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Sustainability in Practice: Furniture Upcycling as A Pedagogical Framework for Circular Design Education

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Abstract
The consumption of linear furniture causes a lot of waste, especially in the situations when the discarded ones are regularly delivered to the landfills even though they still have material and functional potential. To resolve this discrepancy between material worth and disposal procedures is essential to developing the strategies of the circular economy. This paper explores the topic of furniture upcycling as an environmental intervention and a pedagogic methodology of modern design education. Undergraduate design students worked in a learned studio (integrating manual fabrication and digital design tools) using a project-based learning framework to disassemble, redesign, and reassemble discarded wooden furniture. Environmental, educational, and design outcomes in terms of furniture upcycling were evaluated by means of a mixed-methods approach. Environmental assessment was done on the material recovery, landfill waste diversion, approximated carbon reductions and the durability of furniture. Questionnaires and student diaries were used to assess the outcomes of education. The results indicate that furniture upcycling is an efficient way to save the material and decrease waste, raise the awareness of sustainability, the knowledge of the circular economy, and the skill of problem-solving among students. The project led to the change in the perception of discarded furniture to a valuable design resource and enables the incorporation of discarded furniture as a tool of designing curricula and shows the possibility of community sustainability programs and environmental education.

Keywords: Sustainability; Furniture upcycling; Circular design; Design pedagogy; Circular economy; Product design education; Wood Reuse.

1. Introduction
Furniture disposal has become a key sustainability problem because of the transformation in patterns of urban living and consumerism. Most of the furniture, particularly the wooden one, is disposed of too soon either in aesthetics or space and not wear. This leads to a high concentration of useful contents in waste streams and wooden furniture is especially problematic as this type of furniture carries a heavy environmental cost as a result of its energy-consuming manufacturing processes. Life cycle-based studies consistently indicate that material production accounts for a major share of the environmental impacts associated with furniture products, rendering premature disposal especially inefficient from a sustainability perspective. Despite this, end-of-life strategies for furniture remain dominated by landfill disposal or low-value recycling, reflecting the persistence of linear production and consumption models dominated by landfill disposal or low-value recycling, reflecting the persistence of linear production and consumption models.

These inefficiencies can be answered with circular economy. It has gained prominence as a base framework to maintain material value within closed-loop cycles. Strategies of a circular economy encourage extending the life of a product through reuse, recycling, repair, refurbishment and value retaining processes (Kirchherr et al., 2017; Sehnem et al., 2019). Designers are increasingly employing upcycling, a process which gives discarded materials a new and higher worth through creative intervention. Upcycling leaves intact the integrity of materials and their stored energy by not breaking down the materials and so reduces waste, alongside allowing users to make the items into something else (Sung et al., 2014).

In recent times a variety of studies have examined upcycling furniture as a practical solution to the large amount of waste produced by society, especially on small local scales. The use of this approach has been documented as reducing the amount of materials wasted and encouraging manufacturing on a local level. It is also useful in the development of alternative production systems that challenge the necessity of large-scale production processes (Cooper, 2013; Pitti et al., 2020). Much of this effort is focused on professional practice, community programs and theoretical models. The reuse of teaching furniture in schools and other institutions has not been studied in large volumes in terms of their educational implications and ecological consequences. The digitalization and the need to be sustainable and changing the professional skills are transforming the design education significantly. The skill of training future designers needs a combination of computational, material, ethical, and systems oriented view of the world today. Physical models are substituted with digital tools to explore and assess complicated sustainability problems (Kowasch, 2022; Sung, 2023). This hands-on engagement counters the tendencies of screen based design tools which fail to capture real-world effects such as material variability, disassembling complexity and performance durability.

Emerging research in sustainability-oriented pedagogy suggests that the methods of project based learning are highly effective in inspiring people to look after the environment and in improving the ability of individuals in their profession. By engaging with actual waste materials, students gain a deeper understanding of sustainable principles, and they start to think about their purchasing habits, their own accountability and that of designers in relation to waste (Campbell et al., 2024; “Issues and Trends in Education for Sustainable Development,” 2018). While there have been a number of investigations into the environmental benefits of upcycling, along with the educational benefits, it is still true that there are very few studies which have looked at the environmental impacts of upcycling alongside the educational gains.

In this context, the present research examines furniture reuse not only as an environmental conservation strategy but also as a pedagogical tool within design education. Through a research-led academic project based on the upcycling of discarded wooden furniture, the study evaluates material reuse, waste reduction and associated environmental benefits. The students’ knowledge, skills and attitudes related to sustainability and circular economy principles are analysed. The project presents the way in which involvement in changing material supports intellectual comprehension and accountability through the introduction of hands-on experience in a structured design learning system. In particular, the paper explores the opportunities to understand the role of furniture upcycling projects in reflecting the goals of the circular economy as well as promoting the design process towards environmental responsibility in the pedagogy of education.

2. Literature Review

The sustainability of the design field is studied within three different areas in this review, including design based sustainability practices, including upcycling, contemporary design education practices that help develop sustainability and the application of a circular economy in the furniture industry. This body of work is the foundation of knowing the relevance of furniture reuse as a way of contributing to the environment and a form of teaching.

Circular Economy and the Furniture Sector

The furniture industry is being perceived as a sector that has a high potential of the circular economy implementation. Furniture is a material-intensive substance with such elements as solid wood or metals which

imply significant environmental and financial impacts. Studies show that re-use furniture strategies can minimize green house gas emissions, lessen the extraction of raw materials and energy needs. Circular approaches, specifically, are best suited to wood-based furniture because its long-lasting properties and the ability to be used in more than just one way (Ofori-Agyei et al., 2023; Pomponi & Moncaster, 2017).

