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INTEGRATION OF BIOMIMICRY INTO SCIENCE EDUCATION

Merve ÇOBAN

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Department of Mathematics and Science Education

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Advisor

Prof. Dr. Bayram Coştu

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A thesis submitted by Merve ÇOBAN in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE is approved by the committee on 04.07.2019 in Department of Mathematics and Science Education, Science Education Program.

Prof. Dr. Bayram COŞTU

Yıldız Technical University

Advisor

Approved By the Examining Committee

Prof. Dr. Bayram COŞTU, Advisor
Yıldız Technical University ____________________

Prof. Dr. Osman Serhat İREZ, Member
Marmara University ____________________

Doç. Dr. Hakan AKÇAY, Member
Yıldız Technical University ____________________

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Merve ÇOBAN

Dedicated to my family

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Merve ÇOBAN

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LIST OF ABBREVIATIONS

BEN	The Biomimicry Education Network
NASA	National Aeronautics and Space Administration
NGSS	Next Generation Science Standards
NSTA	The National Science Teachers Association
MIT	Massachusetts Institute of Technology
STEM	Science- Technology- Engineering- Mathematics

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ABSTRACT

Integration of Biomimicry into Science Education

Merve ÇOBAN

Department of Mathematics and Science Education

Master of Science Thesis

Advisor: Prof. Dr. Bayram COŞTU

Biomimicry is called "innovation inspired by nature". This study aims to integrate biomimicry into science education by proposing a teaching approach for primary school students. Action research approach as the qualitative research method was used. The developed "Biomimicry Teaching Approach" has been applied in a 5^{th} grade classroom the researcher teaches in a public school in Gaziantep. According to this model, the students firstly were presented with different kinds of organisms in order to develop the ability to observe organisms and make relationship between structure and function. Secondly, they were introduced biomimicry with a variety of examples. Finally, the students were engaged with "Biomimicry Design Model". At the end of the biomimicry lessons, the students designed their models through drawing and modeling inspired by a variety of organisms. The effects of "Biomimicry Teaching Approach" on student designs were analyzed. Results showed that 5^{th} grade students mostly created their own design ideas inspired by the organisms which were presented throughout the biomimicry lessons. The students' attempts to make different designs by taking inspiration from the organisms in nature and considering the function behind the physical structure of the organisms show that the students can produce creative and applicable design ideas inspired by nature when they are introduced biomimicry through "Biomimicry Teaching Approach".

Key words: Biomimicry, Nature inspired design, Biomimicry Teaching Approach, Biomimicry Design Model, Science education

ÖZET

Biyomimikrinin Fen Bilimleri Eğitimine Uyarlanması

Merve ÇOBAN

Matematik ve Fen Bilimleri Eğitimi Anabilim Dalı

Yüksek Lisans Tezi

Danışman: Prof. Dr. Bayram COŞTU

Biyomimikri "doğadan ilham alan inovasyon" olarak tanımlanır. Bu çalışmada ilköğretim seviyesinde bir öğretim yaklaşımı sunularak biyomimikrinin fen eğitimine uyarlanması amaçlanmıştır. Çalışmada nitel araştırma yöntemlerinden eylem araştırması kullanılmıştır. Geliştirilen "Biyomimikri Öğretim Yaklaşımı", araştırmacının Gaziantep'teki bir devlet okulunda dersine girdiği 5. Sınıf öğrencilerine uygulanmıştır. Bu modele göre, ilk olarak canlıları gözlemleme ve yapı ile fonksiyon arasında ilişki kurma becerisi geliştirmek amacıyla öğrencilere farklı türdeki canlılar sunulmuştur. İkinci olarak, "biyomimikri" öğrencilere çeşitli örnekleriyle tanıtılmıştır. Son olarak öğrenciler "Biyomimikri Tasarım Modeli" kapsamında öğrendiklerini uygulamışlardır. Bu tasarım modeli sonunda öğrenciler çeşitli canlılardan ilham alarak kendi tasarımlarını çizerek ve modelleyerek ortaya koymuşlardır. Çalışmada biyomimikri öğretim yaklaşımının öğrenci tasarımları üzerindeki etkileri analiz edilmiştir. Çalışmanın sonuçları 5. sınıf öğrencilerinin çoğunlukla biyomimikri derslerinde sunulan canlılardan ilham alarak kendi tasarım fikirlerini oluşturduklarını göstermiştir. Öğrencilerin doğadaki canlılardan esinlenerek ve canlıların fiziksel yapısının arkasındaki işlevi göz önünde bulundurarak farklı tasarımlar ortaya koymaya çalışmaları, öğrencilerin biyomimikriyi "Biyomimikri Öğretim Yaklaşımı" yoluyla öğrendiklerinde doğadan ilham alan yaratıcı ve uygulanabilir tasarım fikirleri üretebileceklerini göstermiştir.

