Gamified App to Increase the Quantity and Quality of Household Recycling

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Abstract

Despite recycling being one of the simplest and most impactful ways for citizens to protect the environment, less than 1/3 of American households recycle. This lack of involvement leads to valuable resources being landfilled and harmful greenhouse gases being produced. To motivate individuals to recycle, an app with the gamification features of a monetary incentive, carbon counter, and statistics page was built using the Flutter framework. The app was tested for one week by three groups of individuals: non-recycling senior citizens, local, and remote. Each participant's recycling output and motivation to overcome recycling barriers, such as not knowing the impact of ones' recycling on the environment, before and after the implementation of the app, were compared. After using the app, over 90% of participants reported an increase in motivation to recycle. Additionally, 100% of participants reported that using the app increased their awareness of the impact of their recycling on the environment. These findings show that gamifying recycling in an app is a viable strategy to increase individuals' motivation to recycle and overcome their barriers to recycling. Additionally, this study has found that non-recycling senior citizens can be motivated to recycle when using a gamified app. This conclusion is crucial because improving recycling habits in a population that does not recycle can make more of an environmental impact than improving the habits of those who already recycle. In future iterations of the app, additional gamification strategies such as points, leaderboards, and teams may be implemented.

Keywords: household recycling, gamification, motivation, app development

Acknowledgements

Designing and Testing a Gamified App to Increase the Quantity and Quality of Household

Recycling

The need for improved recycling habits across the globe is emphasized in the United

Nation's 12th sustainable development goal (Helmefalk & Rosenlund, 2020). In 2018, the US

alone produced over 292 million tons of municipal solid waste (MSW), and of these, only 69

million tons of waste was recycled (United States Environmental Protection Agency, 2022). As

climate change has progressed, in part due to the increasing waste production, recycling has been

recognized as a tool worth investing in since it supports a circular economy (Nixon & Saphores,

2009; United States Environmental Protection Agency, 2019) and has been shown to lower

greenhouse gas emissions (Klaiman et al., 2017). Despite recycling being a simple, practical

solution to a pressing global issue, only 32% of households recycle (United States Census

Bureau, 2021).

Household Recycling

Positive recycling habits on a household level are crucial to the success of a waste

management system. On the simplest level, these habits include actively participating, and

effectively cleaning and sorting the recyclables. Unfortunately, the household recycling rate is

significantly less in the United States than in other countries (Klaiman et al., 2017). Previous

studies have concluded that those with lower income and less education were less likely to

recycle (Klaiman et al., 2017), although other studies have produced opposite results (Nixon &

Saphores, 2009).

Household recycling habits are crucial to the recycling process, because if households

produce better quality recycling, then material recovery facilities (MRFs) can be more efficient

and process more recyclables. A 2022 study by Dr. Carlos Correa and colleagues found that only

50% of the recyclables collected by Sao Paulo's waste collection system were processed by the

MRFs (Correa et al., 2022). Additionally, because the quality of recyclables was low, meaning

that the products were missorted and/or contaminated, over 35% of the recycling batch was

rejected even though only 7.4% of the batch was rejectable material (Correa et al., 2022). Thus,

improving household recycling habits, by increasing citizen participation and the quality of the

recyclables produced, is greatly needed.

Barriers to Effective Household Recycling

Currently, there are many barriers which dissuade households from recycling. In a 2009

study, Nixon and Saphores determined that space, time, and safety were the population's main

obstacles to recycling. Additional barriers include not knowing the consequences of poor sorting

on the recovery process (Helmefalk & Rosenlund, 2020) and not knowing the significance of

one's actions on the environment (Klaiman et al., 2017). Lastly, needing to hand clean

recyclables before sorting them is seen as a major barrier to effective recycling since it

necessitates time and effort (Klaiman et al., 2017). If these barriers cannot be overcome, then a

household will either choose not to recycle or will produce low quality recycling.

This project aims to address the barriers of cleaning recyclables, lacking knowledge of

significance, and sorting properly. These barriers were chosen, because if they are relieved, the

user will be able to produce high quality recycling, even if another barrier causes them to do so

at a lower volume.

Existing Solutions

There are many existing solutions to encourage citizen recycling. On the App Store, there

are apps such as SortIt, by Victor Salamanca, and Catch the Trash, by John Palevich, that teach

users to recycle through a sorting game. Although these apps teach users how to sort effectively,

they do not encourage any real-world recycling habits. Similarly, apps such as Recycle Coach by

Municipal Media help users to determine if a product is recyclable and where they can recycle it.

These apps act as educational resources but rely on users being self-motivated to use them.

Apps like ZeLoop, by ZeloopTech, and the smart bin system created by Briones and

collogues in their 2018 study, have successfully increased citizen recycling participation by

offering a monetary reward for reaching defined goals (Briones et al., 2018). However, both

systems require users to use specific collection bins. There is currently no solution that motivates

and supports users in actively and accurately recycling within their own homes.

Gamification

Gamification is the process of implementing a motivational affordance that triggers a

psychological outcome that further produces a behavioral outcome. This tool has been shown to

successfully intrinsically motivate users in many studies (Hamari et al., 2014). Gamification

takes game mechanics such as competition, collaboration, points, badges, and leaderboards, and

applies them to nongame contexts. This makes users want to complete tasks that were once

viewed as unfavorable. Often, gamification effectively is used in education or work settings

(Hamari et al., 2014).

Gamification in Recycling

Overcoming one's barriers to recycling necessitates intrinsic motivation, and

gamification is a tool that is recognized for its ability to intrinsically motivate its users

(Helmefalk & Rosenlund, 2020). When gamification is applied to recycling it can help the users

overcome their own barriers to recycling and to produce a higher quality and quantity of

recyclables.

