

# Effects of an informational waste management app on a user's waste disposal habits

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## SUMMARY

For several decades, the issue of mismanaged waste has been of paramount importance. While 75% of waste in the United States is stated to be recyclable, only about 34% truly is. Furthermore, one in four pieces of waste is recycled incorrectly, leading to inefficient, expensive, and environmentally detrimental impacts. The foundations of this problem lie in the lack of environmental awareness and personal knowledge about waste disposal. This project takes a stance to combat the pillars of mismanaged waste through a modern means of convenience: the TracedWaste app. The purpose of this study was to identify how individuals' waste disposal habits improved and knowledge increased (i.e. correctly disposing of waste, understanding negative consequences of incorrect waste disposal) due to their use of an informational waste management app as measured by a survey using a 1-5 Likert Scale. We surveyed 104 participants using 27 questions regarding the effectiveness and specifications of the app. A chi-squared test of independence was performed for the survey data, revealing a significant relationship between TracedWaste app usage and improved waste disposal habits, ( $X^2 = 477.75, p < .001$ ). Ultimately, this indicates that the data is statistically significant, with a confidence level of over 99%, demonstrating that the app created a positive difference in individuals' everyday lives. Therefore, the results supported our hypothesis: the TracedWaste app helped conserve abundant resources such as energy and wood, decrease carbon emissions, and minimize financial toll all through reducing individual impact.

## INTRODUCTION

The world produces 2.01 billion tons of solid municipal waste annually, and over 33% of that waste is disposed incorrectly, resulting in an unsustainable and hazardous environment (1). By 2050, annual waste is expected to grow to 3.4 billion tons, and so, undoubtedly, there is a need for a solution to this impending crisis (2). While the United States, one of the most developed and wealthiest countries, has only 4% of the world's population, it produces 12% of the global

waste at 4.5 pounds of trash per person per day, resulting in 239 million tons annually (3).

Waste management has become a rising issue in the fight against climate change, as well as environmental sustainability. The rates of consumption and production in the world have been exponentially increasing the amount of waste generated. According to Stanford's EPA Waste Reduction Model, just one ton of recycled plastic saves 5,774 kWh of energy, 16.3 barrels of oil, and 30 cubic yards of landfill space (4). With the projected populations rising at a tremendous rate, recycling has been deemed the easiest and most efficient process to undertake (3). In 2017, there were 35.4 million tons of plastic waste generated, which was 13.2% of total municipal solid waste, but only 8.4% of this plastic was recycled (5). The only way to reduce the amount of waste going into landfills and incinerators is to push this waste into other areas, such as compost, recycling, and other sustainable uses. The United States Environmental Protection Agency (EPA) states that even though 75% of the waste in the United States could be recycled, only 35.2% is (5). Not only this, but one in four pieces of waste that are recycled in the United States are incorrectly recycled (6).

The environmental impacts of the lack of proper recycling are many, such as landfills becoming overfilled due to the amount of waste growing faster than they can decompose. The increase of waste in landfills results in toxic leachate seeping into the groundwater, contaminating both the water and soil. Additionally, by depleting resources, we are increasing the demand for new resources and therefore increasing the prices on these highly valued materials, such as coal, oil, and timber. Recycling helps not only the environment and economy but also the health of fellow humans across the globe. Through the leachate, toxicity, and pollution caused by incorrect waste disposal, human health impacts are at their peak and mismanaged waste kills hundreds of thousands of people every year (7). By recycling, we will reduce the amount of waste sent to landfills, conserve natural resources, such as timber and water, prevent pollution by reducing the need to collect raw materials, and reduce greenhouse gas emissions. On the contrary, the impacts of mis-recycling include a decreased efficiency in the recycling centers. The incorrectly recycled waste must be removed manually, which takes a lot of time and money. Not only that, but there are also economic

implications; by mis-recycling, the facility’s equipment can be damaged, costing money to fix as well as posing a danger to the employees operating them. More importantly, incorrectly recycled waste can contaminate large pools of recyclable waste, rendering it all useless and turn away buyers, which can then drive down the recycling business’s profitability.

Mis-recycling, as well as a void of recycling, are problems of a global scale and affect every single individual in both developing and developed countries. The primary causes of the lack of recycling and mis-recycling have been deemed to be the misinformation of proper recycling and unawareness to recycling’s necessity (8). Waste360, a site dedicated to issues of waste and environment, surveyed 2,000 Americans, and 62% of the respondents said “[they] worry that a lack of knowledge is causing them to recycle incorrectly.” It seems that many Americans have trouble finding resources to help them properly dispose of waste and implement recycling into their waste routines, indicating that a lack of knowledge is the largest reason why we are not green (8). According to Ramayah, *et al.*, environmental awareness is significantly related to an attitude towards recycling (9).

