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A Biomimicry Course in an ID Department: Nature-Driven Innovation for Food Systems

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ABSTRACT
This paper explains a case study on biomimicry-based education work in an industrial design undergraduate program. It seeks to outline and explain an elective design course and its framework, GST116 Biomimicry, in the Department of Industrial Design (ID) and the Faculty of Fine Arts. Furthermore, it proposes recommendations for use in similar courses. The research questions are: "What can be the possible stages of a biomimicry lecture in an ID department?" "What recommendations can be made for educators concerning a biomimicry course? Moreover, "What are the learning outcomes of a Biomimicry lecture in first year ID department? Seventeen students collaborated in pairs or trios with their classmates during this course. Twelve design projects were showcased in total. Students applied the Biomimicry Institute Design methodology to design biomimicry-based products related to the sub-stages of food systems. Besides these methods, the teams conducted brainstorming sessions, produced sketches, perspective, orthographic, and technical drawings, and created 3D mock-ups. The students' projects also focused on UN Sustainable Development Goals (SDGs) issues. To sum up, recommendations for further biomimicry courses were proposed.
Keywords: Biomimicry, Industrial Design Education, Sustainable Food Systems, UN Sustainable Design Goals, Packaging, Hands-on Learning

1. INTRODUCTION
Biomimicry is a nature-inspired innovation methodology that seeks answers to difficulties of manufactured objects such as products, buildings, vehicles and energy systems by imitating nature. Benyus (1997), who initially introduced biomimicry in her book Innovation Inspired by Nature, explains biomimicry as the purposeful imitation of life's brilliance to find creative and sustainable solutions.

The biomimicry innovation method has gained importance in product development processes in recent years. It offers multiple benefits, such as enabling sustainable solutions (MacKinnon, Oomen, and Pedersen Zari, 2020), providing innovative material applications (Volstad and Boks, 2012), and reducing costs by minimising waste, pollution and resource depletion (Ivanić et al., 2015). Furthermore, various studies explain the significant use of biomimicry in industrial design education (Boga-Akyol and Timur Ogut, 2016; Tavsan and Sonmez, 2015; Rivas and Acuna(2024))

Boga-Akyol and Timur Ogut (2016) explain that students are not utilising biomimicry in their design projects due to limited biological knowledge and inadequate understanding of the technique. Furthermore, they stated that the students' approach changed from morphological imitation to using materials, textures, and operations inspired by natüre. The study of Tavsan and Sonmez (2015) defined the 6-stage processes in their lecture, including a seminar on biomimicry personal research, selection of a product, formation of 2D and 3D models, selection of the best design, and application of the design on a 1:1 scale. This study examines the relationship between biomimicry and design and presents a method that brings solutions by looking at nature. Rivas and Acuna (2024) show two design methods based on biomimicry spirals for developing products using

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recycled materials and share the results of their implementation in three courses taught to students from different disciplines.

Although there is much research in biomimicry and design education, as mentioned above, the literature is still limited in this field. The research questions guiding this study are: "What can be the possible stages of a biomimicry lecture in an ID department?" "What recommendations can be made for educators concerning a biomimicry course?" and "What are the learning outcomes of a Biomimicry lecture in a first-year ID department? Focusing on these questions, GSF116 Biomimicry (2023-2024 Fall Semester), an elective course of the ID department, was analysed. The course includes hands-on learning and combining biomimicry and industrial design methodologies.

The remainder of this paper is organised as follows: Section 2 includes a theoretical framework. This section explains the Bio-mimicry Institute Design stages, defines the project scope: food systems, and includes literature on the biomimicry applications in Industrial Design education. Section 3 describes the methods and materials; Section 4 presents the findings; Section 5 includes the discussion part; and Section 6 concludes the paper with recommendations for future studies.

2. THEORETICAL FRAMEWORK

2.1. Biomimicry Institute Design Model

Numerous models exist for biomimicry applications. One of them belongs to the Biomimicry Institute (BI). Biomimicry Institute, a non-profit organisation, was founded by Benyus and Schwan in 2006. The Biomimicry Institute has been dedicated to making biology a natural part of the design process (URL-1). It proposes a unique design process depending on biomimicry, including six steps (Figure 1-URL-3): define, biologise, discover, abstract, emulate, and evaluate (URL-3). These methods are explained below.

- **Identify**—Formulate a design brief addressing the human necessity.
- **Biologise** — Approach the inquiry from a biological standpoint; ask for the design brief from the perspective of nature. Inquire, "How does Nature perform this function?" "In what ways does Nature fail to perform this function?"
- **Discover**— Seek leaders in nature who address the challenges.
- **Abstract**— Identify nature's recurring patterns and mechanisms that lead to success.
- **Emulate**— Create ideas and resolutions derived from natural paradigms. **Evaluate**— In what manner does the created design or product correspond with the design brief and the Principles of Life, which are the fundamental laws of nature?

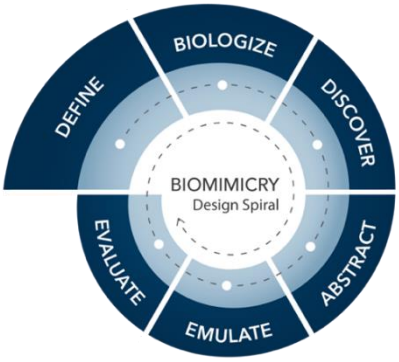

Figure 1. Biomimicry Design Spiral (URL-2)

In the lecture, students conducted a simplified version of this methodology. The Biomimicry Institute Design Model is appropriate for anyone, regardless of design degree level. However, this study eliminated some stages because designers already have

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abstraction abilities. Designers generally conduct abstraction and emulation in the same sketch or drawing. Therefore, in the course, students combined abstract and emulate stages. On the other hand, each design researcher uniquely approaches biomimicry. A few examples of these approaches are shown below.