Anahtar kelimeler: Biyomimikri, Doğadan ilham alan tasarım, Biyomimikri Öğretim Yaklaşımı, Biyomimikri Tasarım Modeli, Fen bilimleri eğitimi

1
Introduction

1.1 Literature Review

Biomimicry is defined as "innovation inspired by nature" in the book of Janine Benyus who is a biologist introducing biomimicry as a branch of science with its initial principles (1997). The term is originated from Greek words "bios" meaning life" and "mimesis" meaning imitation, so by a simple definition it is "imitation of life" (Benyus, 1997). Benyus defines biomimicry with one phrase: "conscious emulation of life's genius" (1997). Biomimics study nature's forms, principles, and systems to learn and get inspire with the purpose of creating sustainable designs and technologies. Neither the technology nor the biology is the definition of biomimicry by oneself. At the intersection of technology and biology, biomimicry emerges as the "technology of biology" (Benyus, 2014). Biomimicry is differentiated by its vision putting the respect for nature at the hearth of this field from other bio-approaches seeing nature as a source of material or prototype for production (Benyus, 2014 & Goss, 2009). It is about living respectfully on this planet by seeing the nature as model, measure and mentor (Benyus, 1997).

Biomimicry is based on the idea that nature has already solved the problems which human face today such as energy, transportation, food production, waste management and cooperation (Benyus, 2014). It follows the fundamental principles of nature such as manufacturing renewable energy sources, using energy efficiently, recycling, and producing eco-friendly materials. The nature is like an open book waiting to be read, understand and model. Being able to invent solar cells like a leaf, to stay clean and dry without using any chemicals like lotus plant, to make fiber like a spider, to climb vertical surfaces without using adhesive are possible if the nature is learned to be read like a book (Goss, 2009).

Mimicking the nature's principles and designs are significant to create a sustainable world for the future of our planet. Furthermore, in 21st century the way of designing a sustainable future is to embrace different disciplines with a collaboration and cooperation. Therefore, the educational system has been modified depending on the 21st century skills (Cortese, 2003). Accordingly, science education program has included different disciplines such as science, technology, engineering and mathematics (STEM) with an interdisciplinary approach. The program also gives important place to the recognition of the interaction between individual, environment and society (MEB, 2018).

Biomimicry is in line with the objectives of science education by creating opportunities for teachers to teach STEM subjects, environmental sciences and to develop 21st century skills. Thus, biomimicry does not only offer a method to learn from the natural world heritage to solve human problems, but also aims to educate nature lover and environmentally conscious students (Biomimicry Institute, 2017, p.3).

The significance of biomimicry approach has been recognized by universities, education networks and multiple organizations worldwide beside designers, architects, and engineers (Benyus, 2014). Although, biomimicry has been incorporated into education programs through new interdisciplinary centers in universities, review of the literature regarding biomimicry shows that the research conducted about biomimicry is mostly related to the industrial design, architecture and engineering. In other words; in the literature, insight into how biomimicry is integrated into science education and the outcome of biomimicry design process and products are lacking. In addition, although the Biomimicry Institute made recommendations for educators to share biomimicry with younger students, a biomimicry design model appropriate to the level of elementary school students has not been created.