Additionally, communication and education efforts are effective in encouraging recycling behavior. The encouragement of recycling could be a key factor in making recycling more widespread and correctly done. Once people worldwide learn more about the environmental implications of recycling and the necessity of this task, they may realize that their actions have an important impact on the world. Not only would citizens be doing a civil responsibility, but they would also likely feel emotions of self-pride by being a positive change to make the world a more sustainable place. To promote this change, people are currently attempting to solve mismanaged waste through writing, rallies, trials, signs, posters, informational sessions, and other ways to encourage one another to participate in this easy task.

In addition, “It has been found that satisfaction with an app leads to pro-environmental and increased/better recycling behavior...emanating from an altruistic feeling which aims to preserve the environment” (10). Nowadays, over three billion people in the world interact with a variety of apps on their smartphones (11). We recognize the massive platform and influence an app can have; therefore, to strive for properly managed waste and an increase in recycling, we believe an explanatory app would be the best plan of attack to do so. In this study, we test the effects of a custom waste management app. We hypothesize that an app on a daily device can reinforce principles of waste disposal, leading to better waste allocation habits and thus creating a greener community. Our app will contain multiple features enhancing the user’s knowledge of waste management, from a community blog to fun minigames. Our app is crucial for our cause as “Greatest success is likely to come from...using educational interventions together with incentives, normative pressures, and removing barriers to change” (12). We present our users with minigames to inspire enjoyment and fun while learning

about the consequences of incorrect waste disposal. We also provide a community blog, where we want to create more bonds within the community from a learning standpoint – other users learn from one another. The news feature allows us to be kept up to date with the latest waste disposal developments worldwide, allowing more information to be available on our app. We also enable our users to put themselves to the test, as they can take quizzes on their waste knowledge – with provided incentives to always be better than before. Having the recycling center feature enables our users “to know both that these toxic materials are harmful [and] the nearest drop-off recycling center”, which helps them dispose of their waste correctly (13).

We will test this informational waste management app’s effect on individuals’ waste disposal habits in this research paper. We hypothesize that if users fully interact with an informational waste management app, their waste disposal habits will significantly improve regarding the correct disposal of waste as they will realize that incorrect waste disposal leads to dire consequences. In addition, once users utilize all the app features, they will understand the extent to which their actions can positively affect the environment, economy, and human health.

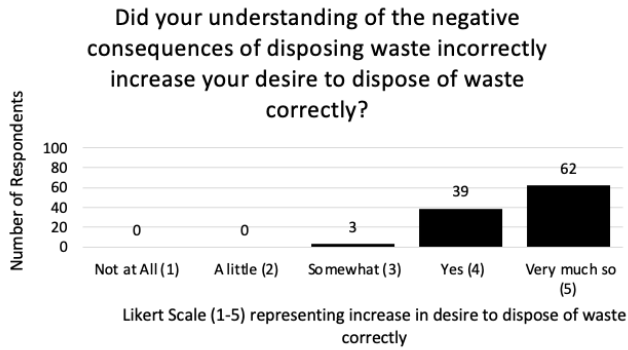
## RESULTS

We surveyed 104 randomly selected people, aging from 10 to 78 years old, from all around Washington, USA, as well as Bengaluru, India (from a total of 312 possible participants) and deemed the questions listed in **Table 1** (out of 27 total) as the most critical in determining the usefulness and engagement of our app, as well as the impact our app had on the opinions of participants.

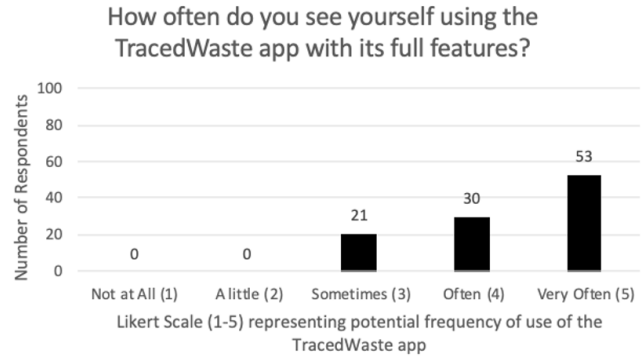
A chi-squared test of independence showed that there was a significant relationship between TracedWaste app usage and improved waste disposal habits,  $\chi^2 (92, N = 104) = 477.75, p < .001$ . Through the survey, participants who had used the features of the TracedWaste app reported that they improved their waste disposal habits (**Figure 3**), decreased

