

A STUDY ON THE APPLICATION OF BIOMIMETIC DESIGN IN THE INNOVATION AND OPTIMIZATION OF CHILDREN'S STUDY DESKS AND CHAIRS

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Abstract:

Enhancement of living standards in contemporary society has prompted people to seek products that not only satisfy functional needs but also have aesthetic appeal and a refined design. However, the school desks and chairs used in Taiwan generally have outdated designs that no longer meet such demands. This study employed the biomimetic design approach by drawing inspiration from the form of the stingray to develop an innovative school desk and chair set. The inspiration for the stingray design comes from the stingray in Finding Nemo. Like Ray, who protects the young fish on their way to school, this symbolizes safeguarding students' learning journey. By integrating this concept with biomimetic technology, we have innovated the design of school desks and chairs. Compared to traditional desks and chairs, the innovative design offers enhanced ergonomics, with adjustable legs allowing students to customize the height and fit according to their stature. The design was refined through education and Taiwanese manufacturers expert interviews and evaluated using strength and stability tests to ensure its safety, durability, and ergonomic adaptability. The resulting desk and chair design integrates natural aesthetics with ergonomic principles, striving to achieve a balance between functionality and aesthetic appeal. The design employs pre-embedded screws to provide height adjustability - length of 50, 80, or 110 mm - thereby ensuring flexibility and accommodating children's growth. Stability and strength tests were conducted in accordance with the CNS14430 standard, and the results confirmed that the design meets regulatory requirements and ensures both aesthetic quality and safety. The final prototype achieved a 15% improvement in ergonomic comfort rating and passed 10 of 13 CNS14430 stability tests. Overall, the findings of this study contribute to advancing Taiwan's educational environment and foster greater awareness of aesthetic considerations and sustainable development within learning spaces.

Key words: Bionic designs; Creative design; Ergonomics.

INTRODUCTION

Background and Motivation

Education has long been regarded as the cornerstone of societal progress, with schools serving as the primary venues for learning. Of the school furnishings that students interact with most frequently, desks and chairs play a critical role in supporting learning activities and shaping the educational environment. However, the design and standards of elementary school desks and chairs in Taiwan have remained largely unchanged for many years and are inadequate for current lifestyles and the rapidly evolving demands of contemporary technology. Children's living conditions continue to improve, and their learning needs are diversifying, but existing school furniture is increasingly unable to meet basic functionality and comfort requirements.

Children between the ages of 6 and 12 years undergo rapid physical development and vary considerably in height and body size. The current desk and chair designs in Taiwan have not adequately accounted for these changes, resulting in many students adopting a poor sitting posture for long periods during class. This situation has been linked to health problems including muscle fatigue and spinal stress (Bendix 1987; Brunswic 1984). Studies have indicated that in children, improper posture can cause pain in the back, legs, arms, neck, shoulders, and feet (Veenstra & Molenbroek 2003) and that poorly designed furniture may reinforce unfavorable posture-related habits, potentially exerting both direct and indirect negative effects on children's development (Dianat et al. 2013; Gouvali & Boudolos 2006; Panagiotopoulou et al. 2004; Parcels et al. 1999).

Another notable problem is the mismatch between furniture dimensions and ergonomic standards. Even among children of the same age group, height differences can exceed 20 cm; however, the desks and chairs used in a single classroom are often standardized in size and fail to accommodate variation among individuals. Consequently, students must frequently use unsuitable furniture for extended periods, which compromises their learning efficiency and well-being. The design of desks and chairs should prioritize comfort and good posture to enhance learning performance (Domljan et al. 2010; Guat-Lin 1984; Parcels et al. 1999).

Beyond functionality and ergonomics, the aesthetic design of furniture should not be overlooked. Bjerke et al. (2007) noted that the design and aesthetic appeal of a work environment considerably affect employees' satisfaction and productivity. Because desks and chairs are furniture with which students engage for long periods, their external design should integrate practical and aesthetic considerations. Such design can increase the overall quality and aesthetic appeal of learning spaces.

The present study adopted principles of biomimetic design as its central concept to reconceptualize and optimize the design of children's school desks and chairs. The main objective was to address shortcomings in the ergonomics, functionality, and aesthetics of such furnishings while aligning with the policy direction on educational reform in Taiwan. The study results will contribute to the healthy development and learning efficacy of children and offer valuable insights into innovations for future educational environments.

OBJECTIVE

In the 12-year basic education system of Taiwan, elementary school students spend the majority of their time engaged in classroom-based learning. This developmental stage is critical to both their physical and psychological growth. Desks and chairs are the primary tools for these students' daily learning activities, and the design and functionality of this furniture directly affect students' learning quality and physical health. However, most desks and chairs have fixed designs that fail to accommodate the diversity in height, body type, and posture associated with children's rapid growth. This inadequacy contributes to poor sitting posture, low concentration, and even physical discomfort.

In addition, the height and angle of the majority of school desks and chairs currently in use are fixed, and the external design of these desks and chairs fails to balance aesthetics with durability. These deficiencies often lead to damage and operational inconvenience, which in turn may negatively affect students' motivation to learn and reduce the overall quality of the classroom environment (Veenstra et al. 2003).

The present study developed an innovative design for Taiwanese school desks and chairs that incorporates biomimetic design concepts, ergonomic principles, adjustability, and aesthetic appeal. Through design optimization, this study sought to enhance the adaptability and comfort of desks and chairs, improve students' posture and health, and create a more engaging and functional learning environment, thereby responding to the growing emphasis on learning spaces' quality within the broader context of educational reform.

