Achieving Zero Waste: Waste Sorting Behavior, Knowledge, and Barriers at a University of California, Berkeley Residence Hall

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ABSTRACT

Providing university students with an education on how to correctly sort waste on campus is a common method used to theoretically reduce waste contamination levels, but there is a lack of concrete data proving that education on waste sorting results in an increase in correct waste sorting and a reduction in waste contamination levels. In this study, I researched if increasing education on waste sorting would reduce waste contamination levels at University of California, Berkeley. I did this by holding an educational campaign on waste sorting accompanied by pre-/post- waste audits at a residence hall to investigate behavior change and pre-/post- waste sorting quizzes to investigate changes in knowledge. Following this, I interviewed 36 students on the waste sorting process on campus and the challenges they may face with it. From this study, I found that there were no statistically significant waste behavioral changes after the educational campaign, but knowledge on the waste streams did have a statistically significant increase after the educational campaign, and students face waste related infrastructural barriers at the residence halls. The improvement in downstream infrastructure only would not allow us to meet the campus's zero waste goal. To the meet the campus zero waste goal, upstream solutions are needed.

KEYWORDS

waste contamination, waste diversion, infrastructure, waste audit, education

INTRODUCTION

In the US, 292.4 million tons of municipal solid waste (MSW) were generated in 2018, and this is equivalent to about 4.9 pounds of waste generated per person per day. Of this MSW, approximately 50% was landfilled, and the remaining was diverted from the landfill through methods such as recycling, composting, and incineration. Waste generation in the US continues to increase, and this has major environmental impacts especially when the MSW is landfilled (EPA 2022). Landfills are a major driver of environmental degradation due to their impacts on climate change, pollution, and habitat loss. As organic waste breaks down in landfills it releases large amounts of methane, a potent greenhouse gas that is 84 times more potent than carbon dioxide, thus having a major impact on climate change (Lisk 1991; Vasarhelyi 2021). In the US, landfills are the third-largest source of methane emissions (Fullmer 2021). Landfills can also pollute surrounding areas through the leakage of toxic leachate. In the US landfills are required to be lined with plastic or clay, but these linings often leak releasing toxic leachate into the local environment which can then pollute nearby bodies of water with high levels of ammonia and heavy metals. To build a landfill, the wildlife habitat that was previously there had to be destroyed thus increasing the environmental burden of landfills (Lisk 1991; Vasarhelyi 2021). Recycling and composting are key methods to reduce the environmental burden of our waste by reducing the amount of waste disposed of in landfills, but these methods are not always effective due to incorrectly sorted waste.

When waste is placed into the incorrect waste stream (e.g., compost, recycling, or landfill), it is considered contamination. When there is a large amount of waste contamination in the recycling or compost bin, custodial staff often must send that waste to the landfill. This increases the overall amount of waste that is sent to landfills, which increases the overall environmental burden of the waste. Materials that could have been saved via recycling or composting are also lost when sent to a landfill, thus shortening the resources' potential lifespan. Similarly, when recyclable or compost items are placed in the landfill, the materials are often no longer salvageable and it increases the number of landfills needed. Sometimes contaminants are also missed by custodial staff and remain in the recycling and composting waste streams. These contaminants in the recycling waste stream are then transferred into the new products made of post-consumer recycled materials, causing these products to contain higher levels of hazardous contaminants than products made with virgin materials (Knapp et al. 2017). Contaminants in waste sent to

composting facilities can also end up in the compost produced, polluting agricultural fields with microplastics and other fragments of man-made materials (Echavarri-Bravo et al. 2017). Other negative impacts of waste contamination include jeopardizing worker safety, requiring more labor to process the waste, potentially damaging or breaking equipment, and it could lessen the value of other salvageable materials (Heiges and O'Neill 2022; Marshall and Bandhauer 2017). Because of these factors, it is crucial to reduce waste contamination levels, and a typical method to do so is through education.

In the University of California, Berkeley's Zero Waste Plan, education on how to correctly sort waste into the four waste streams on campus (Landfill, Compost, Cans & Bottles, and Mixed Paper) is a key method to decreasing waste contamination levels to reach the campus's zero waste goal of diverting 90% of waste away from the landfill (King et al. 2019). But there is a lack of concrete data proving that educating students on how to sort their waste actually results in an increase in correct waste sorting and a reduction in waste contamination levels. According to a study at a large Midwestern university, there was no significant change in dining hall waste behaviors after the administration of a waste-related educational campaign, although the educational campaign did have a positive effect on students' opinions related to food waste at the university (Ellisona et al. 2019). In a similar study on dining hall waste at a university in the Netherlands, it was found that a waste-related educational campaign had no significant effect on waste sorting behavior in the dining hall (Árnadóttir et al. 2018). There have been some studies that show that education on waste sorting could have a positive impact on waste contamination rates. In a study on waste sorting at the Arizona State University baseball stadium, waste contamination levels were significantly lower when there were volunteers at the waste bins educating fans on how to sort their waste (Hottle et al. 2015). In a similar study on waste sorting at a festival at the University of British Columbia, when volunteers at the waste bins were educating people on how to sort their waste, contamination levels were significantly lower (Zelenika et al. 2018). At UC Berkeley, there are many resources and programs to educate students on how to sort their waste into the four waste streams on campus, but as of 2019, only 54% of the waste produced on campus is diverted away from landfills (UC Berkeley 2022). Even with the current educational programs on waste sorting, it is evident that there is something missing in the process because the diversion rate is still low. It is also crucial to have a higher rate of proper waste sorting to reach the campus's goal of a landfill diversion rate of 90%.

In this study, I will be attempting to answer the question: Would increased education on waste sorting reduce waste contamination levels at UC Berkeley? To answer this question, I will first answer three sub-questions: (1) Did the waste contamination levels decrease after education on waste sorting was increased?, (2) Did the educational methods used increase students' knowledge of waste sorting?, and (3) What are other barriers students face to properly sorting their waste? To answer these questions, I held a waste-related educational campaign and conducted pre-/post- waste audits at a UC Berkeley residential hall. I also administered pre-/post- waste sorting quizzes with the educational campaign. Lastly, I conducted interviews with residents of the residential hall on the waste sorting process on campus and the challenges they may face with it.

BACKGROUND

Campus zero waste goal

Currently, the campus has the goal to "Achieve Zero Waste by 2020 & Beyond." To achieve this goal, the campus would need to achieve a 90% diversion of municipal solid waste from landfills, but the current diversion rate is only 54% (UC Berkeley 2022). To reach a 90% diversion rate there needs to be a combination of upstream, downstream, and educational programs (King et al. 2019). For my thesis, I will be focusing on the education side of waste reduction. It is crucial that all incoming students are provided with an education on the waste streams at UC Berkeley and how to properly sort their waste since the waste streams on campus are much different than common waste streams in the US. Most importantly, UC Berkeley has industrial composting and two recycling waste streams. It is crucial that students understand the waste streams on campus so that they properly sort their waste and the campus can reach its waste reduction goal.

UC Berkeley's Single-Use Plastic Elimination Policy

In April of 2020, UC Berkeley signed a policy that requires the elimination of all non-essential single-use plastic by 2030. This policy has created the strongest ban on single-use plastic in the US. This policy does not just focus on plastic bags and foodware, but it applies to all aspects

of campus. Other items that fall under this policy are single-use office supplies, packaging, event materials, lab supplies, and many other items (CALPIRG Students 2020). Since all single-use plastics are being phased out on campus, there will be more alternative products and students need to know how to dispose of them properly. One of the largest categories of single-use plastics on campus is disposable foodware. Much of the plastic foodware is being replaced with compostable alternatives, and it is important that students can identify the different types of foodware so that they can dispose of them properly. These compostable alternatives are also more expensive, making it even more important students dispose of them correctly. But since these compostable alternatives are not commonly used across the US, it is important that students are educated on how to dispose of them.