Considering the compelling vision of biomimicry for the sustainability of our planet and the educational opportunities that biomimicry creates for students to become scientifically and environmentally literate, it is important to introduce biomimicry to younger students through integration with science education. In this context, creating a biomimicry teaching approach appropriate to the level of primary school students can guide educators to introduce and practice biomimicry in their science lessons.

1.2 Objective of the Thesis

When the significance of biomimicry education is taken into account from many aspects such as developing knowledge and skills and instilling values, the main purpose of this research is to integrate biomimicry into science education by proposing a design model for science educators to introduce and implement biomimicry. Based on this purpose sub goals are set as follows:

- To introduce the biomimicry concept, biomimicry design approaches and the place of biomimicry in science education.
- To evaluate the effectiveness of "Biomimicry Teaching Approach" through "Biomimicry Design Model".
- To determine the ways 5th grade students engage with biomimicry.

1.3 Hypothesis

In the present study, action research approach as the qualitative research was utilized. Therefore, no hypotheses are developed. According to the objective of the research, following research questions guide this study:

- What are the implications of integrating biomimicry into science education through "Biomimicry Teaching Approach"?
- In what ways do 5th grade students engage in "Biomimicry Design Model"?

2
The Concept of Biomimicry

Biomimicry is a branch of science which studies the nature's forms, principles, and systems to learn and take inspiration from it in order to create sustainable designs and technologies for human problems (Benyus, 1997). Furthermore, it can be categorized as a design discipline, an approach to problem solving, an environmentalist stance, or a new viewpoint of valuing and respecting biodiversity (Goss, 2009). It is an interdisciplinary field in which biologists, chemists, ecologists, engineers, architects and industrial designers work together to make contribution to the creation of technological design solutions by taking the nature as an inspirational model (Bartholomew, Strimel & Yoshikawa, 2017).

The idea behind the biomimicry is based on the thought that nature is full of design ideas which have been developed and perfected over time (Benyus, 2014). To clarify, leaves absorb sunlight to produce energy; humpback whales can easily make acrobatic maneuvers although they have large bodies thanks to the special structure of their flippers. Lotus plants can stay dry and clean even though they live in dirty waters thanks to nano scale bumps on their leaves. Woodpeckers can strike their beat into tree at shocking rate, but experience no brain damage by means of their skeletal structure (Goss, 2009). There are numerous examples of such strategies in nature. The nature is like an open book waiting to be discovered and modeled.

2.1 The Definition of Biomimicry and its Etymology

The concept of "biomimicry" was firstly introduced with its initial principles by Janine Benyus who is a biologist and co-founder of the "Biomimicry Institute" (Fisch, 2017). Janine Benyus explains where the word "Biomimicry" comes from in her book "Biomimicry: Innovation Inspired by Nature (1997). The term "Biomimicry" consists of two parts which are more melodious form of Greek words "bios" and "mimesis". Bios means "life" and Mimesis means "imitation" (Benyus, 1997). Although biomimicry is defined as "imitation of life" when two words come together, the term "Biomimicry" actually means a lot.

Benyus in her book which she introduces Biomimicry (1997) makes a brief but profound definition of that term with one phrase: "conscious emulation of life's genius". Each word has a reason to be chosen in this phrase. Firstly "Conscious" implies that learning practice from organisms is intended before something is designed. In other words, after something is designed, realizing that the design is similar to something in nature is not biomimicry. Secondly, the word "Emulation" refers that the process of biomimicry is not simply copying the nature; it is more than mere imitation. For example, studying an animal does not end up creating that animal in biomimicry. Biomimicry studies that animal in detail to learn its design principles and to apply them in a convenient way. Finally, the word "Genius" is chosen to point out well-adaptive solutions of organisms. Each organism is perfectly adaptive to its environment by developing different kinds of strategies to solve their problems (Benyus, 2014). The underlying idea of biomimicry is based on the thought that the nature has already solved the problems which people struggle today. Thus, in order to well adapt to this planet like other living things which were in here before humans, people have to learn life's principles from organisms which have the life's genius in order to create technologies offering a sustainable life.

