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Empowering Sustainable and Quality Education via 3D Printing: A Case Study of Kindergarten Environment Creation

Hung-Chi Yang, Mengfei Wang*, Jingtao Li

Institute of Education, Huanggang Normal University, Huanggang 438000, Hubei, China

Corresponding author: Mengfei Wang, 771351353@qq.com

Abstract: This study explores the application of 3D printing technology in preschool curricula with a focus on the Dragon Boat Festival, examining its potential in cultural transmission, cost-effectiveness, and Education for Sustainable Development (ESD). Twenty preschool teachers participated as research subjects. Data were collected through written responses and semi-structured interviews, and based on their feedback, three age-appropriate 3D-printed teaching aids were designed: Zongzi Stamps/Dragon Boat Drawing for younger children, Assembly Dragon Boat for inner groups, and Handmade Small Boat for older groups. Cost analysis revealed that the printing time for each item ranged from 1.5 to 1.7 hours, with material costs below 1 RMB, demonstrating both affordability and feasibility for classroom implementation. Further analysis suggested that the use of recyclable or biodegradable materials could reduce environmental impact while fostering children's awareness of ecological responsibility, thus aligning with the core principles of ESD. Moreover, the study revealed that teachers did not need advanced 3D modeling skills; instead, they could rely on pre-set template selection mechanisms based on teaching themes and difficulty levels. This lowered the technological barrier, enabling teachers to pay greater attention on integrating the printed products into interactive learning activities. Overall, the findings indicate that 3D printing, when combined with artistic education and sustainability principles, not only enhances preschoolers' engagement and promotes their hands-on skills, environmental awareness, and cooperative learning abilities but also provides a practical model for innovation in early childhood education.

Keywords: 3D Printing; Sustainable Development; Environmental Creation in Kindergartens
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1.Introduction

In the current process of global educational development, the United Nations' Sustainable Development Goals (SDGs) have become a crucial reference point for national education policies. Among them, Goal 4: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all is particularly central, underscoring the pivotal role of quality education in sustainable development. With the sweeping wave of technological innovation worldwide, the integration of 3D printing into the agenda of sustainable quality education has entered the mainstream, gradually permeating primary and secondary school curricula as well as early childhood education environments. More than a technological advancement, 3D printing can be regarded as a vital catalyst for realizing the United Nations' SDG 4 on quality education. In 2019, I conducted a study on environmental design in a kindergarten in Putian City, where I found that creating and arranging educational environments was both highly costly and time-consuming. The emergence of 3D printing technology now offers a promising solution to this challenge. Moreover, the impact of 3D printing on education can be observed on multiple levels, among which its influence on traditional teaching methods and environmental design is the most direct and evident. It disrupts the conventional teacher-centered, textbook-based, one-way knowledge transmission model and instead fosters a new ecosystem characterized by interaction, inquiry, and creativity. Early childhood education, as the starting point of lifelong learning, exerts a profound influence on children's cognitive, emotional, and social development as well as their future learning attitudes (Sylva, Melhuish, Sammons, Siraj-Blatchford & Taggart, 2010). However, how to effectively integrate the concept of sustainable development into the creation of kindergarten environments, and to employ the environment as a form of "hidden curriculum" to cultivate children's sustainability literacy, has become a pressing issue for both academic research and educational practice (Elliott & Davis, 2009). From the perspectives of educational sociology and philosophy of education, the kindergarten environment is not merely a physical space but also a site of cultural reproduction and value transmission (Brooker, 2002). Through consciously designed environments, teachers can guide young children to understand core concepts of sustainable development—such as resource recycling, energy conservation and carbon reduction, and ecological protection—in the course of everyday activities (Davis, 2015).