Although this is such a possibility, the practice of furniture production and disposal systems has been shown to be largely linear. Cost effectiveness, aesthetic quality and quick manufacturing schedules often guide the design choices at the cost of repairability, dismantling or prolonged reuse (Kolb, 1984). As a result, numerous furniture products are discarded at an early stage of their life cycle into the landfill or low-end recycling streams, which leads to the deterioration of embodied energy as well as the value of the material. Scholarly articles published in platforms like Sustainability and the Journal of Cleaner Production will continually mention that design-for-disassembly and reuse continue to be peripheral to standard furniture production, with the exception of specialization or artisanship (Geissdoerfer et al., 2017; Ofori-Agyei et al., 2023; van Hees et al., 2025a).

Recent studies on the circular economy have shifted their attention off theoretical frameworks on to practical implementation issues, with the research taking sector-specific strategies into account, taking into account material properties, user behavior, and institutional constraints (van Hees et al., 2025b). Furniture upcycling is identified as an untapped prospective but promising tool of keeping material value by localized design interventions. Through the combination of material usage and imaginative activities and by considering the contextual concerns, upcycling is a possible solution to the application of the principles of the circular economy in practice-based design.

Upcycling as a Design-Led Sustainability Strategy

Upcycling is becoming an important sustainability practice that is opposing the conventional mode of recycling. It is a way of maintaining or improving the functional, aesthetic and symbolic importance of things that are discarded by creatively redesigning them instead of just converting them into raw materials. Recent findings point at the upcycling as one of the value-retention strategies that preserve embodied energy and enables the innovative reinterpretation of existing resources (Kirchherr et al., 2018; Sung et al., 2023).

In the context of furniture, there are more specific benefits of upcycling, which are especially associated with the natural resistance of wooden materials and available methods of connecting and coating surfaces. According to empirical research, furniture upcycling can significantly lower the amount of waste in terms of materials and enable alternative production strategies that focus on craftsmanship, customization, and the use of local resources (Braungart et al., 2007; van Hees et al., 2025b). In comparison to the traditional recycling practices, which tend to be energy-consuming and imply re-processing of materials, in furniture upcycling, the designer is able to operate with the structures at hand. By so doing, surface patina, wear and imperfection are not addressed as a defect but as generative factors that instruct new designing possibilities.

The existing studies on upcycling have benefits but the major limitations include the qualitative nature of the studies conducted so far with little quantitative evaluation of environmental performance such as material recovery performance or carbon reductions. The majority of the research focuses on professional and community measures, overlooking its possible implementation in the context of formal education. This void implies that there is a possibility of investigating the concept of upcycling as a sustainability policy and a pedagogical solution that bridges the environmental harm and educational achievements.

Educational Value of Hands-On Sustainability Projects

Simultaneously with the changes in the evolution of the concept of the circular economy, the sustainability-focused design education has been experiencing significant change in the last several years. There is growing worry among scholars that sustainability competencies can no longer be taught through theoretical teaching but rather need substantial experience working with actual materials, systems, and constraints (Derkach et al.,

2023). In particular, it has been demonstrated that project-based learning techniques can enhance the capacity of students to internalize multifaceted sustainability ideas, problem-solving skills, and explore and critically assess their design choices.

In the context of design education, the concept of material-based projects has been closely connected to the better grasp of the life cycle thinking, resource constraints, and moral accountability (Puji Utomo & Sutanto, 2023). The upcycling of furniture related projects, especially, subject students to hands-on problems including difficulties in disassembly, biases in materials, and stability of performance (Sterling, 2024). Such experiences make sustainability a material design process and not an abstract ideal, but a process created by constraints and trade-offs of the real world.

Meanwhile, continuing digital change is transforming design pedagogy. The recent generation of discussion makes it clear that not only physical making is covered by digital tools, but it is complemented by them (Bishop, 2011; Braungart et al., 2012). Digital modeling, visualization and documentation technologies assistance allow exploring and making informed decisions through the iterative approach, whereas physical and environmental reality through working with materials helps sustainability learning not to lose its physical and environmental base (Romli et al., 2015). The combination of the digital and material practice is now considered to be a critical component of training a designer to address the complicated sustainability problems efficiently.

Even though the existing literature covers the principles of the circular economy, upcycling of furniture, and education aimed at sustainability-oriented design, all these aspects are usually studied separately. There are still few empirical investigations combining environmental performance evaluation with systematic analysis of educational results. Specifically, limited studies embrace mixed-methodology designs that can be used to associate the material recovery, waste diversion, and environmental advantages with the change in student knowledge, skills, and attitudes. This research addresses this gap by exploring the furniture upcycling as an environmental approach and a pedagogical intervention and adding empirical evidence to the development of the research on the circular economy and the design education with sustainability in mind.

3. Methodology

The proposed research design was the mixed-methods one to investigate the connection between the environment performance and learning outcomes in terms of sustainable furniture design. This methodology has been matched with the existing practice of using quantitative environmental indicators and qualitative data on the experience of students by connecting the results to the established methodologies of sustainability-oriented design learning (Brändström et al., 2024; Yang & Vezzoli, 2024). A convergent mixed-methods research approach was adopted, which involved integrating data on material recovery rates and environmental performance and final product assessment with accounts of reflective and group discussions and documentation of design decisions. The respondents included undergraduate students at a product and furniture design course. They operated in small working groups of 3 to five individuals allocated the abandoned wooden furniture of urban and peri-urban settings, such as chairs, tables, and storage structures. In a guided studio setting that reflected course learning outcomes, students worked in collaborative roles that included disassembly, concept development, fabrication and documentation.