City of Berkeley Single Use Foodware and Litter Reduction Ordinance

In 2019, the City of Berkeley passed the Single Use Foodware and Litter Reduction Ordinance and the ordinance went into effect in January 2020. Under this ordinance, foodservice businesses in the City of Berkeley that offer take-out options must BPI-certified compostable foodware, charge $0.25 for disposable cups, and only provide disposable accessory items such as straws, utensils, and napkins upon request. Foodservice businesses that office on-site dining must use reusable foodware for on-site dining and they must have color-coded bins for compost, recycling, and landfill trash. Currently, the enforcement of the ordinance is solely complaint-based, meaning that the city only enforces the ordinance when someone alerts them of a non-compliant business. When a non-compliance issue is brought to their attention, enforcement consists of written notice, an offer of support from the city, and the opportunity to comply or request a waiver (City of Berkeley 2022). Even though UC Berkeley is exempt from the Single Use Foodware and Litter Reduction Ordinance, it still greatly affects the campus waste streams because a large amount of disposable foodware from off-campus restaurants is disposed of on campus (King et al. 2019).

METHODS

Site description

This study was conducted at Spens-Black Hall in Unit 3 at the University of California, Berkeley (Figure 1). For this study, I specifically focused on a dorm-style residence hall, not the apartment-style residence halls which have full kitchens. Spens-Black Hall had 289 residents in the Spring 2022 semester (Cal Housing 2022). In each room, there a two of each type of bin: landfill, compost, and mixed paper (Figure 2). Students are not provided with a cans and bottles bin. At Spens-Black Hall, the landfill, mixed paper, and cans & bottles toters are located outside and the compost toters are inside the building on the ground floor (Figure 3). Spens-Black Hall was constructed in 1964, and at the time of construction the hall was built to only support one waste stream (UCB DAC 2022). The target population of this study is the freshmen class of the 2021-2022 school year. We focused solely on freshmen because they make up the majority of residents in the residence halls at UC Berkeley.

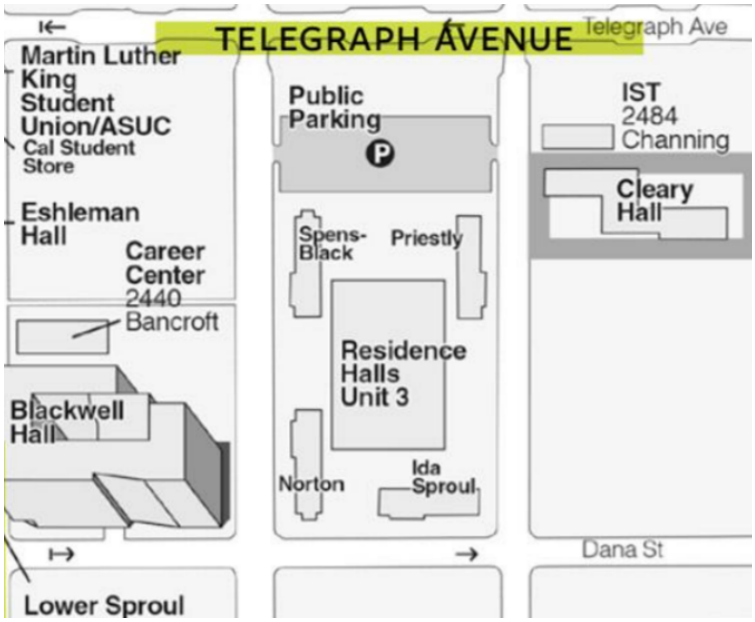


Figure 1. Map of Unit 3 at UC Berkeley. (UC Berkeley 2022)

Figure 2. UC Berkeley Residence Hall Three Bin System.

Figure 3. Location of large toters at Spens-Black Hall. The landfill, mixed paper, and cans & bottles toters are located outside and the compost toters are located inside the building on the ground floor.

Waste audits

Waste collection

For the first waste audit before the educational campaign, we collected the waste from all four waste streams from Spens-Black Hall for seven days, Friday through Thursday. We labeled all bins with the type of waste stream (e.g., landfill, compost, mixed paper, cans & bottles) and the day the waste was generated. Once the bins were full, we stored them separately from the full bins from other halls at Unit 3. Cal Zero Waste staff picked up the full bins each day after the waste was generated, except Sunday, and brought them to the waste audit sorting location. We followed the same procedure for the second waste audit after the educational campaign.

Waste sorting

For this study, I followed Cal Zero Waste's standard methods for preforming a waste audit. For the first waste audit, we emptied each large rolling bin onto a table and separated the contents into Slim Jim bins for each of the four waste streams. Once the Slim Jim bins were full, we weighed each bin and recorded the weights. The weight of each emptied Slim Jim bin was subtracted from the recorded weight of the full bin. We repeated this for each waste stream for each day. We also combined the waste from Friday, Saturday, and Sunday because we were unable to differentiate the waste produced on these days. It should also be noted that we did not empty out bottles or cups that contained liquid, and we did not consider the liquid to be contamination for this study, and we removed the women's bathroom waste bags from the audits. We followed the same procedure for the second waste audit after the educational campaign.

Analysis

To prepare my data, I subtracted the weight of each empty Slim Jim bin from the full bin weight. I then summed the weights of the full Slim Jims for each of the waste streams on each day to get the total weight generated for each waste stream per day. From this data, I calculated the contamination rates for each waste stream per day using the following equations:

$$Landfill\ contamination\ rate = \frac{Compost\ (lbs) + Mixed\ Paper\ (lbs) + Cans\ \&\ Bottles\ (lbs)}{total\ weight\ (lbs)}$$

$$Compost\ contamination\ rate = \frac{Landfill\ (lbs) + Mixed\ Paper\ (lbs) + Cans\ \&\ Bottles\ (lbs)}{total\ weight\ (lbs)}$$

$$Mixed\ Paper\ contamination\ rate = \frac{Landfill\ (lbs) + Compost\ (lbs) + Cans\ \&\ Bottles\ (lbs)}{total\ weight\ (lbs)}$$

$$Cams\ \&\ Bottles\ contamination\ rate = \frac{Landfill\ (lbs) + Compost\ (lbs) + Mixed\ Paper\ (lbs)}{total\ weight\ (lbs)}$$

For this study, I defined waste contamination as any waste that should have been sorted into any of the other waste streams. This process was repeated for the data from the second waste audit following the educational campaign.

After calculating the waste contamination rates for each waste stream per day for both waste audits, I conducted a paired t-test for the landfill, compost, and mixed paper waste streams to determine if the waste contamination rates significantly decreased during the second waste audit. I excluded the cans and bottles waste stream from statistical analysis because I did not have sufficient data due to people removing waste from the cans and bottles bin outside of Spens-Black Hall.

To calculate landfill diversion rate, I used the following equation for each of the two waste audits:

$$Landfill\ diversion\ rate = \frac{C_{nc} + MP_{nc} + CB_{nc}}{total\ weight\ (lbs)}$$

$C_{nc} = Non - contaminated\ Compost\ (lbs)$
$MP_{nc} = Non - contaminated\ Mixed\ Paper\ (lbs)$
$CB_{nc} = Non - contaminated\ Cans\ \&\ Bottles\ (lbs)$

To calculate the potential landfill diversion rate, I used the following equation for each of the two waste audits:

$$Potentail\ Landfill\ diversion\ rate = \frac{C_t + MP_t + CB_t}{total\ weight\ (lbs)}$$

$C_t = Total\ Compost\ from\ all\ waste\ streams\ (lbs)$
$MP_t = Total\ Mixed\ Paper\ from\ all\ waste\ streams\ (lbs)$
$CB_t = Total\ Cans\ \&\ Bottles\ from\ all\ waste\ streams\ (lbs)$

Waste sorting educational campaign

Pre-/ post- quiz design

For my first quiz, I recorded their email addresses and asked four demographic questions and twenty waste sorting questions to test participant knowledge of the four waste streams on campus (Appendix A). I used Qualtrics to conduct this quiz. I recorded participant emails so I could send them the second waste sorting quiz. The demographics collected consisted of year, major, double major and/or minor(s), and if they lived at Spens-Black. I asked if participants lived at Spens-Black so I could later determine what percentage of residents at Spens-Black participated in my study, which provided them with increased education on waste sorting. For the waste sorting quiz questions, I included a picture and word description for twenty common waste items generated in the residence halls. Students selected which waste stream the item should go into, and if they were unsure, they could select the "unknown" option.

For the second quiz, I recorded participant emails, asked them if they were a resident of Spens-Black, and included twenty waste sorting quiz questions (Appendix B). I also used Qualtrics to conduct this quiz. For the waste sorting quiz questions, I used the same structure and waste items as the first quiz, but changed the order of the questions.