2.Problem Statement and Research Objectives and Motivations

2.1 Problem Statement

In contemporary kindergarten pedagogy, the construction of learning environments—particularly through the provision of toys and instructional materials—frequently stands in tension with the principles of sustainable development. The manufacturing of such toys typically entails substantial energy consumption, while their design often privileges novelty and marketability over durability and pedagogical value, resulting in markedly shortened life cycles. Moreover, the prevalence of standardized and highly homogeneous teaching aids not only neglects the cultural diversity and developmental heterogeneity of children but also reinforces a paradigm of disposability within early childhood education. This "use-and-discard" logic contributes to the proliferation of non-biodegradable plastic waste, thereby exacerbating environmental pressures. More critically, it conveys to young learners an implicit but problematic value orientation toward consumption, which undermines the early cultivation of ecological consciousness and responsibility that is essential for sustainable education.

2.2 Research Objectives and Motivations

In response to the aforementioned challenges, emerging digital manufacturing technologies provide new opportunities for transformation in educational practice. Three-dimensional (3D) printing, also referred to as additive manufacturing, is characterized by its ability to generate artifacts "from nothing", with high customization and rapid prototyping capabilities. These features highlight its considerable potential within the educational domain (Trust & Maloy, 2017). The present study is motivated by the need to explore how 3D printing technologies can operationalize the principles of the Sustainable Development Goals (SDGs) within early childhood education settings. We argue that 3D printing should not be regarded merely as a fabrication tool, but rather as an educational medium that integrates design thinking, local culture, and circular economy perspectives. Through concrete case analyses, this paper demonstrates how 3D printing empowers both teachers and young children to collaboratively design and produce toys and educational materials that are environmentally sustainable, pedagogically meaningful, and locally contextualized. In doing so, kindergartens can be transformed into micro-societies for the practice of sustainable development.

3.Literature Review

Since its emergence, 3D printing technology has progressively shifted from industrial applications to educational contexts, attracting increasing scholarly attention. Existing research has predominantly focused on its integration into STEM education, where 3D-printed artifacts—such as molecular structures, geographic terrains, and engineering components—serve to concretize abstract concepts. Scholars generally highlight two distinctive advantages of this technology: rapid prototyping and high levels of customization. Through iterative cycles of design manufacture test revise, students are able to engage in hands-on engineering practices, which in turn enhance conceptual understanding, creativity, and problem-solving abilities.

3.1 The Current Application Situation of 3D Printing Technology in Kindergarten Environment Creation

At present, the overall implementation of 3D printing in the educational system remains at an early stage (Ford & Minshall, 2019). Its applications are diverse but relatively fragmented, lacking systematic curriculum integration and interdisciplinary collaboration (OECD, 2017). The use of 3D printing in teaching has been categorized into six major types (Ford & Minshall, 2019), among which the most relevant to the creation of kindergarten environments include: producing tangible teaching aids that concretize abstract concepts, developing assistive technologies to support special educational needs, and providing technical training for both teachers and students (Ford & Minshall, 2019).

The primary focus of these studies lies in the customization and personalization of teaching aids. The technological potential of 3D printing is reflected in its ability to rapidly and cost-effectively produce customized and complex educational tools (Gershenfeld, 2012). For instance, it can be applied to create tactile teaching materials specifically designed for children with special needs, or to transform abstract curricular concepts—such as anatomical structures or geographical models—into tangible objects, thereby deepening learning experiences (Ford & Minshall, 2019). Secondly, another line of emphasis is the empowerment of maker education. The growing accessibility and affordability of 3D printing contribute to the "democratization of technology" (Gershenfeld, 2012), enabling even kindergartens to establish miniature "Fab Labs". Such environments can foster exploratory learning and embody the spirit of hands-on maker culture.

3.2 How Does 3D Printing Technology Support the Sustainable Development Goals of Kindergarten Education

Relevant literature indicates that, if properly applied, 3D printing technology can support the sustainable development of kindergarten education across three dimensions: resources, supply chains, and product life cycles. From the perspective of global sustainability, studies suggest that the widespread adoption of 3D printing holds the potential, in the medium to long term in 2025, to significantly reduce energy consumption and CO_2emissions in the manufacturing sector (Gebler, Schoot Uiterkampl and Vusser, 2014).

