power analysis[2] using G*Power (Faul et al., 2007). Given a Cohen's d of 0.69 based on a prior study testing the effect of immediate feedback (Butler and Roediger, 2008), a minimum of 92 participants was required to have 90% power (alpha = 0.05) to reveal the effect in our experiment. Thus, we recruited 100 participants in this experiment. From the pilot study, the 40 items with the lowest accuracy were used as stimuli, with ten item images in each bin. To test the effect of learning, we also created a second set of images of the same 40 items, but each item was represented by a different image. The two sets of images are listed in Section C of Supplementary Materials. The code of all experiments is available at: https://osf.io/frqu7/.

3.2. Procedure

There were two conditions in the experiment: learning condition and control condition (N = 50 in each). In the learning condition, participants completed two blocks of trials with 40 trials in each. In the first block, they sorted each item into one of the four bins, just as in pilot study (Fig. 1a), except now they received immediate feedback after each trial, which informed them whether they sorted the item into the correct bin (Fig. 1b). The feedback appeared below the item after participants pressed a key to sort. For correct trials, the feedback was simply "Correct!" but for incorrect trials, the feedback informed the participant into which bin the item should be sorted (e.g., "Wrong! This should go to Food Scraps"). The feedback remained on the screen for 1 s before the next trial started. In the second block, participant performed the same sorting task, with a different set of images, but no feedback was provided in order to test whether participants had learned to sort better after the first block with feedback (Fig. 1b).

In the control condition, participants performed the same sorting task in two blocks, except that they did not receive any feedback in the first or the second block (Fig. 1c). Thus, the only difference between the two conditions was the presence or the absence of feedback in the first block. The inter-trial interval was 1 s, and there was a 2-min break between the two blocks. In both conditions, participants viewed the same bin signage to help guide sorting decisions (see Section A of Supplementary Materials). The order of two sets of images was counterbalanced across participants. The order of trials in each block was randomized. Participants received eight practice trials before starting the experiment, and a debriefing session was conducted after the experiment to answer any questions the participants had about the study.

4. Results and discussion

4.1. Overall sorting accuracy

We first calculated the overall sorting accuracy for each participant using the number of items that were correctly sorted divided by the total number of items (40) in each block and in each condition. We then analyzed the overall accuracy using a 2 (condition: learning vs. control;

[1] The participants in this experiment were from the Human Subjects Pool from the Department of Psychology at UBC, which consists of more female than male students (female students represent 64% in the Faculty of Arts at UBC in 2017). In Experiment 2, participants were not limited to psychology or Arts students (female students represent 55% of all the undergraduates at UBC in 2017).

[2] A power analysis is used to estimate the sample size that is required for an experiment in order to ensure that the effect of the manipulation (e.g., immediate feedback) can be detected based on the statistical power, alpha level, and effect size (Cohen, 1988; Faul et al., 2007).

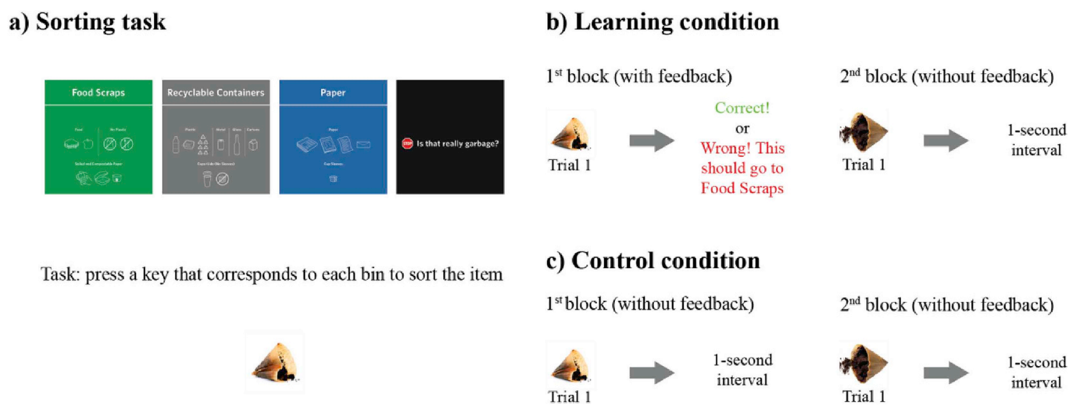

Fig. 1. Experiment 1 Methods. (a) In each trial, participants sorted an item into one of four bins (food scraps, recyclable container, paper, or garbage) by pressing a key on the keyboard. (b) In the learning condition, participants received feedback after each trial in the first block, but not in the second block. (c) In the control condition, participants did not receive any feedback in either block.

between subjects) × 2 (block: first vs. second; within-subjects) mixed-effects ANOVA. There was a significant effect of condition [$F(1,98) = 51.92$, $p < .001$, $\eta_p^2 = 0.35$] and of block [$F(1,98) = 131.48$, $p < .001$, $\eta_p^2 = 0.57$], and a significant interaction [$F(1,98) = 74.09$, $p < .001$, $\eta_p^2 = 0.43$] (Fig. 2a, post-hoc Tukey results were presented in Table S1). This means that the accuracy was higher in the learning condition than in the control condition, higher in the second block than in the first block, and the difference between the first block and the second block was greater in the learning condition than in the control condition. These results demonstrate that immediate feedback in the first block increased sorting accuracy in the second block in the learning condition even when feedback was no longer provided.

To identify who showed the most improvement in sorting performance, we ran a correlation between the accuracy in the first block of the feedback condition and the difference between the accuracy in the first block and in the second block in the feedback condition. We found that participants who were worse in the first block showed greater improvement in the second block ($r = -0.47$, $p < .001$), suggesting that those who initially lack sorting knowledge improve the most after immediate feedback.