2.2 The Principles of Biomimicry

With regard to learning life's genius, Benyus remarks three main principles of biomimicry through related questions (Benyus, 1997):

Nature as model ("What would nature do here?"): Biomimicry sees nature as a model, an open book for people to discover and learn from its designs in order to solve the problems they face.

Nature as measure ("What wouldn't nature do here?"): Biomimicry uses the ecological standards which nature determines to judge the appropriateness of human innovations.

Nature as mentor ("Why or why not?"): Biomimicry is a new perspective to view and to value the nature. The idea behind it is based not on what we can extract from the nature but on what we can learn from it.

2.3 Three Levels of Biomimicry

Biomimicry can be scaled in order to describe, comprehend and apply it. It is important to understand scale in biomimicry in terms of understanding how biomimicry can be practiced. If the strategies presented by organisms are analyzed in broad perspective, it is seen that the biomimicry examples fall under three categories as form based, process based, and system based (Biomimicry Institute, 2017, p.14).

2.3.1 Form Based Biomimicry

The first level in the application of biomimicry is at the level of "form". In this category, the natural form of the organism is mimicked with the purpose of functioning in the same way with organism. The "form" does not always refer to the whole part of the organism. One of the specific shapes or the structures of organisms' parts can become the subject of the biomimicry from micro level to macro level. For example, lotus leaves have a micro scaled rough surface resulting hydrophobicity and kingfisher's beak has a specific beak structure allowing it to enter into the water without splashing (Brusic, 2013). Such examples are well-known examples of biomimicry from micro and macro world respectively.

2.3.2 Process Based Biomimicry

The second level adds deepness to the practice of biomimicry. In this level organisms are not only mimicked because of their forms, but also the process how the materials are produced and which behaviors are performed in nature are mimicked (Benyus, 2014). Analyzing organisms in such level requires understanding green chemistry in nature. For instance, in order to produce clean energy from sunlight via green leaves, it is important to study the natural process of photosynthesis. Thus, this level is more complex to some extent compared to the form based biomimicry.

2.3.3 System Based Biomimicry

The last level embraces all the principles of biomimicry by creating a nature inspired ecosystem. In a natural ecosystem, organisms are in relationship with each other by affecting each other's life, so a system includes different kinds of forms and processes of nature inside of it (Biomimicry Institute, 2017, p15.). As having an inclusive role, the system level biomimicry requires to be able to see the big picture of nature by looking at the organisms deeply. To make it clear, an organism should be thought as a member of a habitat which is a part of a biome that is involved in a sustainable biosphere. Likewise, while organisms are inspired to design as solutions to certain problems, the designs should also be considered as a part of an industrial economy. The process of fabrication of such products and even the working conditions in these fabrics are also taken into consideration in the system based biomimicry (Benyus, 2014). In other words, designing a product inspired by nature by examining the forms and processes of nature is just the beginning for this level. Regarding the system based biomimicry attention must be paid from the design of a product to its place on the shelves. Beside the physical design; the manufacturing process, packaging, and shipping decisions have significance for appropriate implementation of biomimicry (Macnab, 2012). For example, although a nature inspired design is environmentally friendly and sustainable, if the transfer process of the product is done with vehicles releasing polluting gases, or if people are working in poor conditions in factories where this product is produced, the system based biomimicry does not take place there. Indeed, mimicking the nature at this level requires considering the whole process of biomimicry from a wide perspective in order to create a true sustainable world.