Waste tabling

For my research, we conducted a week-long waste sorting educational campaign at Unit 3. We tabled at the Café 3 dining hall, located in the middle of Unit 3, Monday 3/7 through Friday 3/11 during the main lunch and dinner hours: 11 am to 2 pm and 5 pm to 8 pm. I chose to table at Café 3 because it is the nearest dining hall to Spens-Black residence hall, and is a highly trafficked and central location. The table, we had waste sorting infographics, extra waste sorting flyers, example waste items, prizes, a prize wheel, and QR codes that linked to the wasting sorting quiz (Figure 4).

Figure 4. Educational Campaign Tabling Set-Up.

During the time we were outside Café 3, we asked as many people as possible if they would like to learn about waste sorting and win a prize. When students stopped by the table, we first

asked them to scan the QR code with their phone so they could take the first waste sorting quiz. Once the students finished the quiz, we gave a brief talk on how to sort your waste into the four different waste streams and the environmental impacts of waste sorting (Appendix C). After this, we played an interactive waste sorting game with the students. In this game, we selected three of the waste props on the table for the student or group of students to sort. We held up each item and asked the student which bin the item should go in. If they answered incorrectly, we told them which bin it belonged in and why it belonged in this bin. Following this, the students were able to spin the prize wheel for a prize.

Follow-up waste sorting quiz distribution

I distributed the second waste sorting quiz via email to everyone who took the first quiz. To incentivize students to take the second quiz, I raffled off two gift cards to the campus zero waste store, randomly selecting two winners from everyone who took the second quiz. I released the second quiz four days after the last day of tabling at Café 3 and it was left open for a total of thirteen days. I also sent a total of two email reminders to everyone to take the second quiz. I sent the first reminder three days after the initial email and the second reminder seven days after the first reminder. I closed the quiz three days after the second reminder.

Analysis

To prepare the data, I removed incomplete and duplicate responses from the two waste sorting quizzes. For duplicate responses, I kept the first complete response and deleted the second response. I determined the total impact of the week-long educational campaign on Spens-Black by counting the total number of respondents who selected “yes” to living in Spens-Black, and then calculating the percentage of Spens-Black residents who participated in the tabling and first quiz. To determine if there was an increase in knowledge from before to after the active learning intervention at the tabling event, I conducted a paired t-test using scores from the two quizzes for students who took both.

Interviews

To better understand students' experiences with waste sorting in the residence halls, I interviewed residents of Spens-Black Hall. I tabled outside of Spens-Black from Monday 4/11 to Friday 4/15 from approximately 5 pm to 8pm, assuming this was the main time students were returning to their rooms from campus. I asked students as they walked past the table if they were a resident of Spens-Black Hall and if they would like to participate in an interview on waste sorting. If they were not a resident of Spens-Black Hall, I informed them that this was only for Spens-Black Hall residents. I also had zero waste themed prizes for students to incentivize students to participate. For the students who agreed to participate, I asked seven questions on how they sorted their waste, challenges they faced, and what would help them sort their waste (Appendix D). I recorded responses by hand and transferred the answers to an Excel spreadsheet following the interviews. After I transferred interviewee answers to an Excel spreadsheet, I coded their responses by grouping similar answers. I then calculated percentages of each response type for each question. For several questions, many students had multiple responses, so I counted each response towards the total responses.

RESULTS

Waste audits

For both of the waste audits, we separated the waste from each waste stream per day into the four different waste categories (Table 1). From this data, I was able to calculate the waste contamination rates for the landfill, compost, and mixed paper streams, and the current and potential landfill diversion rates.

1. Waste Audit Weights. Table contains the separated waste from all four waste streams each day for both audits. Weights are recorded in pounds (lbs) and the weight of pty bins have already been subtracted. "Pre-Edu" stands for pre- educational intervention and "Post-Edu" stands for post- educational intervention.

		Landfill				Compost				Mixed Paper				Cans & Bottles			
		Landfill	Compost	Mixed Paper	Cans & Bottles	Landfill	Compost	Mixed Paper	Cans & Bottles	Landfill	Compost	Mixed Paper	Cans & Bottles	Landfill	Compost	Mixed Paper	Cans & Bottles
	Fri-Sun	135.36	138.6	14.42	32.32	20.64	182.04	3.36	6.82	1.9	4.48	27.88	1.42	1.06	1.3	1.3	31.21
	Mon	27	41.54	2.88	10.44	13.36	65.26	0.58	2	0.94	0	6.94	6.22	0.6	0.34	0.54	21.54
ĸ	Tues	44.2	39.16	3.48	5.08	6.26	73.44	0	1.76	2.08	2.4	14.24	2.08	-	-	-	-
	Wed	26.52	35.82	3.02	10.8	4.02	65.28	0.54	1.16	0.78	1.3	7.36	0.08	2.38	1.86	1.18	11.8
	Thurs	39.18	53.42	5.04	11.12	6.84	75.23	0.24	2.72	0.5	0.6	1.88	4	0.98	0.6	0.36	5.46
	Total	272.26	308.54	28.84	69.76	51.12	461.25	4.72	14.46	6.2	8.78	58.3	13.8	5.02	4.1	3.38	70.01
	Fri-Sun	155.68	154.88	17.98	47.68	23.28	145.38	1.06	6.74	4.93	3.56	21.24	2.88	2.34	1.32	0	53.54
	Mon	37.28	51.52	1.48	6.18	3.04	52.52	0.12	1.52	0.56	1.66	17.14	2.8	0.5	0.42	0	18
ĸ	Tues	46.6	45.16	5.74	18.82	7.22	53.12	0.48	4.7	1.08	1.2	7.98	2.3	-	-	-	-
	Wed	61.54	47.74	3.5	6.16	6.74	59.34	0.48	3.32	0.76	0.68	13.02	0	0.24	0	0.5	12.62
	Thurs	44.68	48.22	3.26	6.58	7.84	57.9	0	5.04	0.58	1.44	7.68	0.38	0.26	0.62	0.36	13
	Total	345.78	347.52	31.96	85.42	48.12	368.26	2.14	21.32	7.91	8.54	67.06	8.36	3.34	2.36	0.86	97.16

Waste contamination rates

I conducted a paired t-test for the waste contamination rates of the landfill, compost, and mixed paper waste streams at Spens-Black Hall to test my hypothesis that the waste contamination levels would decrease in all three after the educational campaign. For the landfill waste stream, I found that the waste contamination levels did not significantly decrease after the educational campaign (p=0.1839). For the compost waste stream, I found that the waste contamination levels did not significantly decrease after the educational campaign (p=0.2396). For the mixed paper waste stream, I found that the waste contamination levels did not significantly decrease after the educational campaign (p=0.1343).

