

雑紙回収による環境配慮 コミュニティ設計(CDfE)： 小学校での紙のリサイクル実験の効果と課題

Community Design for the Environment (CDfE) through Mixed
Paper Collection: Exploring the Effects and Challenges of a Paper Recycling
Experiment at an Elementary School

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要 旨

本研究では、小学生に対して、紙のリサイクルを体験してもらうワークショップを開催し、実施前後の子供達の環境意識の変化を調査した。その結果から、雑紙の回収によるポイントの付与や、クイズなどのゲーム性を加えたごみ分別支援 AI アプリ「エコボン」の開発を計画した。そして、「ごみになった後でも消費者が責任をもって分別回収に協力するための地域設計」として、「環境配慮コミュニティ設計(CDfE)」を提案した。

Abstract

Progress in the circular economy (CE) may lead to restrictions on the import of raw materials. This study proposes a community design for the environment (CDfE), which is a regional design approach aimed at encouraging consumers to sort and collect recyclable materials from household waste. This concept extends the idea of “design for the environment” to local communities. A model for effectively sorting and collecting mixed paper in cooperation with elementary school students was tested in a school district. A paper recycling experiment was conducted to engage elementary school students in sorting mixed paper from household waste. Changes in the students’ environmental awareness before and after the experiment were surveyed, and key points for maintaining their

motivation were identified. Based on the results, this study proposed ECOPON, an AI system combining game elements, such as a point system and quizzes related to the Sustainable Development Goals, with environmental education, as a key tool to help sustain students' awareness of sorting and collecting mixed paper. With the deployment of ECOPON in elementary schools, the proposed model can enhance students' motivation to continue sorting and collecting mixed paper. The results may then contribute to the design of an environmentally friendly community that efficiently collects local resources. To further promote the social implementation of CDfE, the application of ECOPON must be extended beyond schools by installing it in city halls, community centers, and private commercial facilities. These efforts are crucial to Japan's long-term resource strategy.

Key words : paper recycle, design for the environment, environmental education

Introduction

The circular economy (CE) is a concrete approach to realizing the Sustainable Development Goals (SDGs). The European Commission's "Closing the Loop – An EU Action Plan for the Circular Economy¹⁾," also known as the "CE package," proclaimed that CE is set to become the centerpiece of environmental policy in Europe. CE policies aim to reform not only environmental policies but also economic frameworks in Europe. The rapid adoption of CE, especially in Europe, is strongly linked to anticipated constraints on natural resources, such as oil, iron, and biomass.

In Japan, efforts have been made to establish a sound material cycle (SMC) society based on the Basic Law for Establishing a Sound Material Cycle Society (2000)²⁾. In this regard, Japan has been working ahead of other countries. The CE can be viewed as a progression of the SMC society that Japan has been developing for over two decades. The 3R strategy (reduce, reuse, recycle) has gained strategic significance in securing and improving resource efficiency. In particular, in material cycles, design for environment (DfE) policies have been proactively integrated into various stages of production to promote the use of recycled materials across industries. As this trend continues, the use of recycled materials instead of raw materials is expected to become increasingly common in the near future. However, the continuation of current linear economic practices is expected to result in natural resource shortages. Given Japan's limited access to natural resources, a community-based system

雑紙回収による環境配慮コミュニティ設計 (CDfE) : 小学校での紙のリサイクル実験の効果と課題 tailored to optimizing local resource use is critical.

In the current study, we propose an efficient resource recovery system for mixed paper in a small community, specifically within an elementary school district, based on findings from our previous research³⁾. The benefits of mixed paper recycling are twofold: 1) it requires less energy and produces lower CO₂ emissions than the virgin paper-making process⁴⁾, and 2) it fosters a culture of responsible consumer behavior by encouraging the sorting of paper waste from garbage⁵⁾. As a practical initiative, a mixed paper recycling workshop was held at an elementary school during an open school event. The environmental awareness of the pupils who participated in the workshop was assessed using a simple questionnaire administered before and after the event. The survey results suggested the need for a platform to sustain students' interest in sorting mixed paper from waste. On the basis of these findings, this study aims to reveal a new community design for the environment (CDfE).