It highlights three major areas. First is the enhancement of resource efficiency: due to its additive manufacturing nature, 3D printing can significantly reduce material waste (Gebler, Schoot Uiterkampl and Vusser, 2014; Khosravani & Reinicke, 2020). In the kindergarten context, this means that teaching aids can be produced with fewer materials or with recyclable and bio-based printing resources, thereby reducing environmental burdens (Shuaib, Haleem and Kumar, 2021). Second, supply chain optimization and carbon footprint reduction: by enabling localized production—such as printing the required items directly within the kindergarten or community—3D printing shortens traditional supply chains and substantially decreases transportation-related carbon emissions. Finally, the extension of product life cycles: the technology facilitates customized designs, rapid prototyping, and on-demand repair, such as directly printing replacement parts for broken teaching aids. This not only prolongs their usability but also minimizes disposal and waste (Gebler, Schoot Uiterkampl and Vusser, 2014).

3.3 What challenges are encountered when applying 3D printing technology in the creation of kindergarten environments?

Although applications of 3D printing in education are increasing, overall implementation remains immature, with many practices still confined to isolated projects rather than being embedded into long-term curriculum design (Ford & Minshall, 2019). The main challenges can be summarized as follows:

1.Cost and efficiency barriers: High-quality and environmentally friendly printing materials remain expensive, while the relatively slow deposition rates limit scalability, making it difficult to meet large-volume and rapid production needs. These constitute major obstacles to broader adoption (Baumers et al., 2016).

2.Insufficient teacher capacity and training: The diffusion of 3D printing requires educators to acquire new skill sets. However, systematic teacher training programs are still largely absent, highlighting the urgent need for professional development initiatives (Ford & Minshall, 2019; OECD, 2017).

3.Potential environmental and safety risks: The sustainability of 3D printing is not inherent; its ecological benefits depend heavily on technological choices and policy interventions (OECD, 2017). Certain processes may consume more energy and emit more carbon than traditional manufacturing (Khosravani & Reinicke, 2020). Moreover, issues such as material toxicity and waste recycling raise important ethical and safety concerns (Shuaib, Haleem and Kumar, 2021).

Nevertheless, current studies reveal an imbalance in research orientations. While the majority of literature emphasizes applications in science and engineering education, relatively few investigations have explored the pedagogical potential of 3D printing in early childhood contexts. This gap is particularly salient given that 3D printing can reduce the cost of producing small-scale, customized educational resources, thereby offering possibilities for creating developmentally appropriate, tailored materials for young children. From this perspective, extending the discussion of 3D printing beyond STEM to early childhood education not only responds to emerging pedagogical demands but also expands the scope of research on educational technologies.

Although substantial progress has been achieved in both domains respectively, integrative investigations that explicitly link 3D printing technology, early childhood education, and sustainable development remain scarce. Most existing studies focus on STEM education in primary and secondary schools, while this study fills the gap by exploring 3D printing's application in cultural-themed early childhood education and its role in ESD practice Existing studies on the educational application of 3D printing have predominantly focused on STEM subjects at the primary and secondary school levels, while its pedagogical potential in kindergarten settings has received limited scholarly attention. Similarly, current research on early childhood education for ESD largely emphasizes curriculum design and nature-based experiences, yet pays insufficient attention to how emerging technologies may fundamentally reshape the material environment to mitigate resource waste. Against this backdrop, the present study addresses this research gap by examining how 3D printing, as both a technological tool and an educational approach, can contribute to sustainable kindergarten environment design, serving as a strategic lever for advancing SDG 4 (Quality Education) and SDG 12 (Responsible Consumption and Production).