4.2. Sensitivity analysis by bin

Since the overall sorting accuracy did not take into account the contamination in each bin, we further calculated *d'* as a sensitivity measure for each bin to get a better sense of contamination. *d'* was calculated as the difference between the z-scores of hit rate and false alarm rate. The hit rate was determined by the number of correctly sorted items to the bin divided by the total number of items that should be in that bin (e.g., the hit rate of food scraps bin = the number of correctly sorted items to the food scraps bin/10 food scraps items). The false alarm (FA) rate was determined by the number of incorrectly sorted items to the bin divided by the total number of items that should not be in that bin (e.g., the FA rate of food scraps bin = the number of incorrectly sorted items to the food scraps bin/30 non-food items). In order to avoid infinite *d'*, scores of 0 or 1 were adjusted to 1/(2 × total number of trials) and 1-1/(2 × total number of trials) respectively, based on the recommendations in Macmillan and Creelman (2005). We have also conducted overall sensitivity analyses (see Section D of Supplementary Materials), and the results were largely consistent with the overall sorting accuracy analyses.

For all four bins, we found that sorting performance was significantly higher in the learning condition than in the control condition [$F(1,98) = 47.49$, $p < .001$, $\eta_p^2 = 0.33$], higher in the second block than in the first block [$F(1,98) = 155.78$, $p < .001$, $\eta_p^2 = 0.61$], and the difference between the first block and the second block was greater in the learning condition than in the control condition [$F(1,98) = 89.91$, $p < .001$, $\eta_p^2 = 0.48$] (Fig. 2b). Based on a deeper analysis of the interaction using Tukey's HSD post-hoc tests, performance increased significantly from the first to the second block in the learning condition for all bins (p's < 0.001), but there was no difference between the two blocks in the control condition for any bin (p's > 0.05, Fig. 2b). Moreover, in the second block performance was significantly higher in the learning condition than in the control condition for all bins (p's < 0.001). Even in the first block, performance was higher in the learning condition than in the control condition for the recyclable container bin and the garbage bin (p's < 0.001), suggesting the feedback already improved performance in the first block. Detailed ANOVA and Tukey's HSD post-hoc test results on the sensitivity for each bin are shown in Section D of the Supplementary Materials.

These results demonstrate that immediate feedback in the first block increased sorting performance in all four bins even when feedback was no longer provided in the second block. This suggests that participants have learned to sort more accurately after receiving feedback in the first block. In addition, these results were largely replicated when analyzed using the sorting accuracy by bin (see additional analyses in Section D of Supplementary Materials). We also examined the sorting speed in terms of response times, but there were no significant differences in sorting speed between learning condition and control condition, except for garbage bin (see additional analyses in Section D of Supplementary Materials). Overall, the results suggest that immediate feedback increased sorting performance even when feedback was no longer provided.

4.3. Two replications

Two replication experiments were conducted to examine the robustness of the findings in Experiment 1. Since sorting items into bins in daily life is a manual task involving hand motions, we replicated this experiment using motion tracking in order to better capture the daily sorting actions, where participants sorted each item by dragging it to one of the four bins in each trial (the first replication experiment is described in Section E in Supplementary Materials). The results were largely consistent with those in Experiment 1. In the second replication, we tested sorting performance in the second block one week after the first block. We found that immediate feedback in the first block improved sorting performance after a one-week delay, again replicating the results in Experiment 1 (the second replication experiment is described in Section F in Supplementary Materials).