In their 2020 study, Helmefalk and Rosenlund conducted a series of focus groups which discussed the features they would like to see in a gamified recycling app. The participants highlighted that a digital solution was preferred to a material one and that while the recycling process should feel like a game, it should not literally be turned into a game, such as tossing the recyclables into the bin, or interfere with the physical recycling process The focus groups also stated that they would like to have a solution that gives them immediate feedback and praise for their positive environmental actions. Users would also like to receive frequent reminders to recycle and be able to compete against other neighborhoods and zip codes to see who could produce the most recyclables (Helmefalk & Rosenlund, 2020). Leaderboards, badges/awards, and social interactions were also suggested. Monetary motivators have also been shown to be effective in increasing both user participation and mass of recyclables (Briones et al., 2018). Lastly, a gamified recycling solution should be adaptable to diverse home recycling processes (Helmefalk & Rosenlund, 2020).

Impact and Success

Criteria determining the success of the app include the app's ability increase the quality and quantity of the recyclables of the individuals that use it. As previously stated, this increase in recycling will work to decrease the amount of greenhouse gas emissions (Klaiman et al., 2017). The improved quality of the recyclables will also improve the efficiency of MRFs (Correa et al., 2022). Additionally, if recyclables are removed from compost and landfill streams, the compost and ash produced after processing will be of higher quality since they do not include plastics (Nixon & Saphores, 2009). Combined, these attributes work to support the United Nation's 12th sustainable development goal, and combat climate change.

Problem Statement

There is a lack of motivation to practice good recycling habits such as cleaning and sorting products, especially among those who do not understand the positive effects of recycling on the environment.

Objective

> Obj. 1a: The objective of this project is to program a motivating gamified app for Apple and Android devices that increases the quality of individual's recycling in a manner that allows them to maintain their current system of recycling. Here, quality refers to how clean and correctly separated the recyclables are.

> Obj. 1b: The objective of this project is to program a motivating gamified app for Apple and Android devices that increases the quantity of individual's recycling in a manner that allows them to maintain their current system of recycling. Here, quantity refers to the number of recyclables of each material type (plastic, glass, paper, cardboard) that an individual produces.

> Obj. 1c: The objective of this project is to program a gamified app for Apple and Android devices that increases the user's knowledge of proper recycling habits, motivation to recycle and overcome recycling barriers, and belief in the impact of their recycling on the environment.

<p align="center">Section II: Methodology</p>

Role of Student vs. Mentor

Over the past 5 months, I have spent over 175 hours on this project. During this time, I have been responsible for researching the field/need, conducting a survey on gamification,

programming the gamified recycling app from scratch, conducting testing of the app with human

participants, gathering numerical and survey data from participants, and analyzing the gathered

data. My mentor, Dr. Kevin Crowthers, assisted in project management.

Equipment and Materials

The app was programmed in Dart using Google's Flutter framework. Visual Studio Code

(VS Code) was used as an integrated development environment (IDE). Within the app, three

plug-ins were used. Provider (version 5.0.0) was used for state management and the passing of

variables between classes. Shared Preferences (version 2.0.7) was used to persist data in the app.

URL Launcher (version 6.0.13) was used to launch URLs outside of the app to bring users to

helpful recycling resources. Calculations within the app determining how much CO_2 the user

had prevented from being emitted were based on the emission factors found in "Greenhouse gas

emission factors for recycling of source-segregated waste materials" (Turner et al., 2015). The

app was deployed to devices using Xcode and Android Studio 2 for iOS and Android devices

respectively.

All surveys used throughout the testing process were created using Google Forms.

Technique 1: Gamification Survey

To determine which gamification strategies to include in the app, an anonymous survey

was conducted using Google Forms. The survey was sent by email to over 500 individuals (ages

13+) across the United States. The majority of survey participants were contacted due to their

connection to the Mass Academy of Math and Science or Marianapolis Preparatory School. The

questions gathered information regarding how much participants knew about proper recycling

habits and how motivated they were to recycle. Participants were also asked to rank how strongly

they agreed that each of ten proposed gamification strategies would increase their motivation to

recycle and overcome barriers to recycling. For a list of all questions used in the survey, see

Appendix 1.

Technique 2: App Development

The app, Carbon Crush, was programmed in Dart using the Flutter Framework. The top

three gamification strategies, as determined by the gamification survey, were each given a page

in the app. The "monetary incentive" became the Quests page, where users are given a set of

tasks that they must complete in order to receive a gift card to an eco-friendly company. The

"carbon counter" became the Carbon Counter page. Here, users are shown the amount of CO_2

emissions that their recycling habits have prevented from entering the atmosphere. The page also

displays relatable measurements such as the CO_2 equivalent in gallons of gas and number of

smartphone charges. Lastly, the "analytics report" gamification strategy took the form of the

Stats page. It must be noted that the Stats page used in the app differed from the description used

in the gamification survey. Whereas the survey described a weekly report that highlighted how

the user's recycling habits improved or worsened over time, the implemented page was an ever-

present counter that displayed totals for the number of each material recycled and percentages

representing the user's accuracy of recycling habits. This decision was made because, with

participant's only testing the app for one week, the report would not be able to show their trends

over time.

Additional pages added to the app were the Log Items, Resources, and Home pages. The

Log Items page contains a series of dropdown menus where users record the number, material,

cleanliness, and how well separated their recyclables were. The resources page contains links to

external sources that can educate the user on various recycling topics. Lastly, the Home page

shows an overview of the user's Carbon Counter and a visual representation of their progress

towards the quest. See Appendix 2 for images of each of the app screens.

Technique 3: In Home testing

Three testing groups, Local (5), Remote (4), and Non-Recycling Senior Citizen (2), were

created to measure the effect of the app on individuals in various circumstances. The Local group

was created to test how the normal usage of the app effects recycling habits. The Remote group

tested whether the added step of taking a picture of one's recycling before disposing of it had a

further effect on the quantity and quality of recyclables. Lastly, the Non-Recycling Senior

Citizen group tested the app's ability to impact individuals who chose not to recycling in their

household.