The ergonomic and learning environment problems arising from the prolonged lack of updates in the design of elementary school desks and chairs in Taiwan were addressed. Centered on biomimetic design and aesthetic education, this study proposed an innovative and adjustable design solution in response to the following research objectives:

- (1) To analyze and evaluate the strengths and weaknesses of the desks and chairs currently used in elementary schools in Taiwan; identify deficiencies in their functionality, comfort, and aesthetics; and establish a foundation for design improvements.
- (2) To propose a desk and chair design that conforms to ergonomic principles, integrates aesthetic value, and offers a high degree of adjustability to ensure that the diverse body sizes and learning needs of growing students are accommodated and both posture and spatial quality in the learning environment are enhanced.
- (3) To validate the proposed design through fatigue testing, examine its compliance with relevant provisions of the national standard CNS14430, and ensure the products' safety, durability, and practical feasibility for real-world application.

METHOD

This study conducted a literature review and arranged expert interviews to explore how the design of elementary school desks and chairs in Taiwan can more effectively respond to the learning and developmental needs of children.

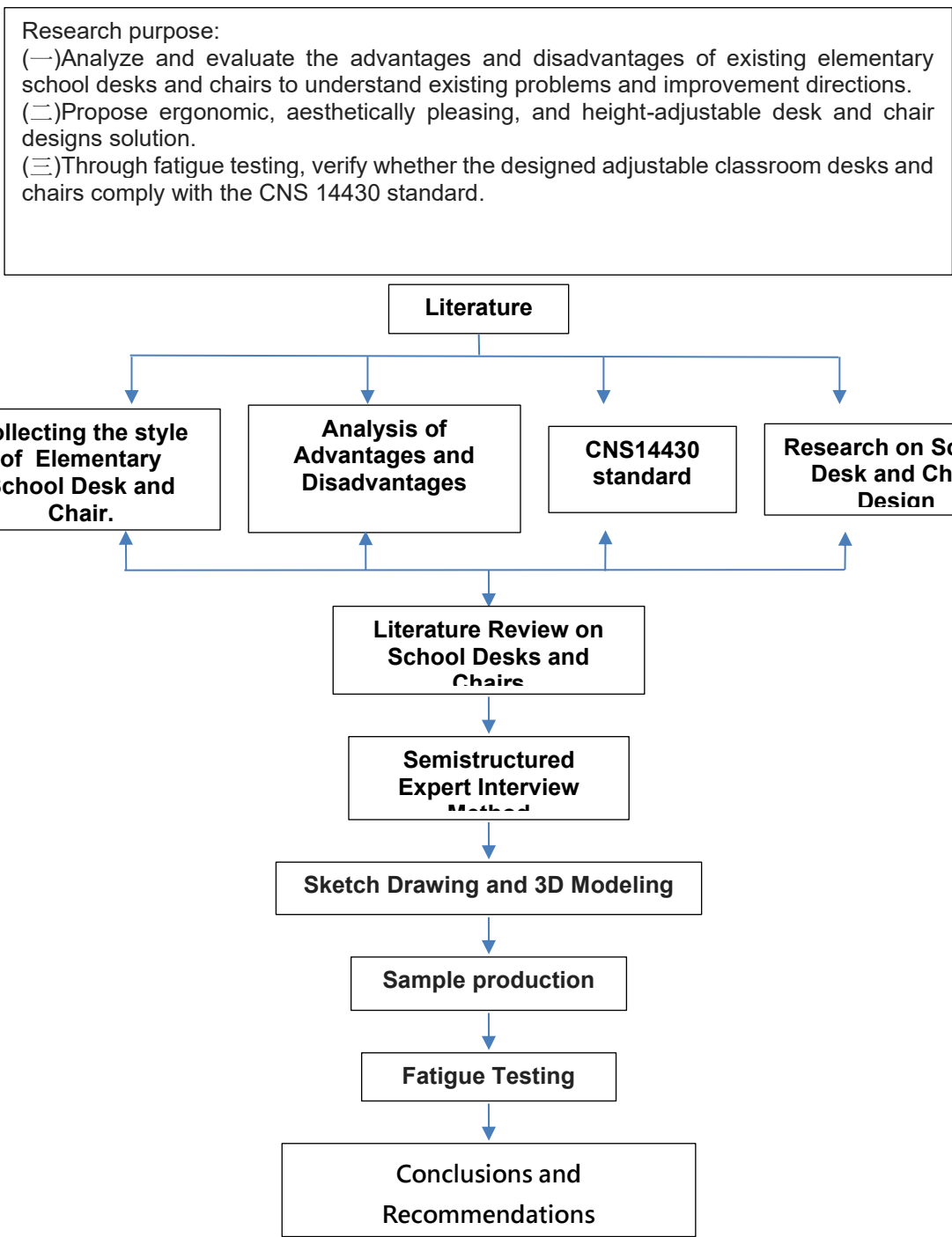
First, the literature review systematically examined the evolution of school desk and chair design in Taiwan over the past several decades. How the design philosophy has shifted from a purely functional orientation to having increasing emphases on students' physical health, comfort, and overall learning experience was investigated. This research stage helped identify prevailing design trends and technological developments and clarify the challenges and limitations associated with existing school desks and chairs.

Second, expert interviews were conducted to gather first-hand insights from educators, designers, and specialists in ergonomics. These interviews provided a deep understanding of actual usage scenarios and real-world needs, thereby addressing gaps in the literature and offering practical recommendations for the present study's design direction.

