Imperial College London

EE2 Group Project

Interim Report

Self-sorting Recycling Machine

Group 06

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Submission date:
08.02.2017.

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1. Abstract

This project aims to tackle the issue of waste management in universities as current models of manual sorting of recyclables are tedious, time-consuming and discourage students from recycling more regularly. Market analysis and primary research in the form of surveying Imperial students was conducted. The technical solution proposed addresses this problem with a self-sorting recycling machine that separates the waste on site and in return awards the students with YOYO points. This reduces the time and manpower needed for sorting of recyclables and encourages students to recycle more as the YOYO points can be redeemed. To design the self-sorting recycling machine, several options were considered based on feasibility, advantages and limitations. It was decided that the image recognition software will be used to identify items to be sorted, a step motor with a rotating tray to deliver the items into their respective compartments and an app designed to interact with users of the machine to gain the YOYO points.

2. Introduction

2.1 Problem Being Addressed and the Target Group

The project aims to tackle the problem of waste management in the UK. Currently, tremendous amount of materials is wasted in England and 'recycling rates have fallen for the first time in 2016' (The Guardian, 2016). While huge budget cuts to authorities in charge of recycling are a primary reason, people are still 'confused about recycling - what they can put in recycling and what needs to go in the residual bin' (The Guardian, 2016) dissuading them from making this a habit.

Although this is a nationwide problem, the scope of this project has been narrowed down to focus on university campuses which are a major source of waste. Through research major causes of this problem have been identified:

Problem 1: Low Rates of Recycling Among Students

Students in general have a lower habit of recycling compared to households. This can be seen from a survey carried out by SITA UK which shows students are half as likely to recycle (SITA UK, 2016) compared to anyone else in the UK. Currently, recycling targets set by universities such as Imperial College London are only 40% (Imperial College London, 2016) which means there is a large area for improvement. This was further validated through our primary research that showed that 50% of Imperial students do not recycle on a regular basis[1].

Problem 2: Contamination of Recyclables

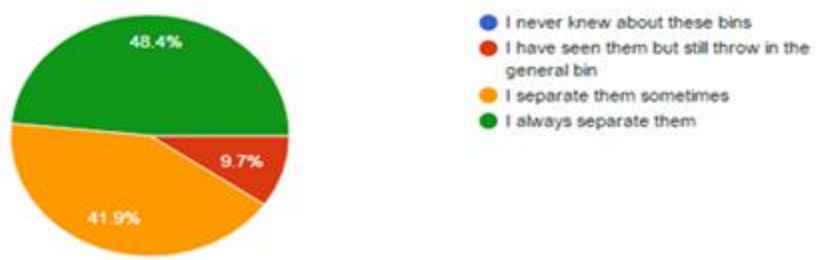

Figure 1: Result from the survey carried among Imperial students

[1] See Appendix for full results if the primary research carried out

Another problem identified is that even if the 50% attempt to recycle, a majority have poor knowledge of recycling procedures. As seen from the figure above, it was identified that more than 50% of students at Imperial do not always sort out their waste. The effects of this are adverse as a single non-recyclable in a bin can result in the whole recycling bin contents being rejected due to contamination. This can be supported by the general trend of how ‘rejected recyclable waste has (increased by) 84% in England since 2011’ (BBC, 2016). The high cost involved in re-sorting these contaminated items means that they are immediately sent as waste (BBC, 2016).

2.2 Problem Discussion

In the UK all of the dry recyclable materials are being sent to Material Recovery Facilities where the recyclables are mostly being separated manually into different material types before being sent to recycling factories. The same procedure is followed at universities in the UK, including Imperial which can be time consuming. The technical solution to improve the recycling rates has to be one that improves the existing process by addressing the root causes mentioned earlier.

To mitigate the issue of disinterest towards recycling among students, the solution should aim to incentivise students to recycle more regularly. Existing rewarding systems such as YOYO Wallet are a good platform as they keep track of these transactions and encourage this behaviour by giving points that can later be redeemed. The survey conducted validated this: 3 in 4 Imperial students said they would recycle more if there was a rewarding system[2].

Next, to minimise contamination and facilitate efficient sorting of materials, a recycling machine that automatically sorts items is a plausible option. This would not only make material recovery facilities redundant, it could also in turn increase recycling rates among students as their recycling experience is made faster, easier and seamless.