All participants followed the same framework for testing. Participants began by

completing a pre-survey. This survey measured the participants' motivation to recycle and

knowledge of the impact of recycling on the environment. See Appendix 3 for a complete list of

Pre-Survey questions.

The testing took place over the course of two weeks. For the first week, participants

recycled according to their exhibiting habits. For the senior citizens, this meant continuing their

practice of not recycling. Local participants were instructed to keep their recyclables separate

from those of other members of their household. The Remote participants were instructed to take

a picture of their recyclables. Remote participants were given the option of taking individual

pictures of products or larger group pictures. If any product had contained food, participants

were asked to capture the inside of the container in the image so that it could be analyzed for

cleanliness. At the end of week 1, Remote participants uploaded all images of their recyclables to

a shared Google Photos album. Additionally, the recyclables were collected from each Local and

Senior Citizen participant. See Appendix 4 for a copy of the Testing Information packet that was shared with all participants.

On the first day of week 2, the app was installed for all participants. The app was not published on the App Store or Google Play Store. Instead, it was simply run in release mode on each device. This allowed the app to run on the participants' phones for one week without having to pay a large developer fee. Xcode was used to download the app for participants with iOS devices and Android Studio 2 was used to download the app for Android devices. After the app was installed, participants were given a demonstration outlining the app's key features. All participants were instructed to use the resources page to fill any recycling knowledge gaps that they may have.

The senior citizens received an extra conversation about the importance of recycling and the impact of an individual's impact on the environment. This conversation included describing how material recovery facilities worked and what happened to one's recyclables after they were collected. Then, materials' various emission factors were outlined. Amounts of recycling were related to the amount of CO_2 emissions produced by common activities such as driving a car. Lastly, it was restated why, economically, and environmentally, recycling is an advantage. This conversation was introduced because face-to-face communication has been shown to be one of the most effective ways to get individuals to change their recycling habits (Nixon & Saphores, 2009).

At the end of week two, the recyclables were collected from Local and Senior Citizen participants. Remote participants uploaded their week 2 photos to a secondary shared Google Photos album. Additionally, all participants completed a post-survey. This survey asked users if they believed that the app had increased their motivation to recycle and their knowledge of the

impact of their recycling on the environment. These repeated questions allow for not only the

change in the participants' recycling output to be analyzed, but also their change in mindset

regarding recycling. The post-survey also asked for feedback on the users' experience with the

app and how the app may be improved in the future. See Appendix 5 for a copy of all post-

survey questions.

The recycling for each participant for each week was logged. The number of products of

each material type were totaled, as well as the number of food-contaminated, unseparated, and

nonrecyclable products. For simplicity, products were simply marked as clean or food-

contaminated, they were not rated on a scale. This caused dirty and extremely dirty products to

be rated as having the same negative affect on the batch of recycling. The same logic was applied

to the other categories.

Statistical Tests

To analyze the significance of the data, a paired T-test for mean difference was used.

This test was used because each participant produced one week's worth of recyclables with and

without the app and the goal was to determine if their recycling quantity and quality improved

with the use of the app. The app will be successful if the mean quantity and quality scores for

week 2 are significantly greater than the mean quantity and quality scores for week 2 for all

participant groups.

Paired T-Test for Mean Difference

$$H_o: \mu_d = 0$$

$$H_a: \mu_d > 0$$

Four paired t-tests for mean difference were conducted. These tested the significance of

the change quantity and quality scores before and after using the app for Local and Remote

groups. Due to the low sample sizes, histograms of the differences of week 2 and week 1 scores

for all four categories were created (Appendix 6). Of the four histograms created, the only one

that portrayed normal distribution of the data was the one representing the local quality scores.

This means that all other results cannot be considered statistically significant. No statistical tests

were run on the Non-Recycling Senior Citizens group as the sample size was two.

Section III: Results

Gamification Strategy Survey

98 participants, ages 13+,
responded to the Gamification
Strategy survey. The respondents'
preferences for gamification
strategies are outlined in Figure 1.
The scores were calculated by
assigning a numerical value to each
of the possible survey responses.
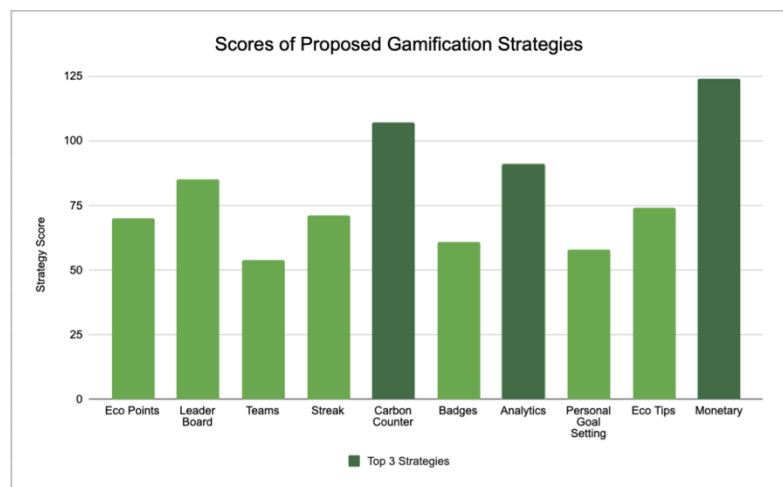
Figure 1: Bar graph depicting the strategy score for each gamification strategy included in the survey. The three highest scoring strategies are marked in dark green.