On the basis of the collected information, an innovative design was created, and prototypes of the proposed desk and chair were fabricated. The prototypes were then subjected to fatigue testing to assess their structural safety and durability. The fatigue test aimed to determine whether the designs complied with the relevant provisions set forth in CNS14430: Furniture - Desks and Chairs for General Classroom and were thus feasible and safe for real-world implementation.

Research Framework

This study followed a systematic design process divided into seven key stages, with the aim of improving the design of elementary school desks and chairs in Taiwan to more effectively meet the diverse needs of students throughout the learning process. The first stage involved literature analysis and expert interviews to examine the historical progression of desk and chair design and to identify the usage problems associated with current designs. From this analysis, this study distilled the core design elements that affect students' posture and comfort, establishing a theoretical foundation for the subsequent design process. Next, the principles of subtractive design and biomimetic design were integrated to develop initial concept sketches. Feasible concepts were then selected and refined by using two-dimensional computer-aided drafting to confirm dimensional specifications. The product appearance and color scheme were visualized through three-dimensional (3D) modeling. In the prototyping stage, this study comprehensively analyzed and evaluated structural design, form, manufacturing processes, and material selection to ensure that the final design meets the practical needs of children while also aligning with sustainability and aesthetic values. Once the prototypes had been created, fatigue testing was performed in accordance with CNS14430 to assess whether the developed products met national durability standards. On the basis of the results of these tests, design modifications were proposed for optimizing structural integrity and ergonomic performance. Throughout the entire research process, qualitative and quantitative data were examined to ensure scientific rigor and practical relevance. Finally, conclusions and recommendations were derived regarding the formulation of concrete design guidelines for elementary school desks and chairs and to lay a theoretical and practical foundation for future related research.



Research Process and Implementation Steps

Literature Analysis

The research process comprised multiple stages. The initial stage was comparative analysis of the advantages and disadvantages of new desk and chair designs versus conventional plastic-based designs. This comparison centered on material durability, environmental sustainability, and the effect of each design on students' comfort and learning efficiency. The goal was to uncover the potential effects that various furniture designs may have on the learning environment and student health. The findings from the literature review also served as the theoretical foundation for developing a semistructured expert interview questionnaire. This questionnaire facilitated the effective collection of experienced professionals' practical insights regarding the design and use of school desks and chairs. Through this systematic exploration, this study not only established a theoretical basis that could guide the primary design direction but also laid the groundwork for subsequent design development and empirical validation (Fig. 1).

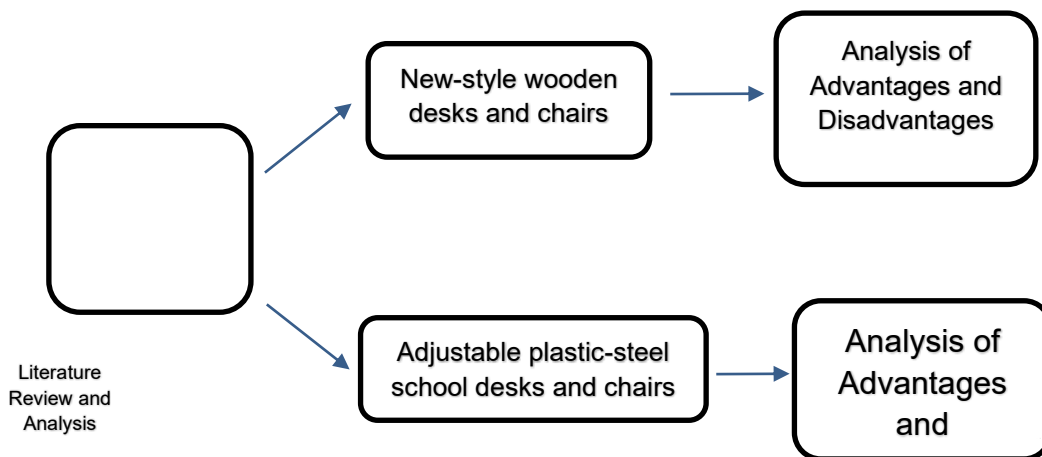


Fig. 1.
Literature Analysis Process.

Semistructured Interviews

This study employed the semistructured interview method as the primary approach for collecting qualitative data. This method adopts a set of predesigned interview questions and enables flexible adjustment of the interview process. Researchers can adjust the sequence or content of questions in response to interviewees’ answers and the interview context. Such flexibility facilitates deeper exploration of interviewee experiences and perspectives while maintaining a focus on the research topic. Through this method, this study engaged in in-depth dialogues with education scholars and experts from relevant fields to examine design requirements and improvement directions for elementary school desks and chairs. The interviews collected professionals’ insights regarding actual usage scenarios, design observations, and the practical needs of schoolchildren. The collected interview data were then incorporated into the design process. All interview content was recorded and transcribed verbatim to support subsequent analysis and synthesis, and the interview data served as a foundation for both design optimization and theoretical development (Fig. 2).

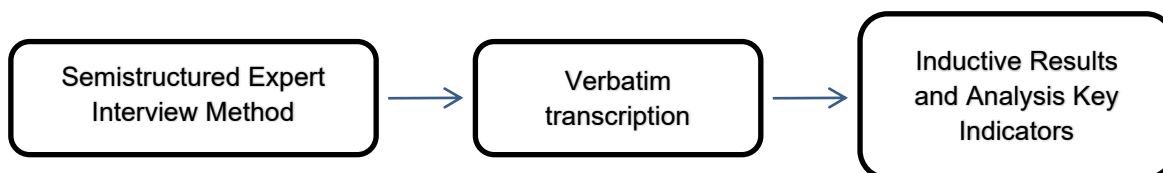


Fig. 2.
Semistructured Expert Interview Execution Flowchart.