**Table 1. Chi-squared values and mean user ratings for analyzed survey questions**

Question	Mean User Rating (1-5)	Chi-Squared Value
1. How beneficial were the questions that were asked in the minigame to your understanding of waste disposal and why it’s an important issue to address and teach the public about?	4.447	31.062
2. Did your understanding of the negative consequences of disposing waste incorrectly increase your desire to dispose of waste correctly?	4.567	17.776
3. Do you understand the positive effects that correct waste disposal leads to?	4.538	17.631
4. Did our app TracedWaste and our minigame Wastify change your perspective on correct waste disposal?	4.625	22.790
5. Do you think it’s important to teach the importance of correct waste disposal to people around the world?	4.964	31.062
6. How often do you see yourself using the TracedWaste app with its full features?	4.355	12.639
7. Do you see your predicted solid municipal waste (trash) output decreasing as a result of your increased efforts to compost and recycle waste?	4.300	12.653
8. Did your waste disposal habits improve after using the different features of our app?	4.590	15.959
9. Did your understanding of how to dispose certain daily items increase?	4.641	12.653



**Figure 1.** Graph showing a positive correlation between the use of TracedWaste’s features and an individual’s understanding of negative consequences regarding incorrect waste disposal. The survey was offered to 104 individuals who used the TracedWaste app’s features and followed up with responses to a series of questions (on a 1-5 Likert Scale). The mean user rating for this question was 4.567 (on a 1-5 scale) and the Chi-Squared value was 17.776.



**Figure 2.** Graph showing a relationship between features of app and potential frequency of use. The survey was offered to 104 individuals who used the TracedWaste app’s features and followed up with responses to a series of questions (on a 1-5 Likert Scale). The mean user rating for this question was 4.355 (on a 1-5 scale) and the Chi-Squared value was 12.639.

their municipal waste output (Figure 4), recognized the positive effects of their corrected waste disposal methods, and understood the negative ramifications of incorrect waste disposal on human health, the environment, and the economy (Figure 1). In addition, we found that survey participants would use this app quite frequently (Figure 2), which they indicated would lead to a more sustainable individual household.

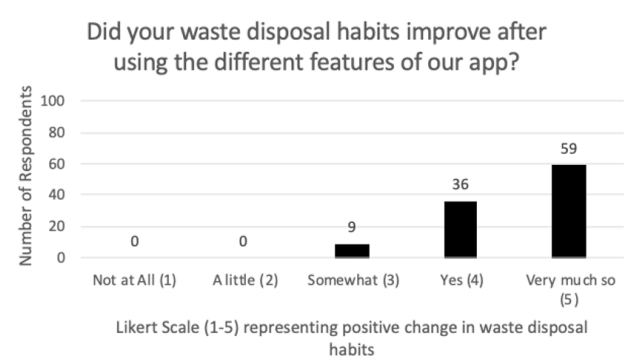
**DISCUSSION**

Our data, which was statistically significant, supported our hypothesis that a majority of survey respondents improved their waste disposal habits, recognized the positive effects of their corrected waste disposal methods, and understood the negative ramifications of incorrect waste disposal on the environment, economy, and human health.

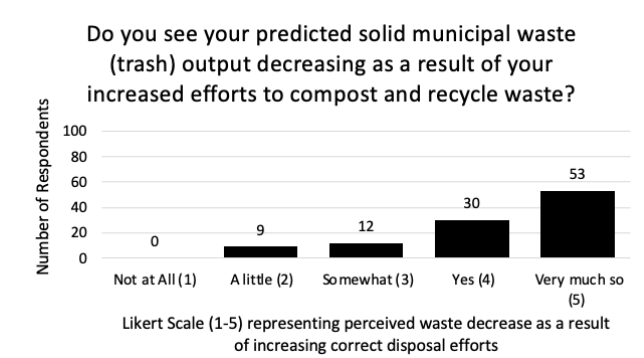
Question #2 in Table 1 resulted in a mean rating of 4.57. As

shown in previous studies (9), an increase in understanding the negative consequences of disposing waste incorrectly can increase an individual’s desire and ability to dispose of waste correctly. We have also confirmed that the TracedWaste app increased the user’s knowledge of the positive effects that correct waste disposal leads to (Question #3). The minigame feature also significantly influenced users’ knowledge about waste disposal as they had to employ their waste disposal decision-making skills to survive fights with bosses and other characters. Users answered with a mean rating of 4.45 to Question #1, portraying a moderate increase in their waste disposal knowledge due to the Wastify minigame.