5. Experiment 2

Experiments 1 was conducted in the lab where participants sorted

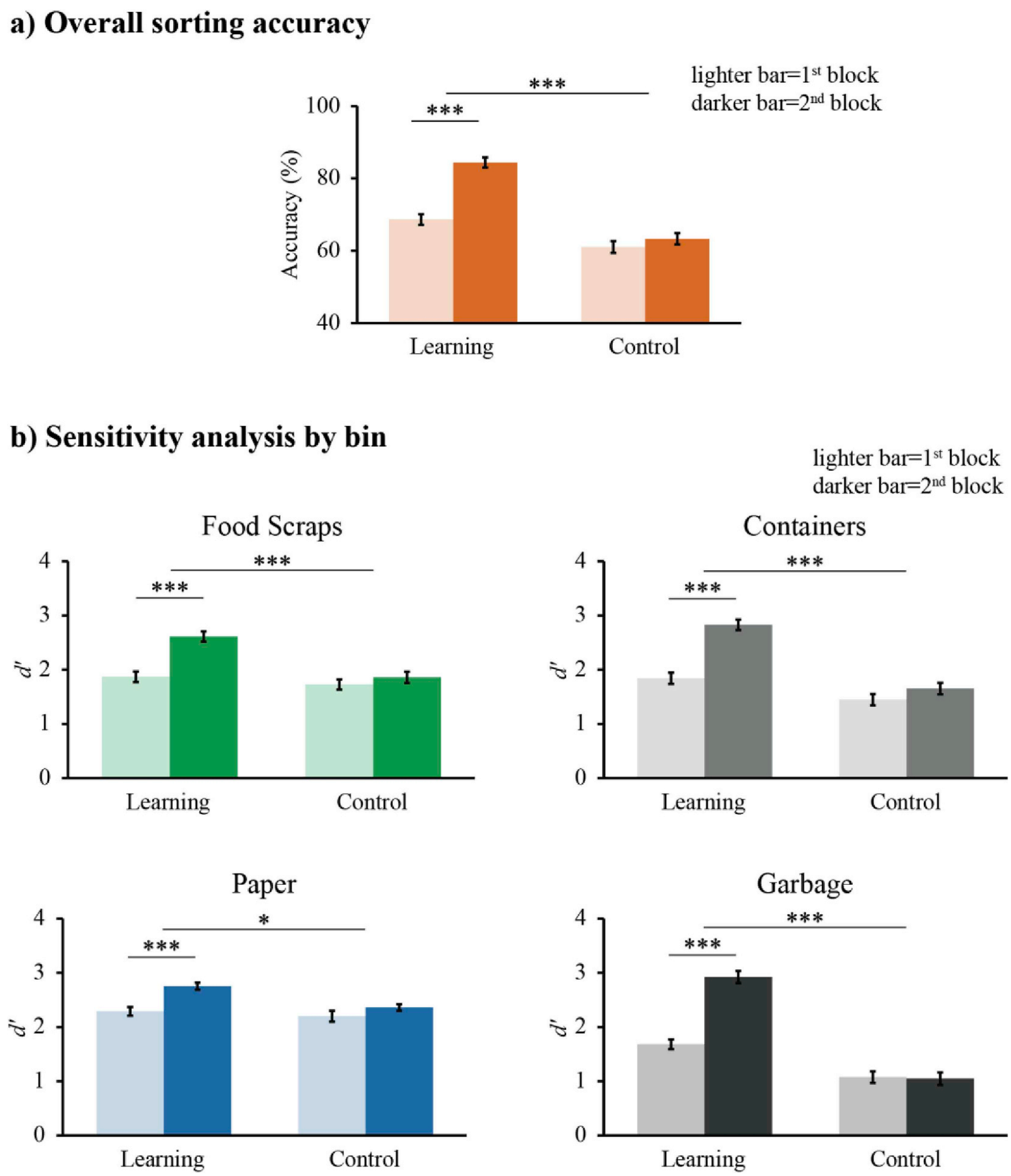

Fig. 2. Experiment 1 Results: (a) The overall sorting accuracy. (b) The mean *d'* of each bin was analyzed using 2 (condition: learning vs. control; between-subjects) × 2 (block: first vs. second; within-subjects) mixed-effects ANOVA. (Error bars reflect ± 1 *SEM*; $*p < .05$; $***p < .001$).

items via a computer interface. While the results showed that the immediate feedback increased sorting accuracy, the findings were limited to the artificial lab settings. To see whether the sorting game influences actual sorting behavior in daily life, in this experiment we implemented the game in student residential buildings on UBC campus and examined whether the game improved actual sorting accuracy and reduced contamination outside the lab.

5.1. Participants

Three high-rise buildings from the UBC Marine Drive (MD) student residence were selected for the experiment, and randomly assigned to 2 conditions. Two buildings were in the game condition, and the third building was in the control condition. The MD residence was selected for the study due to several reasons: the three buildings had similar numbers of residents, apartment units, and floors; and each building had a recycling room with a similar layout and the same sorting signage (including a large sorting infographic poster on the wall, signage on the bin lid, and a transparent box containing sample items that should go into the bin; see Section H of Supplementary Materials). Since both the control and the game buildings had the same recycling signage and infrastructure, this experiment tested the additional impact of the sorting game. The control building is located between the two game buildings. The distance between game building 1 and the control building (entrance to entrance) is 60 m, and the distance between the control building and game building 2 is 30 m. We recruited 334 residents to play the game, and had to exclude 26 responses due to technical problems or incompleteness, resulting in a total of 308 residents who completed the game (149 female, 159 male; mean age = 20.8 years, SD = 1.8) from the two game buildings. The overall participation rate for both towers combined was 43.3%, while the average accuracy was 68%. The detailed description of the buildings, participants' demographics and game statistics are listed in Section G of Supplementary Materials.

5.2. Stimuli

Since the sorting game in the previous experiments took at least 15 min to complete (80 trials in total), we needed to reduce the length of the game in order to maximize participation in the game in the student residence. Therefore, we narrowed the items down to 28 (7 in each bin), which had the lowest accuracy and were identified by the UBC Campus Sustainability Office as the commonly mis-sorted items. This sorting game was identical to the first block (with feedback) in the learning condition in Experiment 1, except only with 28 items, and participants clicked on the bin signage to sort the item. The sorting game took about five minutes to complete. The code of the game is available at: https://osf.io/frqu7/. The sorting game is available at: http://yuluo.psych.ubc.ca/studies/Sorting_MD.

5.3. Procedure

The experiment ran for a total of 11 weeks from January to April (the spring semester), with the first two weeks as the *baseline* period, followed by six weeks as the *intervention* period[3] where we administered the game in the buildings, and the final three weeks as the *post-intervention* period. During the intervention period, we posted a poster on every floor by the elevator in each game building, and on the bulletin board in the recycling room in the basement (see the poster in Section H of Supplementary Materials). Moreover, with the help of research assistants we set up a table in the lobby of each game building every Tuesday, Wednesday, and Thursday during 5–7pm when student traffic was high. We set up a laptop computer and an iPad on the table, as well as chocolates as immediate incentives after completing the game, the sorting game posters, and zero waste posters from UBC Campus Sustainability Office (see the table layout in Section H of Supplementary Materials). We approached and invited students coming in and out of the building to play the sorting game, confirmed that they lived in the building, and offered a chance to win a prize (a $25 gift card) as a reward to play the game. We did not set up the table in the lobby or put up the posters in the control building.

Every week of the 11-week period, we coordinated with the building managers and custodial staff to hold bins in specific areas in the basement for measurements one day before the scheduled collection pickup. Due to the different pickup schedules, paper bin and recyclable containers bin were measured twice a week, and food scraps bins were measured three times a week. While each building had all 4 waste streams, we did not measure the garbage bin due to the large size and the heavy weight of the garbage bins, and the safety concerns of moving them. Thus, we only weighed food scraps, recycling containers, and paper bins. The bin dimension was about 22 × 24 × 40 inches. We weighed each bin with all the contents inside. We also weighed a spare empty bin, and subtracted its weight from the total weight in order to get the weight of the contents inside the bin. The RAs recorded the weight of each bin in kilograms (kg). All paper and recyclable containers bins were weighed by a digital DYMO® S250 shipping scale at the fixed location in the recycling room, because the bins were closer to the scale. All food scraps bins were weighed by a portable Brecknell DS100 industrial scale in the recycling room.

In addition to weight, we also measured the amount of contamination in each bin. Specifically, we used tongs and gloves to visually inspect the items in the bin and counted the number of items that did not belong to the bin. We decided not to count the total number of items in the bin due to logistical and sanitary challenges. Thus, contamination was measured as the number of items that should not be in the bin. Before data collection, each RA was trained on UBC sorting guidelines to ensure that they knew which items should go to which bin. When there were multiple bins in the stream, we collected the weight and contamination data of each bin in the stream, and took the average of the stream for the week. Thus, we had weight (kg) and contamination (number of incorrect items) data in the food scraps, recycling containers, and paper streams in each building every week. Additionally, we calculated the number of contaminants per kg in each bin using the number of contaminants divided by weight.

[3] We originally planned for 5 weeks of intervention to reach as many residents as possible, but due to the low participation rates, we decided to extend the intervention period by one more week.