RESULTS & DISCUSSION

Analysis of Semistructured Expert Interview Results

In the current educational context, the design of school desks and chairs exerts a profound effect on students’ learning experience and well-being. A well-designed desk and chair set not only ensures students’ comfort and concentration but also contributes to high learning efficiency and teaching quality. Therefore, when selecting or designing such furniture, schools must consider multiple factors - including ergonomics, safety, aesthetics, and functionality - to create a learning environment conducive to the holistic development of children. Through semistructured expert interviews, this study collected in-depth insights from educational scholars and design professionals to identify seven key design elements as priority considerations in the development of elementary school desks and chairs. These elements were associated with students’ physical health, posture correction, spatial adaptability, material selection, structural safety, visual aesthetics, and opportunities for interactive learning. They may serve as practical and actionable design guidelines for schools and designers moving forward (Table 1).

Table 1

Design guidelines for elementary school desks and chairs

Key Element	Description
Ergonomic Design	Emphasizes ergonomic integration between the seat and desktop to ensure students' comfort and efficiency during learning. This includes backrest support and appropriate height and dimensional proportions.
Reduction of Distractions	Considers the minimization of noise during desk and chair movement and ease of operation to minimize environmental disturbances during learning.
Storage and Management Functionality	Provides sufficient storage space and instructional material management features, such as drawer-style compartments and hook attachments, to ensure the organization and accessibility of learning materials.
Stability and Safety	Ensures the structural stability of desks and chairs and adopts rounded edges and nontoxic materials to protect students' health and safety.
Material Selection	Combines aesthetics with practicality by selecting suitable materials such as wood (offering natural texture and comfort) or plastic steel (providing durability and a modern appearance).
Adjustability and Flexibility	Incorporates high adjustability and modularity to accommodate various ages, heights, and instructional modes, thereby ensuring broad usability.
Design Aesthetics	Employs light color tones and minimalist forms to create a harmonious and focused learning atmosphere, enhancing the overall aesthetic quality of the learning environment.

Design Concept

Biomimetic Subtractive Design: Creative Stingray-Inspired Children's School Desk and Chair

This study adopted principles of biomimetic subtractive design as its core concept and proposed the design of a product titled the Creative Stingray-Inspired Children's School Desk and Chair. The smooth and elegant form of the stingray (Fig. 4) served as an inspiration for this study's reconceptualization of the morphology of the desk and chair. Conventional design frameworks focus on ergonomics and functionality; by contrast, this study's design was developed to achieve a balance between form and function such that students are physically comfortable during learning and benefit psychologically from the aesthetic appeal of the furniture, which may enhance their learning concentration and promote a more enjoyable learning experience (Table 2).

Contemporary design trends emphasize simplicity and functionality. In the context of aesthetic education being increasingly integrated into school environments, the core objective of the design developed in this study was to create spaces that support focused and comfortable learning while also embracing resource sustainability. Conventional designs of wooden desks and chairs used by students in school often have excessive ornamentation and unnecessary components. By contrast, this study adopted subtractive design principles to focus on students' essential needs. The structural form of the designed product was simplified, and only the indispensable elements, such as pencil grooves and storage space, were retained. This approach not only reduces production costs and maintenance complexity and enhances classroom safety but also improves environmental sustainability by minimizing resource consumption and the manufacturing burden.

By integrating natural forms with the practical requirements of contemporary educational settings, this study designed a desk and chair set that is aesthetically appealing and functionally sound. Inspired by nature, the developed design addresses real-world usability problems and enhances the aesthetic value of the

learning environment, fostering a space in which students can learn and grow in an inspiring and creative atmosphere.



Fig. 3.
Mobula birostris.

Table 2

Characteristics of biomimetic design in stingray applications

Stingray Characteristic	Application in Desk and Chair Design
Flexibility and Adaptability	The design was developed to have high adjustability and accommodate the varying needs of students of different ages and heights.
Streamlined Form	A streamlined exterior was adopted to minimize spatial footprint, thereby improving traffic flow in the classroom and the perception of spaciousness.
Natural Shape	Natural curves and forms were adopted to create a learning environment that is harmonious, aesthetically pleasing, and connected to nature.
Comfortable Contact Surfaces	Soothing and comfortable materials were selected to enhance the tactile experience and learning comfort during prolonged use.
Adaptability to Diverse Settings	The desk and chair configuration was designed to support various instructional activities, such as group discussion and individual study, ensuring flexibility for teachers.
Aesthetic and Inspirational Qualities	Aesthetic design elements were incorporated to stimulate students' creativity and learning interest and ensure the visual and psychological comfort of the learning space.

Design Sketches of Creative Stingray-Inspired Children's School Desk and Chair

The principles of biomimetic and subtractive design were employed to develop conceptual sketches for a creative elementary school desk and chair set. Three design concepts were developed as part of this process (Fig. 4 - 6). During the design process, the fluid and elegant form of the stingray guided the morphological exploration of the furniture, and the aim of the design was to embody the aesthetic appeal of natural forms and also to integrate functionality and ergonomic principles. The resulting design is structurally simple, retains essential features, and incorporates natural curves and soothing materials; it can thus create a learning environment that offers comfort, visual appeal, and high learning efficiency. The approach adopted in this study directly responded to the growing importance of environmental aesthetics and user-centered needs in products designed for contemporary education settings.



