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Investigating the Integration of Biomimicry and Eco-Materials in Sustainable Interior Design Education

Iman Ibrahim [1,*] and Rania Nasreldin [2]

[1] Applied Design Department, College of Fine Arts and Design, University of Sharjah, Sharjah 27272, United Arab Emirates
[2] Architecture Engineering Department, College of Engineering, Cairo University, Giza 12613, Egypt; raniaibrahim@eng.cu.edu.eg
* Correspondence: iibrahim@sharjah.ac.ae

Abstract: This paper discusses the adoption of biomimicry and eco-friendly materials as overarching concepts in interior design education. It aims to investigate how biomimicry and eco-friendly materials can be integrated into the existing and established interior design program curriculum. Changes in green and sustainable design concepts used in student capstone projects, which incorporated the reiteration of learning objectives aimed at enhancing student learning outcomes, were identified. This investigation addressed a gap in knowledge by analyzing the influence of nature-inspired designs on students' problem-solving abilities and creativity. It employed a qualitative case study approach to analyze selected designs that employed biomimicry concepts in functional interior spaces, followed by a visualization stage, in which 3D-printed models were created from recycled and eco-friendly materials, closing the loop on sustainability applications. The study revealed that biomimicry and eco-friendly materials are valuable components of various design curricula, particularly in the fields of environmental studies, architecture, and interior design. This research underscores the urgent need to comprehensively integrate biomimicry and eco-friendly materials into design curricula, fostering a new generation of sustainability-conscious designers equipped to lead transformative change in the future of interior design and beyond.

Keywords: biomimicry; sustainable interior design; recycled materials; design education

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1. Introduction and Literature Review

As a sustainable method of interior design, biomimicry uses natural ecosystem-inspired design concepts and techniques to produce environmentally responsible, productive, and aesthetically beautiful interior spaces. Utilizing nature's tried-and-true designs, systems, and processes as models and sources of inspiration, this ground-breaking method tackles issues with sustainability, resource use, and general functionality in the context of interior design [1].

Minucciani and Onay emphasize the potential of various design approaches, notably generative design, in enhancing well-being in interiors, advocating for a framework that systematically integrates well-being criteria into design processes [2]. Rossin suggests grafting a biomimicry phase into the design process to achieve sustainable solutions, backed by case studies demonstrating practical applications [3]. Another study reveals how nature-inspired designs enrich creativity and lead to unique and sustainable furniture designs, as evidenced by student projects collectively advocating for a more profound integration of biomimicry and sustainability in design education and practice [4]. On the

other hand, the "Breathing Window" is a biomimicry-based model inspired by natural systems for ventilation and thermal regulation. It aims to enhance building ventilation and thermal comfort, thereby supporting ecological sustainability and balance [5].

Many design fields, especially in urban design and architecture [6], including interior design, have seen tremendous growth in sustainability and the incorporation of health and well-being as central components of their practices [7,8]. How we live, work, and design today are vital indicators for the designers and consumers of tomorrow [9]. Integrating biomimicry and design materials with a less harmful environmental profile is an essential element in a curriculum that celebrates a radical shift towards a sustainable design mindset. The potential connection between biomimicry, eco-friendly materials, and a curriculum for sustainable interior environments is currently relevant to address contemporary educational needs [8]. Awadalla investigates the potential of biomimicry as a sustainable design strategy in interior spaces. Through a descriptive-analytical approach, the study explores how natural systems can inspire innovative design solutions that contribute to achieving various Sustainable Development Goals (SDGs) [10].

Additionally, the lack of applied research in these areas within design fields presents an excellent opportunity to distinguish a curriculum from others. A natural setting for this is sustainable education, where knowledge transfer methods that emphasize experiential learning can go beyond traditional classroom instruction, offering continuous learning opportunities essential for impactful education [11].

This research employs the literature and evidence to provide a sustainability-driven rationale for developing biomimicry and eco-friendly materials, addressing current educational sustainability goals and the interconnected challenges within traditional interior design curricula in higher education [12]. Educational implications, such as enhancing the integration of sustainability into curriculum design, are analyzed. The quest for quality education and its linking values on campus, in alignment with relevant external stakeholder positions, are listed and justified [13].

The review of the related literature in this study is divided into different parts: Biomimicry in Design Education, Eco-Friendly Materials in Interior Design, Sustainability in Education, Practicality in Education, and Curriculum in Sustainable Interior Environments. Biomimicry in Design Education is related to the use of nature's approach to inspire sustainable design solutions [14]. The learning environment serves as an interdisciplinary catalyst for problem-based learning, experiential education, engineering, sustainability, systems thinking, and creativity. This concept has aspects that can be perceived as eco-friendly and problem-based approaches, offering engineering, architecture, and design to students investigating a problem that they can solve by using biomimicry.

In recent years, designers, construction managers, and various other design-based disciplines have become increasingly interested in the use of alternative surface finishes that are viewed as eco-friendly materials [15]. The use of rice straw, for instance, has entered the world of the interior design industry as a cheaper and more environmentally friendly raw material compared to other facades. This is because rice straw materials are easily accessible and are by-products of farming. The main objective of using these eco-friendly materials is to reduce unemployment by opening opportunities for the manufacture of eco-friendly goods based on people's preferences and to instill the need for eco-friendly products. Interior designers, especially, can minimize negative environmental impacts and enhance the amenities and wellness in constructed indoor spaces. Therefore, interior designers must choose green or ecological materials.

In contrast to interior design and architecture, the concept of sustainability is still new, not only in other fields of study but also in general society. Especially concerning sustainability in the interior industry, it is still very minimal. Only one study focused

on using materials for facades, but it did not cover furniture and decorative materials. Therefore, the sustainable use of materials in interior design education can be a boost for future interior designers to pay attention to and support national growth.

This study aims to explore how biomimicry and eco-friendly materials can be integrated into interior design education to promote sustainability and innovation.

To guide this investigation, the following research questions were posed:

RQ1: How can biomimicry and eco-friendly materials be effectively integrated into interior design curricula?

RQ2: What is the impact of this integration on students' creativity, problem-solving skills, and sustainability awareness?

While no formal hypothesis is tested because of the qualitative nature of this research, this study assumes that incorporating these strategies will positively influence students' design thinking and environmental consciousness.

This research not only discusses the benefits of biomaterials but also documents their application in students' projects, evaluating their impact on heat/moisture management, air filtration, and responsive design.