4.Research Methods and Design

4.1 Research Methods

In the pilot study, an online questionnaire survey using Questionnaire Star was conducted to understand the cognition and current situation of novice kindergarten teachers' perceptions and current practices of 3D printing in kindergarten environment creation. Based on the feedback data collected from 100 teachers between June and July 2025 (see Table 1 below):

Table1: Understanding of 3D Printers by Kindergarten Teachers

Item	Category	Number	Percentage
Gender	Male	12	12%
	Female	88	88%
Age	20–29 years	100	100%
Years of Teaching Experience	1–3 years	33	33%
	More than 3 years	67	67%
Kindergarten Ownership of 3D Printer	Yes	10	10%
	No	80	80%
	Unclear	10	10%

As for teachers' knowledge and understanding of 3D printers, the specific results are as follows: 8 teachers (8%) have heard of and are very familiar with them; 30 teachers (30%) have heard of and have some understanding; 42 teachers (42%) have heard of but do not understand; and 20 teachers (20%) have never heard of them (see Figure 1). In terms of hands-on experience with 3D printers: 2 teachers (2%) use them frequently; 5 teachers (5%) use them occasionally; 10 teachers (10%) have only tried them once or twice; and 83 teachers (83%) have never used them (see Figure 2).

Figure 1: Familiarity with 3D Printing Technology

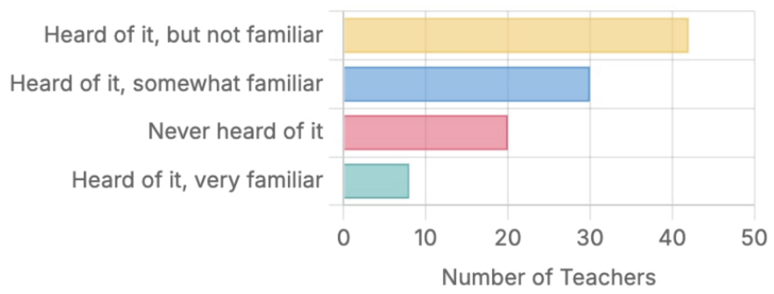
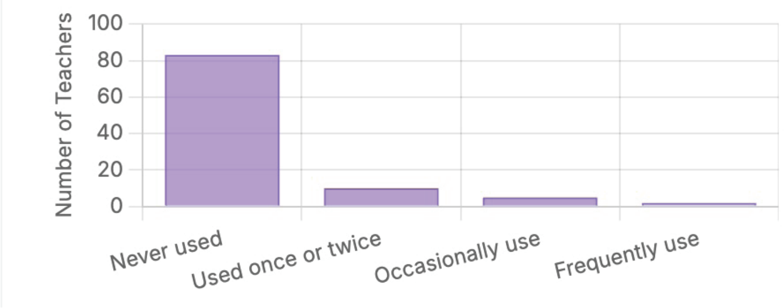


Figure 2: Experience with Operating 3D Printers



According to the survey results in Figures 1 and 2, it is evident that for young teachers aged 20–39, most have limited basic knowledge of 3D printing technology, with even fewer having practical hands-on experience. This study does not focus on training teachers to master complete 3D modeling skills, but rather aims to guide them in flexibly utilizing existing templates and models to enrich the teaching and environmental construction in kindergartens, thereby enhancing innovation and diversity within educational settings.

4.2 Research Design

Given that most teachers still lack the necessary skills and operational limitations in the application of 3D printing technology, this research does not aim to provide a comprehensive teaching of professional skills. Instead, it focuses on guiding teachers to effectively apply 3D printing within the limited technical framework. The research design is based on the traditional Chinese festival - the Dragon Boat Festival, and through contextualized teaching activities and environmental creation, it explores the practical possibilities and educational value of 3D printing in early childhood education.