2.4 Examples of Biomimicry

2.4.1 Burdock burrs- Velcro

Velcro is the most often cited example of biomimicry. A Swiss engineer called George de Mestral realized the sticky characteristics of the burdock burrs on his dog's fur in 1941. As a result of investigation, he understood that the plant has tiny hooks allowing attaching to rough surfaces without using any chemicals. Mestral took inspiration from this strategy to design a product which has two interlocking surfaces. His long-term study on the design process led to the invention of the "Velcro" which also called as "hook and loop" (U.S. Patent No. 2,717,437, 1955). Since the recognition of the "Velcro", it has been used in many different areas of the life all around the world.

2.4.2 Kingfisher/Owl Shinkansen Bullet Train

The story of Japan's Shinkansen Bullet Train is one of the most well-known examples of biomimicry. In this story there are two species of birds which resolved an important problem about high noise level due to the high speed of the train. The engineer and director of Shinkansen series who is named "Eiji Nakatsu" took inspiration from owl feathers and beak of the kingfisher (Mckeag, 2012). Firstly, owls can fly silently by the way of their "serration feathers" which break the larger air vortexes into small ones. Analysis of the owl's silent fly mechanism and application of this principle were resulted by a decrease in the noise level. Secondly, the aero dynamic shape of the kingfisher beak was modeled to design the nose of the train in order to reduce the sonic bomb effect which train was facing while it was passing the tunnels. Reshaping the nose of train as same to the kingfisher beak led to the successful management of the pressure in and out of the tunnel together with energy efficiency (McKeag, 2012).

2.4.3 Lotus Plant- Lotus Effect

Lotus plants have special nanostructures on their leaves that cause the plant to live in dirty waters but still stay clean and dry. The super hydrophobicity is resulted by rolling of water droplets along the micro structures on the leaves with the dirt which adheres to the water. Investigation of this characteristic of the lotus plant led to the development of self-cleaning products. It is called the lotus effect because this effect was discovered through the analysis of lotus plant by a German botanist named Wilhelm Barthlott in 1977 (Barthlott, & Neinhuis, 1997). The well-known example of implementation of the lotus effect is the production of a wall paint called "Lotusan". It has a self-cleaning effect inspired by the lotus plant's microstructure.

2.4.4 Humpback Whale- Tubercle Technology

Humpback whales are nearly 50 feet long and 40 tons. Still, they can swim effortlessly by making underwater maneuvers thanks to the special structure on the leading edges of their flippers. They have tubercles on their flippers which lead the water and air to flow over the surface. This brings easy lift of the body. The characteristic of the humpback whales was analyzed by a scientist named Dr. Frank Fish. He investigated the effect of tubercles on the design of an airfoil. The research showed that the addition of the tubercles to the airfoil has positive outcomes on the lift, energy efficiency and sound level. The result of this experiment led to the design of wind turbines and other type of fans with tubercle technology (Fish, Howle, & Murray 2011).

2.4.5 Gecko- Bandage

Geckos are the member of reptiles which have the ability to adhere to the surfaces and to climb vertical walls. Their strategy lies in the texture of their feet including millions of micro hairs. These micro structures cause an adhesive force between the feet and the surface. The analysis of the mechanism behind the characteristic of the gecko feet led to the development of materials functioning in the way of geckos' feet. A bandage designed by a team of scientist from MIT (Massachusetts Institute of Technology) is an example of nanotechnology mimicking the gecko feed. Today, gecko-inspired materials have been developed to be used in surgeries and in design of robots which can climb vertical walls to perform various tasks (Yanik, 2009).

2.5 The Historical Precedent

Throughout the history people with or without awareness have been looking to nature to take advantage of it as a design idea or source of inspiration. When the concept of mimicking the nature is examined, it would appear that it dates to prehistoric times (Goss, 2009). One of the most important needs of human being is to survive and protect themselves from external factors. Fashioning weapons which are used against the wild animals in prehistoric times are examples of this need. These weapons could serve as a model mimicking the claws of such animals. The camouflage technique which was used by early people to protect themselves from wild animals is another example that can show that the nature is mimicked (Goss, 2009).