However, unresolved issues with interior design education through biomimicry approaches still exist. This paper aims to bridge an essential research gap by attempting to recognize an educational approach to interior design applications inspired by nature, evaluating the approach to sustainability. Students' designs in the same scope are discussed thoroughly, referring to current practices. This unique approach of combining technical practice with a literature review is promising in achieving a dependable outcome. What is expected as a result is conditional on the literature review and how it connects to the students' designs, but, in general, it is expected that technologically advanced methods will be integrated with the educational approach.

Significance of This Study

Sustainable design research aims to address challenges faced by emerging designers and communities. It seeks to inspire changes in design curricula at both the personal and institutional levels by unraveling ethical and environmental dilemmas. This can provide urgency for change.

Design students who do not prioritize environmental issues in their work are not connected with the world's global environmental issues. This research integrates biology into new teaching frameworks, requiring multidisciplinary practices. Stimuli research can provide the necessary guidance for applying these designs. This research shows how biomimicry and eco-friendly materials can shape this idea.

In the short term, design students and academics will benefit from this teaching methodology. There will also be long-term implications for the design industry. However, this research only addresses one part of a complex system and may raise unanswerable questions. Biomimetic principles need to be integrated into design tools for a real sustainability impact. We can only strive to disseminate our limited knowledge to make a positive difference in the long term. For those in design education, they can make a significant impact on future designers. This research challenges academics to invest time in shaping future generations' minds to make a real-world difference.

2. Biomimicry in Design

Biomimicry is the study of how living things solve problems by taking cues from them and adapting them to similar situations that humans and other cultures encounter. The advantage is that nature provides us with unlimited tactics that function in harmony with the rest of nature considerably better than many techniques that have been invented

by humans. Hence, as stated in Ref. [16], the objective is to develop systems, procedures, and goods that responsibly address our most pressing design problems while coexisting peacefully with all living things.

Three key components are involved in the process of biomimicry, which is the translation of natural tactics into designs. Emulation involves the practice of drawing inspiration from the structures and functions of nature to direct human creativity and provide more regenerative design solutions [14]. Ethical framework reflects the understanding that we must preserve and safeguard ecosystems, as well as a dedication to applying the lessons acquired from natural ecosystems in a way that fosters life [17]. Reconnection explores the understanding that all other living things on Earth are interdependent systems and that humans and our actions do not exist outside of nature but rather are a part of it. Reconnecting with nature as a discipline helps designers pay attention to nature and spend time there to gain a better understanding of how life functions.

Having explored the concepts of one great goal and regeneration, the discussion now shifts focus to one of the cornerstones in any biomimicry approach: life's principles. Also known as nature's operating instructions, life's principles are nature's strategies that have been developed over 3.8 billion years for the sustainability of life on Earth [16]. Serving as the primary guidelines for biomimicry, life's principles inform sustainable innovation and design. Though flexible in nature, the idea is that the more these principles are adhered to, the more likely any design will benefit all biological systems of support that make up the overarching system of which a product, process, or organizational system is a part.

Life's principles can be thought of as the catalyst for making products and processes better, not just because they are not as harmful as before, but because they are restorative to natural systems as well [14]. Many companies want to follow life's principles to mitigate the costs of the environmental damage they cause; however, if they do not innovate fast enough or correctly, then regulation can also drive innovation and design [18].

The Design Spiral, as shown in Figure 1, aims to provide practitioners with a high-level view of the methodology necessary to implement principles within the Life's Principles concept in the product development process [19]. Ecologically inspired, all phases are iterative to build in feedback and refinement at each stage.

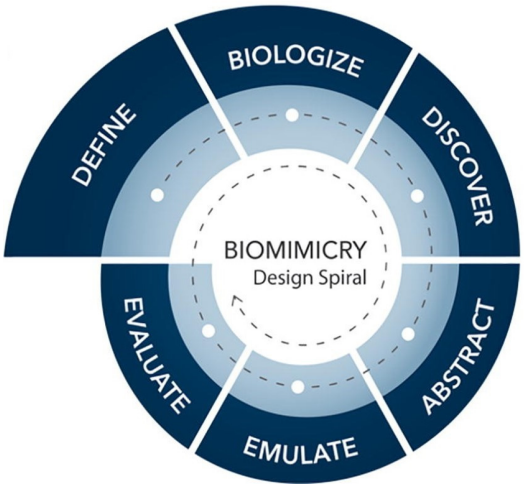


Figure 1. Biomimicry Design Spiral; obtained from https://toolbox.biomimicry.org/methods/process/ (accessed on 14 September 2024).

The Design Spiral comprises four phases (with feedback going both forward and back) and seven iterations. This inherently cyclic approach encourages designers to revisit each of the domains of nature to interact as the premise develops. In practice, biomimetic solutions often emerge as a direct result of revisiting, enriching, or increasing the internal syntropic

loops, and are often not anticipated at the outset of the project. In general, every step changes every other step in the spiral, so the whole thing changes every time you complete a revolution. The payoff for transformative wealth creation at the end of a Design Spiral impact loop is 20-20, if performed properly [20].

3. Design by Nature

Biomimicry, often described as "sustainability within nature's boundaries," refers to an approach in materials, product development, architectural design, and engineering that imitates nature to achieve a harmonious balance between environmental, economic, and social performance [3,14]. Human beings have been learning from nature since the beginning of observing living materials, understanding the anatomy of plants, and studying natural wonders. Today, the concept of bio-geometry, also known as "the geometry of life", reflects this deep connection to natural forms and processes [16]. Despite challenges in incorporating ecological sound design into interior design curricula, it is increasingly feasible to integrate sustainable practices and materials. To effectively integrate biomimicry and eco-friendly materials into sustainable interior design education, design and art schools should offer specialized courses and establish partnerships with corporations and government organizations that support sustainable design research [14].

Eco-Friendly Materials in Interior Design

Materials play a major design role in both physically shaping design objects and interior spaces and guiding the behavior of users, occupants, or observers. In interior design, many materials are now recognized for their minimal environmental impacts, such as reclaimed lumber, bamboo, cork, linoleum, wool, and more [15]. These materials, often referred to as green, sustainable, or eco-friendly materials, can thus be used in modern design projects in combination with architectural techniques to create a composition of elements that require less space, consume less energy, and are made with more sustainable elements, such as alternative energy, post-consumer, and post-industrial waste [21,22].