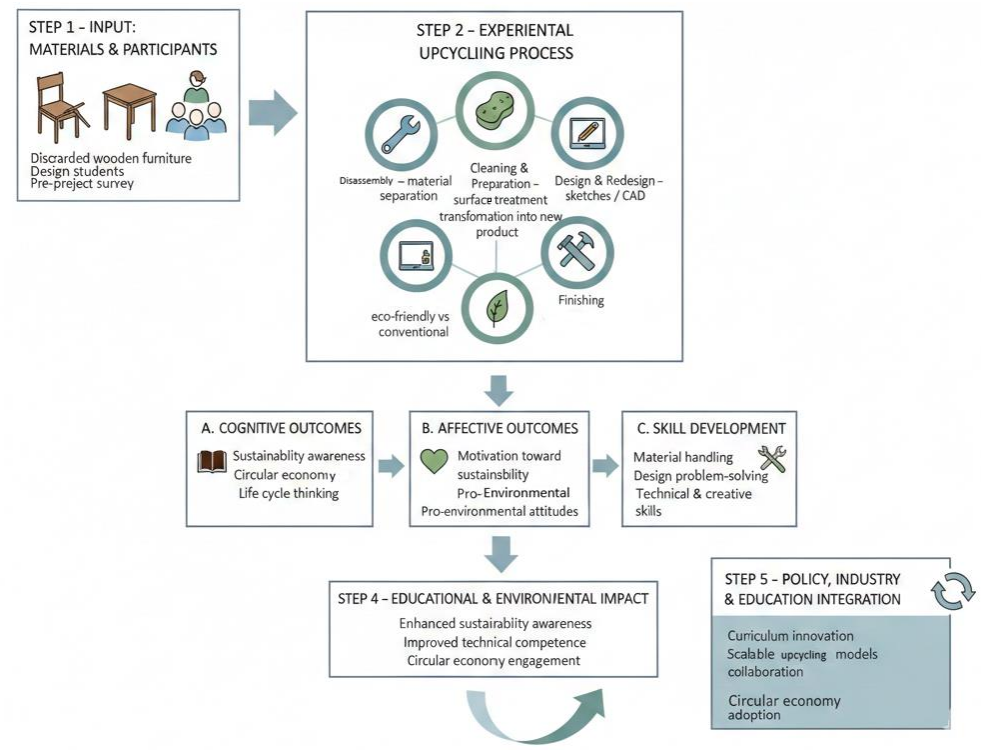

Figure 1: Upcycling-Based Learning Framework for Sustainability and Circular Design

The process of upcycling was divided into five steps. To begin with, the furniture was dismantled manually, and the students were expected to evaluate the state of materials, determine which components can be reused and how much waste there is that cannot be returned. This step helped to learn about material movements and recovery opportunities. Salvaged components were then cleaned, de nailed, sanded, and ready to be used again which allowed them to assess the quality of the surface and its structural integrity. Sketches and technical drawing were conceived onto the design requirements, sustainability requirements, and aesthetics, based on the functional requirements. The reclaimed material was later reused to create functional pieces of furniture using both handcrafting and computer technology to indicate the modern hybrid design patterns. Finally, selected products were subjected to eco-friendly as well as conventional surface treatments, thus, eco-friendly and conventional environmental performance, durability, and user perception could be compared.

During the process, the students were recording flows of materials, design cycles, fabrication issues, and decisions related to sustainability in a systematic way. This documentation was useful to quantitative analysis of environmental outcomes as well as qualitative analysis of learning experiences. Together, the approach allowed the combined study of the way in which the design education may promote the sustainability-oriented thinking and produce the environmentally responsible design solutions.

4. Data Collection

The research design used in the study was mixed-methods research to investigate the connection between environmental performance and educational outcomes in sustainable furniture design. The quantitative measures of environmental conditions were combined with qualitative data about the learning experiences of students, as is common to the approaches of sustainability-oriented design research (Mahalakshmi et al., 2024; Pellegrino et al., 2024). The mixed-method convergent approach was adopted because of the integration of material recovery information, environmental and performance measures of completed furniture with student commentaries, group discussions and design decision records.

Students on a product and furniture design course were put into small groups where they were asked to repurpose discarded wood furniture, including chairs, tables, and storage units. It was taught toward disassembly, concept development, fabrication, and documentation, as well as encouraging technical skills and sustainability awareness in a highly organized studio environment.
Subsequently, quantitative and qualitative results were combined to study the correlations between material performance and environmental impact and the learning outcomes. This holistic methodology allowed to assess holistically the way practical upcycling projects can facilitate the sustainable design education and bring tangible environmental improvements.

SECTION A: Participant Demographics
The background diversity of people participating in the upcycling-based learning intervention was determined with the help of demographic data. The variables were gender, age and academic program. To improve the interpretability, the descriptive statistics were calculated using frequencies and percentages and bar charts were prepared using the visual representation.
A survey of 22 respondents (n) was undertaken and the intervention questionnaires were completed before and after the interventions.

