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Computer-Aided Design AND APPLICATIONS

The Development of STEAM Workshop with PET Bottles Upcycling and Computer-Aided Design

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Abstract. Many PET bottles were used every day. Although being designed to be single use, the durability of these plastic bottles enables possibilities for other purposes. However, many of these still-usable used bottles were being transferred into rubbish bins and landfills. Not only does it waste the potential, but these plastic bottles also pollute the environment. Before taking 450 years to decompose, these bottles can be upcycled for better use. Considering the high accessibility, possibilities in functions and creative expressions, PET bottles can be excellent teaching material for STEAM education. This article provides a guideline for teachers on a STEAM education curriculum in upcycling plastic bottles. By studying the bottles and the plastics material, observing, and identifying their design problem and utilizing CAD software and 3D printers to create their prototype, students may master design thinking, problem-solving skills, and 3D modelling skills. With a workshop being conducted, successful attempts in student upcycling projects can be seen.

Keywords: Sustainability, Upcycle, STEAM, Design thinking, Computer-Aided Design, 3D modelling
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1 INTRODUCTION

Plastic Bottles are ubiquitous nowadays. Every day, there were approximately 1.3 billion bottles sold around the world [7]. Being designed for single use, most of these plastic bottles were discarded in landfills. As of 2015, research has shown that only approximately 9% of the ever-made plastics had been recycled, 12% was incinerated, and 79% was accumulated in landfills or the natural environment [6]. These still-usable wastes not only take up valuable land for disposal [6] but also pollute the environment with their toxicity [4]. Before taking 450 years to decompose [2], these bottles can be upcycled for better use.

Due to the extensive usage of plastic bottles in the modern world [6], these used bottles can be highly accessible, making it easy for students to collect them at home. Regarding durability, lightweight, chemical resistance, safety and massive design freedom [1], PET bottles may serve as outstanding teaching material for advanced up cycling. Students may maximize opportunities for plastic and create designs by integrating used plastic bottles, thus, prolonging the lifespan of the PET material.

STEAM (science, technology, engineering, art, and mathematics) is a form of interdisciplinary education strategy [3]. With research that has proven its success and popularity around the globe [8], the strategy suggests a structure of the article's proposal of the up-cycling workshop. With standardized screw-cap bottles and universal manufacturers around the world, students may gain insights from the nowadays' technology in manufacturing. Through the PET bottle up-cycling workshop, students can learn the science and properties of PET or related plastics. Students may reinforce their analytical sense, problem-solving skills, design-thinking abilities and creativity while developing concepts. Lastly, the use of 3D printers and computer-aided design software may provide opportunities to students master the concept and capabilities of rapid prototyping, CAD (computer-aided design) and CAM (computer-aided manufacturing) if applicable. The design and structure of the used bottle up-cycling workshop strictly align with the ideology of the STEAM education strategy.

2 OVERVIEW

Considering the advantages and potential value mentioned above, recycled plastic bottles can be excellent teaching material for STEAM education. The following section will cover guidelines and suggested steps for teachers in a STEAM workshop on upcycling plastic bottles. By studying the bottles and the plastics material, observing, and identifying their design problem and utilizing CAD software and 3D printers to create their prototype, students may master design thinking, problem-solving skills and 3D modelling skills. Teachers may adjust the content if required depending on the students and the accessible equipment.

Steps	*Number of Weeks*	*What to Do*	*What to Learn*
Home Recycle	1-2	Gather bottles for later stages	First-handed experience with material recycling and an in-depth understanding of the condition of their materials
Material Study	1-2	Lab experiment and online research	Understand the possibilities and technical limitations of these collected used bottles.
Design Brief	1	Set scenario for study and design	Study and analyze their scenarios, thus identifying the problems, pain points and opportunities
Computer-Aided Design	2	Learn software and build model	Understand the basics of 3D modeling and how to incorporate with software to develop and optimize design
Additive manufacturing	2-4	3D printing and final model	First-handed experience with 3D printing technology

Table 1: Overview of the STEAM Upcycling Workshop Proposal.

2.1 Step 1: Home Recycle

Before the workshop begins, students would be instructed to collect their used bottles from their families or other sources. The suggested time for bottle collection would be one to two weeks prior to the workshop to reduce the possibility of students purchasing additional plastic bottles just for the project.