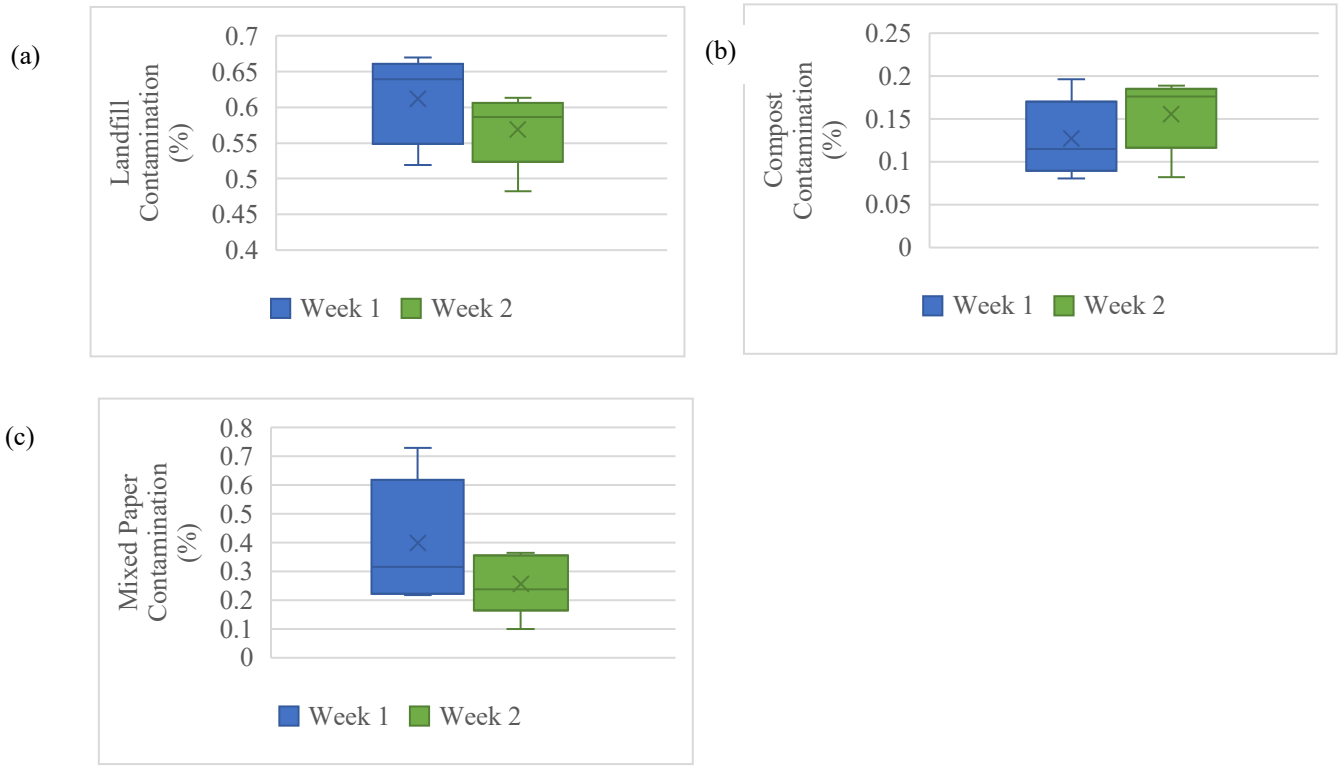
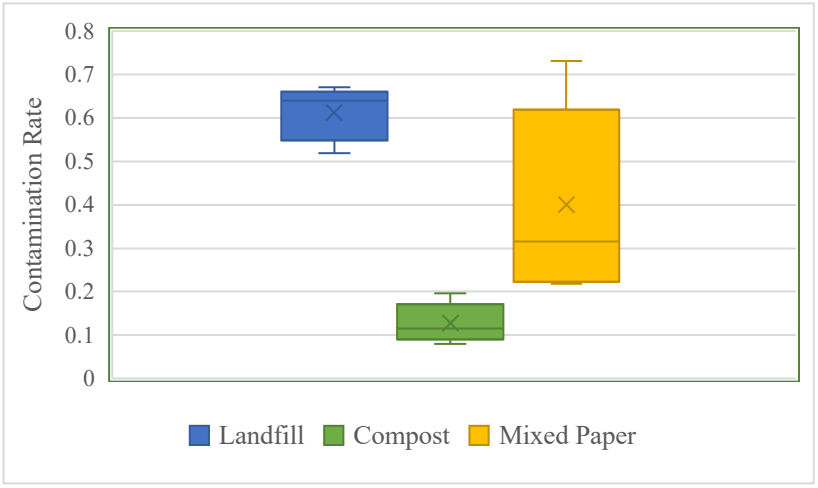


Figure 5. Waste Contamination Rate by Waste Stream.

Next, I compared the waste contamination levels from the different waste streams at Spens-Black Hall between each week to determine if the waste contamination levels were significantly different from each other. For the first audit, the landfill waste stream was significantly more contaminated than the compost waste stream (p=3.38x10^{-5}), the landfill waste stream was

significantly more contaminated than the mixed paper waste stream (p=0.0389), and the mixed paper waste stream was significantly more contaminated than the compost waste stream (p=0.0279). The contamination rates followed similar trends for the second waste audit. For the second audit, the landfill waste stream was significantly more contaminated than the compost waste stream (p=1.15x10^{-4}), the landfill waste stream was significantly more contaminated than the mixed paper waste stream (p=3.6 x10^{-4}), and the mixed paper waste stream was significantly more contaminated than the compost waste stream (p=0.0419).

(a)



(b)

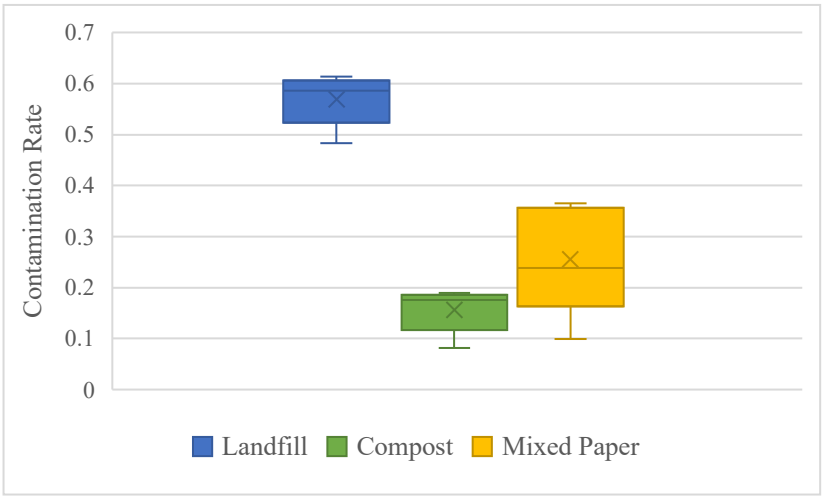


Figure 6. Waste Contamination Rates by Week. Graph (a) is the contamination rates from the first week waste audit and graph (b) is the contamination rates from the second week waste audit.

Current and potential landfill diversion rates

I also calculated the current and potential landfill diversion rates for each audit to compare them to the campus's zero waste goal of reaching a 90% landfill diversion rate (King et al. 2019). For the first waste audit, the current landfill diversion rate is 42.71% and the potential landfill diversion rate is 75.76% (Figure 7). For the second waste audit, the current landfill diversion rate is 36.82% and the potential landfill diversion rate is 71.98% (Figure 7). Both the current and potential landfill diversion rates decreased slightly in the second waste audit compared to the first waste audit.

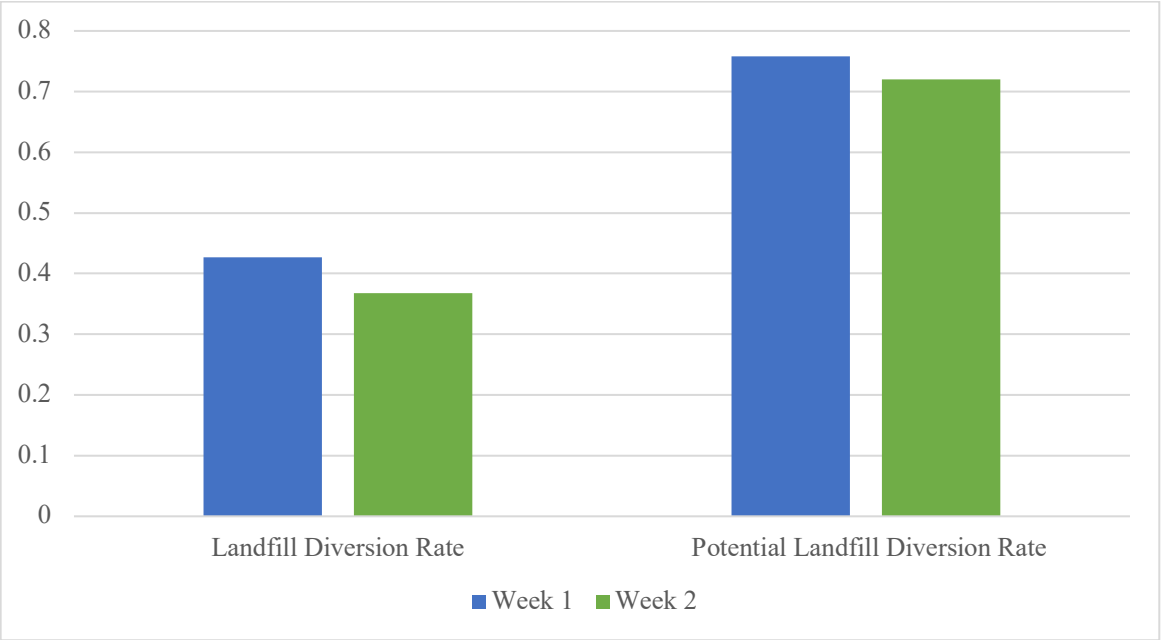


Figure 7. Current and Potential Landfill Diversion Rates.