Method

1. Workshop Site

A paper recycling workshop was held as part of an annual open school event at Hirama Elementary School, Kawasaki City, Kanagawa Prefecture (Fig. 1), from 12:00 PM to 3:00 PM on August 3, 2024. As the event was open to the public, the workshop participants represented a wide range of generations, including not only school students but also families with kindergarteners and older people. Half of the science laboratories were designated for the workshop activities. Two laboratory tables were used for the paper recycling experiment, and an additional table was prepared to decorate the recycled products. Two university students were assigned to assist the participants at each table.

Fig. 1 Location and status of paper recycling workshop site. The black arrow shows Hirama Elementary School, Kawasaki City.

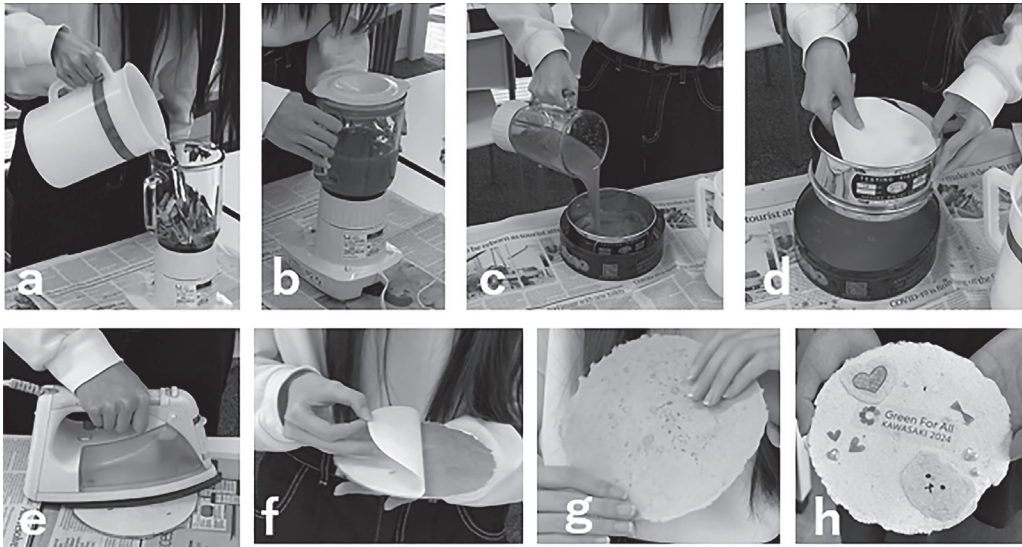


2. Paper Recycling Experiment

2-1 Regeneration of Mixed Paper

The materials for the paper recycling experiment included previously collected mixed paper, such as those used in dessert boxes, advertising flyers, and used copy papers, etc. Each piece of paper was shredded by hand into approximately 2 cm^2 pieces, which were then placed in a household blender containing approximately 200 mL of tap water (Fig. 2 a). After 1 min of blending and ensuring that the pieces of paper were fully dissolved (Fig. 2 b), the paper mixture was evenly poured into a laboratory sieve (Fig. 2 c). Once excess water was drained, the experimental filter paper was placed on the surface of the sieve. The sieve was then inverted to transfer the contents to a table. Another piece of filter paper was placed on the exposed surface, the remaining water was squeezed out by wrapping the paper in a towel, and the paper was dried using a household iron for a few minutes (Fig. 2 e). After drying, the experimental filter paper was peeled off from both sides of the regenerated paper (Fig. 2 f).

Fig. 2 Paper recycling experiment methods (a–g) and example of results (h).



2-2 Decoration of Regenerated Paper

The newly regenerated paper (Fig. 2 h), which was thick and durable with a diameter of 20 cm, was decorated using colored pencils, markers, and colorful stickers. The paper was then crafted into various items, such as fans, photo frames, and handmade medals, using additional colorful materials. The decoration process required approximately 15 min to complete. The participants took the final products home as souvenirs (Fig. 2 h).