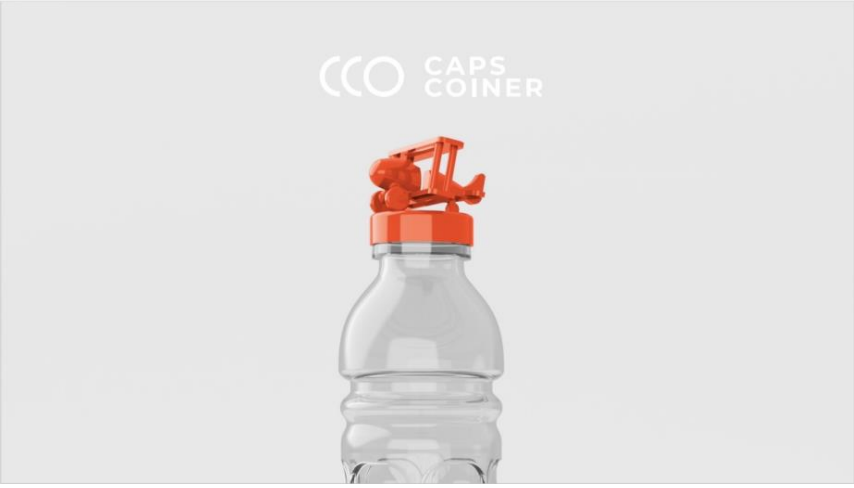

Figure 1: Caps Coiner, an example for the expected outcome of the STEAM workshop.

These bottles will be crucial for the workshops, as all the design, modelling references and structure of the outcome rely on the parameters and types of the collected bottles. Regarding collecting PET bottles, students are recommended to collect bottles with identical or similar sizes at the beginning to prevent unnecessary difficulties in the later workshops. Students should also be reminded of the conditions of the bottles to make sure the samples they gather are useful in the later project. Students may further collect additional bottles if needed in the prototyping phase. In the process, students will gain first-hand experience with material recycling and an in-depth understanding of the condition of their collected PET bottles.

2.2 Step 2: Material Study

Studying the properties of the material would be crucial for students to gain insight into the potential and possibilities of their designs. Teachers may instruct students to study the bottles and the plastic material through simple tests, such as vertical and horizontal loading tests. Through first-hand studies on the form, structure and strength, students may better understand [5] the possibilities and technical limitations of these collected used bottles. Students should also be encouraged to conduct secondary research from books, articles, and online resources to understand some existing applications of recycled plastics. Inspirations from other people’s work might help the students with their design brief in the later stage.

2.3 Step 3: Design Brief

With a substantial understanding of what the PET material is capable of, students may begin constructing their design brief with requirements to fulfil and criteria to access the successfulness. Teachers may or may not provide students with a general theme regarding the topic and direction, depending on the degree of freedom teachers would like to provide. Suggested themes include furniture, houseware, or even personal vehicle if plausible after assessing students’ capability. Students are required to study and analyze their scenarios, thus identifying the problems, pain points and opportunities to construct their own design brief for the project.

2.4 Step 4: Computer-Aided Design

In the computer-aided design stage, teachers will guild students in studying the dimensions of the bottles’ cap-screws. By drafting a technical drawing of the cap-screw section, students may reverse-engineer the bottle cap-screw adaptor to connect their designed add-on with the PET bottles. Lastly, students may build their three-dimensional computer model with the help of CAD software. Multiple analyses of any collision or conflicting components can be instructed to the students after the completion of their 3D models.

For the CAD software, the article suggests three different software for teachers and students to choose from depending on their project's directions and needs. For organic forms and designs with fewer requirements on precisions, authors suggest Blender 3D, an open-source modelling software with digital sculpting, simulation, and even motion tracking. For projects that require high precision, Solidworks may provide excellent performance in developing sophisticated 3D models and simulation parameters. If students are looking for something in between these two suggestions, Rhino 3D is perfect for design and engineering analysis with deep analysis and visualization features. However, other CAD software can also be used if the students are comfortable with it. An interview with local product design students reveals students usually choose CAD software based on their personalities and tendency on the nature of their projects.

Expecting the students to be unfamiliar with CAD software, the series of workshops aims to provide minimal training on the basics of computer-aided design to enable students to realize their concepts. Authors suggest having at least two weeks of introductory classes on computer-aided design. While the software may be vastly different in interface and approach, they share the principles of CAD. The suggested flow for the introductory classes of computer-aided design consists of four steps: understanding the basic concept of a 3D object, getting familiar with a software interface, learning the basics of modelling, and then exploring and creating their designs. A simplified teaching flow for learning different CAD software is as follows:

	Solidworks	*Rhino*	*Blender3D*
Class 1	Understand the basic concept of Boolean, Extrude & Cut	Understand the basic concept of Points, Curve, Surface & Solids	Understand the basic concept of Points, Line, Face, Solids & Subdivision
	Get familiar with the interface.		
Class 2	Practice Sketches	Practice Curve	Practice Add Object & Vertex Editing
	Practice Creating Features: Boolean, Extrude & Cut	Practice Creating Features: Join, Trim, Extrude & Boolean	Practice Creating Features: Join, Trim, Extrude & Boolean
	Free explore and create.		