2.2. Education on Biomimicry

Biomimicry is employed in diverse educational contexts across design disciplines, including industrial design engineering, architecture (undergraduate and graduate levels), and STEM (primary, elementary, or secondary education). Stevens et al. (2021), Boğa-Akyol and Timur-Öğüt (2015), and Tavsan and Sonmez (2015) examined the application of biomimicry in industrial design education. Tavsan et al. (2015), Amer (2019), and Yurtkuran et al. (2013) utilised biomimicry in architectural education. Furthermore, Gencer et al. (2020), Coban and Costu (2023), and Canbazoğlu Bilici (2021) employed biomimicry in STEM education.

The core concept of these studies is identical; they all rely on biomimicry-based design applications. Furthermore, these studies were typically conducted through action research. Moreover, these papers are usually based on student or academic projects. However, most of these projects are in the conception stage. Only a few of them have more advanced product design proposals. The papers shown below (Table 1) were categorised into groups according to the levels of project development and the types of project representations. These representations are sketches, 3D CAD models, technical or visual solutions and explanations, texts, and 3D mock-ups.

Table 1. Categories of papers in terms of project representation forms

	Authors	**Types of Project Representations**				
		Sketch-based	**3D CAD model-based**	**Technical or visual solution-based**	**Text-based**	**3D mock-up-based**
1	Santulli and Langella (2011)	-	x	x	x	-
2	Pauw et al. (2014)	x	x	-	-	-
3	Kyratsis et al. (2014)	x	-	x	-	-
4	Tavsan and Sonmez (2015)	-	-	-	x	x
5	Tavsan et al. (2015)	x	-	-	-	-
6	Miray and Timur Ogut (2015)	x	x	-	x	x
7	Lenau (2019)	x	x	x	-	-
8	Amer (2019)	-	x	x	-	-
9	Abbaslı and Arslan Selcuk (2019)	-	x	-	x	-
10	Dobras et al. (2021)	x	x	x	-	-
11	Stevens at al. (2021)	x	-	x	x	-
12	Semlali et al. (2021)	-	x	x	-	-
13	Canbazoğlu Bilici et al. (2021)	-	-	-	-	x
14	Coban ve Costu (2023)	-	-	-	x	x

In this study, students utilised representations of sketching, visual solutions, texts and 3D mock-ups. On the other hand, because they are first-year students, they could not create 3D CAD models. The effects of not utilising CAD programs in this lecture are explained in the Discussion section.

Furthermore, students focused on sustainable food systems in the course. They developed biomimicry-based projects on these topics. A short description of the food systems is defined below.

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2.3. Sustainable Food Systems

The lecture's scope required refinement due to the difficulties of working in a wide scope. Therefore, sustainable food systems were selected as a topic. This subject was selected for three primary reasons. First, numerous examples of biomimicry innovations in food packaging are available online for students' research. 1st-year students can discover them effortlessly. Secondly, creating packaging mock-ups is suitable for first-year students. Lastly, this topic might be appropriate for working on sustainability.

The food system comprises six stages (Figure 2, URL-4): production, processing, distribution, retail and market, consumption, and waste recovery (URL-5).

- **Production—** During the production phase, food is cultivated or grown. It encompasses agriculture, aquaculture, and the care of animals. This phase emphasises the cultivation of crops, livestock rearing, and the extraction of natural resources.
- **Processing—** During the processing/manufacturing phase, food is gathered and/or raw ingredients are converted into recognisable food products. This phase encompasses cleaning, sorting, grinding, preserving, packaging, and frequently cooking or preparing goods for distribution.
- **Distribution—** This phase encompasses logistics, storage, and transportation, guaranteeing that food goods arrive at marketplaces, grocery shops, restaurants, and consumers.
- **Retail and market**—Retailing involves directly selling food products to consumers. Local food is available at farms, farmers' markets, or roadside stands. Retailing covers extensive establishments like small and large grocery stores and internet commerce.
- **Consumption—**During the consumption phase, customers ultimately engage with food. During this phase, individuals acquire, cook, and consume foods, all actions associated with buying, meal preparation, kitchen practices, and dining experiences.
- **Waste recovery—**The concluding phase, disposal, relates to how to dispose of uneaten food. Food waste can occur at any stage of the food system: during cultivation, at processing facilities, throughout transit, and inside households.

Figure 2. A chart of the food system (URL-4)

In the study, students especially preferred packaging (retail and market), waste recovery, distribution, and consumption phases of food systems.

3. MATERIALS AND METHODS

As mentioned above, several researchers, such as De Pauw et al. (2014), Rivas and Acuna (2024), and Hapsari et al. (2022), followed the Biomimicry Institute Design methodology in hands-on design learning activities. Students utilised this technique in the lecture and used various industrial design skills such as sketching, perspective,

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orthography, technical drawings, and creating 3D mock-ups. The whole process of the hands-on learning in this Biomimicry course is shown below (Figure 3).