Moreover, an individual can significantly reduce their negative impact through the TracedWaste app and positively change their waste disposal habits. Respondents answered, with a mean rating of 4.64 (Question #9), that their waste disposal habits truly moved towards the better, resulting in our



**Figure 3.** Graph showing a positive correlation between the use of TracedWaste’s features and the user’s improvement in waste disposal habits. The survey was offered to 104 individuals who used the TracedWaste app’s features and followed up with responses to a series of questions (on a 1-5 Likert Scale). The mean user rating for this question was 4.590 (on a 1-5 scale) and the Chi-Squared value was 15.959.



**Figure 4.** Graph showing a positive relationship between the use of TracedWaste’s features and the decrease of a user’s solid municipal waste output, due to their composting and recycling effort. The survey was offered to 104 individuals who used the TracedWaste app’s features and followed up with responses to a series of questions (on a 1-5 Likert Scale). The mean user rating for this question was 4.301 (on a 1-5 scale) and the Chi-Squared value was 12.653.

app's validation, which is working towards fostering correct waste disposal habits. In addition, users have indicated that they would use the TracedWaste app more than 'often' as the mean rating was 4.36 (Question #6), which indicates that this effective behavior can continue over time.

This app may have the potential to be a positive influence for change across the globe regarding environmental sustainability. Climate change, a result of exponentially increased carbon emissions; the Pacific garbage patch, a vast area in the ocean full of recyclable waste; and the size of landfills, emitting toxins and leachate into the ground, can all be minimized through gradual change into a sustainable and consistent method of correct waste disposal. Increasing evidence has shown that a lack of environmental awareness and knowledge regarding waste disposal has led to catastrophically incorrect management of waste. Through the data we gathered, we have determined that TracedWaste, or similar apps, can potentially be a stepping stone in the process of slowing climate change, preventing the waste of natural resources, such as energy and timber, increasing economic efficiency, and saving precious lives across the world by informing and inspiring action from individuals.

One source of error that could have impacted our study is the limited number of options on the Likert scale. As a result of the limited categories, the Likert scale converts the qualitative data into quantitative data, which results in no in-between values and possibly inaccurate data. Another source of error could be the relatively modest number of survey respondents, which totaled 104 surveys randomly sampled from 312 possible applicants. Compared to other studies similar to this, our number of surveys are on the lower end of the spectrum. Thus, we would like to expand the range of survey applicants and create a larger sample size. In addition, every participant in our study had access to a computer that had the feasibility to run both our programs. As individuals

in higher socioeconomic classes tend to desire increased environmental protection, our research may have sample bias (14).

Another limitation users may encounter is that the waste classifier (Figure 5) may not identify all types of waste. In addition, our waste classifier requires a well-lit environment, which may not be plausible in every scenario. The minigame currently has 50 set questions, which must be significantly expanded for the users to learn more content and continuously stay engaged with the game. Furthermore, the features of our app are extensive in size, which can result in both lag and substantial storage space being used. Finally, this was a self-reported survey, so users may have had a bias to choose answers that positively reflected on the app. Adding to the previous point, we never gave a rubric for the users to grade the app, so they may have misinterpreted how the app is supposed to function – all leading to less meaningful survey ratings.

In future work, we would aim to expand the categories of items that our waste classifier can categorize, as stated in the limitations. We would also want to be able to use flash in our waste classifier to allow for a well-lit area, even in darker situations. Another feature we would like to implement is an interactive platform that allows users to bond on a societal level based on their management abilities and share their strategies within the community. We would also like to survey users on additional features such as the news portal, calendar, and the natural resources saved, which will provide us more information regarding the use of these new additions and whether it helps users advance their knowledge on waste. At the time of this survey, our app was not fully completed, so all the features that we desired could not be tested by the users (Figure 6), but now we have published our app on both the App and Google Play Stores.