Observations

For the landfill waste stream during the first waste audit, I observed a large amount of compostable to-go foodware and food waste. I also saw trash bags full of unsorted waste containing compostables and recyclables in the landfill bins. In the compost waste stream, common contamination I observed included milk cartons, plastic salad bowl lids, and sauce packets. I also

observed trash bags full of unsorted waste in the compost bins, but this was infrequent and much less common than other forms of contamination in the compost waste stream. For both the landfill and compost waste streams, I frequently observed food containers full of uneaten food. Common contaminants I observed in the mixed paper waste stream included soiled tissues, soiled napkins, greasy pizza boxes, cans, and bottles. It should also be noted that one of the mixed paper toters from Thursday of the first waste audit contained only cans and bottles. Most of the correctly sorted waste in the mixed paper was cardboard boxes, and there was much less loose paper. I recorded similar trends in observations for the second waste audit.

Educational campaign

During the week long waste sorting educational campaign we educated 258 students from various residence halls and years on how to properly sort their waste at UC Berkeley and about the positive environmental impacts of sorting waste correctly. Of these 258 students, 32 stated they were residents of Spens-Black Hall in the first survey. Through the educational campaign we were able to educate approximately 11% of Spens-Black Hall residents on waste sorting.

Pre-/ post- quiz scores

To determine if there was a significant increase in knowledge on the waste streams at UC Berkeley after participating in the educational campaign, I conducted a paired t-test using the quiz scores from the pre-/post- quizzes for students who took both. For the first quiz, 258 students took the entire quiz, and the mean score was 15.47 out of 20 with a standard deviation of 3.15. The mean score of the first quiz for the students who took both quizzes was 16.31 out of 20 with a standard deviation of 3.01 (Figure 8). For the second quiz, 84 students took the entire quiz, and the mean score was 17.08 out of 20 with a standard deviation of 2.16 (Figure 8). For the students who took both quizzes, I found that the quiz scores increased significantly after the educational campaign (p=0.0011).

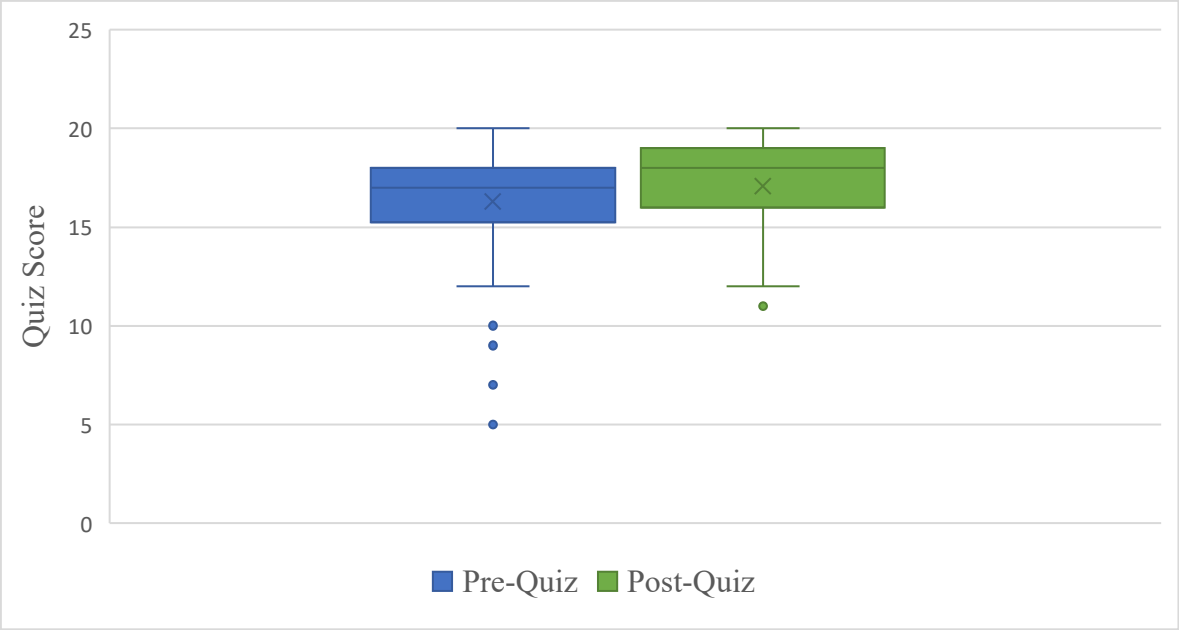


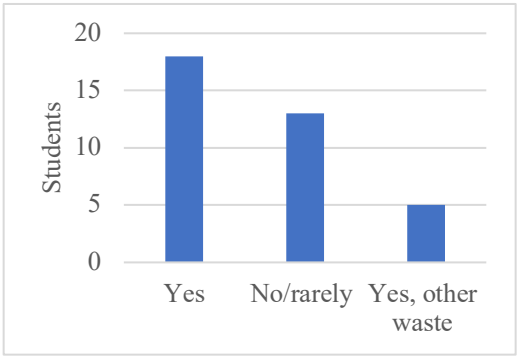
Figure 8. Pre-/Post- Quiz Score Distributions.

Interviews

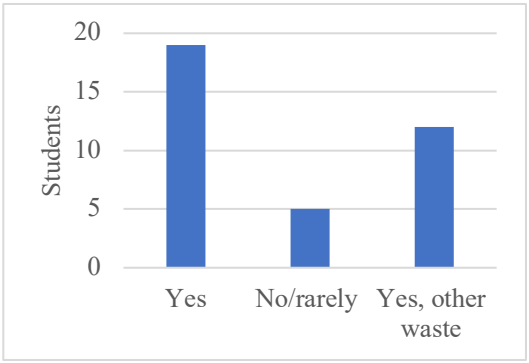
Over the five days I tabled outside of Spens-Black Hall, I interviewed 36 residents or 12.5% of the total number of Spens-Black residents. From the first interview question, I found that 36.11% of the interviewed residents stated that they do use the black bin provided in their room, 50% do not use it or rarely use it, and 13.89% use it for other waste besides landfill waste (Figure 9). From the second question, I found that 52.78% of the interviewed residents stated that they do use the blue bin provided in their room, 13.89% do not use it or rarely use it, and 33.33% use it for other waste besides mixed paper waste (Figure 9). Many students who use the blue bin for other waste besides mixed paper waste stated they use the blue bin for landfill waste. For the third question, I found that 30.56% of the interviewed residents stated that they do use the green pale provided in their room and 69.44% do not use it or rarely use it (Figure 9). Based on the responses for the fourth question, I found that 47.22% of interviewed residents only use the three-bin system provided in the rooms, whereas 52.78% mentioned using other methods besides just the three-bin system (Figure 9). Common alternative methods for waste disposal mentioned included using bags, other waste bins, waste bins in the communal bathrooms, and bringing their waste directly outside.

The last three interview questions focused more on waste soring challenges and potential motivations, whereas the first four questions focused more on the waste sorting process. For the fifth interview question, 52 total responses were given by the 36 interviewees. From their responses, I found that the top three challenges they face to properly sorting their waste are that the waste bins in the rooms are too small (44.23%), the distance to the large toters is inconvenient (17.31%), and confusion on how to sort their waste (9.62%) (Figure 9). For the sixth interview question, 55 total responses were given by the 36 interviewees. From their responses, I found that the top four methods they believe would help motivate students to sort their waste are to reduce the distance to the large toters (25.46%), provide larger waste bins in the rooms (18.18%), use trash shoots on each floor (10.91%), and provide students with incentives (9.09%) (Figure 9). For the seventh interview question, 56 total responses were given by the 36 interviewees. From their responses, I found that the top three methods they believe would help increase composting among students are to have bigger compost pales in the rooms (17.86%), reduce the distance to the large compost toters (17.31%), and empty the large compost toters more frequently (12.50%) (Figure 9).