Table 1: Combined Demographic Profile of Respondents (N = 22)

Variable	Category	Frequency (n)	Percentage (%)
Gender	Female	15	68.18
	Male	7	31.82
Age (Years)	18	1	4.55
	19	4	18.18
	20	14	63.64
	21	2	9.09
	22	1	4.55
Academic Program	Product & Industrial Design	22	100.00

The demographic report shows that the sample population was mostly female (68.18%), as a male population of 31.82% was included in the category. This balance of genders indicates high involvement of the female gender in design and sustainability academic activities. Regarding age, most of the participants were 20 years (63.64%), students with 19 years (18.18%), and students with ages in the 5-9 years range (12.32%). The age 18, 21 and 22 showed smaller percentages, which was a pointer of the sample being dominated by undergraduate students in their first two-year of education. Such age distribution is very consistent with the age group targeted in the experiential and project-based learning programs. In terms of the educational background, all the participants enrolled in the Product and Industrial Design program, which guaranteed the consistency and relevance of the sample to the goals of the upcycling-based teaching-learning process. This uniformity intensifies internal validity by reducing the variation of disciplines.

SECTION B: Knowledge & Awareness of Sustainability
The section assesses the level of knowledge of the students on the concepts of sustainability before and after the intervention. Awareness about sustainability, circular economy, life-cycle thinking and environmental impact in product design was measured with the help of six Likert-scale statements (1 = Strongly Disagree; 5 = Strongly Agree). Statistical tools such as mean and standard deviation were used to determine the pre- and post-project survey outcomes. A total awareness score was calculated by taking the mean of all the six items.

Table 2: Descriptive Statistics for Awareness Items (Pre- and Post-Project Survey)

Sr. No.	Awareness Statement	Pre Mean	Pre SD	Post Mean	Post SD	Mean Difference	t / Z Value	p-value	Cohen's *d*	Effect Size Interpretation
1	Understanding sustainability in the context of product design	3.23	0.81	3.67	1.02	0.38	1.321	0.2016	0.29	Small
2	Familiarity with the principles of the circular economy	2.82	1.01	3.62	0.80	0.76	2.685	0.0142*	0.59	Moderate
3	Ability to explain the difference between recycling and upcycling	2.82	1.01	3.81	1.08	0.95	2.682	0.0143*	0.59	Moderate
4	Awareness of the environmental impact of furniture waste	3.18	0.96	3.90	1.04	0.67	2.044	0.0543	0.45	Small–Moderate
5	Understanding how design choices influence environmental footprint	2.95	0.90	3.81	0.93	0.81	2.719	0.0132*	0.59	Moderate
6	Understanding the role of life cycle thinking in sustainable design	2.73	0.88	3.67	1.11	0.90	2.939	0.0081*	0.64	Moderate
Overall Awareness Score		**2.95**	**0.73**	**3.75**	**0.87**	**0.80**	**-**	**-**	**≈ 0.60**	**Moderate**

Note: $p < 0.05$ indicates statistical significance.

Paired-sample *t*-tests were used to compare pre and post intervention scores. Effect size interpretation based on Cohen (1988): small (0.2), moderate (0.5), large (0.8).

Overall Awareness Score: An overall awareness score was computed by averaging the six awareness items for each respondent:

$$\text{Mean Awareness Score} = \frac{Q1 + Q2 + Q3 + Q4 + Q5 + Q6}{6}$$

The findings support the statistical significance of the positive change in the sustainability awareness of the students after the instructional intervention. Mean scores got increment in all six items of awareness with the overall awareness score improving M=2.95 (SD=0.73) in the pre-survey to M=3.75 (SD=0.87) in the post-survey which signifies a moderate impact of education (Cohen's d ≈ 0.60). This trend suggests that there is a significant improvement in the abstract knowledge of ideas of sustainability and design responsibility among the students as opposed to a gradual one.

A significant increase ($p < 0.05$) was statistically significant in 5 out of six domains of awareness, specifically

the knowledge of students on the principles of the circular economy, the difference between recycling and upcycling, the effects of furniture waste on the environment, the idea of making design-based choices based on sustainability concerns, and the concept of the life-cycle. These domains had an effect size of moderate to strong ($d \approx 0.59–0.64$), implying that the intervention had the effect of enhancing higher-order conceptual learning via experiential learning in reusing materials and solving design problems.

According to the learning theory, these results correspond to the updated taxonomy by Bloom, where the progress in terms of cognitive domain is observed between understanding and application/analysis. The students did not just passively acknowledge sustainability concepts in their cognition, but started employing and assessing them in real-world design situations, which suggests that there was a profound cognitive reorganization and not an act of surface memorization. Even though the positive change in the general sustainability awareness was not statistically significant ($p = 0.2016$; $d = 0.29$), the resulting positive value of the mean difference indicates a positive learning curve. This relatively minor impact could be attributed to the prior knowledge of students about the general knowledge of sustainability, but more technical and practical aspects of life-cycle thinking and upcycling indicated more significant improvements due to practical education.

Such results indicate the efficacy of experiential, project-based education in design education that the involvement of students in upcycling-oriented design projects can improve cognitive growth and contribute to the competency in sustainability in design education.

SECTION C: Attitudes Toward Sustainability & Upcycling

It has been shown that there exists an inverse correlation between cognitive and affective engagement in regard to sustainability and upcycling. The awareness resulted in an increased motivation, personal valuation and readiness to apply the principles of sustainability in the future. This upholds the hypothesis that cognitive knowledge can be used to bring about attitudinal change particularly within experiential learning contexts. The section compares the attitudes towards sustainability and upcycling of the students prior and after the instructional intervention.