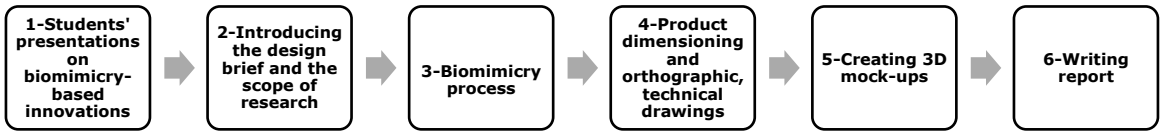

Figure 3. The process of hands-on learning in the Biomimicry course

3.1. Students' Presentations on Biomimicry-based Innovations

Twenty to twenty-five projects from the AskNature website (URL-7), which feature various innovations grounded in biomimicry, were shared with students. This webpage comprises two primary contents: biological strategies and innovations. Each innovative Project on the AskNature website (URL-7) is categorised into safety, transportation, software IT, renewable energy, materials, robotics, medical biotechnology, and manufacturing. Furthermore, this website provides a comprehensive explanation of these innovations. At the beginning of the semester, a PowerPoint format that included information on a company named Amphico was provided to the students. *(This company manufactures waterproof textiles inspired by arthropods (URL-8)).* The format of the PowerPoint document includes the advantages of the innovative product, its applications, the relevant UN sustainable development goals, a definition of the problems the product addresses, a proposed solution, and a detailed examination of how it emulates natural processes and technical solutions. Students presented these selected biomimicry-based innovative projects in 3-4 minutes using PowerPoint during class. Hence, they started studying biomimicry and its practical applications.

3.2. Introducing the Design Brief and the Scope of Research

Following this exercise, the design brief on sustainable food systems was introduced to the students. General information on food systems was shared with them. Additionally, the students investigated the components of this system, including food production, marketing, distribution, consumption and waste recovery, in detail. All groups concentrated on one of the food systems' sub-stages mentioned above.

3.3. Biomimicry Process

After the students analysed the stages of the food system, they organised into groups. Subsequently, students developed five design problems related to the food system following the Biomimicry Institute "define" stage. Initially, students utilised Mural for these studies and collaboratively documented five problems on this platform. After one week, four questions (Fig. 4) on Post-it notes were presented to the student on Mural. Then, the students chose two problems from a set of five and responded to these questions (Fig. 4) by focusing on the selected two problems. After that, they chose one problem among the two.

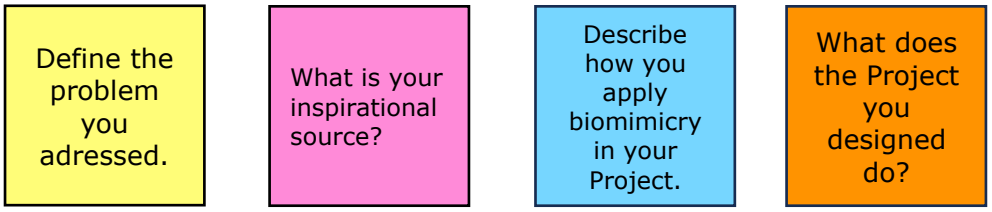

Figure 4. The Post-it used in the biomimicry process in the Project

Students have completed their biomimicry project for three to four weeks. In these weeks, students refined their topics, identified a unique idea for the food system, emulated an aspect of nature, and eliminated irrelevant projects for this lecture. Certain

group members choose a single topic and develop several solutions for the same problem; others focus on a singular challenge, while some select the same domain but address diverse problems. They utilised written text, sketching, and verbal communication throughout this process.

Following the schematic representation of the problem and potential solutions, students submitted three posters for the midterm examination (Table 2). The initial poster contains project information (problem definitions, inspiration sources, and properties of the inspired source). Students also presented these project information posters during the final exam, so they are placed in Table 5. The second poster includes product form alternatives and several sketches. The third poster comprises one selected product form from a perspective view and a project idea within the text. All the posters were created in A3 format and presented by students during the examination. They further submitted them in digital format.

3.4. Product Dimensioning and Orthographic, Technical Drawings

After completing the concept development process and selecting the form, they drew the Project in orthographic views. Because they are 1-st year students, the orthographic views were explained technically. In the following lecture, they created technical drawings of their Projects. In this lecture, they solved the problems of their projects' form and dimensions.

3.5. Making Mock-up

Subsequently, a presentation on creating a mock-up, referencing Hallgrimsson's (2012) book, Prototyping and Modelmaking for Product Design, was given to the students. Following that, they created mock-ups using several materials. They completed their mock-ups in three to four weeks.

3.6. Writing Report

Finally, a report format was shared with students concurrently with the mock-up lecture. Students get 3 to 4 weeks to finalise their report (Table 3, Table 4). Additionally, they have had opportunities to ask questions on reports during these weeks. Students collaborate in pairs or trios during all these processes.

4. FINDINGS

In this part of the study, the outputs of the projects are explained below. Definitions, visual, mock-up, and written submissions are defined. Furthermore, the analysis of Project Outputs and general evaluation of the lecture are presented at the end.

4.1. Projects' Definitions

Eight projects were presented during the course. Summaries of the product proposals are provided below:

Project 1 (© Esmanur Çayır): Yogurt container indicating the expiration of the product's shelf life.
Project 2: (©Abdullah Salah Salem, ©Merve Kapucu, ©İrem Nur Umay) Marine waste collection vehicle
Project 3: (© Sıla Hepcoşkun) Fruit crate extending the freshness of strawberries
Project 4: (©Nefize İçöz) Kettle that inhibits the evaporation and reduction of boiling water.
Project 5: (©Ece Irem Durak) Healthy natural snack packaging that can be adhered to any surface
Project 6: (©Suden İlhan) Healthy fruity yoghurt snack and packaging
Project 7: (© Kübra Türkmen, ©Nisanur Keşab) Long-lasting wooden fruit crates
Project 8: (© Beyza İnci) Egg carton box to protect eggs from shattering.