3. Questionnaire Survey

3-1 Questionnaire Entries

The participants were first asked for attributive information such as grade level and gender. To confirm their basic knowledge of paper recycling, they were then asked, “Do you know the correct way to sort paper?” Their response was either “yes” or “no.”

Before the paper recycling experiment, the participants answered the following four questions:

Question 1: Interest in Sorting

Do you always try to sort paper waste, such as dessert boxes and advertising flyers, from household garbage?

Question 2: Interest in Recycling

Are you interested in sorting and recycling your paper waste?

Question 3: Recognizing the Importance of Sorting and Recycling

Do you think it's important to sort and recycle paper waste?

Question 4: Participation in Recycling Activities at School

Would you like to participate in a paper waste sorting activity at school?

The answers were recorded on a four-point scale: “strongly agree” (4), “somewhat agree” (3), “do not really agree” (2), and “do not agree at all” (1).

After the experiment, the participants were asked to complete a second questionnaire printed on the back of the sheet. The second-round questionnaire items were paired with those in the questionnaire administered before the paper recycling experiment. The second-round questions are as follows:

Question 1

After participating in this experiment, are you now inspired to more actively sort your paper waste at home?

Question 2

After participating in this experiment, are you now more interested in sorting and recycling your paper waste?

Question 3

After participating in this experiment, do you now find sorting and recycling paper waste more important?

Question 4

After participating in this experiment, would you like to participate in more paper waste sorting activities at school?

The responses for the second questionnaire were recorded using the same four-point scale as that used in the first questionnaire. In addition, the participants were asked to provide written feedback.

The original Japanese version is provided in the Appendix.

3-2 Compiling Method

Attributive information, the responses to the basic knowledge confirmation question, and the pre- and post-experiment scores for each of the four main questions were entered into an Excel file. Statistical analysis, including calculations of the means and standard deviations and a paired t-test, was conducted using Excel's built-in functions.

Results and Discussion

1. Changes in Participants' Environmental Awareness through Paper Recycling Experiments

The questionnaire yielded 27 valid responses from 8 boys and 19 girls. The sample included 8 first grade students, 4 second grade students, 6 third grade students, 5 fourth grade students, and 4 fifth grade students. No responses were obtained from sixth-year students as they were required to assist with the open school event. Meaningful feedback was minimal.

When asked in advance about whether they had basic knowledge of waste sorting, 7 participants answered "yes" while 20 answered "no." The students who answered "no" were distributed as follows: 8 first grade students (100%), 3 second grade students (75%), 5 third grade students (83%), 1 fourth grade student (20%), and 3 fifth grade students (75%). These results suggest the need to provide additional instructions to lower-grade students on sorting mixed paper.

The results of the main questions are summarized below.

Question 1 : Interest in Sorting. The average scores were 3.04 and 3.19 before and after the experiment, respectively.

Question 2 : Interest in Recycling. The participants' average score increased from 2.67 to 3.81.

Question 3 : Recognizing the Importance of Sorting and Recycling. The average score decreased slightly from 3.78 to 3.67.

Question 4 : Participation in Recycling Activities at School. The Participants' average score increased from 3.19 to 3.37.

The detailed data from the questionnaires are presented in Table 1. Notably, only Question 3 showed a decrease in average score.

Table 1 Questionnaire survey results.

No.	Question topic	N	Before Experiment Mean (SD)	After Experiment Mean (SD)	T value ($p < 0.05$)
1	Interest in Sorting	27	3.04 (1.00)	3.67(0.67)	1.56×10^{-3}
2	Interest in Recycling	27	2.67 (1.02)	3.81(0.47)	1.09×10^{-5}
3	Recognizing the Importance of Sorting and Recycling	27	3.78 (0.42)	3.67(0.72)	0.50
4	Participation in Recycling Activities at School	27	3.19 (0.82)	3.37(0.78)	0.20

The results of the paired t-test ($p < 0.05$) are shown in Table 1. The scores for Questions 1 and 2 were lower than 5% (0.05), thereby indicating a significant increase in the participants' interest in sorting and recycling paper after the experiment. The series of paper recycling processes, such as shredding mixed paper, dissolving it in a mixer, filtering, and drying, might have helped the participants understand the practical aspects of recycling mixed waste paper into regenerated paper. Additionally, this hands-on experience might have sparked technical interest in recycling.