6. Results and discussion

Since there were two buildings in the game condition, we first performed a 2 (building: game building 1 vs. game building 2; between-subjects) × 3 (time: baseline, intervention, and post-intervention; between-subjects) ANOVA for each stream (food scraps, recyclable containers, and paper) and for each measure. There was little difference between the two buildings in the game condition in any stream and in any measure (see game building comparisons in Section I of Supplementary Materials), and therefore we combined the data from the two buildings in the game condition.

To examine the impact of the sorting game on performance, we used a 2 (building: game vs. control; between-subjects) × 3 (time: baseline, intervention, and post-intervention; between-subjects) ANOVA for each stream (food scraps, recyclable containers, and paper) and for each measure. The average weight, contamination, and contamination per kg are shown in Fig. 3.

6.1. Food scraps weight (kg)

The ANOVA analysis showed that there was a main effect of building [$F(1,16) = 8.04$, $p = .01$, $\eta_p^2 = 0.33$] and time [$F(2,16) = 7.89$, $p = .004$, $\eta_p^2 = 0.50$], but no significant interaction between building and time [$F(2,16) = 0.37$, $p = .70$, $\eta_p^2 = 0.04$]. Tukey's HSD post-hoc test showed that in the game building the weight increased from baseline to intervention period ($p = .046$). Additionally, the weight was significantly higher in the game building during intervention period ($p = .02$) and post-intervention period ($p = .04$) than the control building, but no difference between the game building and the control building during baseline ($p = .99$). This suggests that the game increased the weight of food scraps when students were playing the game, and importantly, the effect remained after the game period.

6.2. Food scraps contamination

For contamination, there was no effect of building [$F(1,16) = 1.64$, $p = .22$, $\eta_p^2 = 0.09$], time [$F(2,16) = 0.03$, $p = .97$, $\eta_p^2 = 0.003$], or interaction [$F(2,16) = 1.76$, $p = .20$, $\eta_p^2 = 0.18$]. Tukey's HSD post-hoc test showed no significant pair-wise differences.

6.3. Food scraps contaminations per kilogram

For number of contaminations per kilogram, there was a main effect of building [$F(1,16) = 6.18$, $p = .02$, $\eta_p^2 = 0.28$], and a marginal interaction between building and time [$F(2,16) = 2.79$, $p = 2.79$, $\eta_p^2 = 0.26$], but no effect of time [$F(2,16) = 2.56$, $p = .11$, $\eta_p^2 = 0.24$]. Tukey's HSD post-hoc test showed that the number of contaminations per kilogram in the game building was marginally significant lower than in the control building in the post-intervention period ($p = .06$). This suggests that the weight increase in the food scraps bin during and after the game was not associated with an increase in contamination, but rather the contamination in the game building decreased after the students have played the game.

6.4. Recyclable containers weight (kg)

For recyclable container weight, there was no effect of building [F

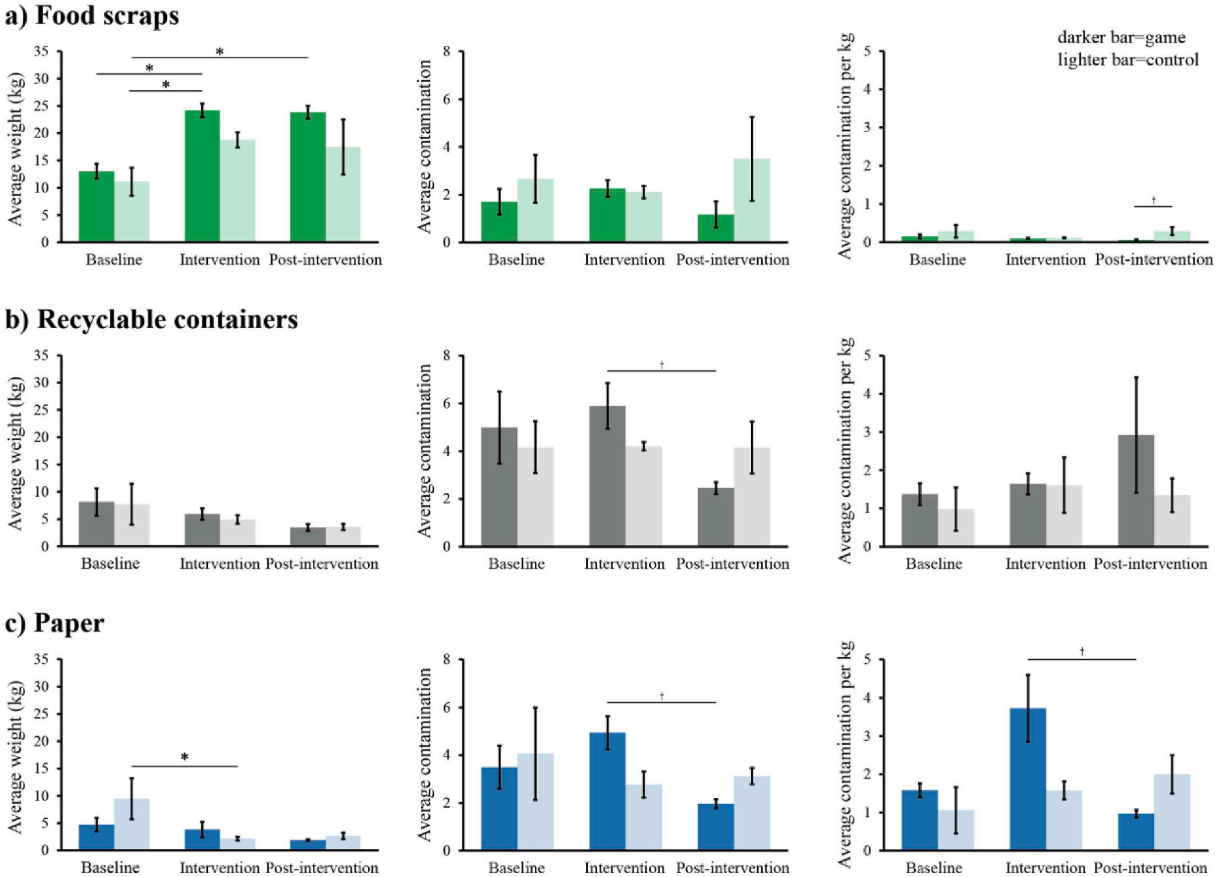

Fig. 3. Experiment 4 results. Average weight (kg), contamination (number of incorrect items), and contamination per kilogram in the (a) food scraps bin, (b) recyclable containers bin, and (c) paper bin, in the game building and the control building in the baseline, intervention when the game was administered in the buildings, and post-intervention period. (Error bars reflect ± 1 SEM; $^{\dagger}p < .10$, $^{*}p < .05$).