The question design consists of 11 questions. Apart from the basic information in the first part, the second part, "Cultural Understanding of the Dragon Boat Festival and 3D Printing Application", has four questions, mainly focusing on the subjects' understanding of the symbolic elements of the Dragon Boat Festival and the appropriate application of 3D printing technology. The third part, "Personal Preferences and Future Outlook", contains three questions, aiming to explore the teachers' willingness to participate in DIY activities and their assessment of the challenges that 3D printing may face in the continuation of traditional culture(As detailed in Table 2).

Table 2 :Summary of Questionnaire Content

Part Two	1. Distribution of teachers' familiarity with 3D printing 2. The most frequently selected representative elements of the Dragon Boat Festival 3. What advantages does 3D printing have in creating the environment for the Dragon Boat Festival 4. The most favored 3D printing application projects
Part Three	5. Analysis of the willingness to participate in DIY activities 6. The main challenges perceived by teachers (such as technical barriers, cost, cultural preservation) 7. What possibilities does 3D printing technology have in the inheritance and promotion of Chinese traditional culture in the future

This study involved 20 preschool teachers as the research subjects. The 20 subjects were selected to cover different teaching experience levels (1-3 years vs. >3 years) and familiarity with 3D printing (familiar vs. unfamiliar), ensuring representativeness of the sample. The researchers, in response to the aforementioned research questions, invited the participating teachers to provide their responses. By collecting their responses, the aim was to understand the teachers' comprehension and viewpoints on the topic, and to further analyze the commonalities and differences among them, in order to serve as a reference for subsequent research and educational practice.

5.Research Results

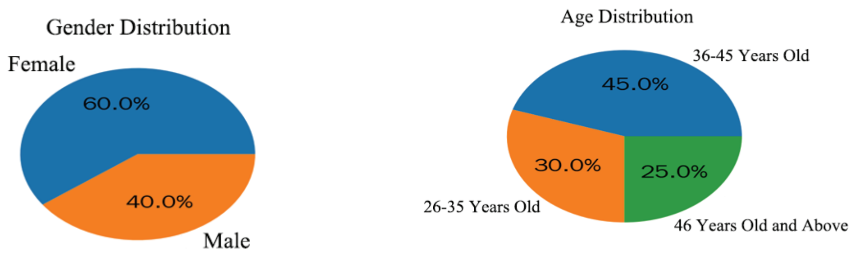
5.1 Gender and Age Distribution

From the data on gender distribution, the number of females is greater than that of males(18:2). This might indicate that within the scope of this survey, women have a higher participation rate in related topics (such as 3D printing and traditional culture-related content), or that the sample selection of this survey has a certain bias in terms of gender ratio. If this is a representative sample, then in the subsequent promotion, product design, or service provision related to these topics, more consideration can be given to the needs and preferences of women.

5.2 Age distribution

In terms of age distribution, the 36 - 45 age group has the largest number, followed by the 26 - 35 age group, and the 46 and above age group has relatively fewer people. This might indicate that the 36 - 45 age group is more concerned about the content related to this survey, possibly because they are in a relatively stable career and life situation, and have more energy and resources to engage with and participate in such topics. The 26 - 35 age group might have a slightly lower participation rate due to reasons such as their career being in an upward phase. The 46 and above age group has the lowest participation rate, which is speculated to be due to factors such as a relatively lower acceptance of new technologies (such as 3D printing) (as shown in Figure 3).

Figure 3: Proportion of Teachers by Gender and Age



5.3 Distribution of Interest in DIY Activities

From this statistical result, it can be inferred that 19 teachers have a positive attitude towards DIY activities, while only 1 teacher shows no interest. This might indicate that DIY activities have a high appeal in this group, possibly because they can satisfy people's creativity, sense of achievement, or social needs, etc. For the organizations or businesses that organize DIY activities, they can fully utilize this high level of interest to promote related activities or products. Additionally, through the questionnaire data, it was learned that they consider the dragon boat and zongzi as the most representative items of the Dragon Boat Festival. The advantage of 3D printing lies in its convenience and low cost. If 3D printing can be applied to other areas in the future, most teachers are also willing to try it.