The response options and their corresponding values are as follows: Strongly Disagree (-2),

Disagree (-1). No Impact (0), Agree (1), Agree Strongly (2). The scores were summed for all

gamification strategies. No significance tests were performed on the survey data.

Inhouse Testing

Local Participants

For each week, participants were given a quantity score. This score was the total number of items that they recycled in the week. Additionally, they received a quality score. The quality score was the percent of the recyclables that were clean, correctly separated, and recyclable.

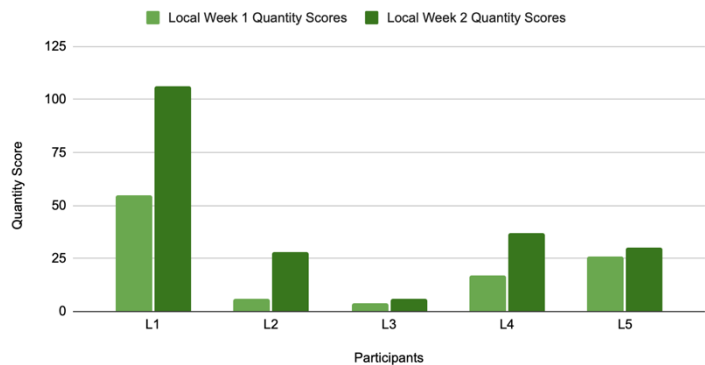Figure 2: Comparison of Local Quality Scores Before and After the Use of Carbon Crush

Figure 2: Bar graph depicting the quality scores of Local participants. The week 1 quality scores are shown in light green, and the week 2 scores are shown in dark green. On average Local participants scored 16.4% higher while using Carbon Crush.

Figure 2 shows the Local participants' quality scores before and after the introduction on the app. On average, participants' quality score for week 2 was 16.4% higher than their quality score for week 1. This increase in quality is significant at the ***$p<0.005$ level.

Local participants were given a quantity score which represented the total number of products they recycled during the week. Figure 3 shows the Local Participants quantity scores before and after the introduction of the app. One average, the participants' quantity score was 19.8 points higher in the second week than the first.

Figure 3: Comparison of Local Quantity Scores Before and After the Use of Carbon Crush

Figure 3: Bar graph depicting the quantity scores of Local participants. The week 1 quantity scores are shown in light green, and the week 2 scores are shown in dark green. On average, Local participants produced 19.8 more recyclables in a week while using Carbon Crush.

Remote Participants.

Remote Participants were given quality and quantity scores in the same fashion. Figures 4 and 5 show the remote participants' quality and quantity scores for the two testing weeks. On average, the Remote participants quality score increased by 6.17% and their quantity score decreased by 3 points between the two weeks of testing.

Figure 4: Comparison of Remote Quality Scores before and After the Use of Carbon Crush

Figure 4: Bar graph depicting the quality scores of Remote participants. The week 1 quality scores are shown in light green, and the week 2 scores are shown in dark green. . On average Remote participants scored 6.2% higher while using Carbon Crush.

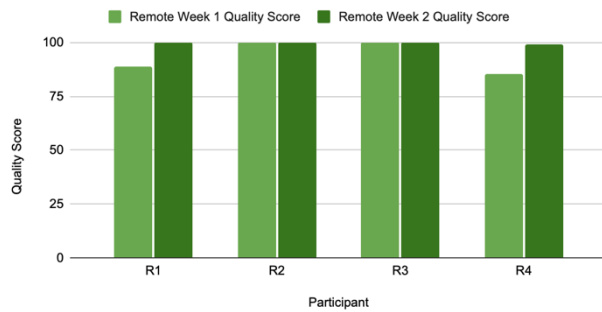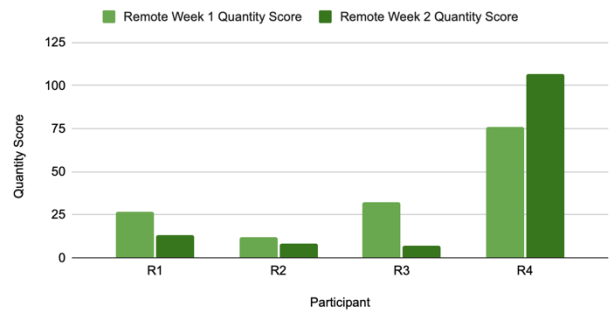Figure 5: Comparison of Remote Quantity Scores before and After the Use of Carbon Crush

Figure 5: Bar graph depicting the quantity scores of Remote participants. The week 1 quantity scores are shown in light green, and the week 2 scores are shown in dark green. On average, Remote participants produced 3 fewer recyclables in a week while using Carbon Crush.

Non-Recycling Senior Citizen Participants

Senior Citizen Participants were given quality and quantity scores in the same fashion. Table 1 shows the senior citizen participants' quality and quantity scores for the two testing weeks. On average, the Senior Citizens' quality score increased by 91 points.

Table 1: Comparison of Non-Recycling Senior Citizen Quantity and Quality Scores Before and After the Use of Carbon Crush

This Table 1 depicts the Non-Recycling Senior Citizens' quantity and quality scores before the use of Carbon Crush. The quality scores are marked as NA for week 1 because the participants did not produce any recycling to be analyzed. The Non-Recycling Senior Citizen's average quality score for week 2 was 96.8%.

Participant	Quantity Score	Quality Score
S1: Week 1	0	NA
S1: Week 2	77	97.40
S2: Week 1	0	NA
S2: Week 2	105	96.19

Recycling Knowledge, Motivation, and Belief in Impact of Recycling

By comparing the reported recycling knowledge, motivation to recycle, and belief in the impact of recycling before and after the implementation of Carbon Crush an increase of at least 20% can be observed in all target areas (Figure 6). Additionally, 90.9% of all participants reported some increase in motivation and 100% of participants reported some increase in knowledge of the impact of recycling.