2.3 Market Research

From market research, it can be seen that there are existing products that are tackling similar issues. One example is the ‘Tesco Automated Recycling Bank’ which provides ‘Clubcard points’ for the public through recycling but the items are manually sorted by the users by recycling category (i.e. glass, plastic, paper, etc.) the waste belongs to (Mail Online, 2011). However, 25% of the machines were removed due to vandalism and malfunctioning.

On the other hand, existing automatic sorting systems, such as the ones developed by “Beston Group”, operate on large scale scenarios. These machines make use of various mechanical methods to sort waste, such as magnetic separators or air blowers (Beston Group, 2015).

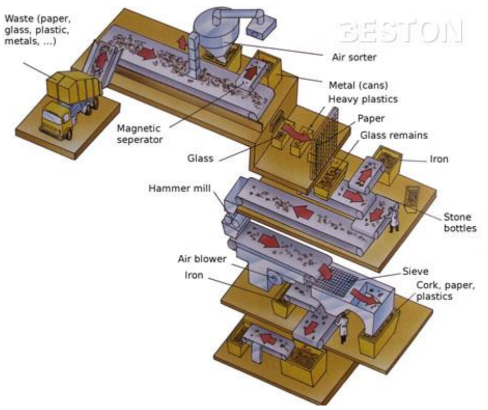

Figure 2: Automatic Sorting Machine by Bestion

[2] See Appendix for full results if the primary research carried out

A better option would be a product that interacts with customers directly, allowing one to easily separate various types of recycling. Moreover, while these products are present, there is a gap in the market for machines specifically targeting youth. The solution would be geared towards the interests and behaviour of this demographic and made suitable for usage in university campuses.

3. Design Specification

In order to fulfil the task requirements, the product design has to be evaluated in various categories. The self-sorting machines will be placed indoors within university buildings such as corridors, cafeterias and lunchrooms where student traffic is commonly high. Students might not choose the self-sorting machines because general bins are more convenient time-wise but require effort to separate items. According to the survey carried out, 50% of the students who do not recycle said that it takes too much effort to do so. As the purpose of our project is to encourage recycling among university students, the machine needs to involve as little effort from the user as possible while processing the item automatically.

The usage time is estimated to take place during lecture hours (8am - 7pm) to reduce power consumption. Regarding operational and safety requirements, standards will be compared to existing vending machine requirements (DMIE, 2011). Based on the requirements of the problem, the product is needed to act in accordance with the following specifications:

Category	Criteria	Requirement
Manufacturing	Size	Has 4 standard sized compartments of 240l volume (Herefordshire Council, 2012) each to contain a day's amount of waste
	Material	Suitable for indoor operation only
	Cost	Each unit made within £100
Performance	Speed	Able to complete each sorting within 30 seconds
	Storage Capability	Able to store one day's worth of recyclables in campuses and be cleared daily
	Reliability	Able to sort 5 distinct items common in campuses into 4 categories – Plastic, Paper, Can and Others
	Accuracy	Able to distinguish common items purchased in campus at least 80% of the time
Operational Requirements	Power Requirements	Low power consumption. Have standby (idle) mode to save power when not in use
	Maintenance	Able to run smoothly with servicing done twice a year
	Service Life	Able to be in use for a minimum of 5 years
Safety Requirements	Misuse/Abuse	Tray to place recyclables closes after every interaction preventing access into the compartments

3.1 Design Options

The most challenging aspect of the product design is recognising and categorising the items given that their shape could be altered. If the product has been crushed or ripped, the system might not be able to recognise it. Therefore, brainstorming and evaluation of possible methods of identification were considered as follows:

	Summary	Advantages	Disadvantages
Scanning of Barcode	The machine could be integrated with a barcode scanner (Scholarpedia, 2012) that recognises the category using the already existing barcodes items such as canned drinks, processed food etc.	Simple Easy Low cost	Large amount of items that by default do not contain barcodes would not be detected.
Integration with YOYO app	The student indicates what product he or she is introducing into the tray using the YOYO app from previously bought items since the record of purchase already exists.	Innovative way of reusing the YOYO app	Time-consuming for students in the case of multiple item purchases. Products not purchased with YOYO payment would not be recognised.
For both methods, a possible solution would be attaching stickers on the products that currently do not contain barcodes. Nevertheless, this would result in a bigger waste of resources.			
Calculation of Density	Supermarkets are using weighing scales at self-checkout tills to identify products (Kiosk, 2014). A similar method could be implemented by weighing items and analysing the volume to obtain their density. The volume can be estimated with three proximity sensors that would measure item's length, height and width.	Easy to obtain weight of an item as this method already exists.	Inaccurate as many objects in different categories could have a similar density.
Test Material Pressure	Identifying the material composition: a pressure sensor would be inserted through the product that would be categorised by measuring the pressure required to penetrate it: high for cans, medium for plastic and low for cartons and papers.	Could be extended to a large range of materials and products.	Requires extensive knowledge of mechanics and materials. Inaccurate if objects are stacked together.
Image Recognition	Implemented by fixing a camera inside the machine to capture the image of the object to be compared with an array of elements and matched with one of the products that has already been classified.	Reliable Low use of resources: a camera and a suitable software for image recognition.	Objects cannot be crashed or deformed as the machine will only recognize the objects in their original manufactured forms.