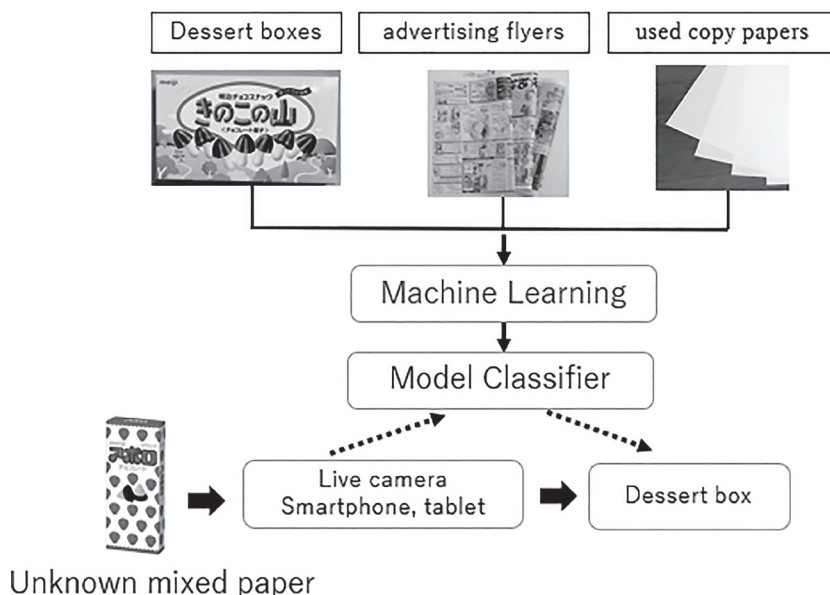
Meanwhile, the scores for Questions 3 and 4 exceeded 5% (0.05), indicating no significant changes before and after the experiment. For Question 3, "Recognizing the Importance of Sorting and Recycling," the average score was already high at 3.78 before the experiment. This result suggests that the participants were already aware of the importance of sorting and recycling paper (a potential ceiling effect). Regarding Question 4, although the average score increased slightly, further efforts are required to help students better understand the importance of school-based recycling initiatives.

2. Advantages of Schools as Mixed Paper Collection Hubs

The responses to Question 4 highlight the need to help students understand the benefits of schools serving as hubs for mixed paper collection. In response to this need, this study is developing an artificial intelligence (AI)-assisted paper sorting application called "ECOPON" in cooperation with Karakurai.Inc. The use of AI for the sorting, collection, and transportation of waste has gained increasing popularity in recent years⁶⁾. This application, which uses image recognition AI technology, will encourage students to sort and collect mixed paper from their household garbage.

A brief summary and the algorithm of ECOPON are shown in Fig. 3. The simplified functionality process is described below.

Fig. 3 ECOPON app algorithm.



Step 1 : Collect images of mixed paper, such as those from dessert boxes and advertising flyers.

More than 100 images of each type of mixed paper are required.

Step 2 : Encourage students to bring sorted mixed paper to school sorting boxes using ECOPON, which has a user-friendly interface on tablets.

Step 3 : ECOPON tracks each student's progress individually, awarding points and providing quizzes upon each registration of mixed paper.

ECOPON identifies individual students who bring in mixed paper, records the type and amount of paper, and generates a score. Based on these scores, it displays rankings, awards points, and allows for prize exchanges. Our plan is to install tablets equipped with the ECOPON app, which provides the aforementioned functions and assists with waste sorting, in recycling boxes (resource collection bins). Each time students register their mixed paper, ECOPON greets them and provides environmental education through quizzes related to the SDGs. ECOPON's combination of game-like elements and educational features is expected to enhance student motivation and encourage continuous participation in mixed paper collection⁷⁾. This target effect is the main driver behind the collaboration with schools as mixed paper collection hubs.