Table 3: Descriptive Statistics for Attitudinal Items (Pre- and Post-Project Survey)

Item	Attitude Statement	Pre Mean	Pre SD	Post Mean	Post SD	Mean Difference	Significance ($p < 0.05$)
1	Sustainability should be a priority in product/furniture design	3.77	1.07	4.10	0.94	0.33	$p = 0.20$
2	Upcycling can significantly reduce waste compared to recycling alone	3.36	1.18	3.81	0.93	0.45	$p = 0.01$
3	Using discarded furniture materials is a valid approach to creating new products	3.45	0.96	3.86	0.96	0.41	$p = 0.01$
4	I would personally consider using upcycled furniture	3.59	0.91	3.57	0.75	−0.02	$p = 0.05$
5	Upcycling can create furniture of equal or greater value than new furniture	3.14	1.21	3.62	0.86	0.48	$p = 0.01$
6	I am motivated to apply sustainability practices in my future career	3.68	0.99	4.00	1.18	0.32	$p = 0.01$
Overall Attitude Score		**3.50**	**0.88**	**3.83**	**0.82**	**0.33**	—

Descriptive statistics of Section C reveal that there was a steady positive change in the attitude of students

towards sustainability and upcycling after the learning intervention. The overall attitude score was improved (M = 3.50 (SD = 0.88) during the pre-survey, M = 3.83 (SD = 0.82) during the post-survey) which indicated that there was a significant change in the value orientation and motivational alignment of students towards sustainable practices.

The post-intervention mean scores were greater than post-intervention ones in all six items proving a definite trend as the positive effect. It is also worth noting that the most significant changes were made in the beliefs of the students in the significance of sustainability in product designing, the effectiveness of upcycling as a waste-saving approach, and their intentions to use sustainability principles in their future practice. These findings indicate that the intervention especially helped in enhancing affective and value-based learning outcomes. According to a learning theory lens, these results are consistent with the revised taxonomy of Bloom especially in the affective domain where learners advance in terms of awareness and acceptance to internalization and value-driven action. The noted gains in motivation and perceived relevance positively signify the progression towards higher order affective learning outcomes that include the internalization and valuing of sustainability principles.

Moreover, the standard deviations of the post-survey scores were rather stable or lower which shows that the student attitudes were more consistent after the intervention. This overlap implies that the learning process did not only lead to the positive attitude improvement but also minimized the difference in perception among the participants, which strengthens the sustainability values shared by the cohort. Comprehensively, the findings can be seen as having high empirical validity to the usefulness of experiential, design-based learning methods in influencing good sustainability attitudes. Through the upcycling workshops involving students in practical applications, the intervention was able to promote not only systems of cognitive engagement, but affective commitment as well, which are essential requirements of sustained behavioral transformation and responsible professional practice in design-related areas.

SECTION D: Skills & Confidence (Pre–Post Analysis)

In this section, the researchers assessed how practical skills and confidence of students regarding sustainable design practices changed after the intervention based on the project. Assessment was based on practical skills, confidence in material handling, creative problem solving and implementation of environmentally-friendly practices.

Table 4. Student Skills & Confidence (Section D)

Item	Skill Statement	Pre Mean	Pre SD	Post Mean	Post SD	Mean Difference	Significance ($p < 0.05$)
1	I feel confident in working with discarded materials (wood, fabric, etc.)	3.52	1.08	3.95	0.80	0.43	p = 0.154
2	I am able to disassemble old furniture safely and effectively	3.24	1.18	3.86	1.01	0.62	p = 0.097
3	I can design new furniture concepts using salvaged materials	3.38	1.02	4.14	0.79	0.76	p = 0.017
4	I can apply eco-friendly finishing methods to furniture	3.57	0.98	3.95	0.86	0.38	p = 0.162
5	I am confident in evaluating the functionality and durability of redesigned furniture	3.62	1.02	4.05	0.92	0.43	p = 0.176
Overall Skill & Confidence Score		**3.40**		**3.99**		**0.59**	**---**

The findings suggest a steady increase in skills and confidence of students as the result of the project-based learning intervention. The total skills and confidence rating went up with M = 3.40 turning to M = 3.99 proving the significant positive change in the perceived ability of students and the practical knowledge of the sustainable design practices. The highest improvement of the individual skills areas was related to the development of the skills of designing new furniture using the salvaged materials ($\Delta = 0.76$, $p = 0.0168$), which is a statistically significant improvement. This may indicate that the experiential aspect of the project

was more effective in enhancing the skill of creative application and material reinterpretation which are some of the core competencies of sustainable design learning. Students also showed moderate improvement in confidence of working with discarded material, using eco-friendly methods of finishes and durability of the products. These changes were not statistically significant, but the fact that all the mean differences were positive means that the learning was moving in the same direction. The standard deviations also are relatively stable which further indicates better consistency of confidence among the participants.

These results are consistent with the updated taxonomy as developed by Bloom that suggests that the development of the skills has moved beyond the conceptual cognition to a higher-order cognitive interaction. Students were active in respect of applying knowledge, evaluating results, and coming up with novel solutions. The project developed pragmatic skills and confidence in sustainable design, which favors the role of experiential, real-life design experiences in developing transferable skills in sustainable-related professional practices.

SECTION E: Perceptions of Educational Value (Post-Project Survey)

This part will compare the perceptions of the students with regards to the educational value of the upcycling project after the project is over. The measures were measuring perceived learning effectiveness, skill development, and perceived pedagogical value of experiential learning.