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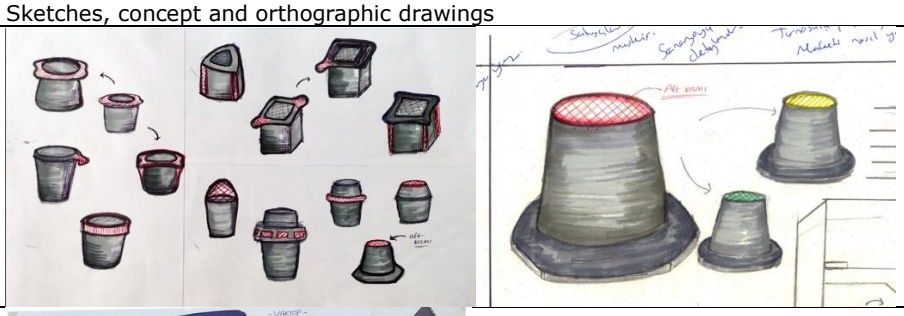
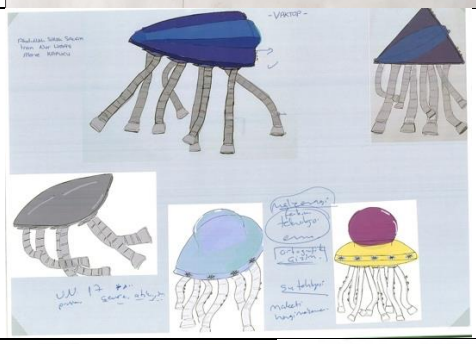
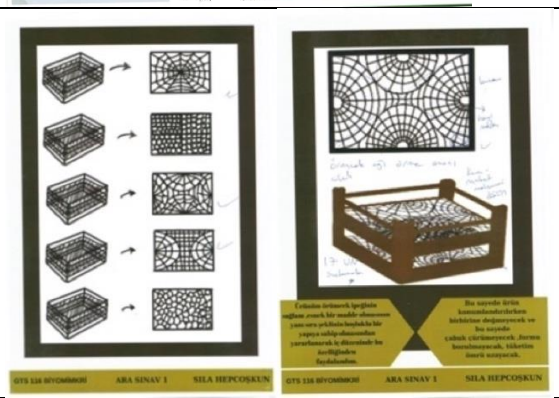
4.2. Visual and Mock-Up Submissions

A midterm assignment comprising three A3 sheets was presented for the course. The criteria for project submissions and an example of midterm exam submission are outlined below (Table 2).

- **Project information sheet:** Inspirational visuals encompass problem definition, relevant details and images about the problem, the name of the inspiration source, images from the inspiration source, and images of the inspired feature and its details (Table 5).
- **Sketching sheet:** Alternative drawings consist of diverse sketches representing the products' form (Table 2).
- **Design proposal sheet:** The drawings encompass perspective illustrations, orthographic representations of the proposed product, and extensive details about this concept (Table 2).

Table 2. Mid-term posters

Designers	Sketches, concept and orthographic drawings
© Esmanur Çayır (1)	
©Abdullah Salah Salem, ©Merve Kapucu, ©İrem Nur Umay (2)	
© Sıla Hepcoşkun (3)	
© Nefize İçöz (4)	

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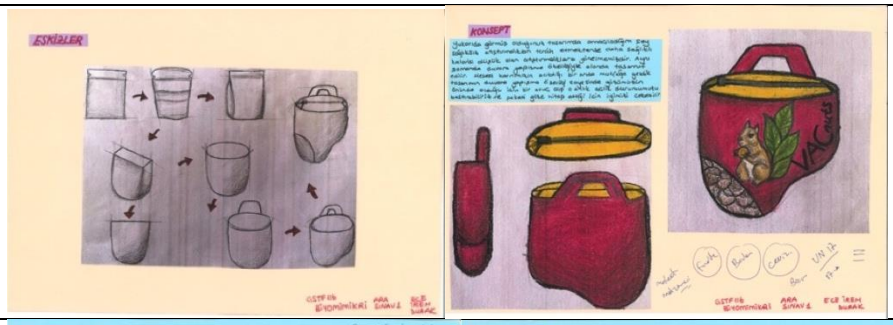
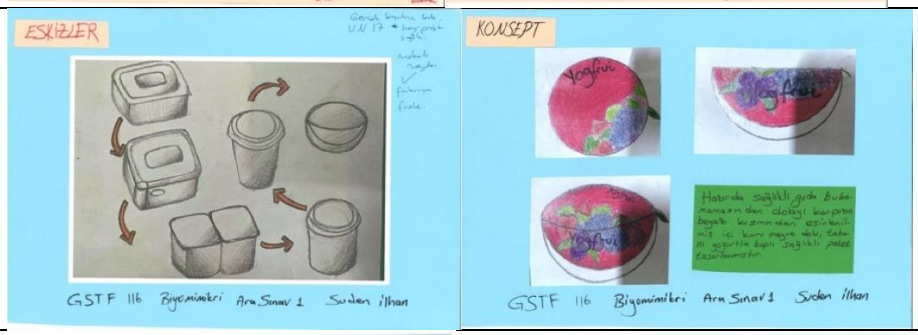
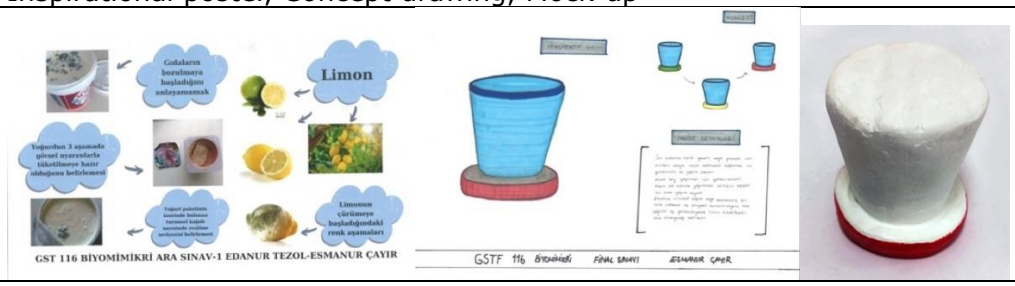
©Ece İrem Durak (5)	
© Suden İlhan (6)	
©Nisanur Keşab (7)	
© Beyza İnci (8)	