Outcome:
Through evaluation, it was decided that the machine will sort the waste by image recognition where a picture is captured and processed with a software as it is the most versatile and adaptable. This one method when implemented allows wide range of items to be identified using the same system in place. The one disadvantage of unrecognizable items can be tackled by isolating them in a separate compartment for General Waste.

4. Technical Specification

4.1 Overview

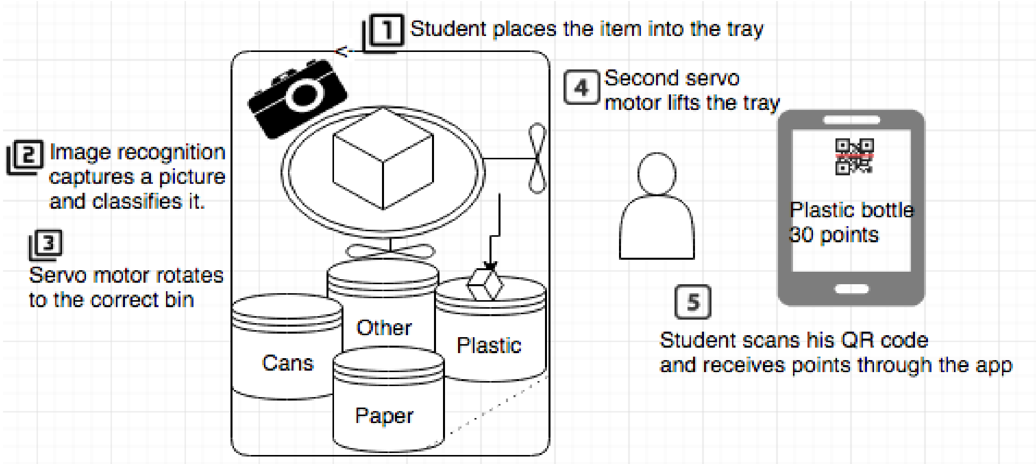

Figure 3: Prototype and mechanism of the self-sorting recycling machine (created in draw.io)

As seen in the figure above, the user will place the waste into tray in the recycling bin, wait for the trash to be sorted by image recognition and then scan their app on the barcode scanner.

The sorting software will receive a photograph of the trash that is to be sorted. The software will recognise the object and sort it into one of three categories with the help of two servo motors: paper, plastic or can. If it fails to associate the object with a category, then it will fall into the 'general waste' category. The software processes the photograph using image recognition and detects objects from a finite catalogue of common items and the rest will be classified as 'general waste'.

Lastly, a mobile app on the Android platform will be created for the user to collect points each time they recycle. The app generates a barcode to be scanned by the barcode scanner connected to the recycling machine. When it detects that a valid recyclable item has been deposited, the barcode scanner will be activated - ready to be used. The points will be accumulated and the user can eventually spend it to buy tangible items.

4.2 Image Processing

There are various techniques to implement an image recognition algorithm and some of the options considered are discussed below.
Problems that could be encountered in the implementation are as follows:

- Photographs having different image resolutions
- Objects being deformed or compressed
- Objects placed in different orientations

Types of algorithms considered:

1) **Colour histograms**:
Images can be broken down into individual pixels. Each pixel can be categorised into one of the three primary colours: red, green or blue (Stackoverflow, 2013). The colour histogram algorithm counts the number of pixels in each colour category. The image is then compared to images with pre-calculated colour histograms. The theory behind this algorithm is that images with similar objects will have similar colour histograms. Drawback of using colour histograms is that different objects may have the same colour information, and could therefore confuse the machine.