Table 5: Descriptive Statistics for Section E (Post-Project Survey)

Item	Statement	Mean	SD
1	The upcycling project enhanced my awareness of sustainability.	3.95	0.80
2	I gained practical skills that can be applied beyond the classroom.	3.86	1.01
3	I developed teamwork and collaboration skills during this project.	4.14	0.79
4	This project improved my appreciation for circular economy principles.	3.95	0.86
5	Hands-on projects like this are more effective than lectures for learning sustainability.	4.05	0.92

Section E results indicate that the perceptions of the learning value related to the upcycling based learning experience are strongly positive. The average score of all five items was between 3.86 and 4.14, which implies the strong agreement between the participants with the aspects of the instructional effectiveness of the project. The means always remain high implying that the students referred to the learning experience as meaningful, engaging, and useful in their academic and professional growth. The most rated item is I acquired teamwork and collaboration skills over the course of this project ($M = 4.14$, $SD = 0.79$) which serves as an indication of the usefulness of collaborative, hands-on learning settings in the process of interpersonal and teamwork skills acquisition. This would be in line with the experiential learning theory that focuses on social interaction and reflective engagement as critical processes of deep learning. In a similar way, the high level of agreement with the statements connected with the awareness of sustainability and appreciation of the principles of the circular economy ($M \approx 3.95$) confirms that the project was helpful to enhance the conceptual knowledge and enhance the value-based orientation of the students on the issue of sustainable design. The standard deviations of the items are also relatively low, which indicates that the perceptions of students are highly consistent, and they share learning experiences and engage in similar cognitive activities.

On the whole, the results can be related to the taxonomy introduced by Bloom, which means that learners successfully acquired the ideas of sustainability and were willing to implement them in real-life situations. The upcycling project was a valuable pedagogical experience, which increased the perceived value of learning, practicality, and the desire to learn sustainability among students. These results emphasize the applicability of experiential learning and the project-based learning in supporting cognitive and attitudinal

growth in sustainability-oriented curriculum.

SECTION F: Qualitative Analysis of Open-Ended Responses (Pre- and Post-Project)
The section contains a qualitative discussion of the open-ended responses of students taken before and after the upcycling project. The objective was to understand the variations in perceptions, learning and understanding of sustainability, circular economy, and skill development. Thematically analysis technique was settled on and it was based on three phases, which are coding, theme development and interpretive synthesis.

Coding of Responses: The open-ended responses were reviewed line-by-line. The main words were picked and designated first code indicating similar concepts and meanings. Inductive coding was used because it enabled the themes to arise naturally out of the information.
Preliminary Codes Uncovered: Sustainability awareness; Environmental responsibility; Resource efficiency; Creativity and innovation; Practical skill development; Problem solving; Teamwork and collaboration; Material reuse and waste reduction; Technical difficulties; Confidence and motivation.
Theme Development: The codes were organized in larger themes of analysis that reflected common trends in the responses. Four key themes were identified, namely Learning Outcomes and Skill Development; Environmental Awareness and Sustainability Understanding; Barriers and Practical Challenges; Social, Collaborative, and Educational Value.

Table 6: Qualitative Thematic Analysis of Open-Ended Responses

Theme	Description	Student Responses (Anonymized)
Learning Outcomes & Skill Development	Students reported gaining hands-on skills such as material handling, furniture disassembly, design problem-solving, and creative reuse of materials.	"I developed hands-on problem solving and learned how to reuse materials effectively." "I learned how to join wood pieces and redesign old furniture."
Environmental Awareness	Increased understanding of sustainability concepts, circular economy principles, and environmental responsibility.	"Sustainability means using resources wisely so future generations can benefit." "I now understand how waste impacts the environment and how reuse can reduce it."
Barriers & Challenges	Participants reported technical difficulties, material limitations, and lack of prior experience as key challenges.	"Disassembling old furniture was difficult." "Working with damaged materials was challenging at first."
Social & Educational Impact	Students highlighted teamwork, collaboration, and the value of experiential learning compared to traditional lectures.	"Working in teams helped me learn faster." "Hands-on projects teach more than classroom lectures."

The qualitative results are in solid support of the quantitative findings presented in Sections B and C since the

reflection of students shows that there was a distinct change of their initial awareness on the basic concept of sustainability to the in-depth understanding and application of the principles of sustainability. The pre-project responses were mostly a general or abstract understanding of sustainability and in many cases, it did not go past the environmental friendliness or material reuse. Conversely, the post-project feedback was more conceptually clear, more applied in understanding and more reflective especially on circular economy principles, reuse of materials, and the decisions on the design that were driven by sustainability. The development of the themes concerning the development of skills and teamwork are in close correlation with the statistically significant post-survey scores in attitude and awareness. This overlap confirms the effectiveness of the quantitative results and reinforces the general interpretation of the learning impact. The qualitative results are very much supported by the quantitative results found in the sections B and C:

- A higher level of awareness is associated with the perceived knowledge of sustainability and environmental responsibility among students.
- Attitude improvements go in line with thoughts on motivation, engagement and appreciation of practical learning.
- Themes that determine skills substantiate statistical increases in perceived ability and confidence.

This body of evidence confirms the usefulness of the project-based learning methodology and promotes the validity of the results by methodological triangulation. In terms of the learning theory, students moved on the level of basic knowledge and understanding towards higher levels of cognitive abilities with application, analysis and evaluation. Also, the high affective reactions like motivation, responsibility and appreciation show progress in the affective sphere of the Bloom taxonomy especially in the valuing and internalization levels.