There was a final project submission in the course. The requirements for the final Project, which are an inspirational poster, concept drawing, orthographic drawing, technical drawing, and 3D mock-up, are shown in Table 5. Eight projects are presented below.

Table 5. Final inspirational posters, concept drawings of students

Designers	Inspirational poster, Concept drawing, Mock-up
© Esmanur Çayır (1)	

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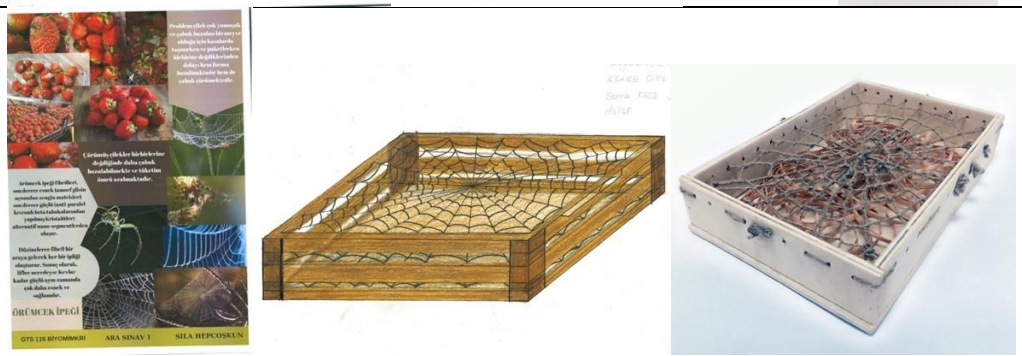
©Abdullah Salah Salem, ©Merve Kapucu, ©İrem Nur Umay (2)	
© Sıla Hepcoşkun(3)	
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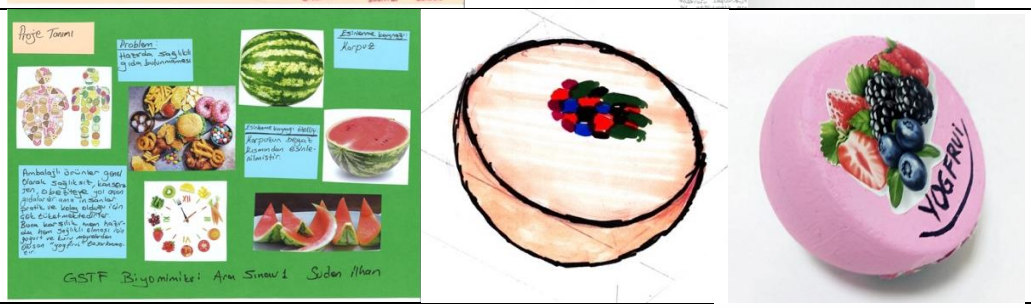
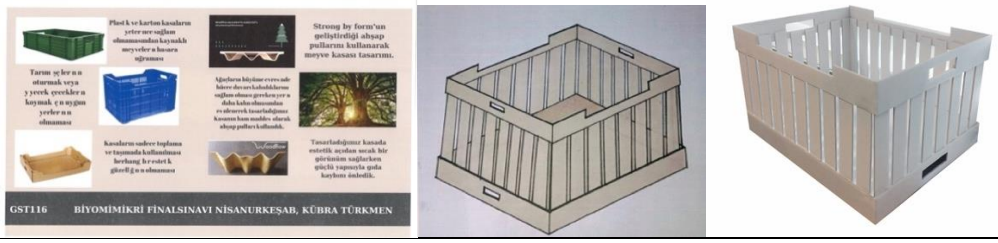
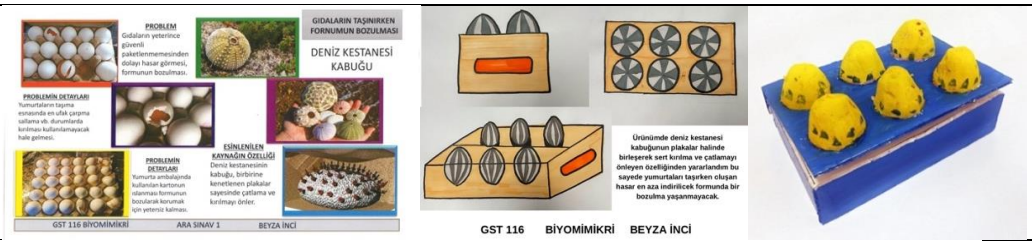
©Ece Irem Durak (5)	
© Suden İlhan (6)	
© Kübra Türkmen, ©Nisanur Keşab (7)	

© Beyza İnci (8)	

*Technical and orthographic drawings were also submitted in the final; however, they are not shown in this paper.