Using green materials highlights important design considerations that can be embraced by users or occupants, making sustainability a meaningful part of the interior design philosophy. The production of environmentally friendly designs and objects is but a subset of the entire sustainability perspective. It considers the selection of non-toxic materials and cleaner manufacturing processes to produce a healthier indoor environment for occupants [17].

Despite the potential benefits of using recycled materials, there are current limitations in their availability and concerns about increased consumer costs. A critical aspect of eco-friendly material research is its intersection with material science and sustainable design. While this connection has been previously explored, there is a common misconception that materials emerging from material science research are inherently environmentally friendly or connected to sustainable practices [15]. Therefore, advances in material science can contribute to studies of sustainable intentions and sustainable design education.

Given that sustainable environments strive to appeal to sensory perception while enhancing health, happiness, and performance, we argue that material is fundamental to this aim, and a broadened understanding of its principles will improve sustainable design educational pedagogy.

In the sustainable interior environment course (our case study), we managed to use 3D printing technology to produce the final prototype model for students. The filament is usually made from plastic materials. However, in this case, we collected plastic bottles from the campus and managed to segregate different types of plastics to guarantee having the same material. Then, we used a shredder to shred PET, the plastic bottles' bodies, without

the caps. After drying the shredded materials using a dryer, we used the composer to create new filaments that were mixed with waste wood fibers, creating new recycled filaments.

4. Methodology Approach

The methodology section provides a detailed account of the research design used in this study. Given the limited and emerging research base in biomimicry and eco-friendly materials in interior environments, calling for in-depth insights, a qualitative case study approach was selected as the research design. A case study is suitable for research that explores a single or multiple instances in a real-life context and in-depth, while also embracing the complexity inherent in theoretical perspectives. This qualitative case study analyzed the work of interior design students who employed biomimicry principles to propose sustainable interior solutions. This study, as shown in Figure 2, focused on the conceptualization, design process, and creation of 3D-printed models using recycled filaments from plastic bottles and wood fibers. The data collection methods included student design portfolios, alongside a review of the final 3D-printed models to assess the application of sustainable design principles and materials.

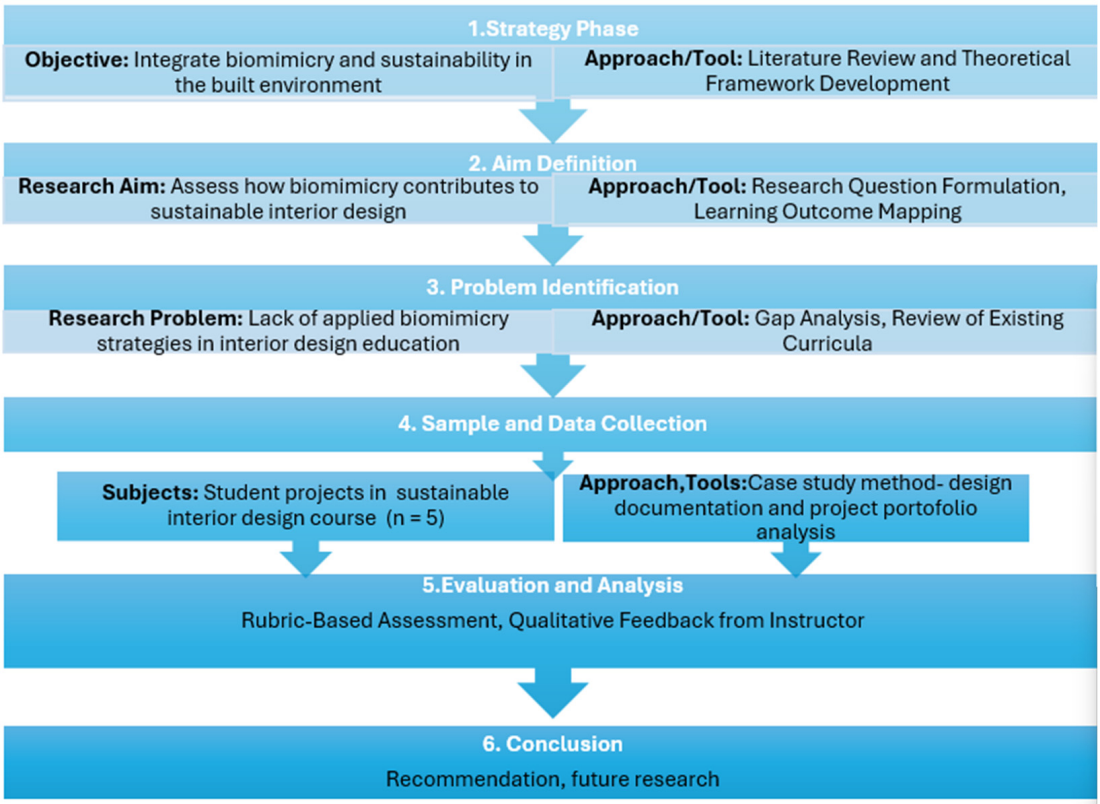


Figure 2. Paper methodology. Source: Authors, 2024.

This study followed a balanced approach of guided biomimetic form and open student inquiry. While the students were completely free to research in an open and intuitive framework, each project was situated in a rigorous process that formed a strong connection between the selected biological inspiration and the ultimate design results. In particular, the students operated step by step: they found a natural model, analyzed its functional strategies, drew out useful principles, and translated these into design intent and material choice. The process was open, with free-form experimentation and formal analysis of how biomimicry concepts influenced geometry, material choice, and resulting building performance.

4.1. Course Assignment Overview

Based on the knowledge and studies on biomimicry theories, the students at the college of art and design, University of Sharjah, were asked to design one prototype that would be printed using AM technology (3D Printers), with other bio-based, recycled, or sustainable materials in a box sized 30 × 30 × 30 cm. They could choose to design wall panels/wall cladding/column cladding/ceiling design/interior partition or screen/custom interior detail, which should solve the interior design problem by mimicking nature's solutions.

In all student case studies, the prototype models were fabricated using a custom 3D-printed filament composed of shredded post-consumer plastics and wood fibers. This approach not only diverts waste from landfills but also demonstrates practical upcycling, directly supporting sustainability objectives within the curriculum.