Table 7: Coding Frequency (Open-Ended Responses): Pre vs Post

Sr. No.	Code	Frequency (n) Pre	% Pre (n=22)	Frequency (n) Post	% Post (n=21)
1	Motivation / future application	5	22.7	19	90.5
2	Sustainability awareness / environment	16	76.2	19	86.4
3	Practical / technical skills	2	9.1	14	66.7
4	Upcycling vs recycling understanding	14	66.7	16	72.7
5	Challenges / barriers	2	9.1	10	47.6
6	Creativity / innovation	7	31.8	10	47.6
7	Circular economy thinking	0	0.0	7	33.3
8	Problem solving / efficiency	0	0.0	6	28.6
9	Teamwork / collaboration	0	0.0	4	19.0

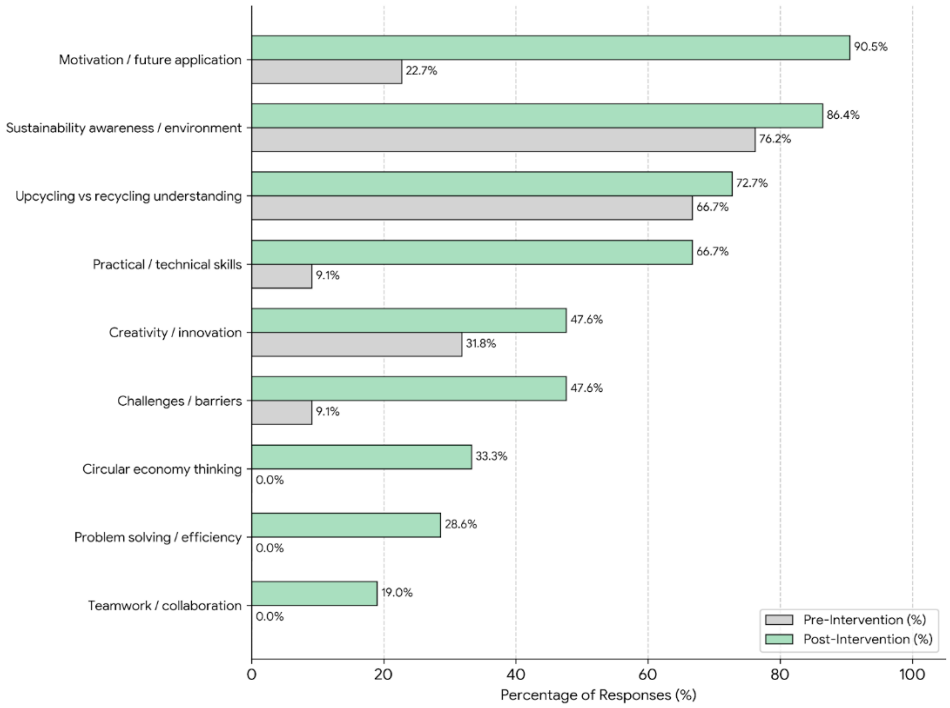

Figure 2: Frequency of Themes in Qualitative Responses (Pre vs Post)

5. Results & Discussion

The quantitative results show that there is a distinct improvement in sustainability awareness and attitudes of students after the intervention. The general awareness scores were raised, M = 2.95 before (pre) and M = 3.75 after (post), with small-to-moderate effects (Cohen's d ≈ 0.29–0.64), indicating meaningful cognitive improvements instead of random error. Attitudinal scores also improved favorably with mean scores increasing between M = 3.50 (SD = 0.88) to M = 3.83 (SD = 0.82) with greater support of sustainability and upcycling values.

The quantitative trends are supported by qualitative findings. The reflections of the students before the intervention mainly abstractly or generally defined sustainability. After project reflections, though, there was an obvious turn to more practical knowledge, problem-solving, and actual use. This shift is manifested in significant growth in the code concerning technical skills (9.1 to 66.7) and the motivation or future oriented thinking (22.7 to 90.5). Simultaneously, the appearance of the reported obstacles and difficulties (47.6% post-intervention) also gives valuable background information suggesting that as much as the understanding and motivation rose, effective constraints like the lack of materials and the complexity of disassembling the product mollified the confidence of students in the personal adoption.

The results can be interpreted using the revised taxonomy by Bloom, which implies the development of both cognitive and affective domains. The enhancements in Section B are evidence of the transition between the conceptual knowledge and the application and analysis because students have started to analyze the design decisions based on sustainability lenses. Modifications on Section C with the backing of reflective data demonstrate that there is an increase in internalization of value and the desire to practice sustainability in future designs. This trend is typical of experiential learning set ups, in which exposure to real constraints promotes more in-depth learning as well as exposes practical pitfalls.

Table 8: Design Pedagogy, Creativity, And Functional Transformation Analysis

Group ID	Furniture Collected (Type)	Quantity	Condition	New Product	Functionality Change
G1	Wooden Closet	1	Good	Children's multi-purpose storage & activity unit	Storage → Books & toy storage, seating, chalkboard, drawers, side rods
	Pine wooden blocks	4	Very Good		
G2	Dressing Table	1	Very Good	Display shelves with storage cabinet	Storage → Decorative display & cabinet storage
G3	Wooden Showcase	1	Good	Shoe rack with seating	Storage → Shoe storage & seating
	Extra wood panels	3	Very Good		
G4	Chair back	1	Broken	Console table with framed mirror	Unusable pieces → Display unit, storage table, mirror frame
	Wood piece	1	Good		
	Sofa hand support	2	Very Good		
	Board	1	Very Good		
	Drawers	2	Good		
G5	Wooden Showcase	1	Broken	Media console	Storage → Display & storage
G6	Dressing Table	1	Broken	Modular cube table	Storage → Seating & game board table
	Bed panels	2	Good		

On the whole, the quantitative and qualitative results are combined to increase the validity of the findings. Skills and motivation change are associated with improved awareness and attitudes. Qualitative data offers the reasons behind the small attitudinal improves, which point to the significance of a mixed-methods design. These results indicate that practical upcycling interventions are effective in fostering sustainability education and making participants experience real-life design issues.