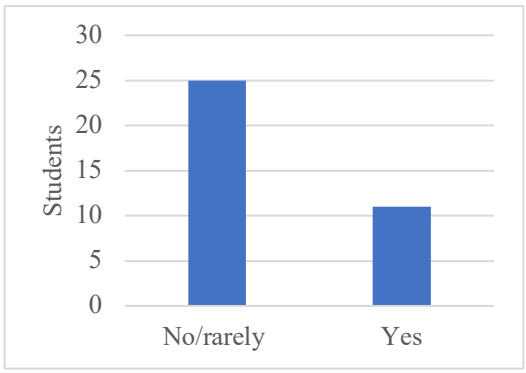
(a)


20
15
10
5
0
Students
Yes
No/rarely
Yes, other waste

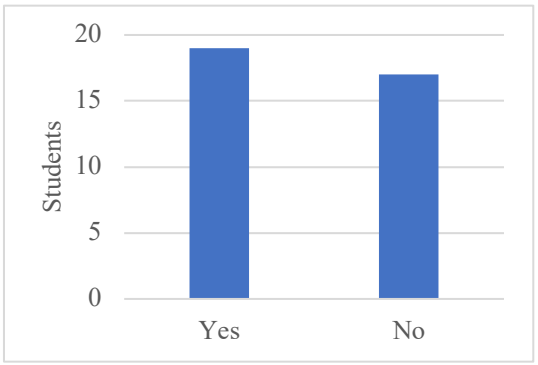
(b)


20
15
10
5
0
Students
Yes
No/rarely
Yes, other waste

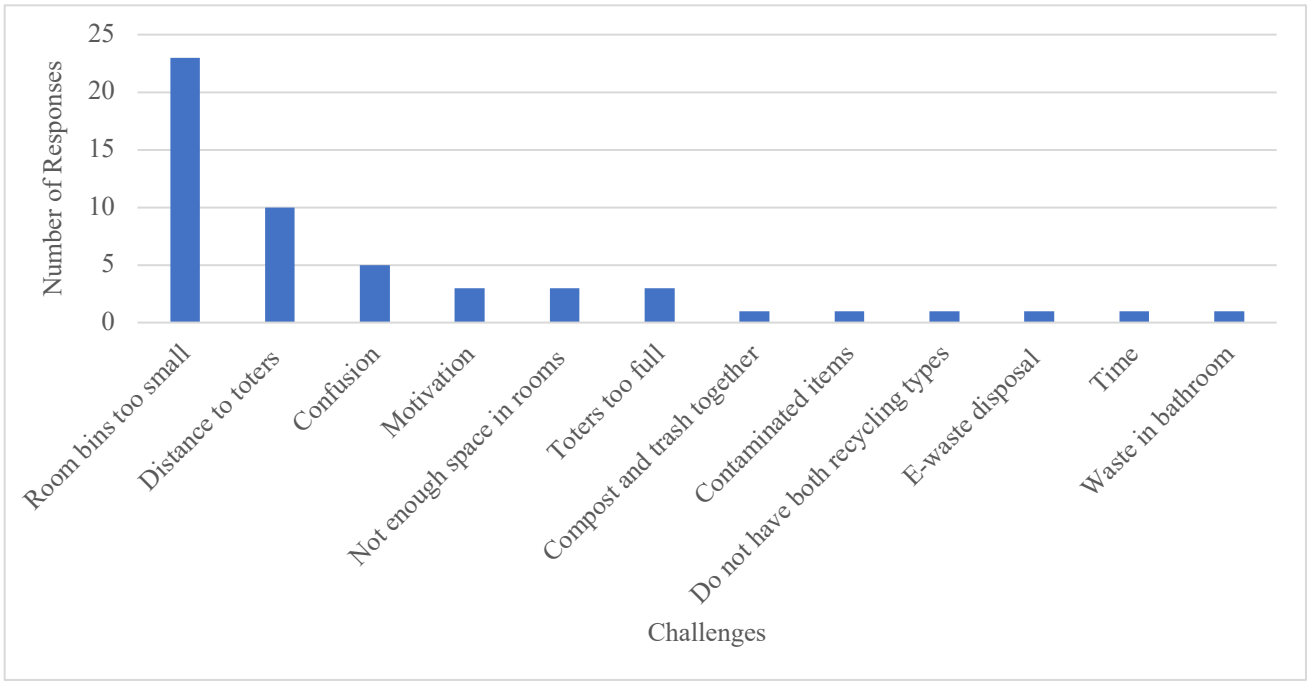
(c)


30
25
20
15
10
5
0
Students
No/rarely
Yes

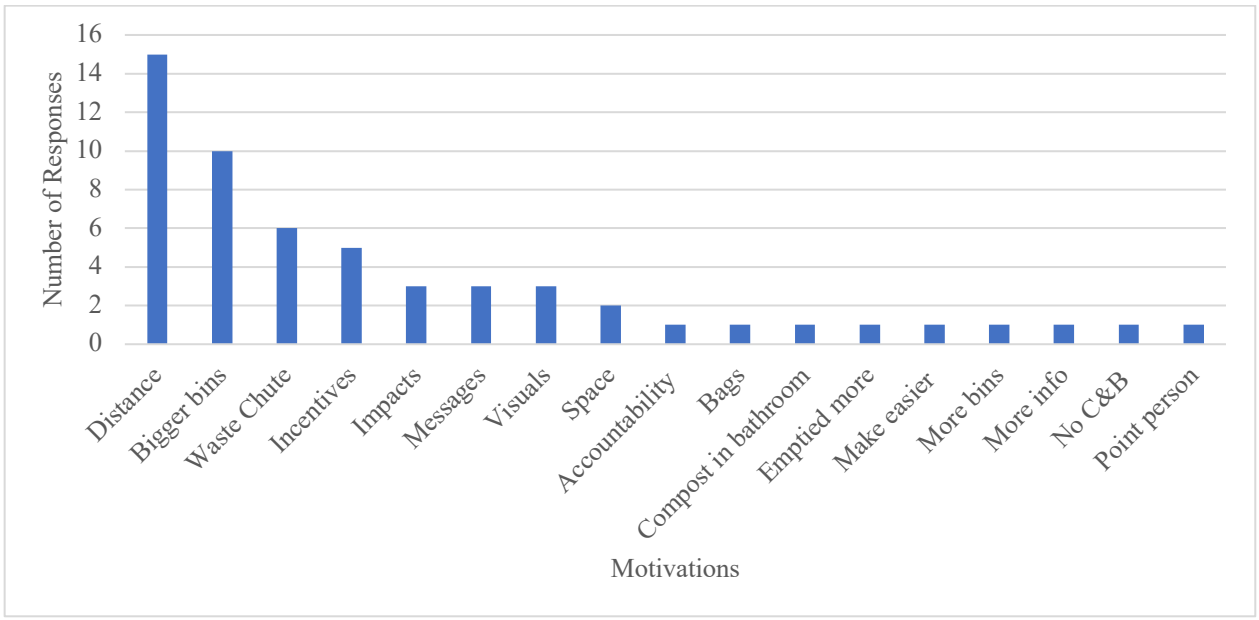
(d)


20
15
10
5
0
Students
Yes
No

(e)


25
20
15
10
5
0
Number of Responses
Room bins too small
Distance to toters
Confusion
Motivation
Not enough space in rooms
Toters too full
Compost and trash together
Contaminated items
Do not have both recycling types
E-waste disposal
Time
Waste in bathroom
Challenges

(f)



(g)