4.1.1. Phase 1 (Concept)

Biophilic design seeks to create a good habitat for people, as biological organisms in the modern built environment advance people's health, fitness, and well-being. In Phase 1, the students were tasked with identifying a natural system or organism as inspiration and analyzing its functional strategies to inform their interior design concept. Based on the students' understanding of nature systems, the students had the freedom to generate a "nature-inspired concept". They wrote about 300 words on the selected cell/unit from nature, explaining its uniqueness and values using images and freehand analytical sketches. Then, they determined the Nature–Design relationship (direct/indirect), i.e., whether the design solution directly mimics a natural form or process (direct) or is inspired by broader principles, and the selected pattern of biophilic design from the 14 patterns of biophilic design, including Visual Connection with Nature, Non-Visual Connection with Nature, Thermal and Airflow Variability, etc., which could be more than one. Finally, they determined the biomimicry level (organism/behavioral/ecosystem) with analytical sketches. Biomimicry operates at three distinct levels of imitation: the organism level, which involves mimicking a specific organism's form or function; the behavioral level, which is focused on emulating natural behaviors or interactions; and the ecosystem level, which replicates system-wide relationships and flows found in nature.

4.1.2. Phase 2 (Visualization)

Working on the selected design concept inspired by nature, the students were required to emphasize the biomimicry design concept related to the Parametric Form selected (fractal/Voronoi)—where fractal refers to a self-similar, repeating natural pattern and a Voronoi structure refers to a pattern dividing space into efficient, organic cells—to visualize their nature-inspired concepts. They were also asked to create a 2D drawing with RHINO software (version 8.1) as follows:

1. Create 2D drawings from the concept analytical sketches using RHINO/Grasshopper.
2. Show different alternatives to your design based on the selected cells/units from nature.
3. Form geometrical potentials based on algorithms, creating innovative form generation.

4.1.3. Phase 3 (3D Printing and Interior Design Visualization)

The finalization of the concept and the form generation was followed by panel detailed drawings using Rhino software, where the students were required to present these drawings and reflect the panels in their design studio project. This included the following:

1. Two-dimensional drawings for the designed wall panel (selected interior detail).
2. Three-dimensional-rendered shots for the designed panels within the design studio project.
3. Three-dimensional-printed design products.

4.2. Case Studies Selection

In this section, the authors explain the student work as case studies. The methodology is not very common, but it is one step closer to involving teaching methods in the research arena. The students were aware of their involvement in this academic paper. It is essential to highlight that the data collection was based on the concepts made by the students, not the other way around. This exactly makes the method legitimate and educationally based. The data was provided by the students as part of their submission, and then, the authors relied on it to conduct the second part: the literature review.

The five student projects were selected based on the following criteria:

- **Design Quality**: The projects demonstrated a high level of creativity, technical execution, and alignment with sustainability and biomimicry principles.
- **Thematic Relevance**: Each project addressed a distinct aspect of the research themes.
- **Diversity of Approach**: The projects reflected a variety of design strategies and methodologies, including digital modeling, material experimentation, and user-centered design.
- **Representativeness**: The selected projects collectively represented the broader outcomes of the course and included students with different academic performance levels and design perspectives.
- **Completeness of Documentation**: The projects with well-documented development processes, including concept sketches, 3D models, material choices, and reflective statements, were prioritized for inclusion.

4.3. Qualitative Case Study Approach

A qualitative case study approach was chosen for this research because of its suitability for the research objectives and interest in providing an overview of the range of experiences participants have from a specific standpoint [23,24]. It allows a researcher to recount participants' experiences and provides an in-depth description of a particular event, program, or educational initiative, occurring organically and over which the researcher has no direct control. Again, a qualitative approach contributes to addressing the research objectives and questions because of its ability to reveal detailed insights not only through participant memories and perceptions but also by allowing interpretation and understanding to occur during the collection and analysis phases. A further rationale for utilizing a case study approach in this piece of research was the fact that an intricate approach to integrating sustainability in higher education design is more likely to reveal deeper and richer information about how and why these approaches were integrated within specific contexts.

The approach is also flexible in terms of moving with the teachings of educational discourses and paradigms. This is essential given the rise in sustainability education, the critique of linear approaches, advances of second generations of sustainability, and their yield. In other words, it provides an opportunity to reflect on the status of positive ecological transformation in the sectors that take responsibility for educating in sustainable, zero-carbon, and regenerative futures. As alluded to above, the research method is qualitative and shares the development of sustainability design education through participants' perceptions and interpretations; insights are often best found in qualitative research paradigms. The qualitative case study design allowed the authors to collect rich, abundant, and valid data from a diverse range of participants. The approach was also suitable given the practical participants and background.

4.4. Data Analysis Techniques

The analysis of data is crucial as it interprets the meanings, patterns, and connections. Five techniques are suggested to identify certain strategies used to interpret qualitative

information [25]. The major technique used in this study was thematic analysis, where the written information was synthesized for meaning and to identify inherent patterns within the data.

As a result of this collaborative process, two principal themes emerged and were agreed upon. The probable bias associated with the reflexivity present was recognized and sought to be mitigated by engaging in a thorough discussion of the various themes and ensuring a consensus before finalizing the device for the analysis [26]. This systematic approach was used to ensure reliability through the inclusion criteria based on the solutions and categorization of findings. Drawing meaningful conclusions from the data was the objective of the following section.

5. Examples from Case Studies

The project was applied to 48 students who joined the sustainable interior environment course during spring 2023. The course was conducted over the duration of one semester (approximately three months) within the Interior Design Program under the Applied Design Department at the University of Sharjah. It was led by a single instructor who guided the students through all phases of the project, from concept development to final presentation. They were undergraduate students in year 3.

This paper selected five case studies that represent different project concepts. The methodology was intentionally exploratory, fostering creativity and innovation, but each project was still mapped to the structured biomimetic framework.

5.1. Case 1: Mimicking Camel Eyes in Achieving Shade

The case study shown in Table 1 illustrates the concept of mimicking camel eyes; ''Jufn" is a contemporary Islamic window screen inspired by the form and function of the camel eye. Camels have three eyelids instead of one or even two. The translucent lid, also known as a nictitating membrane, serves as a barrier against sand and grit and can even enhance vision, much like a contact lens. The camel's eyes are cast downward, with three eyelids each, and long, even, tentacle-like eyelashes that shield against sun and sand; occasionally, the camel's third, innermost eyelid nicks sideways like a windscreen wiper.

Table 1. Mimicking camel eyes. Source: student work, 2023.