2) **Region of Interest**:
Some images may have distinctive regions with high contrast in comparison to the rest of the image. The approach identifies more than one region of interest on a single image and calculates the distance between all of them (Electronic Imaging & Signal Processing, 2006). This is then compared with the database of images with already calculated distances between the regions of interest in order to match the given image. The problem of this method is that most of the objects that need to be sorted are simple and do not have distinct regions of interest that can be used for identification.

3) **Signal Processing:**
Images can be treated as signals and viewed as summation of impulses (scaled and shifted delta functions) (The Scientist and Engineer's Guide to Digital Signal Processing Linear Image Processing, 2011). It is therefore possible to invert the signal (image) and add it to signals (images) from the database. The addition of the exactly opposite signals will cancel out. The image being identified is inverted, added to each image from the database and is matched with the one that has most of its parts neutralised.
The drawback is that this method only works with images of the same brightness and would therefore be hard to implement.

4) **Scale-invariant Feature Transform (SIFT)**
The algorithm is invariant to rotations, translations and scaling transformations of images (Scholarpedia, 2012) which is highly important for the project as objects that are placed for recycling are likely to be placed differently each time before the picture is taken. The algorithm consists of the following procedures (OpenCV, 2014):

- Edges and other significant points of the image with high contrast are identified as potential keypoints
- Potential keypoints are examined and ones with poor intensity are eliminated in order to get more accurate results
- Orientation to each keypoint is assigned and as well as the relative distance between them in order to achieve orientation invariance.
- The data obtained above is used to create a histogram of keypoint descriptors

This process is applied to all images stored in the database and results obtained are saved. When an image of an object to be identified is received the same process is followed, the result is compared to the database results and the best match is identified. As the method is invariant to object orientation, this method will be used.

4.3 Step Motor

The sorting would be implemented in two steps: rotation of the tray to the correct compartment and tilting of the tray so that the item slides down into the compartment.

Firstly, the rotation of the tray would require a step motor that can be configured with a servo motor or a DC motor. A servo motor is possible since the angle defined is smaller than 360°. DC Motor was considered due to its high power efficiency if configured correctly. However, given the amount of time available, the servo motor is chosen as it is much easier to program and implement due to its compatibility with Arduino.

Figure 4: Model of the orientation of bins (Glason, 2015)

Next, the materials storage session will be split into different compartments in a circular configuration similar to the image on the left. There will be four parts for Plastics, Cans, Paper and General.

Therefore, each step would require 90° of rotation of the tray. The number of steps will depend on the classification of the item and the Arduino code will follow these conditions:

- 0 steps: plastic — 0 steps to return
- 1 step right: paper/carton — 1 step left to return
- 2 steps right: cans — 2 steps left to return
- 1 step left: others — 1 step right to return

The challenging part of the design is the tilting of the tray once it is in the right position since this was firstly seen from a mechanical perspective. A series of ideas were identified to accomplish this such as a pulley system, a vertically moving platform or a second-servo motor set-up.

A pulley system could be used by attaching the tray to a pulley system with a weight that would be triggered once the tray is in the correct position. The tray would recover its original position by the difference in weight. Another possibility is a vertically moving platform made by placing a screw-like mechanism at the bottom of the tray that would lift the tray up with a clockwise rotational movement and descend with an anticlockwise rotation. These two however would involve higher level knowledge of mechanics that the group does not possess.

After consultation with the lab technicians at the Imperial Electronics Lab, a simple but working solution with a second servo motor was devised. A second servo motor can be placed on the back of the tray and tilt the tray by around 30-40 degrees. It can be implemented using a simple lever. The motor can be connected to a rigid bar, resting on a pivot that will be placed underneath the tray in order to reduce the required power especially for heavier objects. This was confirmed as the design option as it was the most plausible for the pertaining task.

4.4 The App

The app will enable user interaction with the machine and will be developed on the Android platform using Java. When the app is opened, it will display a unique QR code that the user needs to scan onto the machine before disposing of waste. Once the machine sorts out the material that was put in, the points will be allocated to the user and will be displayed in the app. Other app features will include: the total number of points, the list of items available to purchase at campus with the points collected, the user activity containing the date and time of every transaction. The process is illustrated in the figure below:

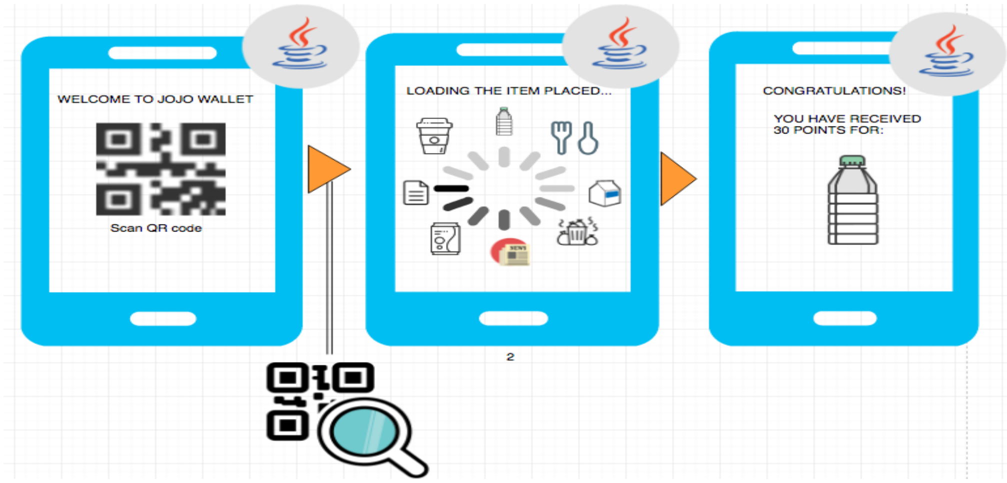

Figure 5: Illustration of the app operation when an item is recycled

5. Project Planning

5.1 Group Management

Throughout the execution of the project, tasks were split among the group members for the market research, technical analysis and implementation. To make the project execution more efficient the whole team was split into smaller groups, each responsible for carrying out a specific subtask in the technical component. The responsibilities were split as follows:

Task	Group Members
Image Recognition and Identification of Materials	Octavian Rosu Guo Liang Liew Abhinaya Mathivanan
Step Motor and Mechanism to Split Materials	Jacopo Carrani Wendy Lu Chen
Developing the App and Designing the User Interface	Katarina Boskovic Sze Tyng Lee

5.2 Timeline

Overall, the entire process was followed according to the following Gantt chart:

				January			February				March		
	Start	End	Duration	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3
Assign responsibilities	09.01.2017.	09.01.2017.	1 day										
Agree on work allocation	09.01.2017	09.01.2017.	1 day										
Research and discuss different design options	09.01.2018	23.01.2017.	2 weeks										
Agree on one option to implement	23.01.2017.	23.01.2017.	1 day										
Split the writing tasks	16.01.2017.	16.01.2017.	1 day										
Design and construct the step motor	27.01.2017.	28.02.2017.	1 month										
Design the app	27.01.2017.	28.02.2017.	1 month										
Work on nad implement image recognition	20.01.2017.	28.02.2017.	1 month										
Order components	10.02.2017.	10.02.2017.	1 day										
Submit the interim report	08.02.2017.	08.02.2017.	1 day										
Build a prototype	13.02.2017.	13.03.2017.	1 month										
Create a website	13.02.2017.	13.03.2017.	1 month										
Submit the final report	13.03.2017.	13.03.2017.	1 day										
Presentation	21.03.2017.	21.03.2017.	1 day										

Figure 6: Gantt Chart

The plan was made at the beginning of the project to make sure the team keeps up with deadlines and that the progress is recorded and checked regularly. Weekly meetings were also carried out where all of the members updated the group on their individual progress regarding the allocated workload. Following this, the group would check if everyone is keeping up with the internally set deadlines and if not would think of possible solutions and actions to be taken so that everyone is on track with the workload.

6. Conclusion and Future Work

The crux of the project revolves around the self-sorting mechanism and the ability for the user to obtain rewards while being socially and environmentally conscious. The group have had many discussions on the best way to implement the idea and have also met up with the project supervisor to get technical advice.

For the remainder of the Spring Term, the group will continue working on the project to present a functioning prototype for the demonstration. This project has three distinct parts: the sorting software, the motor to sort the waste into their respective bins, and the mobile app to collect points. The aim is to build these three parts and demonstrate their capabilities independent of each other. Together, they will form one cohesive self-sorting recycling machine with a mobile reward system.

Our long term goal is to collaborate with a payment app such as YOYO Wallet, so that the points collected from recycling can be used as YOYO points to buy food or drinks on campus. Moreover, any profit from selling the recyclables to recycling facilities can be used for maintenance of the machines to create a self-sustaining system or converted to reward students in campuses with vouchers etc.