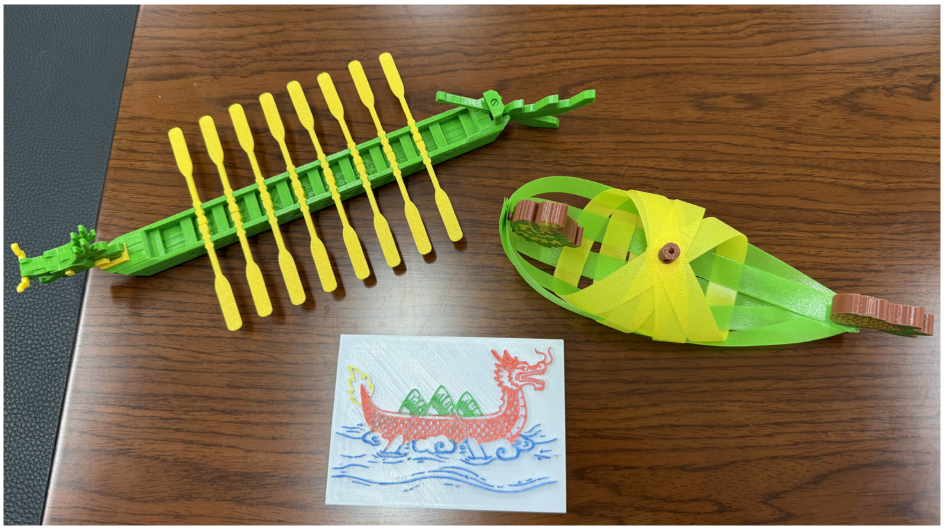
5.4 3D Printing and Sustainable Development

Since most teachers consider the dragon boat and the zongzi as the representative symbols of the Dragon Boat Festival, the researchers designed and developed 3D-printed toys related to these. Considering the operational abilities and cognitive development of children at different age stages, this study planned three different levels of 3D-printed designs(as shown in Figure 4):

1. Low difficulty: Presenting the elements of zongzi or dragon boat in simplified geometric shapes, suitable for younger children to trace or operate.

2. Medium difficulty: Incorporating movable or assembleable parts, encouraging middle-class children to develop spatial concepts and hand-eye coordination during the operation.
3. High difficulty: Designing a more intricate dragon boat model that can be assembled in multiple steps, suitable for older children to challenge and emphasizing the learning process of cooperative construction.

Figure 4: Products related to the Dragon Boat Festival



To further explore the feasibility and sustainability of 3D printed teaching materials in the theme teaching of the Dragon Boat Festival, this study estimated the costs and time required for the 3D printed toys designed for different age groups. Considering the printing time and material costs, the researchers summarized the data as shown in Table 3 below, providing a reference for the teaching site when planning the teaching materials.

Table 3: Printing Costs

	Younger Class	**Middle Class**	**Senior Class**
Toy Name	Zongzi Stamp / Dragon Boat Drawing	Assembly Dragon Boat	Handmade Assembly Small Boat
Printing Time(hr)	1.5 / 1.7	1.5	1.7
Material Cost	0.4	0.42	0.48

Note: Material cost is calculated based on biodegradable PLA filament (unit price: 50 yuan/kg), with each toy consuming ~8-10g of filament; printing time is tested with a FDM 3D printer (print speed: 60mm/s)

As can be seen from Table 3, 3D printed toys maintain a low to medium level in terms of material cost and printing time, indicating that such teaching materials have practical operability in the classroom. Taking the "Zongzi Stamp/ Dragon Boat Painting" in small classes as an example, the printing time is approximately 1.5 - 1.7 hours, and the material cost is only 0.92 - 0.40 yuan. Moreover, the zongzi stamps can be produced in groups of four, further reducing the unit cost and demonstrating high cost-effectiveness.