Figure 6: Average Change in Participants' Recycling Knowledge, Motivation, and Impact Belief

Pre-Survey   Post-Survey

Knowledge +25%: 3.64, 4.55
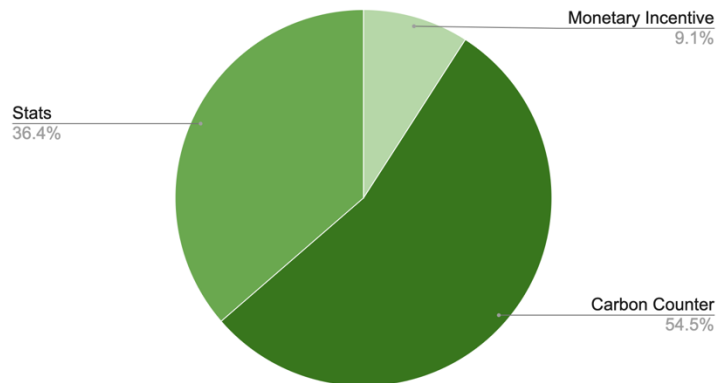Motivation +21%: 4.27, 5.18
Impact Belief +20%: 4.18, 5.00
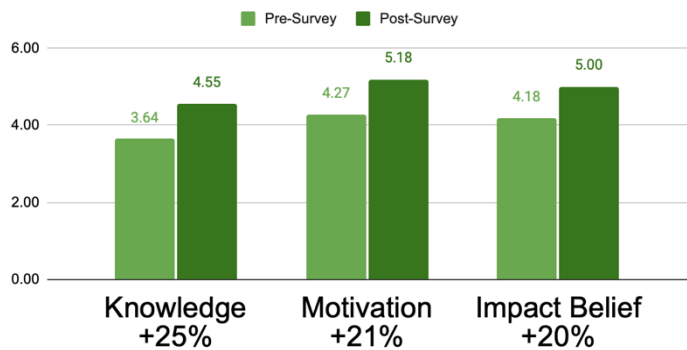
Figure 6: Bar graph depicting the increase in each of the user's target areas (Obj 1c). Participants ranked themselves in each area on a scale of 1-6. The results in this figure represent individuals in all testing groups.

Preferred Gamification Strategy

In the post-survey, participants were asked to rank how strongly they agreed that

gamification strategies (Quests,

Carbon Counter, and Stats)

increased their motivation to

recycle and overcome barriers to

recycling. The scores for these

strategies were calculated in the

same fashion as it was for Figure 1,

Figure 7: Pie chart depicting the breakup of preferred gamification strategies of all participants as reported in the post-survey.

where each survey response was assigned a numerical value ranging from -2 to 2, and the scores

for each strategy were summed. Figure 7 shows the total score for each gamification strategy

calculated from the responses of all participants.

Figure 7: Participant Reported Most Impactful Gamification Feature

Monetary Incentive 9.1%

Stats 36.4%

Carbon Counter 54.5%

Section IV: Discussion

Objective 1a: Increase Recycling Quality

The first objective of this project was in increase the quality of recycling produced by the app's users. As seen in Figures 2 and 4, this objective was fulfilled because the Local and Remote participants increased their recycling quality by 16.4 and 6.16 percent respectively on average. Additionally, the Non-Recycling Senior Citizens achieved an average quality score of 96.8% (Table A). When analyzed with a paired T-Test, it was found that the increase in Local quality score was significant at the $a = 0.005$ level. With this, we may reject the null hypothesis that the difference of the quality scores of Local users' recycling after and before the implementation of the app is 0, in favor of the alternative hypothesis that the difference between the quality scores of the recycling after and before the implantation of the app is greater than 0. This demonstrates that Carbon Crush positively impacts the quality of recycling of users similar to those in the Local group.

Objective 1b: Increase Recycling Quantity

The second objective of this project was to increase the quantity of recycling produced by the app's users. This objective was fulfilled for the Local and Non-Recycling Senior Citizen participants but not for the Remote Participants (Figure 3, Figure 5, Table A). On average, the Local participants scored 19.8 points higher while using Carbon Crush than when not (Figure 3). Compared to their baseline of 0, Non-Recycling Senior Citizens produced on average 91 more recyclables while using Carbon Crush than without (Table A). The Non-Recycling Senior Citizens' average increase in quantity score was greater than that of any other group. This shows that a greater positive environmental impact can be created by motivating those who do not recycle to begin recycling habits. Differing from the other testing groups, the Remote group saw a 3 point decrease in quality score while using Carbon Crush (Figure 5). This is likely because the act of taking a picture of one's recyclables in order to upload it to the shared Google Photos

Album added an inconvenient extra step to the recycling process and discouraged the users from recycling. This is congruent with previous research from Helmefalk and Rosenlund, whose 2020 study determined that a gamified recycling app should not interfere with the process of recycling. Using this knowledge, it can be determined that future iterations of the app should not require users to take pictures of their recycling.

Objective 1c: Increase User's Recycling Knowledge, Motivation, and Belief in Impact

The third objective of this project was to increase the user's knowledge of proper recycling habits, motivation to recycle, and belief in the impact of their recycling. As seen in Figure 6, this objective was achieved since across all testing groups each of the target areas was increased by at least 20% after the implementation of Carbon Crush. These improvements took place over the course of one week. One limitation of tracking these metrics was that if users gave themselves the highest score (6) in the presurvey, they would not be able to reflect growth in that category in the post-survey. For this reason, two additional questions, asking if the user if Carbon Crush increased their motivation to recycle and belief in the impact of recycling on the environment were added to the post-survey. Additionally, his objective was achieved because 90.9% of all participants reported some increase in motivation and 100% of participants reported some increase in knowledge of the impact of recycling. These findings are congruent with previous studies that have shown that gamification is a viable tool to increase individuals motivation (Alsawaier, 2018; Hamari et al., 2014) and congruent with studies that have specifically looked on gamification's effect on recycling (Briones et al., 2018; Helmefalk & Rosenlund, 2020).