(1,16) = 0.75, $p = .40$, $\eta_p^2 = 0.04$], time [F(2,16) = 2.31, $p = .13$, $\eta_p^2 = 0.22$], or interaction [F(2, 16) = 2.15, $p = .15$, $\eta_p^2 = 0.21$]. Tukey's HSD post-hoc test showed no significant pair-wise differences.

6.5. Recyclable containers contamination

For contamination, there was no effect of building [F(1,16) = 0.99, $p = .34$, $\eta_p^2 = 0.06$], time [F(2,16) = 2.43, $p = .12$, $\eta_p^2 = 0.23$], or interaction [F(2,16) = 2.28, $p = .14$, $\eta_p^2 = 0.22$]. Tukey's HSD post-hoc test showed only a marginally significant decrease in contamination between the intervention period and post-intervention period (p = .08) in the game building.

6.6. Recyclable containers contamination per kilogram

For number of contaminations per kilogram, there was no effect of building [F(1,16) = 0.70, $p = .42$, $\eta_p^2 = 0.04$], time [F(2,16) = 0.54, $p = .59$, $\eta_p^2 = 0.06$], or interaction [F(2,16) = 0.57, $p = .58$, $\eta_p^2 = 0.07$]. Tukey's HSD post-hoc test showed no significant pair-wise differences.

6.7. Paper weight (kg)

For paper weight, there was a main effect of time [F(2,16) = 5.25, $p = .02$, $\eta_p^2 = 0.40$], but no effect of building [F(1, 16) = 0.02, $p = .88$, $\eta_p^2 = 0.001$] or interaction [F(2, 16) = 2.59, $p = .11$, $\eta_p^2 = 0.24$]. Tukey's HSD post-hoc test showed only a significant decrease in weight between the baseline and intervention period ($p = .02$) in the control building.

6.8. Paper contamination

For paper contamination, there was a marginal interaction between building and time [F(2,16) = 3.18, $p = .07$, $\eta_p^2 = 0.28$], but no effect of building [F(1,16) = 1.56, $p = .23$, $\eta_p^2 = 0.09$] or time [F(2,16) = 1.75, $p = .20$, $\eta_p^2 = 0.18$]. Tukey's HSD post-hoc test showed only a marginally significant decrease in contamination between the intervention period and post-intervention period ($p = .09$) in the game building.

6.9. Paper contamination per kilogram

For number of contaminations per kilogram, there was a marginal effect of building [F(1,16) = 3.18, $p = .09$, $\eta_p^2 = 0.17$], and a marginal interaction between building and time [F(2,16) = 3.08, $p = .07$, $\eta_p^2 = 0.28$], but no effect of time [F(2,16) = 2.50, $p = .11$, $\eta_p^2 = 0.24$]. Tukey's HSD post-hoc test showed only a marginally significant decrease in number of contaminations per kilogram between the intervention period and post-intervention period ($p = .06$) in the game building.

In sum, the only effect in Experiment 2 was that the sorting game increased the weight of food scraps in the intervention period and also in the post-intervention period. The weight increase in the food scraps bin was not associated with an increase in contamination, if anything, the contamination in the game building marginally decreased in the post-intervention period compared to the control building. For recyclable containers and paper bin, we found a marginally significant decrease in contamination between the intervention period and post-intervention period in the game building.

7. General discussion

The goal of the current study was to examine the impact of a sorting game that delivers immediate feedback on sorting accuracy. In Experiment 1, we found that participants have learned to sort more accurately after receiving immediate feedback after each trial in the first block, even when feedback was no longer provided in the second block, but the feedback had minimal impact on the sorting speed. In Replication 1 of Experiment 1, we found that feedback in the learning condition improved sorting accuracy for all four bins, except for the paper bin because sorting performance increased in the control condition in the second block for the paper bin. One explanation of this anomaly could be due to a campaign in the spring and summer terms on UBC campus when we collected the data for the replication experiment. The campaign specifically aimed to raise awareness that coffee sleeves should go to the paper bin. We speculate that in the first block in the control condition, participants may instinctively throw the coffee sleeves into the food scraps bin or the garbage bin, but in the second block they may remember that coffee sleeves should go to paper bin from the campaign. To confirm this speculation, we examined the sorting accuracy of coffee sleeves and it indeed showed the largest improvement from the first block (70.0%) to the second block (83.0%), whereas the other paper items improved from 71.5% to 74.8%. Thus, this self-correcting behavior based on the retrieval of prior knowledge could explain the improvement in sorting in the paper bin in the control condition of the replication experiment.

We note that feedback did not optimize sorting motion or sorting speed in the replication experiment, except that the sorting speed improved only for the garbage bin. One explanation is a possible ceiling effect in sorting speed in food, containers, and paper bins, so feedback could not improve the speed further. However for the garbage bin, the response time was the slowest, so feedback could improve the sorting speed. Once participants learned how to sort garbage items based on immediate feedback, their sorting speed for garbage items raised to the same levels as for the other bins (see Section E of Supplementary Materials).

In Replication 2 of Experiment 1, we found that participants in the learning condition showed higher sorting accuracy than those in the control condition in all four bins even one week after playing the game, but there was no difference in their sorting speed. This suggests that immediate feedback in the game remains to have an impact on sorting accuracy one week after the feedback was provided.