To gain more valuable insights, we want the users to dive

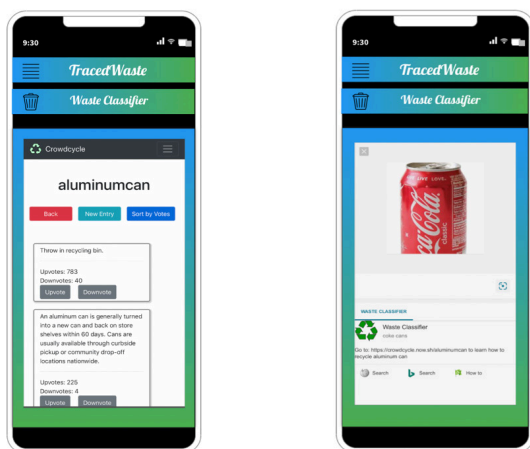


Figure 5. Model User Interface of the TracedWaste app displaying the completed Waste Classifier, showing a link to recycle an aluminum can. The purpose of the Waste Classifier is for the users to be familiar with how to dispose of household items.



Figure 6. Model User Interface showing the cover page of the TracedWaste app with all of the features shown in the icons above such as the waste classifier, minigames, news articles, etc. Our cover page demonstrates a plethora of easy to-go-to features for users to advance their waste knowledge.

deeper. We would give step-by-step procedures on what the user must do to interact with the app appropriately, and what they should be getting out of testing that feature – as this would ensure that we are in the right direction with our goal and receive valid criticism and insight. Lastly, we would want to add more questions into our minigame or make a new one, as users may get bored if they have played the game more than once. Through our research and testing of several features of the TracedWaste app, we believe that in the future, with all these elements, TracedWaste can be a medium of reducing an individual's negative environmental consequences and conserving essential resources.

## METHODS AND MATERIALS

### Software

Our primary operations took place on a MacBook Air and Lenovo IdeaPad 320s. We also used Microsoft Excel and Word to create figures and tables. To make our interactive game, we employed Adobe Illustrator (version 23.1.0) to draw sprites and Unity 2019.3.10f1 as a platform to create our game mechanics and enhance the features of our app to better coach our users. Furthermore, we utilized MockFlow Wireframe 2020 to produce user-friendly designs of how our app will look from a customer standpoint. To complete our waste image classifier, we used Visual Studio Code and the Bing Visual Search Developer Platform. We also employed the versatile program Google Forms (<https://docs.google.com/forms/u/0/>) to create a survey which we later sent out to survey respondents to receive feedback and input on our app designs, Wastify minigame, and waste image classifier.

### Waste Classifier

We used Microsoft Custom Vision ([customvision.ai](https://customvision.ai)) first to create an image waste classifier. We also generated a Web Server to store website files and return a list of all current waste categories in the crowd-sourced front-end website. Next, we implemented a Crowd-Sourced Website by using Crowd Cycle. We handled requests, JSON Data, and the Web Server by coding in Visual Studio Code, employing NLP (Natural Language Processing Techniques) to match the output of the image classifier (even if the output is related to the real name of the item and not the exact same) to the categories (items) of waste generated on the website. The Matching Algorithm was then coded (match output of image classifier to categories of waste on the website) in Visual Studio Code to return the name of the piece of waste that the user uploaded a picture of. To publish our waste classifier, we utilized the Bing Visual Search Developer Platform (15).

Heroku was used to create a service URL, which allowed our Bing skill to receive and return data. Last, the Heroku app was deployed, the Web Server was turned on, and the Waste Classifier skill was published. To summarize, the Waste Classifier was a Bing Visual Search skill where users could take a picture of any piece of waste, and the classifier would output what the waste item is and how to dispose of it safely.



**Figure 7. Screen shot of our minigame, Wastify, where the example question turned green after user correctly answers and score goes up by 10.** Wastify tests the user's knowledge through a fun and interactive quiz game, which enables users to understand their current progress while learning new facts about waste disposal.

Bing Visual Search Skill: <https://www.bing.com/visualsearch/skill/EUGMW9>.

### Wastify Minigame

Five .txt file resources were generated on Unity 2019.3.10f1, that each contained ten questions to increase a user's waste awareness (disposing of items correctly, understanding negative and positive consequences of incorrect and correct waste disposal, respectively).

Next, Adobe Illustrator was employed to produce the background for each of the five levels, the home screen, and the final score screen. Visual Studio 2019 was utilized as the coding IDE, and the final game mechanics were coded in the language C# (loading sprites in the game, enemy and friendly animations, panels with correct questions and options popping up, dialogue boxes, etc.). User actions were coded in another C# file (clicking various buttons), and all changes thus far were pushed to Unity. The full game was tested in Unity, and the Wastify Minigame Application file was published onto the Unity Platform. The overall structure of the Wastify Minigame was in the form of an animated quiz with different levels. Once users answered correctly (or incorrectly), their character would move forward or get eliminated after three wrong answers.