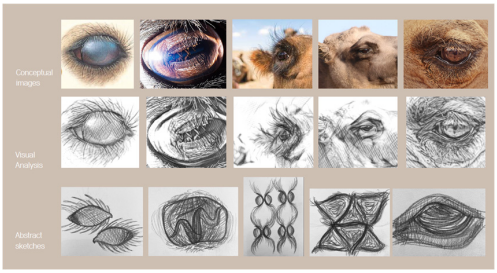
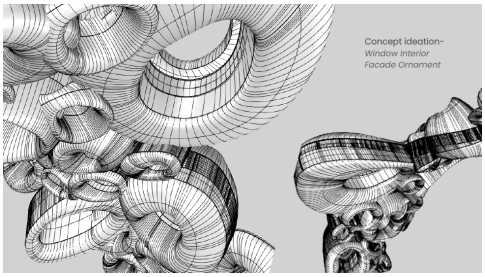
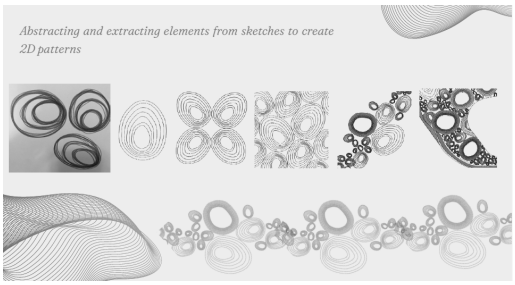
1	**Jufn Project:**	
Phase 1		
Phase 2		

Table 1. *Cont.*

1	Jufn Project:		
Phase 3			

5.1.1. Biomimetic Principle and Level

In this case study, each student selected the climate-responsive nature of the camel eyelid that acts as a shade, heat, and moisture controller. This fit the function selected for design, which was a screen. The level was the organism as the selected natural element.

5.1.2. Design Relation and Geometry Selected

In this case study, each student selected a direct relationship, where the design closely mimicked a specific natural form, which was the camel eyelid, to reflect the concept application in interior design. Each student selected fractal geometry to reflect the shape of camel eyelid cells under a microscope.

5.1.3. Design Function

The exploration of biomimicry in architecture, specifically drawing from the camel's natural adaptations, emphasizes the development of climate-responsive building envelopes. By mimicking the camel's mechanisms for heat and moisture management, architects aim to create buildings that inherently adjust to environmental conditions, reducing the need for artificial heating and cooling. The materials used in 3D printing the prototype model contained shredded plastics and wood fibers, creating new filament out of waste materials and emphasizing the sustainability aspect application.

5.2. Case 2: Mimicking Fungi Based in UAE

Turkey Tail mushroom farming is an extremely new industry in the UAE, but it has been gaining interest as people become more fascinated by complementary and natural remedies. An increasing market for health and well-being in the UAE also fuels the need for premium, locally produced goods. A viable and environmentally acceptable alternative to gathering Turkey Tail mushrooms from natural populations is to cultivate them. It is possible to grow Turkey Tail mushrooms in the UAE, although doing so necessitates environmental factors and specialized tools. The fundamental procedures for growing Turkey Tail mushrooms are fruiting, harvesting, incubation, and substrate preparation.

5.2.1. Biomimetic Principle and Level

In this case study, each student selected the air-purifying nature of Turkey Tail mushrooms in the UAE, which act environmentally against air pollutants. The level of biomimicry was the ecosystem level.

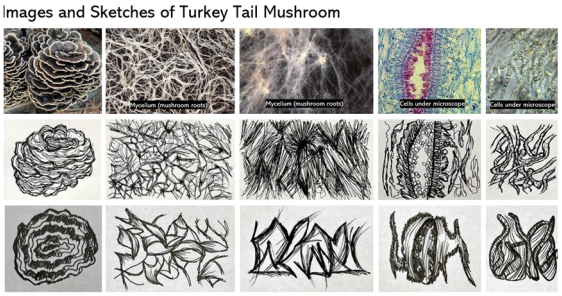
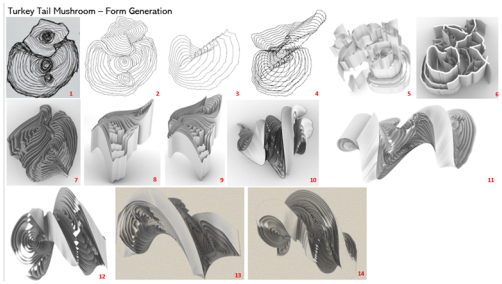
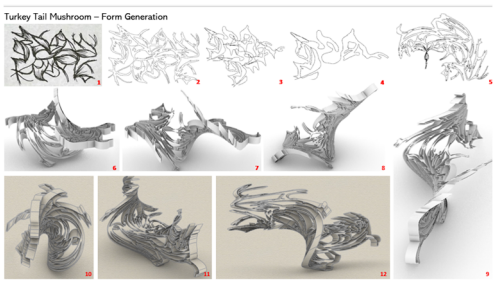
5.2.2. Design Relation and Geometry Selected

In this case study, each student selected an indirect relationship, where the design concept was inspired by the surrounding environment as a system to reflect the concept application in interior design. Each student selected fractal geometry to reflect the shape of Turkey Tail mushroom cells under a microscope.

5.2.3. Design Function

This project aimed to create a sustainable interior space by addressing indoor air pollution. Traditional interior materials often release harmful chemicals, posing health risks. To mitigate this issue, the project proposed using mycelia, the root structure of mushrooms, as a biomimetic wall cladding. Mycelium biofiltration properties can effectively remove harmful indoor pollutants, like formaldehyde and toluene. As shown in Table 2, additionally, mycelia offer excellent thermal insulation, reducing energy consumption. By utilizing this sustainable and innovative approach, the project aimed to develop environmentally friendly building materials.

Table 2. Mimicking fungi based in UAE: student work 2023.

2	**Fungi Project:**	
Phase 1		
Phase 2		
Phase 3	  	

5.3. Case 3: Mimicking Moon Jellyfish Interior Design

Just as moon jellyfish change color, biomimicry can be used to create glass partitions with patterns inspired by these mesmerizing creatures. By studying the migration of chromatophores, we can develop glass that responds dynamically to movement and light. Such material can be used in partitions to provide privacy and light management while still allowing natural sunlight to enter the space. For example, the glass could become opaque in specific sections to ensure privacy when someone enters a room and then return to its translucent state once they leave. Alternatively, it could darken and become more opaque in bright sunlight, reducing glare and providing shade, and then become more transparent as light levels decrease.