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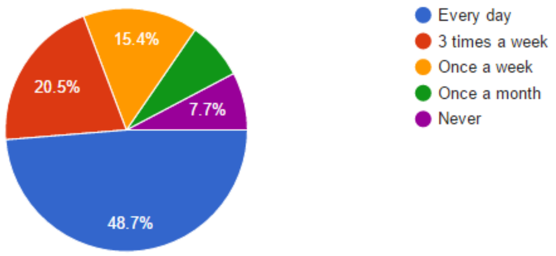
8. Appendix

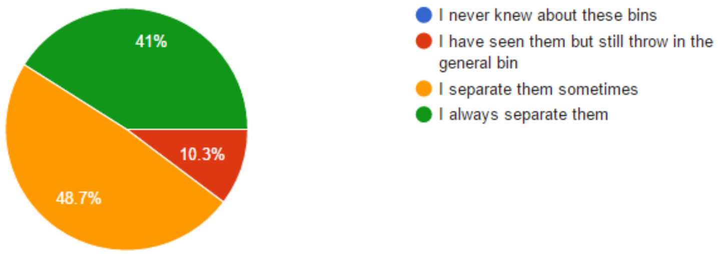
Results of the primary research carried out among students

Questions 1-3:

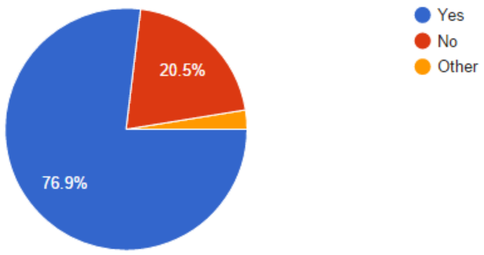
How often do you recycle on the campus? (39 responses)



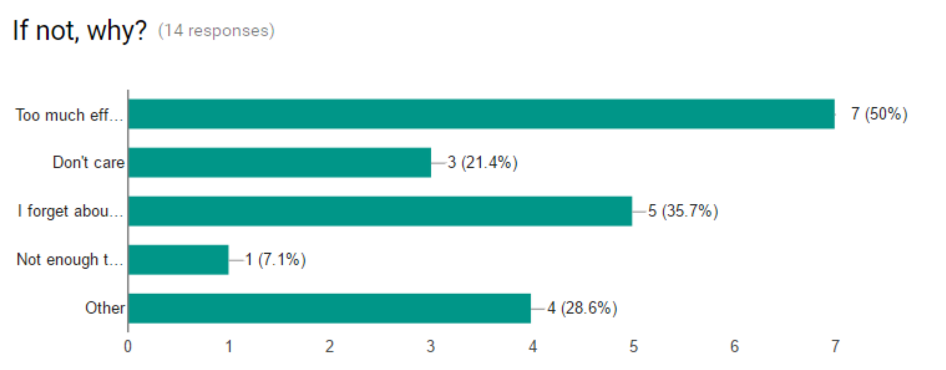
There are bins in campus for Paper (Blue), General (Black) and Dry Mixed (Green). Do you separate your trash?
(39 responses)

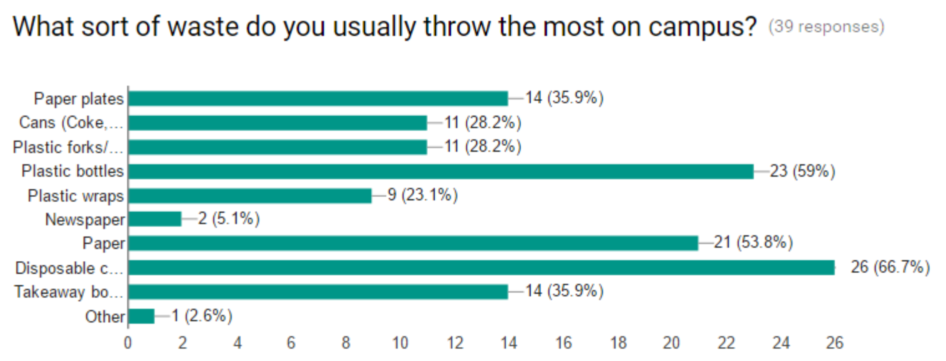


Would you recycle more if given points (like Yoyo) which can be redeemed?
(39 responses)



Questions 4-5:





Flowchart of the Recycling Process