4.3. Written Submissions

Students submitted replies to an inquiry as one of the final submissions. The questions are prepared attentively and help students define their Project in detail. Questions and student's responses to this inquiry are outlined in Table 6 and Table 7.

Table 6. Final Enquiries and Student Responses

	© Esmanur Çayır (1)	**©Abdullah Salah Salem, ©Merve Kapucu, ©İrem Nur Umay (2)**	**© Sıla HEPCOŞKUN (3)**	**© Nefize İçöz (4)**
1 What is the name of your Project?	Bio-change	Vaktop	Çika	Cammle
2-In which step of the food system did you engage?	A study was conducted on food packaging.	We addressed the environmental impact caused by packaging waste.	I was employed in food packaging within the food system.	Access to Clean Water and Sanitation.
3-Which problem did you address in your chosen field?	The emphasis was on the inability to identify when products were spoilt or beginning to spoil.	We address the issue of packaging material thrown into the ocean or transported by the wind, adversely affecting the environment, ecosystems, and living organisms.	Strawberries are delicate and perishable fruits. My idea addressed the issue of strawberries crushing each other during packaging and spoiling strawberries, affecting each other and lowering their shelf life.	SDG 6.3: Improve water quality, wastewater management and safe reuse.
4-What solution did you suggest for the issue?	The acidic properties of yoghurt during the spoiling stages rendered the spoilage evident through a colour change.	We developed a vehicle named "VAKTOP" to suck waste from water. This vehicle utilises sensors in its arms to detect waste, suction it, and extract it from the water. It does not adversely affect biological organisms.	I developed a three-layer case with holes sufficient in size to prevent strawberries from falling and touching each other. This design prolongs consumption and shelf life.	CAMMLE facilitates the evaporation and circulation of water by integrating an ice container into the kettle lid. This approach offers a resolution to the issue.
5-Which organism or natural phenomenon motivated you to address this issue?	A lemon served as my inspiration.	In order to solve the problem, we were motivated by the octopus.	Spider silk served as an inspiration in addressing the problem.	The source of inspiration is the camel's nose.
6-What inspired you about this	The colour transformation of the lemon from its	We were motivated by the presence of	I was inspired by the spider web's elasticity and	The camel's nose captures water vapour from the air

creature or natural phenomenon?	unripe condition to its decaying phases impressed me.	robust suction cups on their legs.	longevity, how it builds its web, and the web's hollow structure.	during respiration, supplying hydration to the camel's body. This Project was motivated by the behaviour of camels.
7-Detail this element's transformation (or abstraction) in your design project.	The green tone signifies that it is consumable, the yellow indicates it is in the deterioration phase, and the grey indicates it has deteriorated.	Our Project has arms like octopus that vacuum waste.	I crafted the spider web design from hemp rope on all three frame layers.	The CAMMLE water heater is designed to emulate the camel's ability to capture and conserve water from the atmosphere. The steam generated from heated water facilitates a primary heat exchange to convert the steam into its liquid form. This device seeks to enhance water circulation and conserve water volume.
8-Explain the technical specifications of the Project and the materials it encompasses.	The yoghurt container includes yoghurt on its top, similar to standard yoghurt containers. A sample of yoghurt is positioned on the bottom, encircled by litmus paper. The litmus paper will remain isolated from the yoghurt that is consumed.	All materials consist of HPPE. A hydraulic press mechanism compresses the materials collected in the vehicle's tank section. Two motors generate suction power to facilitate waste removal and expulsion of water collected during suction. Sensors are installed at the end of each hose to identify solid waste.	My creation uses hemp rope and a poplar wood case. First, I split the case into three equal halves. Once divided into four, I passed ropes through each layer's holes to make the canvas. I then knitted each of the four spider web pieces separately.	Stainless steel and plastic are utilised. The top and handle are plastic, while the ice bin and water heater body are constructed from stainless steel.
9-Identify the target demographic for the product.	The target audience of the product is all consumers and market employees.	Because it helps collect trash and keeps the environment clean, it is aimed at all living animals and society. It is expected that municipalities will employ this technology.	The target audience consists of strawberry consumers and retailers.	Adults
10-Outline the anticipated fields of use of the product.	Intended for display on retail shelves.	It will clean environments such as oceans, lakes, and rivers.	Greengrocers, markets, bazaars	Home, office, and workplaces.
11-Which UN sustainable design goals do the product intend to achieve?	SDG 3.Good Health and Well-Being (URL-6) The objective is to prevent consumers from accidentally utilising expired products.	SDG 11- Sustainable Cities and Communities (URL-6) SDG14. Life Below Water (URL-6) It offers sustainable living environments by maintaining the cleanliness of water-based areas,	SDG 12 Responsible Consumption and Production (URL-6) SDG 12.3 Food Loss and Waste 12.3 (URL-6) By 2030, it is imperative to	SDG 6 Clean Water and Sanitation (URL-6) SDG 6.3 Significantly enhancing global recycling and secure reuse (URL-6)

	Yoghurt poisoning may have significant negative impacts on the foetuses of pregnant women.	including seas and lakes. Maintaining the cleanliness of marine, river, and lacustrine environments prevents the poisoning and mortality of aquatic organisms, thereby protecting aquatic biodiversity.	reduce per capita global food waste by 50% at retail and consumer levels and minimise food losses throughout production and supply chains, including post-harvest losses.	