Fig. 4.
First Version of the Stingray Desk and Chair Design Sketch.



Fig. 5.
Second Version of the Stingray Desk and Chair Design Sketch.

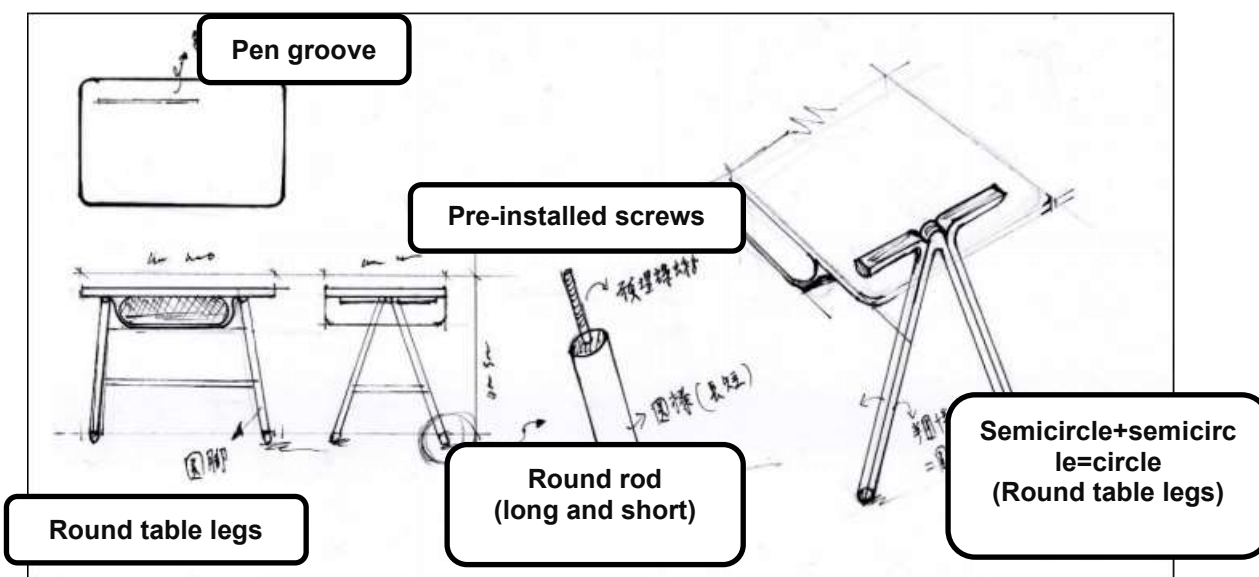


Fig. 6.
Third Version of the Stingray Desk and Chair Design Sketch.

On the basis of integration of the 7 to 10 expert interview results and conceptual sketches, the second version (Fig. 5) was ultimately selected as the final design for the elementary school desk and chair set. This version was thoroughly evaluated in terms of its external form, structural stability, cost-efficiency, and feasibility for mass production. Expert recommendations regarding student posture and the functional requirements of learning spaces were fully incorporated to ensure that the design met real-world usage needs. In terms of functional features, the final version has an innovative round leg frame combined with extendable leg components (corresponding to the adjustable leg column from the third sketch in Fig. 6). Pre-embedded screws are employed (Fig. 7) to ensure that students of all sizes can employ the furniture. The design offers three chair and desk length specifications - length of 50, 80, or 110 mm to accommodate students of diverse heights and developmental stages. Sustainable wood is selected as the primary material for construction of the desk and chair to achieve a natural texture while aligning with environmental considerations. Sustainable wood ensures high energy efficiency and minimal material waste during production, thereby reducing the overall carbon footprint and demonstrating a strong commitment to environmental responsibility.

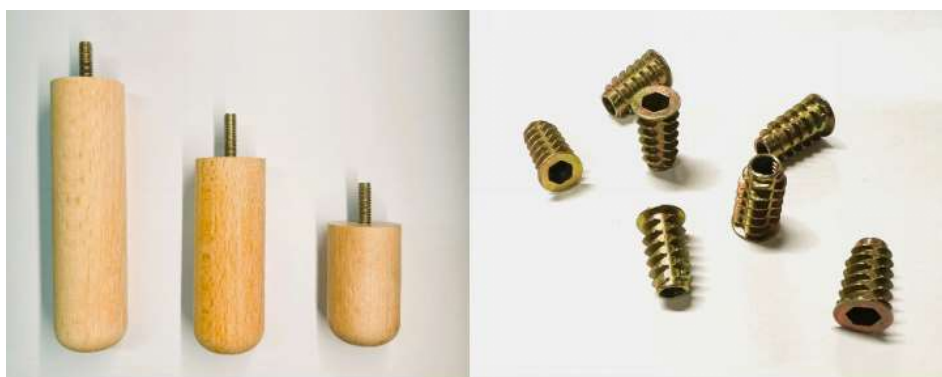


Fig. 7.
Application of Hardware Pre-embedded Screws in Adjustable Leg Design.

Final Version of Creative Stingray-Inspired Children’s School Desk and Chair

The following are final Version of Creative Stingray-Inspired Children’s School Desk and Chair. Figure 8 shows the desk design, while Figure 9 depicts the chair design.