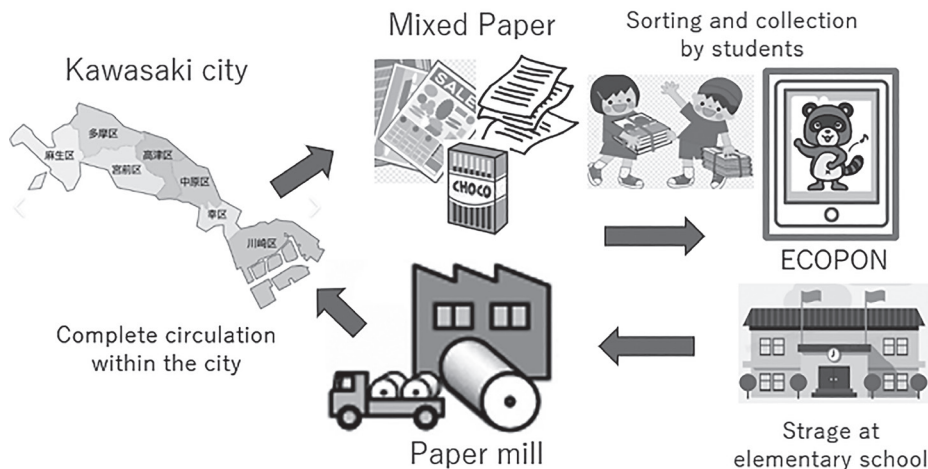
As the development of ECOPON advances in the near future, we plan to install recycling boxes equipped with ECOPON in cooperation with elementary schools to expand the mixed paper collection system.

3. Community Design for Environment (CDfE)

The “Kawasaki Mixed Paper 3R Promotion Research Association” is a study group consisting of paper mills, transport companies, and other related organizations based in the Kawasaki Zero Emission Industrial Park. This study group has set the ambitious goal of achieving 100% recycling of mixed paper within Kawasaki City. It engages in activities such as participating in environmental events and making policy proposals for the local government.

Our laboratory has been collaborating with this group since 2024 as part of a community-based learning initiative. We have participated in various environmental events to increase the mixed paper collection rate in Kawasaki City and conducted environmental workshops at elementary schools. In collaboration with this study group, our laboratory is developing an environmentally friendly community design aimed at increasing the mixed paper collection rate (Fig. 4).

Fig.4 An example of community design for the environment to increase waste paper collection rates in Kawasaki City.



For example, with the cooperation of an elementary school, our study group plans to work with students to sort and collect mixed paper from household waste. In this case, ECOPON will play a crucial role in maintaining students’ awareness of sorting and collecting mixed paper. ECOPON combines game elements, such as a point system and SDGs quizzes, with environmental education. By installing trash bins equipped with ECOPON in elementary schools, the project aims to sustain children’s motivation to continue sorting and collecting

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mixed paper and thereby create an environmentally friendly community that efficiently collects resources within the local area.

Given this background, this study proposes the CDfE as a local design approach that encourages consumers to take responsibility for sorting and collecting waste even after it becomes garbage. This original concept extends the principles of the DfE to the community level. The idea of CDfE emerged from two key factors: 1) the prediction that importing raw materials (natural resources) will become more difficult in the near future as the CE becomes more widespread and 2) the need to design communities with the primary goal of sorting and managing resources at a regional level.

As global environmental problems become increasingly serious, new social systems that address resource constraints at the global and local levels must be developed. CDfE represents a solution to the pressing environmental and resource challenges. To accelerate the social implementation of CDfE, efforts must be exerted to expand its activities, including the installation of ECOPON not only in schools but also in city halls, community centers, and private commercial facilities. In the near future, the scope of the program should be broadened to include not only waste paper but also polyethylene terephthalate bottles, glass, cans, and other recyclables. Such efforts are vital to Japan's long-term resource strategy.