In the middle and senior class teaching materials section, the printing time for "Assembling the Dragon Boat" and "Handmade Assembly of a Small Boat" is 1.5 hours and 1.7 hours respectively, with costs of 0.42 yuan and 0.48 yuan respectively. Although the printing time is slightly longer, since they are assembly-type toys, they can simultaneously promote children's fine motor skills and cooperative learning. Therefore, in terms of educational value, they have a higher return on investment.

Furthermore, if the consumables used in 3D printing can be selected from recyclable or biodegradable materials, it will better align with the core spirit of sustainable development. In other words, the design of this study not only provides cultural-themed teaching aids at a low cost, but also incorporates environmental education into daily teaching through the selection of sustainable materials, achieving the dual goals of "cultural inheritance" and "environmental sustainability".

5.5 Discussion

As the manufacturing industry continues to face pressure to minimize its environmental impact, the energy consumption associated with the 3D printing process is receiving close attention. Although traditional manufacturing typically involves a large amount of material waste and high energy input, 3D printing or additive manufacturing offers a unique opportunity to solve these problems (Shuaib, Haleem and Kumar, 2021). However, can this innovative technology become more environmentally friendly and how can it be promoted to kindergartens? For kindergartens, optimizing print parameters (e.g., reducing infill density to 20% for non-load-bearing toys) or using solar-powered 3D printers could further reduce energy consumption, which deserves further exploration in future research.

This article takes the Dragon Boat Festival as the theme for environmental creation, designs toys suitable for different age groups using 3D printing technology, and analyzes them from the perspectives of cost and sustainable development. In terms of the meaning of sustainable development, the use of recyclable or biodegradable materials for consumables not only reduces environmental burden but also integrates environmental education into children's cultural learning. This makes teaching aids not only fulfill the function of "cultural inheritance" but also embody the value of ESD.

Although the application of 3D printing technology in early childhood education scenarios has significant potential, for kindergarten teachers, the complexity of technical operation, design threshold, and compatibility for teaching integration pose difficulties in practical implementation. This study uses existing resources, where teachers do not need to possess professional 3D modeling knowledge, but only need to select appropriate templates through a preset screening mechanism (such as grading by teaching theme and operational difficulty) to quickly start the printing process. This model not only reduces the time investment of teachers in technical learning and design but also allows them to focus more on how to integrate the printed products into environmental creation. In other words, the application of 3D printing in the Dragon Boat Festival courses in kindergartens does not transform the role of teachers into "technical operators", but strengthens their core functions of "teaching designer" and "learning guide". In summary, this study shows that the combination of 3D printing technology and the Dragon Boat Festival cultural theme can not only support early childhood cultural education with low cost and high flexibility, but also achieve the triple value of cultural inheritance, environmental education, and teaching practice through sustainable materials and low-tech operation modes.

6.Conclusions and Recommendations

This research focuses on the Dragon Boat Festival and designs teaching aids suitable for different age groups using 3D printing technology. It also discusses the design from perspectives of cost-effectiveness, sustainable development, and teaching application. The research results show that this design is not only low-cost and highly feasible, but also can achieve a balance between cultural inheritance and environmental education. At the same time, it reduces the operational threshold for teachers and enhances the possibility of teaching innovation. In the future, further research samples and cultural contexts can be expanded, and the actual teaching effectiveness can be evaluated to verify the applicability and long-term impact of 3D printing textbooks in various courses, thereby promoting the integrated development of early childhood education in culture, technology, and sustainability.

In terms of suggestions, for kindergartens willing to adopt 3D printing: 1) Start with low-cost FDM 3D printers and biodegradable PLA materials to control initial investment; 2) Establish a "3D printing template library" for traditional festivals (e.g., Mid-Autumn Festival, Spring Festival) to reduce teachers' design burden; 3) Integrate 3D printing activities into weekly cultural courses (e.g., 1-2 hours per week) to ensure continuity of teaching practice.

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no

Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

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