5.3.1. Biomimetic Principle and Level

In this case study, each student selected the organism level, where the students focused on the responsiveness and adaptability in the natural model of the moon jellyfish.

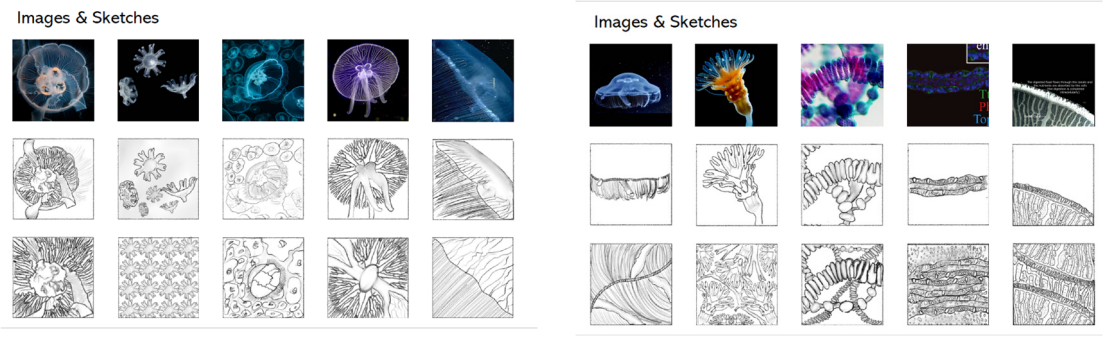
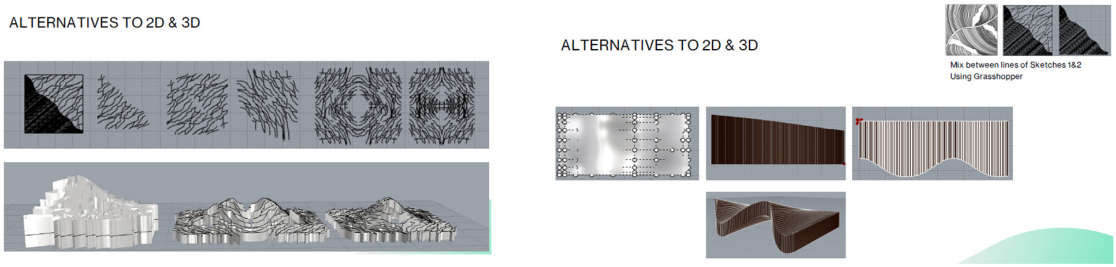
5.3.2. Design Relation and Geometry Selected

In this case study, each student selected an indirect relationship, where the design was inspired by the movement and geometry of the natural element. The students selected Voronoi geometry to mimic the organic and fluid shapes in nature.

5.3.3. Design Function

By designing glass partitions to mimic the color-changing properties of moon jellyfish, we can create aesthetically pleasing products that require less energy for artificial lighting and heating/cooling. The biomimicry level here was behavioral, focusing on the process, as shown in Table 3. The glass partition wall design mimicked the color-changing process of the jellyfish. This level of biomimicry was indirect and inspired by nature.

Table 3. Mimicking moon jellyfish: student work 2024.

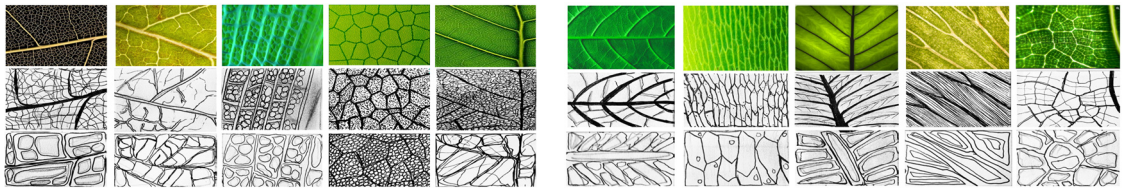
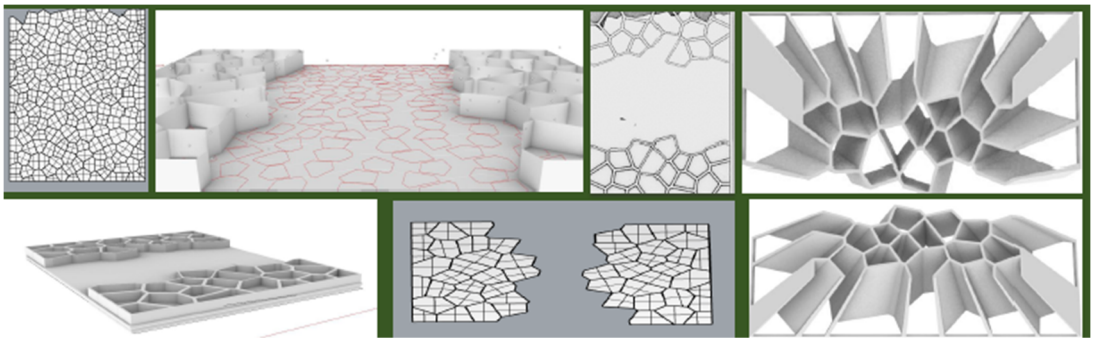
3	**Moon Jellyfish Project:**
Phase 1	
Phase 2	
Phase 3	

5.4. Case 4: Mimicking the Sidr Tree in Achieving Adaptability

This case study's concept is shown in Table 4, which states that the scientifically named "Ziziphus", the Sidr tree, is common in all emirates in sandy, flat, gravel, and alluvial areas,

as well as in valleys. Sidr trees can tolerate salinity, drought, and overgrazing to some extent. By studying and abstracting the form of leaves, graphic designers can take inspiration from nature and living things. They may go to the natural world to obtain ideas about color, shape, texture, and composition [27], as shown in Table 4.

Table 4. Mimicking the SIDR TREE: student work, 2023.

4	**SIDR TREE Project:**
Phase 1	
Phase 2	
Phase 3:	

5.4.1. Biomimetic Principle and Level

In this case study, each student selected the ecosystem level, where the students focused on adaptability and resilience in response to environmental challenges faced by the Sidr tree. The concept aimed to adapt to harsh, variable conditions as a system.