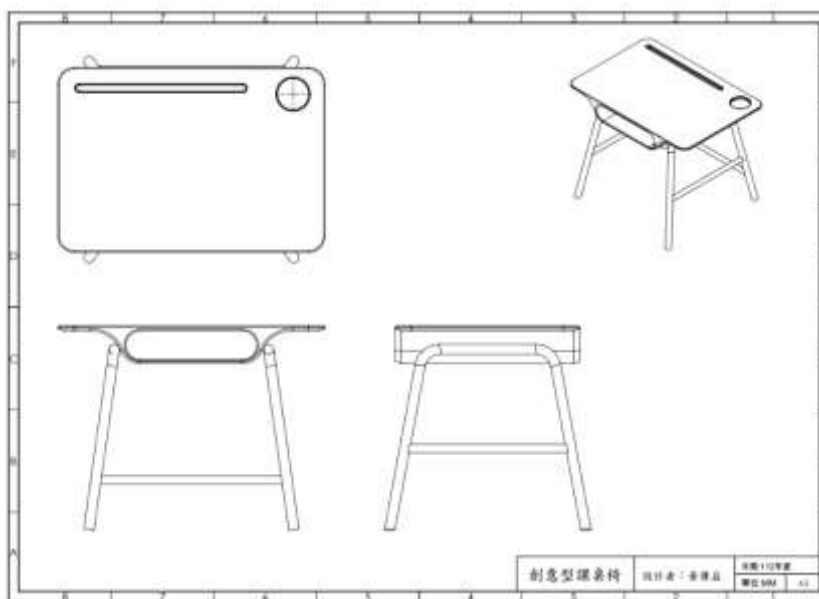


Fig. 8.
Creative Design of Elementary School Classroom Desk.

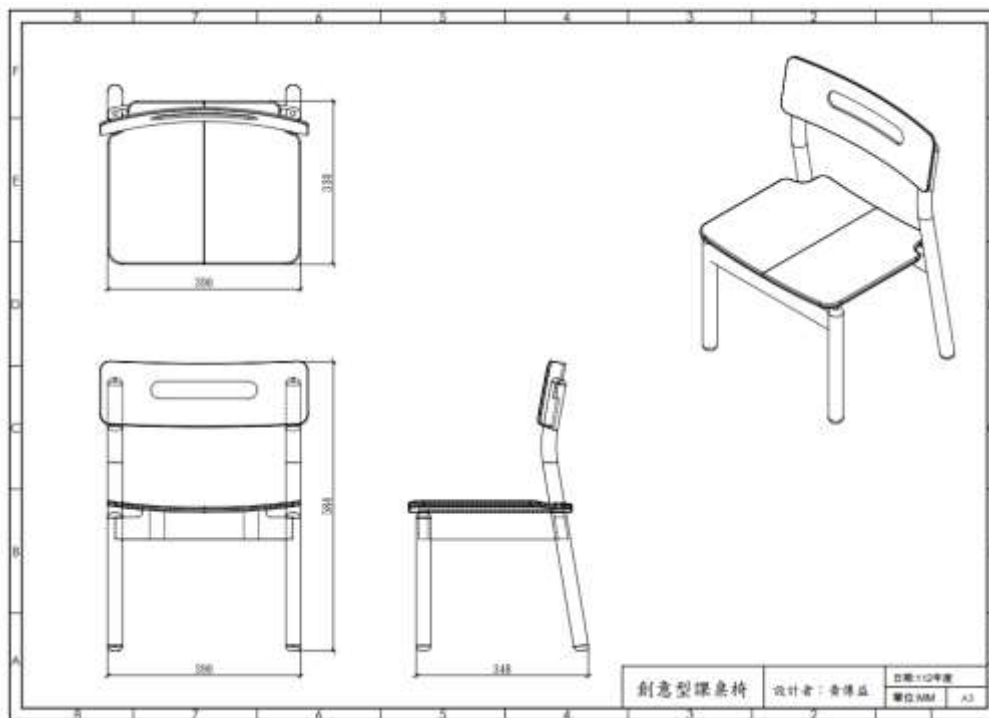


Fig. 9.
Creative Design of Elementary School Classroom Chair.



Fig. 10.
3D Rendering of Creative Stingray Elementary School Desk and Chair.

Prototype Fabrication

To fabricate prototypes, walnut and ash wood were selected as the primary materials to balance the structural characteristics, functional requirements, and visual aesthetics of the desk and chair design. These wood materials offer excellent durability and workability and have a natural texture and warm tactile quality that align with the usage needs of students and the aesthetic values of educational environments. Prototypes were fabricated with strict adherence to the design drawings, ensuring precision in dimensions, form, and

structural assembly so that the prototypes would closely reflect the original design intent. Once prototypes had been created, this study tested their quality in terms of their structural stability, material durability, and ergonomic compatibility. The outcomes of these tests identified potential issues and played a critical role in informing design refinements. These refinements further enhanced the products' functionality, comfort, and safety, thereby laying a solid foundation for future mass production and practical implementation.



Fig. 11.

Usage Scenario of Creative Stingray Elementary School Desk and Chair.

Product Stability and Strength Testing

To ensure the safety and quality of the desk and chair in actual school classroom environments, this study conducted stability testing and strength testing in accordance with Taiwan's CNS14430 standard, Furniture - Standard Classroom Desks and Chairs for Schools (Sections 8.2 and 8.3, respectively). This standard is specifically established for commonly used classroom furniture and aims to ensure students' safety and comfort during daily use. The test results indicated that the products met the standard requirements for stability and load-bearing strength and exhibited satisfactory safety and durability in use (Table 4).