Table 2: A Simplified Teaching Flow for CAD introductory Classes.

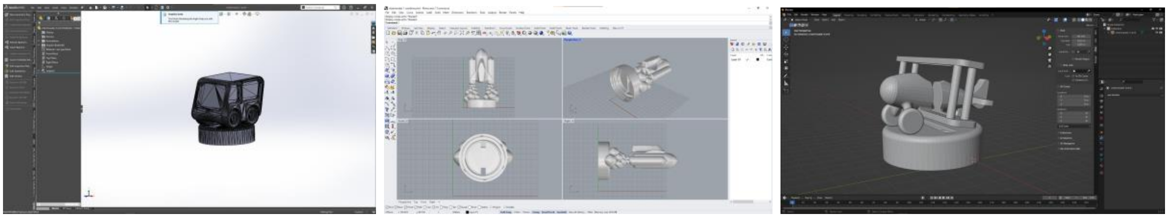

Figure 2: Interface for different CAD software. From left to right. (a) Solidworks, (b) Rhino 3D, and (c) Blender 3D.

2.5 Step 5: Additive Manufacturing

When design developments are mature in computer simulations, students are suggested to create mock-up models to test out their concepts into the real world. With rapid prototyping, students may print out mock-up models through 3D printers. Students will experience a series of plans and preparations before the printing to consistently print out successful prototypes in high quality. Students are suggested to develop a function prototype before any aesthetic prototype to ensure the project can be practical and functional. By comparing and identifying the need for changes in the design through each iteration, students will not only master the techniques in rapid prototyping but also develop an understanding of the design process.

Before prototyping, students must learn the basic concepts of slicing and slicer software. Teachers are suggested to introduce how 3D objects can be printed layer by layer through metaphors, for example, "by sticking papers on top of each other to form volume", as it was tested more effectively to grab students' attention and keep them focused. Students are encouraged to try different settings on their 3D model within the slicer program, understanding how infill percentage and orientation will affect the printing time, amount of support material needed and the surface quality.

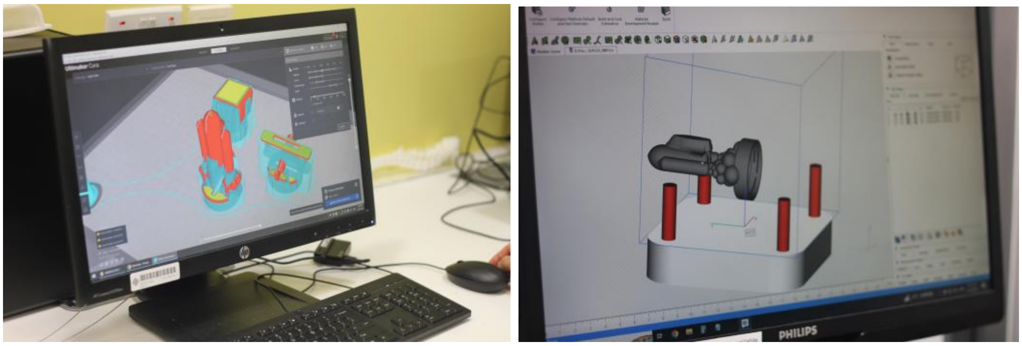

Figure 3: Variations of Slicer Program. From left to right. (a) Slicer before FDM Plastic printing, and (b) Slicer before FFF Metal printing.

As printing technologies are getting more accessible in recent years, authors summarized three different printing methods for reference to teachers and students when making decisions on their projects, including Fused deposition modelling (FDM) and Stereolithography (SLA) for plastic printing and Fused Filament Fabrication (FFF) for metal printing.

When working with FDM, students must remove supports and sand the surface to acquire a model with fine finishing. For SLA, the printed pieces require an extra step of rinsing in isopropyl alcohol (IPA) to remove any uncured resin from their surface before support removal. Some models may undergo post-curing to achieve higher strength and stability. If students and teachers struggle with long printing times and poor surface quality, authors suggest breaking the 3D model into pieces before printing and then manually assembling the parts by glue after printing, as smaller and simpler pieces may save time and material in printing.