5.4.2. Design Relation and Geometry Selected

In this case study, each student selected an indirect relationship, where the design drew inspiration from the Sidr tree's adaptive strategies, abstracting the leaf form and branch patterns. The fractal, branching geometry of the Sidr tree's limbs and leaf venation was abstracted to inform the design of interior partition elements. These patterns were translated into modular, interlocking forms that can be rearranged or expanded, mimicking the tree's adaptive growth.

5.4.3. Design Function

The design also aimed to evoke a sense of connection to local ecology and cultural identity by referencing a native species. It aimed to create adaptable and visually dynamic

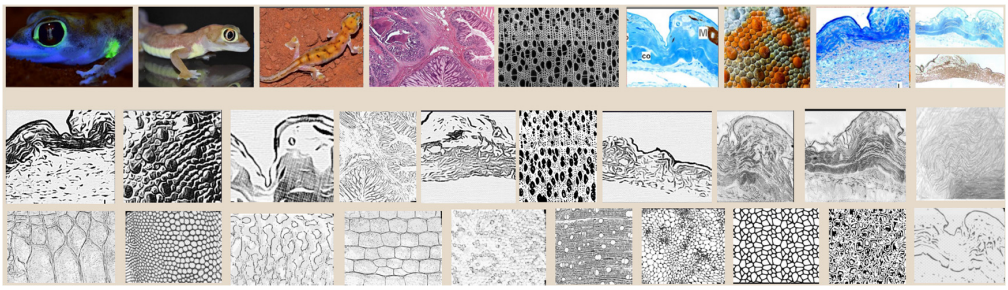
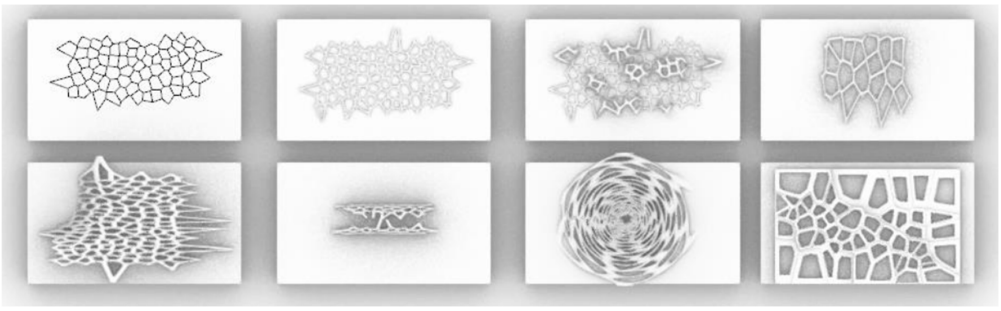
interior partitions or wall panels that can respond to changing spatial needs, light, and airflow—mirroring the Sidr tree's ability to thrive in variable conditions.

A substantial body of research supports the need for interdisciplinary collaboration between plant biology and engineering to advance the development of novel technologies, such as morphing airframes and soft robotics [28].

5.5. Case 5: Mimicking the Gecko in Achieving Energy Efficiency

This case study, as summarized in Table 5, stated the following: The wonder gecko is a species of gecko that has both fluorescent and non-fluorescent iridophores. This glow is among the brightest examples of fluorescence in land animals and is brighter than the glow from chameleons' bones. Geckos use skin pigment cells filled with guanine crystals to produce their light, which absorbs the light from the sun during the day and emits it during the night. This could help with energy efficiency by absorbing the energy needed during the day and emitting it during the night. Some studies showcase biomimicry applications in interior architecture, with a notable mention of the gecko [29]. These applications highlight the gecko's unique dry adhesion ability, leading to the development of products like Tactile and Geckskin, which are environmentally friendly and efficient.

Table 5. Mimicking the gecko. Source: student work, 2024.

5	**Case 5: Mimicking Gecko**
Phase 1	
Phase 2	
Phase 3	  

5.5.1. Biomimetic Principle and Level

In this case study, each student selected the organism level, which is directly inspired by the gecko's skin and cellular structure. The aim was to harness natural fluorescence for energy efficiency in interior lighting.

5.5.2. Design Relation and Geometry Selected

In this case study, each student selected a direct relationship, where the design sought to emulate the gecko's natural light absorption and emission mechanism, using this as a model for energy-efficient surfaces or lighting in interiors.

Each student selected fractal geometry as the design abstracted the micro-patterns of the gecko's skin into repeating, fractal-inspired motifs applied to wall panels or lighting diffusers, aiming to maximize the surface area for light interaction and distribution.

5.5.3. Design Function

The project explored how such surfaces could enhance ambient lighting quality and visual interest in interior spaces. The aim was to create interior surfaces or lighting elements that absorb natural daylight and gently re-emit it in the evening, reducing the need for artificial lighting and thus improving energy efficiency.

6. Results

The incorporation of biomimicry and eco-friendly material design into the interior design curriculum led to a quantifiable enhancement in student learning and project results. The end-of-term evaluation showed that 55% of the course learning objectives were met, and 72% of the students exhibited competence in biomimetic principle application to materials selection, an impressive increase from the pre-intervention rate of 38%. The projects that used recycled 3D-printed filament made from grinding plastic waste and wood shavings scored, on average, 22% more points on sustainability rubrics compared to the projects that used traditional materials, a difference that was statistically significant ($p < 0.05$). Additionally, the end-of-course surveys revealed that 89% of the students took environmentally friendly materials into account when making design decisions, up from just 41% at the start of the course. Qualitative analysis of student projects yielded a variety of innovative solutions. For instance, a morphology-based partition system derived from the camel's eyelid led to a reduction in solar heat gain, illustrating the functional promise of direct biomimicry. The other exercises, like the modular divisions derived from the fractal patterns of the Sidr tree branches, reflected the benefit of indirect abstraction, since 67% of the students noted improved problem-solving capability due to the exercisses. Certain speculative studies, such as the jellyfish-inspired responsive glass, although not yet fully realized as a functioning prototype, initiated important debate on the constraints of available materials and possibilities for biotechnological integration in the future. The student responses overwhelmingly highlighted the revelatory effect of direct manipulation of a sustainable material, with many observing that the direct use of recycled filament turned sustainability into a concrete and practical issue instead of an abstract one, Table 6 summarizing the analysis of the case studies.

Table 6. Summarizing the analysis of the case studies.