Conclusion

As the CE becomes increasingly widespread worldwide, Japan may face restrictions on the import of natural resources. Accordingly, this study proposed CDfE, a regional design approach aimed at encouraging consumers to take responsibility for sorting and collecting waste, even after it becomes garbage. This concept extends the idea of DfE to local communities.

Specifically, we developed and tested a model for collecting mixed paper in cooperation with elementary school students in a school district. We conducted a paper recycling experiment in an elementary school to engage students in sorting mixed paper from household waste. We assessed changes in the children's environmental awareness before and after the experiment and summarized the key points for maintaining their motivation.

The paired t-test results for Question 1 (Interest in Sorting) and Question 2 (Interest in Recycling) showed a significant increase after the experiment involving a series of paper

recycling processes. The experiment might have helped the participants understand the actual paper recycling process, starting from mixed waste paper to regenerated paper. It might have also sparked technical interest in the recycling process. Meanwhile, the paired t-test results for Question 3 (Recognizing the Importance of Sorting and Recycling) and Question 4 (Participation in Recycling Activities at School) showed no significant differences before and after the experiment. For Question 3, the high pre-experiment score suggests that the participants were already aware of the importance of sorting and recycling paper before participating in the experiment (a potential ceiling effect). The results for Question 4 indicate that further efforts are needed to help students fully grasp the importance of school-based recycling initiatives.

In this study, we also proposed ECOPON as a key tool for maintaining elementary school students' awareness of sorting and collecting mixed paper. ECOPON combines game elements, such as a point system and SDG quizzes, with environmental education. By installing trash bins with ECOPON in elementary schools, we aim to sustain students' motivation to continue sorting and collecting mixed paper. This effect would contribute to the design of an environmentally friendly community that efficiently collects local resources.

We believe that schools, where children—who represent the future of society—can engage in sorting mixed paper, are the ideal setting for combining the game-like features of ECOPON with environmental education. To accelerate the social implementation of CDfE, its activities must be expanded, and trash bins with ECOPON should be installed not only in schools but also in city halls, community centers, and private commercial facilities. Such efforts are essential to Japan's long-term resource strategy.

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Appendix

紙のリサイクルの意識についてのアンケート その1

このアンケートは、紙のリサイクル実験の前におこなってください。

ま え 前


- 学年を教えてください。 _____年
- 性別を教えてください。 男子 女子 (←○を付けてください)
- 紙ごみを正しく分別するやり方を知っていますか? はい、 いいえ

次の質問について、どのくらいそう思うか、あてはまる数字1つに、まる(○)をつけてください。

まったく思わない
あまり思わない
少し思わない
思わない

1. いつも家では、紙ごみ (例えばお菓子の空き箱など) を分別しようとしますか? 4-3-2-1
2. 紙ごみを分別してリサイクルすることに興味がありますか? ... 4-3-2-1
3. 紙ごみを分別してリサイクルすることが大切だと思いますか? ... 4-3-2-1
4. 学校で紙ごみを分別する活動に参加したいと思いませんか? ... 4-3-2-1

紙ごみ?..... お菓子の箱や広告の紙など



分別?..... ゴミをリサイクルできるように分けること

リサイクル?... ゴミから使えるものをつくること

紙のリサイクルの意識についてのアンケート その2

このアンケートは、紙のリサイクル実験の後におこなってください。

あ と 後

次の質問について、どのくらい、そう思うようになったか、あてはまる数字1つに、まる(○)をつけてください。

まったく思わない
あまり思わない
少し思わない
思わない

1. このイベントに参加して、家の紙ごみを、前よりも分別してみようと思いましたか? 4-3-2-1
2. このイベントに参加して、紙ごみを分別してリサイクルすることに、前よりも興味が持てましたか? 4-3-2-1
3. このイベントに参加して、紙ごみを分別してリサイクルすることが、前よりも大切だと思えるようになりましたか? ... 4-3-2-1
4. このイベントに参加して、学校で紙ごみを分別する活動に もっと参加したいと思いませんか? 4-3-2-1

紙のリサイクル実習の感想を書いてください

これで質問はおわりです