It is possible to see the examples related to biomimicry in Roman Empire period. For example, an army weapon called “Scorpio”, developed by Roman Marcus Vitruvius looks like a scorpion both physically and functionally (Kuday, 2009). It is a kind of ballista whose arrows act like the stringer of the scorpion as seen in Figure 2.1 (Messina, Reina, Rossi, & Savino, 2015).

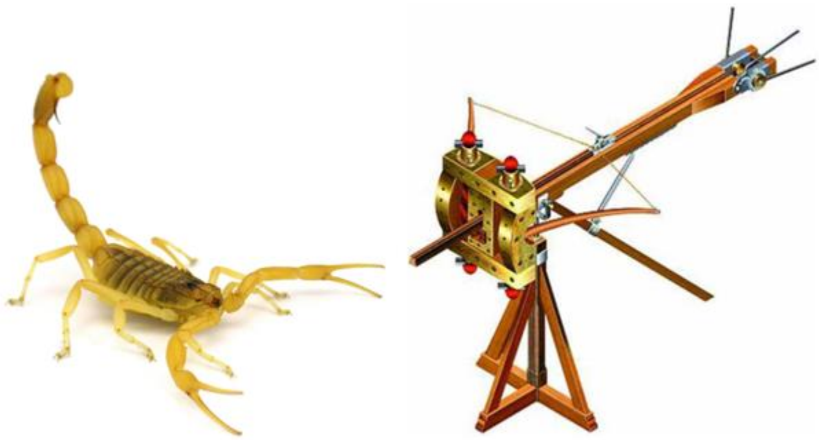


Figure 2. 1 Scorpion and weapon called "Scorpio" (Rossi et al., 2015)

It is also remarkable to see the similarity between roman armors and some animals (Kuday, 2009). For instance, the design in the shield of armadillo can be related with the Roman armor called “Lorica Segmentata” which means segmented armor. Especially the part covering the shoulder corresponds with the nested shells on the back of the armadillo (Figure 2.2).

Figure 2. 2 Armodillo and lorica segmentata (Kuday, 2009)

Another armor which is called “Lorica Squamata” meaning scaled armor can be associated with the scales on reptiles such as snakes and lizards as seen in Figure 2.3. However, the resemblance between the structure of organisms and the design of such materials does not guarantee that the organisms are mimicked as a design model.

Figure 2. 3 Snake and lorica squamata (Kuday, 2009)

The first reliable design models by mimicking the living things may have been presented by Leonardo da Vinci (Lodato, 2005). His thought about nature supports this claim (Knowles, 2001, pp. 464):

“Human subtlety will never devise an invention more beautiful, more simple, or more direct than does nature, because in her inventions, nothing is lacking and nothing is superfluous.”

His most notable design of “ornithopter” which is a flapping- wing aircraft is the result of his careful observations on birds’ anatomy (Figure 2.4). The success behind his designs is based on his efforts to see the nature's secrets (Lodato, 2005).

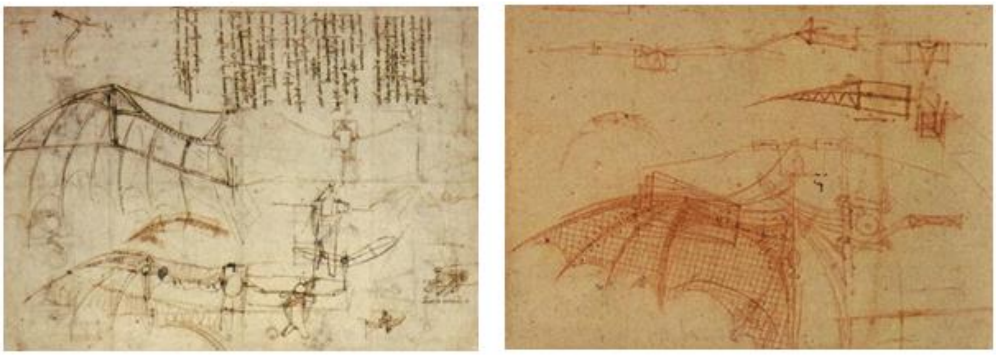


Figure 2. 4 Designs for a flying machine by Leonardo da Vinci

In a similar way, the Wright brothers' analysis of a turkey in order to understand how it uses its body for reducing turbulence led to the creation of stabilizers for their airplanes (Goss, 2009).