Future Research and App Iterations

There are several features that may be added to Carbon Crush in future versions of the app. These would be tested over longer periods of time than the features used in the current study to gain a better idea of the long-term effects of the app and reduce the change in scores that were due to the novelty.

Verification of Recycling Inputs

One current limitation of Carbon Crush is that there is no way to verify if the products that the users have logged have been recycled. Thus, the engineering of a partner product to log materials as a user recycles them may be beneficial to the user. This product would also be compatible with more types of materials than Carbon Crush currently is and warn users If a product they have placed in a recycling bin is nonrecyclable. Additionally, this would remove the extra inconvenient step of taking a picture of recyclables that Remote participants endured.

Additional Gamification Features

Additional gamification strategies that may make Carbon Crush more engaging are Eco Points, Leaderboards, Teams, Inter-neighborhood Competitions, and an Analytics Report. Definitions of these strategies can be found in Appendix 1.

Quests and Monetary Incentive

To respond to feedback left by participants in the post-survey, the quests used in future versions of Carbon Crush should be simpler and more achievable in a 1-week period. Additionally, partnering with more specific eco-friendly companies may work to further increase user's motivation to recycle.

Section V: Conclusion

This project has produced a novel app that motivates individuals to practice the positive recycling habits of cleaning, separating, and sorting recyclables without altering their manner of recycling (curbside, drop-off, etc.) using a monetary incentive, carbon counter, and statistics as gamification strategies. The app successfully increased the users' knowledge of proper recycling habits, motivation to recycle, and belief in the impact of their recycling. This project has also revealed that if the process of recycling is made too inconvenient, the quantity of users' recyclables may decrease. Carbon Crush successfully aided Local and Senior Citizen users in increasing the quantity and quality of their recyclables. This increase in high quality recycling results in a net reduction in greenhouse gas emissions and works to promote a circular economy (Nixon & Saphores, 2009; Turner et al., 2015).

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<div align="center">**Section VII: Appendices**</div>
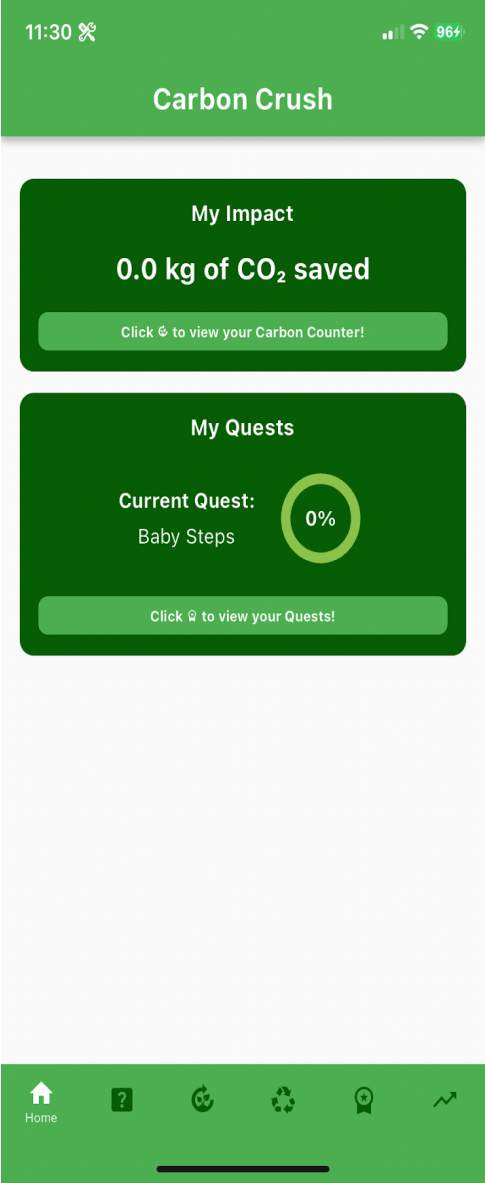
Appendix 1: Gamification Strategy Survey Questions

The following questions were used in the Gamification Strategy Survey. Over 98 individuals

across the United States responded to the survey.

What is your age?
How frequently do you recycle? Assume that waste refers to recyclable materials.
Does your household recycle?
How much do you know about proper recycling habits? 1 signifies that you do not know how to recycle. 4 signifies that you are proficient in recycling habits such as sorting and cleaning recyclables.
How motivated are you to recycle?
Rank how strongly you agree that each feature would increase your motivation to recycle more and improve recycling habits such as cleaning and sorting recyclables. - Eco Points: Points awarded each time the user logs recycling. Additional points are awarded for washing food contaminated recyclables and for sorting new materials. - Leader Board: Allows the user to compete individually against their friends and neighbors to see who can earn the most Eco Points. - Teams: Gives users the ability to form teams with their friends and/or neighbors to compete in long term challenges with other teams. - Streak: Counters that track the number of days in a row that a user meets their recycling goals. - Carbon Counter: Helps users to see their individual effect on the environment by relating the amount of carbon they've prevented from entering the atmosphere to relatable measurements. - Badges: Users earn badges by completing challenges, finishing at the top of a leaderboard, hitting a streak milestone, or completing a defined task. Other users can see which badges you have unlocked and how rare the badges are. - Analytics: A weekly report that gives the user an overview of how they performed during the week. It shows if their habits are becoming more positive or negative and highlights their achievements. - Personal Goal Setting: Allows users to set goals for how they want to improve their recycling habits over the course of a week. If goals are met, they will be rewarded with Eco Points. - Eco Tips: Quick tips on how to improve your recycling habits or about recycling's profound impact on the environment shown when opening the app and when logging activities. - Monetary Incentive: A voucher to an eco friendly company, such as Too Good To Go, that is earned by completing defined challenges. -

Appendix 2: Carbon Crush Screenshots

The following screenshots depict the app that was deployed to Local, Remote, and Non-

Recycling Senior Citizen participants.