In Experiment 2, we found that the sorting game increased the weight of food scraps when students were playing the game during the intervention period, and also in the post-intervention period. The weight increase in the food scraps bin was not associated with an increase in contamination, if anything, the contamination per kg in the game building marginally decreased in the post-intervention period compared to the control building. We also found a marginal decrease in the contamination in the post-intervention period in the game building in recyclable containers bin and paper bin. There are several reasons why the effect was stronger in the food scraps bin. First, the weight and the contaminants of the containers and paper bins were more variable than that of the food scraps bin (see Fig. 3). This could be due to the fact that only food scraps can go to the compost bin, but many other types of items can go to the containers bin or the paper bin. Second, the contamination was the lowest for the food scraps bin, so the game may encourage people to throw more food waste in the food scraps bin. However, contamination remained high for the containers and the paper bins after the intervention. This could be due to the possibility that our game did not capture most of the contaminants in the containers and paper bins.

Taken the experiments together, our study suggests that immediate feedback can improve sorting accuracy even when the feedback is no longer provided. The sorting game provided an additional benefit beyond the existing efforts to promote sorting, since both the control and the game buildings used the same sorting signage and infrastructure. The existing signage at UBC included a large sorting infographic poster on the wall, signage on the bin lid, and a transparent box containing sample items that should go into the bin (see Section H in Supplementary Materials). This signage was present in every building in Experiment 2. Thus, the sorting game represents a novel intervention.

One concern with Experiment 2 is that residents in the control building may have seen the posters or lobby events in the game buildings. This may increase their awareness of sorting or motivation to sort. Since each participant in the sorting game indicated which building they lived in, we found no participants outside of the two game buildings played the sorting game, so it is unlikely that the residents in the control building also played the game and improved their sorting behavior. Regardless, the increased awareness or motivation in the control residents likely only increased the weight of waste but not necessarily the sorting accuracy, since the residents in the control building did not play the same. Indeed, our data showed that weight did not change over time or across streams in the control building. Thus, there was no evidence that residents in the control building changed their sorting behavior due to the game.

Another concern with Experiment 2 is that we advertised our sorting game in the game buildings using posters and lobby events, and these efforts may have raised the awareness in students in these buildings. Experiment 2 could not tease apart whether the results were driven by the sorting game or the increased awareness due to game promotion. To address this issue, we offer two arguments. First, Experiments 1 showed strong evidence in the lab that sorting performance improved in the second block in the learning condition when feedback was no longer provided. Replication 2 also showed that the immediate feedback improved sorting accuracy after a week. This suggests that the immediate feedback in the first block had a positive impact on subsequent performance. By this logic, we reason that participants who played the sorting game and received immediate feedback in Experiment 2 may also improve their sorting performance later on. Second, we should note that the university is constantly running campaigns to promote sorting, and as a default there are already many posters and signage in the recycling room (see Section H in Supplementary Materials). Thus, we speculate that the students may be less sensitive to our efforts to promote the sorting game.

Numerous sorting errors were identified in the pilot study, showing that people had trouble sorting certain items. These errors could be driven by at least two reasons. First, people may categorize the item based on the physical properties of materials. For example, paper towels, napkins, and chopsticks were disposed incorrectly into paper bins, but should be in the food scraps bin instead. All three items shared similar physical properties of paper, which results in the error of sorting them as paper. Second, people may categorize the items based on the physical form of the items. For instance, broken glass bottles and styrofoam were disposed incorrectly into the recyclable containers bin, but should be in the garbage bin instead. Both items possess the form of a container, and therefore are categorized as containers. These errors suggest that some recycling decisions are driven by intuition, where people categorize items based on physical properties or form.

The beneficial impact of feedback on sorting performance can be explained by at least three reasons. First, for incorrect trials, the feedback provided the correct response to the participants, rather than simply informing them whether their decision was incorrect. This correction allowed participants to know where the item should go instead, even if they made an error. This explains why sorting performance improved in the second block, or in the intervention or the post-intervention period after people have played the game. Such feedback provided sufficient information to allow people to acquire new knowledge, thus facilitating learning (e.g., Phye, 1979; Sassenrath and Yonge, 1969; Wentling, 1973). Second, since feedback was provided immediately after each trial rather than delayed to the end of the game, the learning process was efficient and rapid (Corbett and Anderson, 2001; Kulik and Kulik, 1988). Moreover, in some cases higher accuracy was already observed in the first block of the learning condition, compared to the control condition, suggesting that participants had learned to sort better with feedback (Keller, 1983; Mory, 2004; Tosti, 1978). Third, feedback may facilitate the creation of new sorting concept in people's mind. For example, when the broken glass bottle was first disposed as container, and the feedback informed them it should go to garbage, participants may form a new concept that broken items must be disposed as garbage. Thus, feedback could be an effective tool to build new knowledge (Ilgen et al., 1979; Shute, 2008).

Although the effects in the lab were strong, the impact of the sorting game in the student residences was relatively weaker in Experiment 2. This could be due to several factors. First, the overall accuracy of the sorting game was quite low (around 68%), which suggests that participants may not know the correct answers to all items, and therefore continue to make the same sorting errors when they dispose waste in the basement of their residence. In addition, our game only had 28 items to sort while in real life the number of household materials is larger and more complex. Second, less than half of the residents (< 44%) played the sorting game in the two game buildings despite our efforts to recruit as many participants as possible, so the potential effect of the sorting game could only be seen in these residents, while leaving the majority unchanged. Third, there was a key methodological distinction between the experiments involved different levels of data: Experiments 1 tested individual-level accuracy in a lab setting, while Experiment 2 measured the building-level sorting performance (in kg and contamination) without measuring individual-level accuracy. This difference likely influenced the results of Experiment 2 since only half of the residents played the game. This said, we reason that the sorting game would have achieved stronger effects if we managed to reach every resident in the building. Finally, we did not have sufficient statistical power in Experiment 2, since we could only measure the bins for 11 weeks during the spring semester, with a few data points in each week. The experiment had to be terminated at the end of the semester because students moved out of the residence.