Table 4

CNS14430 Furniture - test results for (school) standard classroom desks and chairs

Category	Performance Requirement	Corresponding section in CNS14430	Outcome	
Stability	Desk stability under vertical force	No tipping	8.2.1	Compliant
	Desk stability under vertical and horizontal forces	No tipping	8.2.2	Compliant
	Front stability of chair	No tipping	8.2.3	Compliant
	Side stability of chair	No tipping	8.2.4	Compliant
	Rear stability of chair	No tipping	8.2.5	Compliant
Strength	Vertical load strength of desk	No loosening, damage, or defects that impair use	8.3.1	Compliant
	Sustained vertical load on desk	Deflection within 1% during loading and within 0.3% after load removal	8.3.2	Compliant
	Horizontal load strength of desk	Displacement under 20 mm; no loosening, damage, or defects that impair use	8.3.3	Noncompliant
	Drop test of desk	No loosening, damage, or defects that impair use	8.3.4	Compliant
	Seat strength of chair	No loosening, damage, or defects that impair use	8.3.5	Compliant
	Backrest strength of chair	No loosening, damage, or defects that impair use	8.3.6	Noncompliant
	Seat durability of chair	No loosening, damage, or defects that impair use	8.3.7	Compliant
	Backrest durability of chair	No loosening, damage, or defects that impair use	8.3.8	Noncompliant
	Front leg strength of chair	No loosening, damage, or defects that impair use	8.3.9	Compliant
	Lateral leg strength of chair	No loosening, damage, or defects that impair use	8.3.10	Compliant
	Seat impact resistance of chair	No loosening, damage, or defects that impair use	8.3.11	Compliant
	Backrest impact resistance of chair	No loosening, damage, or defects that impair use	8.3.12	Compliant
	Drop test of chair	No loosening, damage, or defects that impair use	8.3.13	Compliant

Table 5

Strength test for the backrest of a chair (8.3.6)







		
8.3.6(c) Chair during the chair backrest strength test	8.3.6(c) Structural tear in the chair backrest after the test	8.3.6(e) Structural tear in the chair backrest after the test

Table 6

Durability test for the backrest of a chair (8.3.8)

		
8.3.8(b) Chair before the chair backrest durability test	8.3.8(c) Chair during the chair backrest durability test	8.3.8(d) Result of the chair backrest durability test

According to the results of the stability (Section 8.2) and strength (Section 8.3) tests conducted in compliance with CNS14430, the desk and chair prototypes developed in this study met the basic standard requirements and exhibited sufficient structural stability and load-bearing capacity. However, further durability tests revealed signs of structural tearing and fatigue under conditions simulating long-term repeated use. The failure in durability testing was attributed to deviations in material thickness and insufficient joint design strength. These problems indicated that the product did not fully satisfy the durability criteria stipulated by CNS14430. Consequently, improvements are still required in terms of structural reinforcement and material selection. Future design refinement will focus on reinforcing high-stress areas and re-evaluating the connection techniques and material durability to enhance the overall safety and lifespan of the desk and chair set. Through these efforts, designs that can serve reliably and stably in school environments over extended periods of use will be created.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Grounded in the principles of biomimetic design and subtractive design, this study conducted a systematic analysis and innovative redesign of elementary school desks and chairs. Drawing upon a literature review, expert interviews, design conceptualization, and empirical testing, this study proposed a human-centered, functional, and aesthetically integrated design solution that addresses the diverse needs of students in learning environments. The following conclusions were drawn from this study:

1. Through the literature review and semistructured expert interviews, this study conducted an in-depth analysis of the wooden and plastic steel desks and chairs currently used in Taiwanese elementary schools. The findings indicated that although existing designs do incorporate ergonomic principles, they remain somewhat uncomfortable. For instance, wooden desks and chairs are available in up to 15 sizes, which theoretically accommodate a wide range of student body types. However, because of budget constraints, schools are unable to procure the full range of sizes, resulting in students using furniture that does not fit them, which negatively affects posture and comfort during learning. Although wood has environmental benefits and a warm tactile quality, it is relatively soft and prone to damage, and its use thus leads to high maintenance frequency and replacement costs. By contrast, plastic steel desks and chairs are more durable, but their adjustable mechanisms raise safety concerns, particularly their exposed adjustment screws, which can injure students. Furthermore, maintenance of such furniture requires specialized welding techniques, and this presents logistical and financial challenges for schools lacking technical personnel. In summary, the present study's findings highlight the need for further optimization of desk and chair designs such that they more effectively meet the physical and developmental needs of students and the practical conditions of school environments.
2. This study conducted an in-depth examination of the current usage conditions of elementary school desks and chairs and drew design inspiration from comprehensive expert interview data to develop a product titled the Creative Stingray-Inspired Children's School Desk and Chair by incorporating biomimetic design principles. The proposed design has a naturally flowing aesthetic form and high functionality and adjustability, effectively addressing the diverse body sizes and growth stages of elementary school students. A key innovation is how the desk and chair are assembled; specifically, a standardized single-size configuration is combined with pre-embedded screws to simplify both production and assembly processes, thereby improving manufacturing efficiency and ease of maintenance. The design includes three modular leg column heights, enabling adjustment on the basis of a student's height and usage habits. This flexibility enables students to optimize their posture and desk height, enhancing their comfort and concentration during learning. The design successfully overcomes the limitations of conventional fixed-size desks and chairs, demonstrating a flexible structural approach grounded in user-centered design thinking.
3. In response to experts' recommendation to provide storage, this study adopted a deliberate and measured approach in the design process, guided by the core principles of minimalist design. Excessive emphasis on storage functions was intentionally avoided for two key reasons. First, the inclusion of unnecessary storage space could lead to structural complexity, where aesthetic simplicity was instead desired; second, contemporary classrooms are typically equipped with lockers, which are sufficient to meet students' daily storage needs. Accordingly, the design has only the essential storage capacity and adheres to the principles of subtractive design. It provides limited yet sufficient storage, balancing practicality with aesthetic value. The design not only responds to actual user needs but also aligns with the aesthetic standards of contemporary educational spaces, offering students a well-organized, comfortable, and visually appealing learning environment.
4. This study employed a uniaxial multifunctional testing machine to conduct stability and strength tests on the developed desk and chair set. These tests complied with the provisions set forth in Sections 8.2 and 8.3 of the CNS14430 standard and were conducted under conditions of continuous loading and pressure. The results demonstrated that the design generally met the standard requirements for structural stability and basic durability and thus had a reasonable level of safety and reliability in use. However, in the durability testing phase, structural tearing was observed at the joints between the rear legs and side crossbars of the chair seat, indicating potential risks in these areas under long-term use. These findings suggest that these structural components require reinforcement and optimization. Future design improvements should focus on strengthening the connection methods and selecting more durable materials to enhance the overall durability and safety of the desk and chair. This will ensure compliance with school furniture quality standards and suitability for daily use in educational settings.