### Data Compilation

Google Forms was utilized to create a user survey. The survey mainly contained Likert-type items, which fall on the ordinal measurement scale, so we used a chi-squared test to analyze our survey results for each question. Depending on the type of question, a 1-5 Likert Scale, Yes/No, 1-10 Likert Scale, or Short Answer were used as response types to the given questions. We emailed a copy of the human informed consent form and survey to all participants.

Each person that consented to participate in the study was assigned a distinct participant number. We then employed a random number generator ([random.org](https://www.random.org)) until 1/3 of the total

participants had been randomly selected to complete the survey. At the time, our waste classifier server could not handle many users, so we wanted to limit our survey population to 104. We believed that using randomization from the 312 people who desired to be a part of our beta testing would not only achieve 104 participants but also provide a stronger representative sample. We emailed a link to the already created Google Forms Survey, jpegs of the mock app designs, a link to the Google Drive where users can download and play the Wastify Minigame, and a link to the Waste Classifier Bing Visual Search Skill to the participants that had been randomly selected for the survey. Participants in the study used the Waste Classifier and Wastify Minigame at least once but were then allowed to freely navigate the features as much as they wanted to over the week, filling out the survey after a week of utilizing the app. Lastly, the completed survey data of all participants was downloaded from the Google Forms Survey Developer Page and saved in a digital Microsoft Excel file.

### DATA ANALYSIS

We created a data analysis table in Microsoft Word with three columns (questions, chi-squared value, and mean user rating). We then calculated and recorded the chi-squared values for the Numerical Likert Scale Data gathered by all our survey questions, computing the chi-squared value for one survey question at a time using a TI-84 Plus CE calculator. Last, the mean chi-squared value was calculated and documented by taking the average of all the chi-squared values recorded for each survey question in the Numerical Likert Scale Data using the calculator.

We employed the chi-squared test because our survey consisted of single, Likert-type items that were not united into a single composite score/variable during the data analysis process. To specify, a Likert Scale is a rating scale that can quantitatively measure individuals' attitudes or opinions toward certain items (in this case, the TracedWaste App). Likert-type items fall into the ordinal measurement scale, making them appropriate to analyze with a chi-squared test (16). We included all nine questions from **Table 1** in the statistical analysis, excluding two Yes/No questions and sixteen Likert scale questions. The scale of analyzing the Yes/No questions was extremely one-dimensional and would not be able to predict a user's behavior rating accurately with only two options. Also, the insights from the Likert scale questions were encompassed in the nine questions shown in **Table 1**, rendering those sixteen Likert scale questions nonessential to include in the final analysis.

To complete the chi-squared test, we used a normal distribution curve because we expected half of our participants (to the left of the mean) to disagree with the fact that our app helped improve their waste disposal habits and allowed them to understand the positive and negative consequences of correct and incorrect waste disposal, respectively.

Ratings are defined as follows:

Rating of 1 – Strongly Disagree (Definitely No). The participant would give a definite no to the question asked (more confidence in their response).

Rating of 2 – Disagree (No). The participant would give a no to the question asked but without as much conviction as if they had selected a rating of 1.

Rating 3 – Neutral (Sometimes). The participant would not answer yes or no to the question. They are neutral about the question and believe their answer varies (sometimes).

Rating 4 – Agree (Yes). The participant would give a yes to the question asked but without as much conviction as if they had selected a rating of 5.

Rating 5 – Strongly Agree (Definitely Yes). The participant would give a definite yes to the question asked (more confidence in their response).

To put this into numerical terms, the 3rd rating corresponds to 68% on the bell curve (68% of respondents fall within one standard deviation of the mean, meaning that 68% of respondents are expected to answer a question with a rating of 3). The 2nd and 4th rating each correspond to 14% on the bell curve (96% of respondents fall within two standard deviations of the mean, meaning that 28% of respondents are expected to answer a question with a rating of 2 or 4). The 1st and 5th rating each correspond to 2% on the bell curve (~100% of respondents fall within three standard deviations of the mean, meaning that 4% of respondents are expected to answer a question with a rating of 1 or 5). Our chi-squared test measured whether there are significant deviations from these expected distributions or not.

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