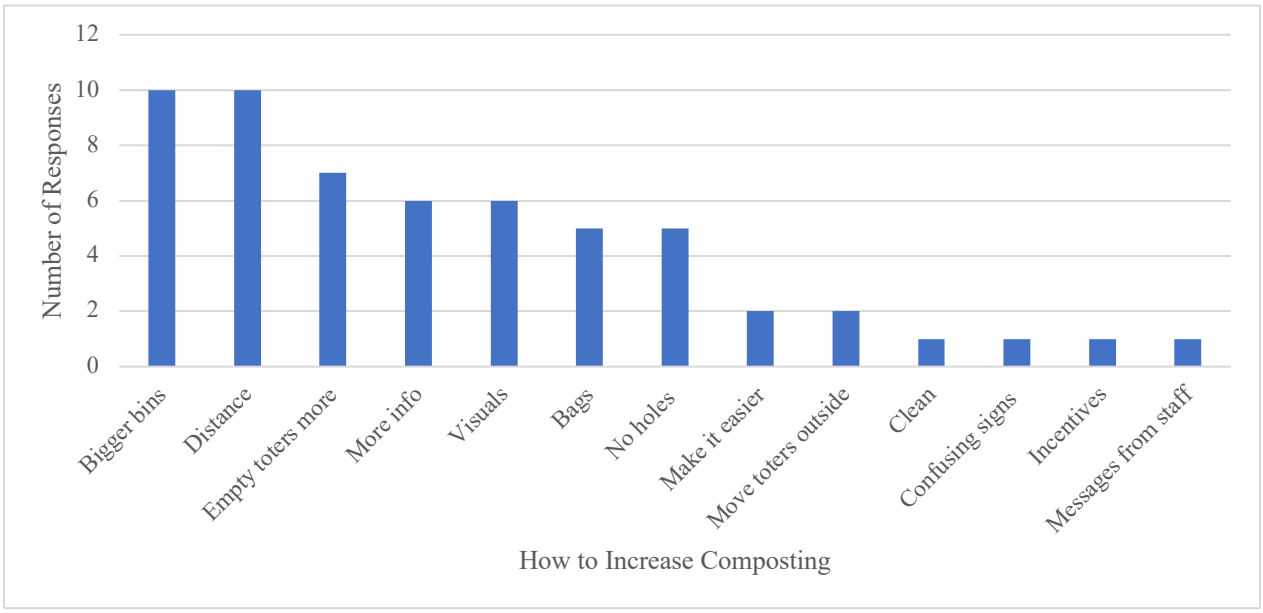


Figure 9. Interview Question Responses. Bar graph displays of responses to interview questions: (a) question 1, (b) question 2, (c) question 3, (d) question 4, (e) question 5, (f) question 6, and (g) question 7.

DISCUSSION

In this study, I researched waste sorting behavior, knowledge, and challenges students face at a University of California, Berkeley residence hall. Results from this study showed that there were no statistically significant waste behavioral changes after the educational campaign, whereas there was a statistically significant increase in knowledge of the four waste streams at UC Berkeley for participants in the campaign. From the interviews I conducted with Spens-Black residents, it is evident that students face major waste related infrastructural barriers at the residence halls which likely impacts their waste sorting behavior. But even if we effectively addressed the waste related infrastructural barriers, we would not reach the campus's zero waste goal. Upstream solutions are needed to meet the zero waste goal in the residence halls.

Waste sorting behavior

From my study, I found that the waste contamination levels did not have a statistically significant reduction in the landfill, compost, and mixed paper waste streams from Spens-Black Hall after the week-long educational campaign on waste sorting. Even after receiving increased education on how to sort your waste correctly into the four waste streams on campus, the students waste sorting behavior did not significantly change, showing there is a sizeable gap between the education received and waste sorting behaviors. Similar studies have also shown a lack of waste related behavior change after an educational campaign intervention. In a study conducted a large Midwestern university dining all, there was a lack of significant waste disposal behavior change after they ran a food waste educational campaign (Ellisona et al. 2019). In a similar study conducted a university in the Netherlands, they also experienced a lack of waste sorting behavior change after running a waste related educational campaign in a dining hall on their campus (Árnadóttir et al. 2018). In both studies, the waste sorting education as delivered separately from when the students are actively sorting their waste. Whereas, in studies when waste sorting education is provided as people are disposing of their trash, there has been significant decreases in waste contamination levels thus, changes in waste sorting behavior (Hottle et al. 2015; Zelenika et al. 2018). In my study, I did not provide students with the waste soring education as they were

disposing of their waste, which could potentially help explain the lack of observed behavior change in my study.

From the results of the waste audits, I also found that for both weeks the landfill waste stream was the most contaminated, the mixed paper waste stream was the second most contaminated, and the compost waste stream was the least contaminated. Overall, the mixed paper and compost bins were relatively well sorted, compared to the landfill bins. Our observations from the waste audits supports this because in the landfill bins there was a large amount of compostable to-go foodware, food waste, and trash bags full of unsorted waste containing compostables and recyclables. From the waste audits, we also found a large discrepancy between the current and potential landfill diversion rates. Not all students in Spens-Black Hall are sorting their waste correctly causing less materials diverted from landfill than they potentially could if more students were sorting their waste correctly. From the results of this study, it is evident that some students know how to sort their waste and are sorting it into the correct bins, but there are some students who are combining all their waste together and are placing it all into the landfill bin. There are major environmental impacts when students put all their unsorted waste in the landfill bin though. Large amounts of organic materials in the landfill release methane gas, a potent greenhouse gas, and sending recyclable materials ends the potential circularity of those materials.

Waste sorting knowledge

The waste sorting educational campaign we ran for this study resulted in a statistically significant increase in knowledge of the waste streams on campus. For the students who took both quizzes, their quiz scores significantly increased after the educational campaign. From this, we can infer that educating student on how to sort their waste and the environmental impacts of waste sorting in person, and then following this, playing an interactive waste sorting game is an effective method to increase knowledge on how to sort waste correctly. However, these educational methods did not lead to waste sorting behavior change. Even though the students received waste sorting education and their knowledge of the waste streams increase, there was no significant behavior change observed. Students still missorted their waste at about the same rate after the educational campaign as before the campaign. From this it is evident that there is a large gap between

knowledge and behavior regarding waste soring, and there could potentially be other barriers to waste sorting at the residence halls that is preventing students to better sort their waste.

Barriers to waste sorting

To investigate the potential barriers to waste sorting students face at the residence halls, I conducted interviews of Spens-Black Hall residents. From these interviews I found that many students are not using the bins provided in their rooms for their intended purposes. Half of the interviewed students either do not or rarely use the landfill bin in their room and nearly 14% use the bin for a different waste stream besides landfill. A third of the interviewed students use the recycling bin for a different waste stream besides mixed paper recycling, and nearly 14% do not use the mixed paper bin at all. Nearly 70% of the interviewed students also do not even use the compost pale in their room, and many of them mentioned that this is because the pale is too small to hold the compostable to-go containers from the dining hall. Over half of the interviewed students also noted they use other methods to dispose of waste in their rooms. Based on these responses it is evident some students are sorting their waste, but others are combining all their unsorted waste together. For the students who are sorting their waste, it is also evident that they found the current room waste sorting system challenging and instead have created their own systems to more efficiently collect and sort waste in their rooms.

From the other interview questions, I also found that that the size of the bins in the rooms and the far distance to the large toters outside are major challenges to sorting waste correctly in Spens-Black Hall, and the interviewed students believe that addressing these challenges would help motivate students to better sort their waste. It is evident that the current room bin system is not efficient or effective and makes it difficult for students to sort waste into the four waste streams. The far distance the large toters outside and on the ground floor is also extremely inconvenient when separating waste into four different waste streams. These challenges students face likely had a major impact on the lack of significant change in contamination rates after the educational campaign and the large difference in current and potential landfill diversion rates. These infrastructural barriers should be addressed to help reduce waste contamination rates and so that we can reach the potential landfill diversion rate.

Could we achieve zero waste?

Based on the results of this study, even if all the waste sorting challenges mentioned by the interviewees were addressed, we would not reach the campus's zero waste goal of diverting 90% of waste away from the landfill at the residence halls. Currently, the potential landfill diversion rate is around 75%, but it would need to be 90% to reach the campus's zero waste goal. So even if students sort their waste correctly, there are still too many waste products that must be placed in the landfill bin in the waste steam to be considered zero waste. As predicted by the campus's zero waste plan, we will need to have upstream solutions to reduce the amount of non-recyclable and non-compostable waste generated on campus to be considered zero waste (King et al. 2019).

Limitations and future directions

During the data collection for this study, we experience a few limitations. First, this study took place during the COVID-19 pandemic, and because of the pandemic students take their food to-go from the dining hall in compostable foodware at a higher rate than before the pandemic. During the second waste audit, the dining hall also ran out of the fully compostable to-go containers and instead only provided salad bowls that have a non-compostable lid. There was also limited participation of Spens-Black Hall residents in the educational campaign which could have contributed to the insignificant waste audit results. Lastly, the scope of this study was limited since we only focused on one residence hall and each waste audit only used a week's worth of waste and the educational campaign only lasted for five days. Future research should expand waste audits to last longer and include more residence halls to get a more representative. In future studies, other factors that affect waste sorting participation could be analyzed, such as social norms.