Recommendations

1. Ongoing Design Optimization: Continual attention should be given to the optimization of desk and chair design, particularly in terms of material selection and adjustability. Designs should be evaluated and

updated regularly to respond to the latest research findings and market demands. Exploring new materials and manufacturing technologies will facilitate the enhancement of product performance and the user experience. This in turn may lead to the creation of more comfortable, healthy, and learning-conducive classroom environments, thereby improving students' academic performance and the overall quality of learning spaces.

2. **Fatigue Testing for Adjustable Desks and Chairs:** Newly designed adjustable desks and chairs should undergo comprehensive fatigue testing to evaluate their long-term durability and safety. The testing should cover aspects such as material strength, structural integrity, and the stability of adjustable mechanisms to ensure that products have sufficient load-bearing capacity and operational safety for daily use in educational settings. Through scientifically structured testing procedures, a design's quality can be validated to provide a foundation for design refinement and mass production, thereby safeguarding the health and safety of students during use.
3. **Use of Wood Certified by the Forest Stewardship Council:** In the redesign and production of elementary school desks and chairs, designers should prioritize the use of wood certified by the Forest Stewardship Council. This certification is an internationally recognized sustainability standard aimed at promoting responsible forest management. The adoption of certified materials not only contributes to the conservation of global forest resources and the reduction of environmental impact but also reflects the commitment of designers and educational institutions to environmental stewardship. Moreover, this practice carries educational significance by subtly fostering students' awareness and understanding of sustainability and environmental responsibility, thereby serving as a positive example of sustainable practices.
4. **Postuse Evaluation:** A designed product should undergo postuse evaluation, which would take the form of broad user experience testing with the participation of both students and teachers. Feedback should be collected regarding a product's comfort, functionality, and aesthetic performance in actual use. Such input will facilitate a deeper understanding of how a design performs in real educational environments, thereby facilitating necessary refinements and optimizations. Postuse evaluation helps validate the practical value of a design and strengthens the connection between design outcomes and user needs, effectively improving product acceptance and enhancing the overall quality of educational environments.

REFERENCES

- CNS14430 (2011) 家具—(學校) 普通教室用課桌椅 CNS14430 (2011). Furniture - Desks and Chairs for General Classroom. Extracted from: https://www.cnsonline.com.tw/?node=result&typeof=common&locale=zh_TW
- Bendix T (1987) Adjustment of the seated workplace - with special reference to heights and inclinations of seat and table. *Danish Medical Bulletin*, 34(3):125-139.
- Bjerke R, Ind N, De Paoli D (2007) The impact of aesthetics on employee satisfaction and motivation. *EuroMed Journal of Business*, 2(1):57-73.
- Brunswic M (1984) Ergonomics of seat design. *Physiotherapy* 70(2):40-43.
- Dianat I, Karimi MA, Hashemi AA, Bahrapour S (2013) Classroom furniture and anthropometric characteristics of Iranian high school students: proposed dimensions based on anthropometric data. *Applied ergonomics*, 44(1):101-108.
- Domljan D, Vlaović Z, Grbac I (2010) Pupils' working postures in primary school classrooms. *Periodicum biologorum*, 112(1):39-45.
- Gouvali MK, Boudolos K (2006) Match between school furniture dimensions and children's anthropometry. *Applied ergonomics*, 37(6):765-773.
- Guat-Lin ET (1984) Anthropometric data and its use for educational building and furniture design.
- Panagiotopoulou G, Christoulas K, Papanicolaou A, Mandroukas K (2004) Classroom furniture dimensions and anthropometric measures in primary school. *Applied ergonomics*, 35(2):121-128.
- Parcells C, Stommel M, Hubbard RP (1999) Mismatch of classroom furniture and student body dimensions: empirical findings and health implications. *Journal of adolescent health*, 24(4):265-273.
- Veenstra R, Molenbroek JFM (2003) Design for all in the working environment : inventory of workspace adaptations. In *Include 2003: inclusive design for society and business* (pp. 12-488). Helen Hamlyn Research Centre.