For future studies, there are several recommendations to boost the impact of the sorting game based on the current study. First, the recruitment during intervention period could be intensified with an attempt to recruit all of the residents in the building. It remains to be tested whether putting a flyer of the game in the student dorm room would be just as effective. Second, the game can be played repeatedly so that the accuracy can be maximized. In other words, the game can be used as an education tool to teach people how to sort in daily life. Third, a follow-up questionnaire can be used to examine whether people's attitude toward sorting and their intentions of sorting have changed after playing the game. Fourth, a limitation of the contamination measure in Experiment 2 was the inability to thoroughly inspect the bins for contamination when they were very full, especially in food scraps. Since we relied on visual inspection using tongs, we could not identify all contaminants in the bins and count all items in the bins to deduce the overall percentage of contamination. New methods of contamination inspection (i.e., scanning or moisture sensing technology) would be more efficient and effective to measure contamination for future research. Finally, we only used student samples in our experiments. Future studies should investigate whether the game improves sorting accuracy in single households or multi-family residences to generalize our findings. To implement this game in a residential setting, municipalities can promote the game by sending a link to the game along with recycling and composting information packages for new residents. Building waste management can also promote the game via posters in the recycling room to encourage residents to play. Since the sorting game is more interactive than traditional signage, competitions with prizes can be organized to entice people to play and learn the correct sorting rules.

The current study is significant in three ways. First, we demonstrated that a digital sorting game which delivers immediate feedback to participants can improve sorting accuracy in the lab and in the field, even when feedback is no longer provided. Second, the current study provided a template for applying basic research to solve real-world problems, where we first identified the most problematic items, designed the sorting game targeting specific items, and examined the impact of the game using rigorous experimental methods. This approach can be used and extended for problems beyond waste. Third, the sorting game can be used as an effective education tool to teach people how to sort, and therefore increase recycling and composting rates and reduce contamination. Environmental sustainability depends on not only an intention to act, but also the accurate implementation of actions. Using a digital sorting game can increase the accuracy of actions, facilitating behavior change toward sustainability.

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Appendix A. Supplementary data

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References

Anderson, R.C., Kulhavy, R.W., Andre, T., 1971. Feedback procedures in programmed instruction. J. Educ. Psychol. 62, 148–156.
Andrews, A., Gregoire, M., Rasmussen, H., Witowich, G., 2013. Comparison of recycling outcomes in three types of recycling collection units. Waste Manag. 33, 530–535.
Ben-Bassat, T., Shinar, D., 2006. Ergonomic guidelines for traffic sign design increase sign comprehension. Hum. Factors 48, 182–195.
Bohm, R.A., Folz, D.H., Kinnaman, T.C., Podolsky, M.J., 2010. The costs of municipal waste and recycling. Resour. Conserv. Recycl. 54, 864–871.
Butler, A.C., Karpicke, J.D., Roediger III, H.L., 2007. The effect of type and timing of feedback on learning from multiple-choice tests. J. Exp. Psychol. Appl. 13, 273.
Butler, A.C., Roediger, H.L., 2008. Feedback enhances the positive effects and reduces the negative effects of multiple-choice testing. Mem. Cognit. 36, 604–616.
Chung, E., 2018. Many Canadians Are Recycling Wrong, and It's Costing Us Millions. CBC News Retrieved from. http://www.cbc.ca/news/technology/recycling-contamination-1.4606893.
City of Vancouver, 2015. A By-law to Emend License By-law 4450 Regarding Food Waste. Retrieved from: http://former.vancouver.ca/blStorage/11091.PDF.
City of Vancouver, 2016. Greenest City Action Plan 2020. City of Vancouver. http://vancouver.ca/green-vancouver/zero-waste.aspx Retrieved from.
Cialdini, R.B., 2003. Crafting normative messages to protect the environment. Curr. Dir. Psychol. Sci. 12 (4), 105–109.
Cialdini, R.B., Reno, R.R., Kallgren, C.A., 1990. A focus theory of normative conduct: recycling the concept of norms to reduce littering in public places. J. Pers. Soc. Psychol. 58 (6), 1015.
Cohen, J., 1988. Statistical Power Analysis for the Behavioral Sciences, Rev. edn. Erlbaum, Hillsdale, NJ.
Connolly, T.M., Boyle, E.A., MacArthur, E., Hainey, T., Boyle, J.M., 2012. A systematic literature review of empirical evidence on computer games and serious games. Comput. Educ. 59 (2), 661–686.
Corbett, A.T., Anderson, J.R., 2001, March. Locus of feedback control in computer-based tutoring: impact on learning rate, achievement and attitudes. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM, pp. 245–252.
Crociata, A., Agovino, M., Sacco, P.L., 2015. Recycling waste: does culture matter? J. Behav. Exp. Econ. 55, 40–47.
De Freitas, S., 2006. Learning in Immersive Worlds: a Review of Game-based Learning. Retrieved from. http://www.jisc.ac.uk/media/documents/programmes/elearninginnovation/gamingreport_v3.pdf.