For FFF, the printed pieces also require extra steps of debinding and sintering. After printing, students should place the model into the debinding station. An organic solvent will remove the binding materials inside the printing piece. Washed printings will then be placed in a furnace to undergo sintering. The model will be heated to slightly lower than their material melting point, removing the remaining binder and solidifying the metal powder of the model into a finished part. These processes can be time-consuming and usually take days. Therefore, the authors suggest students and teachers expect a longer preparation beforehand.

	Plastic printing	*Metal printing*

	FDM	SLA	FFF
Price	Most Affordable	Less Affordable	Least Affordable
Accessibility	Most Accessible	Less Accessible	Least Accessible
Speed	Fastest	Moderate	Slowest
Quality	Lower Resolution and Accuracy	Higher Resolution and Accuracy	Higher Resolution and Accuracy
Strength	Strong	Stronger	Strongest
Suggested Application	Simple Prototyping Model	Functional Prototyping Model	Mechanical Component

Table 3: Comparison of Different 3D Printing Methods.

Regarding the printing material, authors suggest teachers use biodegradable filaments whenever possible. Although the price would usually be higher than regular filaments in the market, the use of biodegradable filaments would significantly reduce the environmental impact the projects bring.

When the final design is delivered, students will master soft skills such as initiative research, situational analysis, critical thinking, spatial abilities, and rational thinking: hard skills such as sketching, handcrafting, 3D modelling and rapid prototyping. Authors believe the mastery of the mentioned abilities may help students to be an initiative with the capability to realize their creative yet practical ideas into reality and contribute to their communities.

Figure 4: FDM Printing process of Capscoiner. From left to right. (a) 3D Printing of the Base, (b) Infill of the Pieces can be shown in the Process, and (c) Printing Pieces after Support Removal.

Figure 5: Caps Coiner, an example of the expected outcome of the STEAM workshop.

3 WORKSHOP FEEDBACK

To evaluate the successfulness of creating a series of engaging and insightful workshops as an introduction to CAD and upcycling, an interview was conducted to collect feedback from the students.

Overall, students responded positively to the workshop. One group of students even won the European Product Design Award (EPDA) Prizes in Packaging Design/Sustainable Design and Toy Design/Educational Toy in 2022. They said it was an opportunity for them to experience the full process from concept to prototype. As for other students who were not familiar with CAD beforehand, they mentioned it was meaningful for them to learn technical knowledge through the STEAM-inspired workshops. They expressed a positive attitude towards the workshops when they stated that it was their first time learning how to make 3D objects. With the experience and new insights, they gain through the workshops, students are now able to not only generate conceptual ideas but also realize them.

When asked for suggestions on enhancing the workshop in the future, students were eager to use recycled plastic filament in both their prototype and the final model. Responding to a raised awareness of plastic pollution, students proposed developing a platform or service to collect printed parts, reducing the impact of plastic waste on the environment.

Figure 6: Introducing Caps Coiner, designed by one of the authors. From left to right. (a) Designed for up-cycling, (b) What is Caps Coiner? and (c) Why Caps Coiner?

Figure 7: Variations of Caps Coiner design. From left to right. (a) Coastal Biplane, (b) Space Shuttle, and (c) Hybrid Vehicle.

Figure 8: Descriptions of Caps Coiner design. From left to right. (a) Coin inserting, (b) Suggesting size of the plastic bottle, and (c) Demonstration on the function of Caps Coiner.

4 CONCLUSIONS

With the durable PET plastic bottles being designed to be single-use, the among of the still-usable materials being wasted and the level of environmental damage is concerning. In response to the situation, the article proposes up-cycling PET plastic bottles as teaching material for STEAM curriculums.

As the design and structure of the used bottle up-cycling workshop strictly align with the ideology of the STEAM education strategy, the workshop consists of five steps, including "Home Recycle", "Material Study", "Design Brief", "Computer-Aided Design" and "Rapid Prototyping". The workshop aims to provide training in soft skills such as initiative research, situational analysis, critical thinking, spatial abilities, and rational thinking: and hard skills such as sketching, handcrafting, 3D modelling and rapid prototyping. In future development of this STEAM workshop, students will develop their printing filaments by grinding PET bottles and extruding recycled wires to inspire future generations to localized circular design.

The authors believe the plastic bottle up-cycling projects with rapid prototyping could be an excellent opportunity for students to exercise their learning in STEAM practices. Overall, students responded positively to the workshop in the evaluation, showing promising potential for further development of the workshop.

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