Conclusion

Missorted waste has major environmental implications, so it so critical we reach a 90% diversion of waste away from landfills to reduce the environmental burden of the waste we generate. To reach our potential landfill diversion rate on campus, I recommend:

- Continue providing students with an interactive, in-person education on how to sort their waste into the four waste streams on campus and the environmental impacts of waste sorting.
- Continue to have clear waste sorting signs with visuals in their rooms, on each floor, and on the large toters to help inform students on how to sort their waste correctly.
- Provide larger waste bins in each room for students to use since the size of the current bin system is likely preventing students from sorting properly.
- Increase the convenience of disposing of waste by having large toters for students to dispose the waste from their rooms in on every floor when possible.

But, even if all these measures are implemented, the campus would still on reach their zero-waste goal in the residence halls.

To reach a 90% landfill diversion rate in the residence halls, upstream measures need to be taken to reduce the amount of waste generated. For this, I recommend:

- Have stronger enforcement of UC Berkeley's Single-Use Plastic Elimination Policy to reduce the use and sale of non-essential single use plastics on campus, including the dining halls and grab-and-go markets, since many of these products must go in the landfill bin.
- Have stronger enforcement of the City of Berkeley's Single Use Foodware and Litter Reduction Ordinance to reduce all not compostable, often plastic, to-go foodware. If this policy had stronger enforcement, more of the to-go foodware from off campus restaurant would be compostable and could potentially be diverted away from landfills.
- Implement a reusable to-go container program in the dining halls on campus since many to-go containers from the dining halls end up in the landfill bins instead of the compost bin, thus it would result in more waste be diverted away from landfills (Harnoto 2013).

If these upstream solutions are implemented with the educational programs and infrastructure improvement, it is likely that UC Berkeley would reach their zero-waste goal in the residence halls.

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APPENDIX A: Waste Sorting Quiz #1

Start of Block: Block 1

Thank you for taking the time to complete this survey for my senior thesis on waste sorting. All responses will be reported anonymously. If you have any questions, please email me at gracemartin1026@berkeley.edu.

End of Block: Block 1

Start of Block: Block 2

Q1 UC Berkeley email

_____

Q2 Year

- ○ 1st (1)
- ○ 2nd (2)
- ○ 3rd (3)
- ○ 4th (4)
- ○ 5th+ (5)

Q3 Major (intended or declared)

_____

Q4 Double major or minor(s)

_____

Q5 Do you live in Spens-Black Hall at Unit 3?

- Yes (1)
- No (2)

End of Block: Block 2

Start of Block: Block 3

In the next section, there will be some questions on waste sorting. For each question, please select which waste stream the pictured item should go in according to UC Berkeley's waste sorting practices. If you are unsure, you may select "unknown".

End of Block: Block 3

Start of Block: Block 4

Q6 Greasy cardboard pizza box

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q7 Chips bag

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q8 Food scraps

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q9 Cardboard clamshell take-out container

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q10 BPI Certified cup

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q11 Plastic bottle

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q12 Paper coffee cup (not BPI certified)

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q13 Paper napkins (clean or soiled)

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q14 Aluminum can

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q15 Eco-products brand cutlery (from Café 3)

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q16 Clean aluminum foil

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q17 Plastic bag

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q18 Cardboard box

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q19 Instant ramen packaging and bowl

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q20 Amazon brown paper mailer

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q21 Boba cup

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q22 Plastic bubble mailer

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q23 Yogurt cup (plastic #5)

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q24 Ice cream container

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q25 Clean Glass Bottle

- Landfill (1)
- Mixed Paper (2)
- Cans and Bottles (3)
- Compost (4)
- Unknown (5)

End of Block: Block 4

APPENDIX B: Waste Sorting Quiz #2

Start of Block: Block 1

Thank you for taking the time to complete this second waste sorting quiz for my senior thesis looking at change in knowledge on waste sorting. All responses will be reported anonymously. If you have any questions, please email me at gracemartin1026@berkeley.edu.

End of Block: Block 1

Start of Block: Block 2

Q1 UC Berkeley email

_____

Q2 Do you live in Spens-Black Hall at Unit 3?

- ○ Yes (1)
- ○ No (2)

End of Block: Block 2

Start of Block: Block 3

In the next section, there will be some questions on waste sorting. For each question, please select which waste stream the pictured item should go in according to UC Berkeley's waste sorting practices. If you are unsure, you may select "unknown".

End of Block: Block 3

Start of Block: Block 4

Q3 Plastic bag

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q4 Eco-products brand cutlery (from Café 3)

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q5 Boba cup

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q6 Clean Glass Bottle

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q7 Clean aluminum foil

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q8 Food scraps

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q9 Paper coffee cup (not BPI certified)

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q10 Instant ramen packaging and bowl

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q11 Cardboard box

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q12 Yogurt cup (plastic #5)

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q13 BPI Certified cup

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q14 Plastic bottle

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q15 Chips bag

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q16 Cardboard clamshell take-out container

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q17 Aluminum can

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q18 Paper napkins (clean or soiled)

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q19 Plastic bubble mailer

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q20 Greasy cardboard pizza box

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q21 Ice cream container

- ○ Landfill (1)
- ○ Mixed Paper (2)
- ○ Cans and Bottles (3)
- ○ Compost (4)
- ○ Unknown (5)

Q22 Amazon brown paper mailer

- Landfill (1)
- Mixed Paper (2)
- Cans and Bottles (3)
- Compost (4)
- Unknown (5)

End of Block: Block 4

APPENDIX C: Waste Tabling Script

Introduction:

Hello!

My name is ___ from [Cal Zero Waste or HADSA] and we are out here today to help educate students on how to sort their waste at Cal and you can get a free zero waste prize!

First, I am going to have everyone fill out this survey by scanning this QR code.

Full Waste Script:

Now I am going to go over the 4 waste streams and then we will play a quick game in which you can win a prize.

First, we will talk about recycling. UC Berkeley has a 2-stream recycling system, one for mixed paper and another for cans and bottles.

In the mixed paper bin, you would put paper and cardboard. You must break down cardboard boxes before putting them into this bin.

For the cans and bottles bin, you can put glass, aluminum cans, clean aluminum foil, and clean plastics 1 and 2 (point to graphic). Make sure that you have emptied out the containers before you put them into the bin.

Next, we have the compost bin which is for food scraps, napkins, tissues, paper towels, and greasy pizza boxes. If you get to-go meals from any of the on-campus dining halls, all of the waste is compostable, including the clamshells, cups, and utensils! But if you are ever unsure if something is compostable, look for the PLA #7 or BPI certified symbols.

Lastly, we have the landfill bin. Most plastic goes into the landfill bin, including all flimsy plastics, plastic bags, and any #3-6 plastics. If items are mixed material, ex they have paper and plastic, throw it into the landfill. These include things such as ice cream containers, ramen bowls, sauce packets, and chip bags. When in doubt, throw items into the landfill bin to make sure you don't contaminate the other bins.

Now that was a lot of information, and you may be wondering why this matters. First, recycling lets us keep materials in the circular economy so we can reuse them many times. And composting is super important because when we put food scraps and compostables in the landfill, they release large amounts of methane gas, a potent greenhouse gas. And we have about 30,000 undergraduates, so that is a crazy amount of methane. But by composting we can greatly reduce our carbon impact!

Now we have a fun game here for you to learn how to sort your waste and win a prize to help you with your zero waste journey.

APPENDIX D: Interview Questions

Pre-Interview Questions:

1. Are you a resident of Spens-Black?
2. Would you like to participate in a 5-minute anonymous interview on waste sorting challenges?

Interview Questions:

1. How often do you use the black bin provided in your room?
2. How often do you use the blue bin provided in your room?
3. How often do you use the green pale provided in your room?
4. Do you use any other method in your room to dispose of waste?
5. What challenges do you or your floormates face when sorting your waste at Spens-Black?
6. What would help motivate you and your floormates to better sort your waste at Spens-Black?
7. Waste audits across Spens-Black showed that the landfills bins consisted of a high percentage of compostable materials -- which should go in the compost bin, not the landfill bin. What do you think would help improve the rate of compostable material going into the compost bin?