Table 7. Final Enquiries and Student Responses

	©Ece Irem Durak	**©Suden İlhan**	**© Kübra Türkmen, ©Nisanur Keşab**	**© Beyza İnci**
1 What is the name of your Project?	Vacnuts	Yogfrui	ForteWood Tray	Lifyol
2-In which step of the food system did you engage?	Processing and packaging (Production)	Marketing	Distribution	Processing and packaging (Production)
3-Which problem did you address in your chosen field?	Food's short shelf life, preference for unhealthy foods, availability of unhealthy foods right now, and inclination to turn to them.	Contemporary youth engage in the consumption of unhealthy snacks.	We primarily address two issues. The initial issue is the damage to the fruits resulting from the insufficient sturdiness of the fruit crates. The second issue is that field workers lack a suitable place for storing their food and beverages.	I examined the issue of eggs frequently breaking and falling during transportation.
4-What solution did you suggest for the issue?	I solved the problem by creating a convenient, healthy snack pack that would always be available. The product impresses with its wall-mounted hoover feature and appealing design, which keeps young people away from harmful food.	The open-and-finish package enabled us to prepare a healthy snack. The visually appealing container design motivated individuals to consume healthier foods.	Our Project enhanced the case's durability by utilising engineered wood. It was supposed to function as a tray when inverted.	Due to its resistance to impacts and degradation, I crafted the riole using pumpkin fibre.
5-Which organism or natural phenomenon motivated you to address this issue?	I used the vacuums on the toes of the bushbaby.	I was inspired by watermelon.	The strength of trees inspired us.	I was impressed with the sponge.
6-What inspired you about this creature or natural phenomenon?	The vacuum inspired me at the tip of the bushbaby's toes to prevent her from falling while jumping from branch to branch or holding on to a tree.	The white interior part of the watermelon inspired me.	We created it by looking at how, as trees grow, the cell walls get thicker where they should be strong.	Its breathability and durability impressed me; the fibres swell in water but do not let water through. I also considered the economic

				benefit of its low cost.
7-Detail this element's transformation (abstraction) in your design project.	Inspired by the vacuum in bushbaby's feet, I added an adhesive to the back of a nut package.	The white part near the base of the watermelon transformed into yoghurt.	Inspired by trees, we made the casings' substantial parts thick.	I implemented pumpkin fibre's complex, flexible, and waterproof characteristics into my product by using it in my viöl.
8-Explain the technical specifications of the Project and the materials it encompasses.	Although my Project is similar to other dried fruit packets found in markets, it differs in crucial ways: The container has a vacuum on its exterior that can adhere to the wall. I use vacuum plastic, zip-lock bags, and long-shelf-life packaging.	Like half a watermelon, the bowl's base is coated with yoghurt and filled with dried fruits.	We used intelligent wood technology produced by Strong by Form.	The viöle I made was in 6. I built it out of cardboard. I also put pumpkin fibre where the eggs were.
9-Identify the target demographic for the product.	Individuals seeking to maintain a healthy diet and achieve weight loss	Individuals who prioritise nutritious diets	Agricultural labourers, suppliers, and consumers.	Egg traders and consumers
10-Outline the anticipated fields of use of the product.	Home, workplace, educational institution, and almost any place where it can be attached to the wall.	It can be consumed at any preferred location.	It can be utilised in any phase of the product's collection, transportation, and distribution and as a tray function for customers.	The product is suitable for all varieties of eggs. The product is utilised at places such as shops, markets, and greengrocers that sell eggs.
11-Which UN sustainable design goals do the product intend to achieve?	SDG 3 Good Health and Well-Being (URL-6) Protecting our health is essential for achieving a quality life.	SDG 3 Good Health and Well-Being (URL-6)	SDG 12 Responsible Consumption and Production (URL-6) SDG 12.3 Food Loss and Waste 12.3 (URL-6) By 2030, halve per capita global food waste in the retail and consumer sectors and reduce food losses along production and supply chains, including post-harvest losses.	SDG 12 Responsible Consumption and Production (URL-6) There is no damage to the products or a reduction in their quantity.

4.4. Analysis of Project' Output and General Evaluation of Lecture

4.4.1. Selected stages of food systems in the Projects

In the study, 6 projects focused on the stages of retail and market, 3 projects dealt with distribution, 2 projects studied in waste recovery and 1 project concentrated on consumption (Table 8). The projects and their related stages of the food system are shown below.

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Table 8. Selected Food Systems

Bio-change	Retail and Market Consumption	Vacnuts	Retail and Market
Vaktop	Waste recovery	Yogfrui	Retail and Market
Çika	Retail and Market, Distribution	ForteWood Tray	Retail and Market, Distribution
Cammle	Waste recovery	Lifyol	Retail and Market, Distribution

4.4.2 SDGs that Projects focused on

In the study, 3 projects focused on SDG 3, Good Health and Well-Being; 3 projects studied SDG 12, Responsible Consumption and Production; 1 project worked on SDG14 Life Below Water; 1 project focused on SDG 11, Sustainable Cities and Communities; and lastly 1 project concentrated on SDG 6 Clean Water and Sanitation (Table 9). The projects and their related SDGs are presented below.

Table 9. SDGs that Projects Focused on

Bio-change	SDG 3 Good Health and Well-Being	Vacnuts	SDG 3 Good Health and Well-Being
Vaktop	SDG 11 Sustainable Cities and Communities SDG14. Life Below Water	Yogfrui	SDG 3 Good Health and Well-Being
Çika	SDG 12 Responsible Consumption and Production	ForteWood Tray	SDG 12 Responsible Consumption and Production
Cammle	SDG 6 Clean Water and Sanitation	Lifyol	SDG 12 Responsible Consumption and Production

4.4.3. Positive aspects of the lecture

The positive aspects of the Biomimicry lecture are explained below.