6. Design Outputs and Functional Transformation

Students were able to reuse old pieces of furniture to produce various other products such as storage, seating, and in-between furniture formations. Most of the recovered materials changed or continued to be extended in functionality, which testifies to the flexibility of the recovered materials.

Table 8 shows the qualitative and design oriented features of the upcycling projects. It records the nature and the state of abandoned furniture, the reused product designs, and the workable changes that were made due to upcycling. As shown in the figure 3 below, the reinterpretation of the existing furniture parts to form novel functions is the way in which the design choices of the students, their creative approach, and the integration of the principles of the circular design were implemented.

Figure 3: The projects of G1 to G6 (Before - After)

Table 9: Circular Economy Metrics, Material Reuse, And Environmental Evaluation

Group ID	Total Weight (kg)	Usable Wood (kg)	Waste (kg)	Material Used in New Product (kg)	New Material Used (kg)	Material Reuse (%)	Waste Reduction (%)
G1	50	48	2	48	0	96.0	96.0
G2	17	13	4	13	9	76.5	76.5
G3	52	47	5	48	1	90.4	90.4
G4	29.5	26	3.5	30	4	88.1	88.1
G5	20	15	3	15	0	75.0	75.0
G6	23	18	5	21	3	78.3	78.3

Note:

- Material Reuse % = (Usable ÷ Total) × 100
- Waste Reduction % = (Waste ÷ Total) × 100

Table 9 presents summarized results of the quantitative material flow of the projects. It records overall material input, usable wood recovered, waste produced, material used in new products and percentage material reuse and waste reduction. This table gives empirical data on the environmental advantages of upcycling

furniture by showing efficiency in resources and avoiding putting the material in a landfill.
Environmental Impact of Furniture Upcycling: The upcycling projects led to a significant material recovery with the principle percent of reclaimed wood not ending up in the landfills. Carbon savings are estimated to show that re-use of wooden components has significant environmental savings in comparison to production of virgin furniture materials.

- CO_2 emission factor for virgin wood:
  1.8 kg CO_2 per kg of virgin wood
  (Derived from timber production and processing averages)
- Embodied energy of virgin wood:
  5.0 kWh per kg of virgin wood
  (Conservative value commonly used in design-education LCA studies)

Table 9: Environmental Impact of Upcycling Projects

Group ID	CO_2 Saved (kg)	Virgin Wood Equivalent Saved (kg)	Energy Saved (kWh)	Source / Assumption Used
G1	86.4	48	240	1.8 kg CO_2/kg wood; 5 kWh/kg wood
G2	23.4	13	65	Same as above
G3	84.6	47	235	Same as above
G4	46.8	26	130	Same as above
G5	27.0	15	75	Same as above
G6	32.4	21	105	Same as above

- Total CO_2 saved: **300.6 kg**
- Total virgin wood saved: **170 kg**
- Total energy saved: **850 kWh**

7. Conclusion

As this paper has shown, furniture upcycling has the potential to extend material lifecycles and help in achieving the major spheres of the circular economy, including resource efficiency and waste reduction. The project recycled the wooden furniture that was discarded and maintained the material value, minimizing the reliance on virgin resources, which validates the idea that upcycling may be an effective alternative to the existing waste management policies. Results also indicate that project-based learning which focuses on experiential learning plays a significant role in increasing the sustainability awareness, attitudes, and applied competencies in students. The quantitative data showed that there were numerical increases in the levels of awareness and confidence, whereas qualitative data showed that there was a deeper comprehension, reflective thought, and motivation to participate in sustainability activities. These results indicate that practical learning helps students to get out of the theoretical level into the level of significance through high order cognitive development that follows the updated taxonomy by Bloom.
Incorporation of upcycling projects in design education is beneficial in technical arts, environmental consciousness, and problem-solving (Mulder-Nijkamp et al., 2019). This paper highlights the importance of experiential learning in implementing the principles of sustainability with the students being involved in making decisions about the material. It emphasizes how educational upcycling programs can enhance the objectives of the circular economy, as academic institutions impact sustainability attitudes and cooperate with the industry to develop the material reuse (Cooper et al., 2021). The results suggest that these educational interventions are equally pedagogical and environmental friendly in the development of future designers and

engineers to contribute in the circular economy. Further studies should be done to include longitudinal studies and wider contexts as a way of strengthening the case on scalability implementation in the future.

8. Limitations and Future Work

The positive results notwithstanding, there are some limitations that should be mentioned. First, the research was carried out on a small and discipline-specific sample and this can be a limitation of generalizing the results to other academic settings. Second, time of the project constrained exploration of materials and the possibility to evaluate the skills and knowledge retention in the long term. Third, differences in the quality of the material and the availability of tools might have affected the personal learning process and the results of the project. The limitations should be overcome in future research by increasing the sample sizes and including longitudinal designs to determine the sustainability of the learning outcomes in the long run. Environmental evaluations would also be enhanced with the application of the methods of life cycle assessment (LCA) to enhance the quantitative data on the sustainability effects. It is also suggested to compare studies in various materials, institutional settings and pedagogical models to provide more transferability. Also, more active partnership with industry members may aid in the practice of scalability and enhance the correlation of academic education and professional practice.

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