Case Study	Biomimetic Principle and Level	Natural Model	Design Relationship	Geometry	Function	Material and Feasibility
5.1	Shade (Organism)	Camel eyelid	Direct	Fractal	Shade	3D-printed filament; feasible for shading, advanced control speculative
5.2	Filtration (Ecosystem)	Fungi/mycelium	Indirect	Fractal	Air flow	3D-printed filament; biofiltration speculative
5.3	Responsiveness (Organism)	Jellyfish	Indirect	Voronoi	Responsive glass	3D-printed filament; responsive function conceptual
5.4	Adaptability (Ecosystem)	Sidr tree	Indirect	Fractal	Kinetic/adaptive	3D-printed filament; kinetic speculative
5.5	Energy efficiency (Organism)	Gecko	Direct	Fractal	Lighting	3D-printed filament; fluorescence speculative

7. Discussion

These findings unequivocally support the effectiveness of an integrative curriculum in biomimicry and sustainable materials in developing sustainability literacy as well as innovative problem-solving skills among design students. The 55% learning outcome achievement rate, with the heightened capacity of the students to operationalize biomimetic frameworks, attests to the merits of formal pedagogical structures, like Rossin's Design Spiral, in spanning the gap between theory and application. The resulting 22% disparity in the sustainability ratings between the projects that employed recycled materials and traditional materials is supported by the literature, which identifies that haptic interaction with eco-materials is one of the most powerful predictors of ecological awareness and literacy. The fact that the projects lacked higher-order functions, like self-healing or even responsive surfaces, testifies to an ongoing need for an exchange between design pedagogy and material scientists to be able to leverage the complete potential of biomimetic innovation.

The high positive correlation between innovation and the use of sustainable materials also reinforces the notion that experiential learning holds the key to unlocking innovative thinking, yet ongoing institutional impediments, like limited workshop access and increased material expense, need to be overcome in pursuit of more widespread curricular implementation. The pedagogical iteration model formulated in this research builds on existing biophilic design principles by integrating material circularity quantification and by promoting students to consider their designs not only from a functional but also from a lifecycle approach. Although a high application of eco-materials was noted, only a meager one-third of the students were able to articulate how such solutions may be scaled up to commercial environments, reflecting the necessity of higher industry involvement and real-world exposure in the curriculum. In conclusion, this research illustrates that the experiential, evidence-based intersection of biomimicry and eco-materials has the potential to lead design education from a superficial to a rigorous, actionable, and innovative treatment of sustainability. Whereas recycled filaments have shown themselves to be suitable for prototyping and conceptualization, the future of the discipline will demand a transdisciplinary intersection of design, science, and industry to codify and scale nature-inspired solutions for a sustainable future.

8. Conclusions

Integrating biomimicry and eco-friendly materials and systems more comprehensively into design curricula is crucial for the future of the field. Our research, which involved both quantitative and qualitative data collection from interior design students, highlights the significant and transformative impact of equipping today's students with the essential skills, abilities, and knowledge needed for tomorrow's design landscape. Our future research will be twofold: first, to disseminate the curriculum narrative developed through this study to the wider design education community for critical feedback and discussion, and second, to translate the insights gained into practical workshops and actionable recommendations. These resources aim to guide faculty members on the most effective, sustainable, and eco-friendly materials for use and the dissemination of research and other forms of knowledge from university faculties to the broader community. While there is ongoing discussion regarding the slow pace of educational adaptation to sustainability needs, we hope this research will inspire grassroots, bottom-up transformation within other design disciplines towards a more sustainable future. The data from this study clearly indicates that change within interior design education is not occurring rapidly enough. Significant advantages exist in educating a new generation of design professionals who are deeply connected to nature and possess an intuitive understanding of working with eco-friendly materials. This research demonstrates that integrating recycled 3D printing filament into student projects effectively grounds sustainability in hands-on learning. While advanced biomimetic objectives remain aspirational, the current approach lays a strong foundation for future material innovation in design education. Nature serves as the ultimate instructor. While biophilia and biomimicry may be perceived as emerging design trends, they represent our earliest design principles, predating the very formation of our aesthetic sensibilities. Our responsibility as educators now is to act as facilitators and conveners. Beyond providing scholarships, we must demonstrate to students, and indeed to everyone, what it means to live and work within an environment free from toxins, based on an ecology that nurtures all life, not just humankind.

Recommendations for Curriculum Integration/Limitations

This section recommends appropriate curricular structures to integrate biomimicry and eco-friendly materials courses into shared design programs from the perspective of portfolio design, portfolio structure, assessment, and curricular connection.

One recommendation is to build university- and industry-wide partnerships among students, faculty, and industry professionals, who include educators of biomimicry and eco-friendly materials as well as design disciplines. When a portfolio structure can be used to house multiple disciplines, we suggest creating a curriculum where students can rotate through the portfolio apparatus, which can be considered as a structured system or toolset used to develop, organize, and evaluate a portfolio. This will require collaboration between the faculties of different design disciplines. Implementing curricular designs that incorporate students from more than one discipline can reflect collaboration on industry project teams, where product designers, interior environmental designers, and architects, for example, all work in a shared industry as engineers or human factors experts. We suggest relying on assessable student learning outcomes within the program. To identify shared outcomes between disciplines, we recommend the use of an assessment map that displays and evaluates all student learning outcomes in the curriculum.

We recommend collaboration with educators in sustainability through professional development because, as our field grows, so does our need to collaborate with organizations that set standards and provide educational opportunities for the professional sustainability-degreed individuals who our graduates will work for. Identifying faculty

mentors and business partners in this field can also provide additional networking for future opportunities, ranging from internships and fellowships to job placements. As educators of biomimicry and eco-friendly materials, we should also encourage students to attain knowledge through relevant coursework. Targeted outcomes for a curriculum including these courses or content should be at the student learning outcome level and address sustainability content. Individual faculty may align one curricular content goal with sustainability SLOs. Indicators of faculty learning may include attending professional development programs offered by industry professionals or attending conference sessions that aim to include sustainability in design education. However, to reach our goals of better educating our students, faculty members may need to conduct further coursework, such as a week-long retreat or workshop. Regular review of our records of student outcomes will help faculty see the growth in student education in sustainability across the curriculum.

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Informed Consent Statement: Verbal informed consent was obtained from the participants. Verbal consent was obtained rather than written because the authors informed the students using consent script the purpose of the study that will include cases from the students' work without using names or personal information.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

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