De Leon, I.G., Fuqua, R.W., 1995. The effects of public commitment and group feedback on curbside recycling. Environ. Behav. 27, 233–250.
De Young, R., 1989. Exploring the difference between recyclers and non-recyclers. J. Environ. Syst. 18, 341–351.
De Young, R., Boerschig, S., Carney, S., Dillenbeck, A., Elster, M., Horst, S., Thomson, B., 1995. Recycling in multi-family dwellings: increasing participation and decreasing contamination. Popul. Environ. 16, 253–267.
Dihoff, R.E., Brosvic, G.M., Epstein, M.L., 2003. The role of feedback during academic testing: the delay retention effect revisited. Psychol. Rec. 53, 533.
DiGiacomo, A., Wu, D.W.-L., Lenkic, P., Fraser, B., Zhao, J., Kingstone, A., 2017. Convenience improves composting and recycling rates in high-density residential buildings. J. Environ. Plann. Manag. 1–23.
Duffy, S., Verges, M., 2008. It matters a hole lot: perceptual affordances of waste containers influence recycling compliance. Environ. Behav. 41, 741–749.
Duprè, M., Meineri, S., 2016. Increasing recycling through displaying feedback and social comparative feedback. J. Environ. Psychol. 48, 101–107.
Environmental Protection Agency, 2013. Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures. Retrieved from. https://archive.epa.gov/epawaste/nonhaz/municipal/web/html/.
Faul, F., Erdfelder, E., Lang, A.G., Buchner, A., 2007. G* Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav. Res. Methods 39, 175–191.
Geyer, R., Jambeck, J.R., Law, K.L., 2017. Production, use, and fate of all plastics ever made. Sci. Adv. 3, 25–29.
Goldenhar, L.M., Connell, C.M., 1991. Effects of educational and feedback interventions on recycling knowledge, attitudes, beliefs, and behaviors. J. Environ. Syst. 21, 321–333.
Hoornweg, D., Bhada-tata, P., Kennedy, C., 2013. Waste production must peak this century. Nature 502, 615–617.
Hossain, M., Santhanam, A., Norulaini, N., Omar, A., 2011. Clinical solid waste management practices and its impact on human health and environment: a review. Waste Manag. 31 (4), 754–766.
Huber, M.Z., Hilty, L.M., 2015. Gamification and sustainable consumption: overcoming the limitations of persuasive technologies. Adv. Intell. Syst. Comput. 310, 367–385.
Humes, E., 2012. Garbology: Our Dirty Love Affair with Trash. Avery.
Ilgen, D.R., Fisher, C.D., Taylor, M.S., 1979. Consequences of individual feedback on behavior in organizations. J. Appl. Psychol. 64, 349.
Intergovernmental Panel on Climate Change, 2007. Climate Change 2007: the Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge Univ. Press, New York.
Jambeck, J.R., Geyer, R., Wilcox, C., Siegler, T.R., Perryman, M., Andrady, A., Narayan, R., Law, K.L., 2015. Plastic waste inputs from land into the ocean. Science 347.
Keller, J.M., 1983. Motivational design of instruction. Instructional design theories and models: An overview of their current status. 1, 383–434.
Knol, E., DeVries, P.W., 2011. EnerCities, a Serious Game to Stimulate Sustainability and Energy Conservation: Preliminary Results. Retrieved from. https://www.openeducationeuropa.eu/sites/default/files/legacy_files/asset/In-depth_25_4.pdf.
Kulhavy, R.W., 1977. Feedback in written instruction. Rev. Educ. Res. 47, 211–232.
Kulik, J.A., Kulik, C.L.C., 1988. Timing of feedback and verbal learning. Rev. Educ. Res. 58, 79–97.
Macmillan, N.A., Creelman, C.D., 2005. Detection Theory: a User's Guide, second ed. Lawrence Erlbaum Associates, Mahwah, N.J.
Mitchell, A., Savill-Smith, C., 2004. The Use of Computer and Video Games for Learning. A Review of the Literature. ULTRALAB. Learning and Skills Development Agency Retrieved from. http://dera.ioe.ac.uk/5270/.
Mory, E.H., 2004. Feedback research revisited. Handbook of research on educational communications and technology 2, 745–783.
Pashler, H., Cepeda, N.J., Wixted, J.T., Rohrer, D., 2005. When does feedback facilitate learning of words? J. Exp. Psychol. Learn. Mem. Cognit. 31, 3.
Phye, G.D., 1979. The processing of informative feedback about multiple-choice test performance. Contemp. Educ. Psychol. 4, 381–394.
Sassenrath, J.M., Yonge, G.D., 1969. Effects of delayed information feedback and feedback cues in learning on delayed retention. J. Educ. Psychol. 60, 174.
Schlossberg, T., 2017. The Immense, Eternal Footprint Humanity Leaves on Earth: Plastics. The New York Times Retrieved from. https://www.nytimes.com/2017/07/19/climate/plastic-pollution-study-science-advances.html.
Schultz, P.W., Oskamp, S., Mainieri, T., 1995. Who recycles and when? A review of personal and situational factors. J. Environ. Psychol. 16, 106–121.
Schultz, P.W., 1999. Changing behavior with normative feedback interventions: a field experiment on curbside recycling. Basic Appl. Soc. Psychol. 21, 25–36.
Secretariat of the Convention on Biological Diversity, 2014. Global Biodiversity Outlook 4. Montréal: Global Biodiversity Outlook 4.
Shin, N., Sutherland, L.M., Norris, C.A., Soloway, E., 2012. Effects of game technology on elementary student learning in mathematics. Br. J. Educ. Technol. 43 (4), 540–560.
Shute, V.J., 2008. Focus on formative feedback. Rev. Educ. Res. 78, 153–189.
Statistics Canada, 2013. Waste Management Industry Survey: Business and Government Sectors: 2010. Minister of Industry ii-38. Retreived from: http://www5.statcan.gc.ca/olc-cel/olc.action?objId=16F0023X&objType=2&lang=en&limit=0.
Statistics Canada, 2014. Disposal and Diversion of Waste, by Province and Territory. Retrieved from. http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/envir32b-eng.htm.
Tammemagi, Y.H., 1999. The Waste Crisis: Landfills, Incinerators, and the Search for a Sustainable Future. Oxford University Press.
Thomas, C., Sharp, V., 2013. Understanding the normalisation of recycling behaviour and its implications for other pro-environmental behaviours: a review of social norms and recycling. Resour. Conserv. Recycl. 79, 11–20.
Tosti, D.T., 1978. Formative feedback. Perform. Improv. 17, 19–21.
Tüzün, H., Yilmaz-Soylu, M., Karakuş, T., Inal, Y., Kizilkaya, G., 2009. The effects of computer games on primary school students' achievement and motivation in geography learning. Comput. Educ. 52 (1), 68–77.
United Nations Environment Program, 2015. Global Waste Management Outlook. Retreived from. http://www.unep.org/ourplanet/september-2015/unep-publications/global-waste-management-outlook.
Wentling, T.L., 1973. Mastery versus nonmastery instruction with varying test item feedback treatments. J. Educ. Psychol. 65, 50.
World Economic Forum, 2016. The New Plastics Economy: Rethinking the Future of Plastics. Retrieved from. https://www.weforum.org/reports/the-new-plastics-economy-rethinking-the-future-of-plastics.
Wu, D.W.L., DiGiacomo, A., Lenkic, P.J., Wong, V.K., Kingstone, A., 2016. Being in a “green” building elicits “greener” recycling, but not necessarily “better” recycling. PloS One 11, 1–13.
Zelenika, I., Pearce, J.M., 2012. The Internet and other ICTs as tools and catalysts for sustainable development: innovation for 21st century. Inf. Dev. 29 (3), 217–232.