1. Students were enthusiastic about the Project because they were at the beginning of product design education.
2. Students have expanded their knowledge about SDGs, understood the significance of these goals, and successfully worked with them.
3. Students may use their knowledge and experience in biomimicry in their businesses after graduation. Furthermore, they can become entrepreneurs in biomimicry-based product design.
4. Learning outcome 1: Students improved industrial design skills such as orthographic, perspective, technical drawing ability and making 3D mock-up skills.
5. Learning outcome 2: Students have expanded their knowledge about biomimicry innovation methodology.
6. Learning outcome 3: Students experienced a design thinking approach because they focused on a design problem, empathised with users and attempted to find design solutions.
7. Learning outcome 4: Students have gained the ability to create design alternatives and select the most valuable one.

4.4.4. Negative aspects of the lecture

The negative aspects of the Biomimicry lecture are explained below.

1. One of the challenges first-year students face is their lack of experience with 3D modelling. This situation might cause to slow down the design process. Designers generally transform design inputs into design outputs in a cognitive process. CAD knowledge might accelerate this process.

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2. Because of time restrictions, students could not visit a natural environment such as a lakeside or forest to observe and sketch nature.
3. Students could not attend a design competition because the projects included solely hand drawings.

5. DISCUSSION

The primary issue in this lecture is that the course participants are ID first-year students. Given this situation, they have not previously attended a product design lecture and lack knowledge of 3D modelling. In Bakirlioglu's (2012) master's thesis, he described a biomimicry-based design lecture. In this lecture, students designed and rendered their ideas using 3D software besides sketching. This lecture has successful outputs. Therefore, applying biomimicry methods may be easier for students proficient in 3D modelling programs who have passed a product design lecture before and are familiar with product idea generation, detailing, presentation, and prototyping. Consequently, relocating this lecture to the syllabus and recommending it for second or third-year students, similar to Bakirlioglu's (2012) design lecture, is proposed in this study.

The second issue identified in this lecture is the students' confusion regarding the application of biomimicry. At the beginning of the lecture, students supposed that the biomimicry method could be solely employed for product form design and colour. Nonetheless, they gained a deeper understanding of biomimicry through critiques of design projects, examinations and presentations of innovations from the Ask Nature website (URL-4). Coban and Costu (2021) described biomimicry methods with form-based, structure-based, and function-based techniques. On the other hand, Zari (2007) discussed biomimicry with form, material, construction, process, and function-based techniques. This lecture concentrated on function-based biological modelling. However, at the beginning of the course, students attended several exercises focusing on colour-based, form-based and material-based biomimicry, as illustrated below (Figure 5). It may benefit students to explain all aspects of biomimicry in Biomimicry courses for ID departments.

Figure 5. Colour and form-based Biomimicry exercises (1-© Meryem Akpınar, 2-©Sıla Hepcoşkun)

In this lecture, students had opportunities to start product design education. They enhanced their skills in a new product design based on a design brief. Furthermore, they improved their sketching, drawing, rendering, and presentation abilities. Moreover, engaging with UN Sustainable Design Goals heightened students' awareness of global issues. They composed a report on the Project that concentrated on the SDGs, which helped them develop academically. According to several researchers, design departments should focus on the SDGs. Watkins et al. (2021) emphasised that

integrating sustainable product design education into the core design curriculum is essential for achieving meaningful impact. Meyer and Norman (2020) also highlighted the importance of global challenges for design education.

In this study, students have developed SDG projects by considering issues such as warning consumers about expired products, gathering waste from seas, preventing water waste, supporting consumers to consume healthy foods, delaying food spoilage and using biomimicry-based sustainable materials. These results show that the lecture assisted students in designing sensitive projects related to SDGs. Students mostly focused on SDG 3, Good Health and Well-Being, and SDG 12, Responsible Consumption and Production in the course. The Project's general scope is in packaging design, and packaging problems are frequently related to SDG 3 and SDG 12.

In summary, working on SDGs might support industrial design students for further studies, especially those who desire to work in Non-Government Organizations (NGOs). Moreover, this lecture may benefit students with global problem-solving and design skills.

6. CONCLUSION AND FURTHER STUDIES

Throughout the semester, 17 students delivered 12 projects. Despite these projects' varying levels of innovative thinking, they are significant for students undertaking product design lectures for the first time. The primary design methodology of the projects is biomimicry. Furthermore, this study employed other methods besides the biomimicry process, including sketching, orthographic drawing, technical drawing, model making, colour applications, report writing, and critical design processes grounded in critique. The study also centred on the SDGs and is expected to establish a framework for other biomimicry lectures.

The end-of-term results in this Biomimicry lecture produced the following proposals applied in the lecture. In a biomimicry course, students should

- do presentations on biomimicry projects already designed with biomimicry innovation methodology.
- sketch on natural objects in the class before starting the main Project.
- conduct the double diamond design method: create numerous alternatives and select one.
- draw orthographic views and create technical drawings.
- draw perspective views.
- create mock-ups and prototypes.
- collaborate in teams and brainstorm together.

The end-of-term results in this Biomimicry lecture produced the following proposals that were not applied in the lecture. In a biomimicry course, students should

- conduct design exercises in toolbox.biomimicry.org (URL-2), including specific questions, checklists, sketching, drawing charts, brainstorming, and mind map sessions.
- use tips and suggestions in toolbox.biomimicry.org (URL-2).
- divide the lesson into 5-6 sections (form, process, colour, function, material and construction (Zari,2007)), including related exercises for each section.
- attend biomimicry competitions.
- create 3D CAD models of the Project
- utilise 3D printing opportunities for the Projects.
- observe and sketch nature outside.

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