Home

11:30 ✂

⚫⚫⚫ 🔋 96⚡

Carbon Crush

My Impact

0.0 kg of CO$_2$ saved

Click ♺ to view your Carbon Counter!

My Quests

Current Quest:

Baby Steps

0%

Click ♙ to view your Quests!

🏠 Home   ❓   ♺   ♻   ◉   📈

Resources

11:30 ⚒

◦◦◦ 📶 96⚡

Carbon Crush

Resources

What can be recycled?
♻

Overview of what can be recycled from the EPA

♻

Directory to locations to recycle non-curbside materials

♻

Guidelines for Pratt single stream curbside recycling

♻

Recycling information specific to MA with information on local collection centers

Why is recycling important?
♻

Recycling basics and benefits, outlines challenges to the recycling system

♻

Benefits of recycling from the National Institutes of Health Environmental Management System

♻

Overview of the United States' recycling 1960-2018

Information on cleaning and sorting recyclables

🏠　❓　♺　♻　🏅　〽
　　Resources

Carbon Counter

Log Items

Carbon Crush

Log Your Recyclables

Remember to only log materials that you have actually put in the recycling.
If you have any questions, check out the references tab.

Select the material type and quantity.

| Material ▾ | Quantity ▾ |

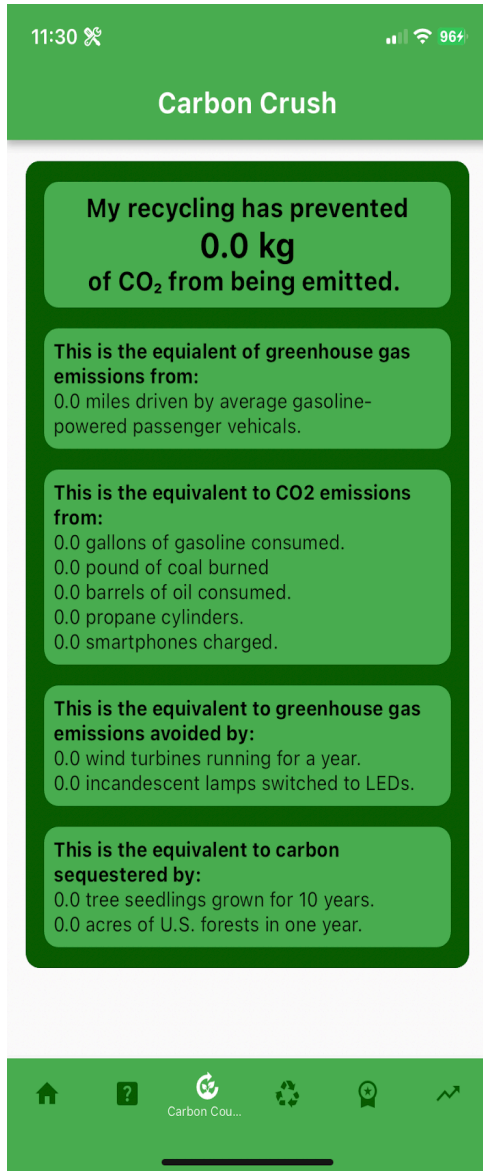| Material ▾ | Quantity ▾ |

| Material ▾ | Quantity ▾ |

Select the number of food contaminated products and the number you cleaned.

Carbon Crush

| Material ▾ | Quantity ▾ |

Select the number of food contaminated products and the number you cleaned.
Ex. Peanutbutter jar or yogurt container

| # Dirty Items ▾ | # Washed Items ▾ |

Select the number of multi-material products and the number that you correctly separated.
Ex. Water bottle with plastic label.

| # Multi Material ▾ | # Correctly Separated ▾ |

Submit

Log Items

Quest

11:30 ✂

▪▫ 📶 96⚡

Carbon Crush

Quest 1: Baby Steps
Goal: Recycle 10 materials in each category
Reward: Gift card to an eco friendly company!

Progress:

To reach your next checkpoint you need:

♻10 more glass products

♻10 more paper products

♻10 more plastic products

♻10 more washed products

♻10 more separated products

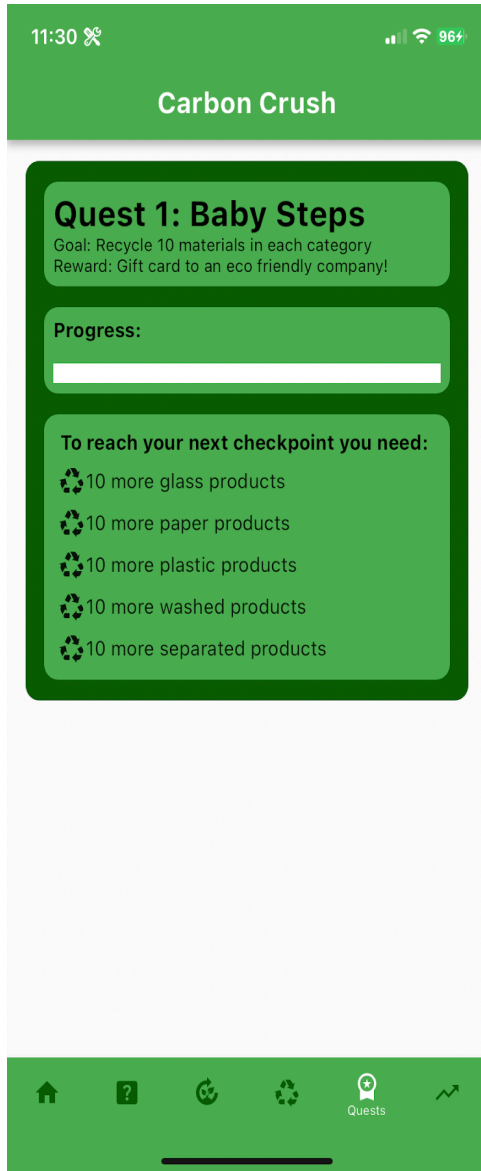🏠   ?   🔄   ♻   🏅   📈
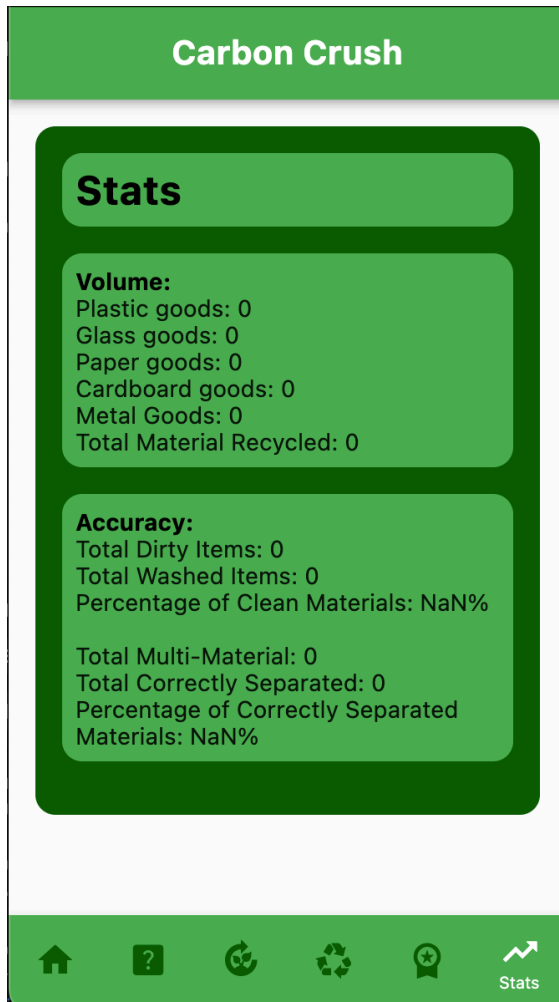   Quests

Stats

Appendix 3: Pre-Survey Questions

The following questions were answered by Local, Remote, and Non-Recycling Senior

Citizen participants before the beginning of their in-house testing. The survey was created using

Google Forms.

What is your name?
What is your age?
Which testing group are you?
What operating system does your smartphone use?
How do you currently recycle?
How much do you know about proper recycling habits? 1 signifies that you do not know how to recycle. 6 signifies that you are proficient in recycling habits such as sorting and cleaning recyclables.

How motivated do you feel to recycle?
Do you believe that your recycling has an impact on the environment?
What barriers are currently preventing you from practicing proper recycling habits such as cleaning and separating recyclables? (ex. lack of knowledge, time, motivation, etc.)

Appendix 4: Testing Information Packet

The linked document was shared with all Local, Remote, and Non-Recycling Senior

Citizen Participants. It outlines what is expected of each group throughout the testing process.

Link:

https://docs.google.com/document/d/1W0wIP7WcdbU55yo4LEjCbwaeFeD8Ry2L9n001f9X6g/

edit?usp=sharing

Appendix 5: Post-Survey Questions

The following questions were answered by Local, Remote, and Non-Recycling Senior

Citizen participants after concluding their in-house testing with Carbon Crush. The survey was

created using Google Forms.

What is your name?
Which testing group are you in?
How much do you know about proper recycling habits? 1 signifies that you do not know how to recycle. 6 signifies that you are proficient in recycling habits such as sorting and cleaning recyclables.
How motivated do you feel to recycle?
Did the app increase your motivation to recycle?
Do you believe that your recycling has an impact on the environment?
Did the app increase your awareness of the impact of your recycling on the environment?
Mark the degree to which you agree that each gamification feature increased your motivation to recycle properly and overcome your barriers to recycling. - Monetary Incentive - Carbon Counter - Stats
Which of the gamification feature impacted you the most?
Why was this feature so impactful?
Did you experience any issues with the app?

| In what ways could the app be improved? |
| Please upload screen shots of your the Home page and Stats page from the recycling app. If you cannot upload them here, please email them to me. |

Appendix 6: Histograms of Local and Remote Participants' Quantity and Quality Scores

The following histograms represent the distribution of the differences of quantity and quality scores for Local and Remote participants. It can be observed that only the differences in Local Quality scores were normal.

Appendix 7: Limitations and Assumptions

<u>**Limitations**</u>:

Listed below are the limitations of my project which were out of my control.

1. External funding was not available to enroll in the Apple Developer program. This

   limited me to testing my app with users for only one week.

2. Participants were limited to those who I could meet in person to deploy the app from my

    laptop. This meant that I could not test with individuals outside of the New England area,

    which I had originally hoped to.

Assumptions:

The following statements were assumed to be true for the purpose of this project.

1. Participants provided honest responses in the Gamification Strategy Survey, Pre-Survey, and

    Post-Survey.

2. Local, Remote, and Non-Recycling Senior Citizen participants produced recycling during their

    first week of recycling that was a true representation of their unaltered recycling habits.

    Additionally, during both weeks, all participants submitted (physically or virtually) all products

    that they recycled and did not omit materials that they did not clean or separate properly.

3. The samples used for the Gamification Strategy Survey and in-house testing were

    representative of the population.

4. The trends observed in the present study are predictive of the future.