When it comes to the recent history, due to the changes in humans' needs, the relationship between nature and human and the ways people take inspiration from nature differentiated. The most well-known attempt of biomimicry before the term was defined in the recent time is the design of Velcro invented in 1941 by an engineer whose name is George de Mestral (Goss, 2009). His invention Velcro was inspired by the burdock burrs he observed that they stuck to his dog's fur. He mimicked the tiny hooks of this plant in the design of the fabric so that two surfaces interlock to each other without using an adhesive.

From past to the present people were in interaction with nature to take advantage of it with different purposes. Before the concept of biomimicry was introduced as a branch of science, the main historic precedents of it were given in this section. The term "biomimicry" and the related bio terms are explained in the following section.

2.6 Biomimicry, Bio- inspired design, and other Bio- terms

Biomimicry appeared as a term in 1982 and it was invented and published for the first time by Janine Benyus in 1997 in her book named "Biomimicry: Innovation

Inspired by Nature" (Aziz, 2016 & Benyus, 1997). Before this term was appeared, there were already several "bio" terms asking nature for solutions such as bio-inspired, biomimetics, bioengineering and bionics (DeLuca, 2014).

Among the bio-terms, "Bio-inspired design" plays an umbrella role for design and engineering approaches by encompassing them all including biomimicry (Biomimicry Institute, 2017, p.12). All biomimicry designs can be accepted as "bio-inspired design" since both share the same inspirational resource. On the other hand, not all bio inspired designs are biomimicry, because bio inspired designs contain any design inspired by nature. In order a nature inspired design to be biomimicry, the design has to be based on functional purposes (Biomimicry Institute, 2017, p. 12).

At this point, it is significant to clarify two design approaches within the scope of bio-inspired design: "biomorphism" and "bioutilization" (Biomimicry Institute, 2017, pp. 12-13). In biomorphism, the design visually resembles an organism in nature such as a chair looking like a tulip but the function of tulip does not correspond to the chair. Bioutilization is another confusion related to biomimicry. It refers to the use of biological organisms or materials in design and technology such as using tree woods for furniture. Therefore, bioutilization is distinct from biomimicry which uses nature as an inspirational source of knowledge instead of a material (Bernett,2015).

The other bio-approaches addressing the nature as a source of idea for technological invention and innovation are termed "bionics, "biomechanics", "bioengineering", and "biomimetics" in various branches of science (DeLuca, 2014). Bionics studies biology for development of technical and electronic systems. The subject of bionics is mostly involved in the field of engineering and medicine. Biomechanics analyses the anatomic principles of organisms' motions and then applies these principles to the human made mechanisms. Bioengineering and biomimetics also connect biology with technology. Among these terms biomimetics is called 'the abstraction of good design from nature' by Julian Vincent who is a professor studying biomimetics (Aziz, 2016). The reason why Benyus created a new term "biomimicry" instead of using the existing terms is that she wanted it to be more approachable and she thought that the existing ones could sound technical for some readers (DeLuca, 2014). In fact, although these terms share a common approach in terms of taking inspiration and knowledge from nature, biomimicry is distinguished by its vision emphasizing on re-connection with and respect for nature as well as learning from nature's lessons for more healthier and sustainable technologies for human (DeLuca, 2014). In other words, from the viewpoint of biomimicry, nature's genius is seen as solutions to environmental problems compared to the other bio-approaches which use nature as a prototype for production as independent of sustainability (Goss, 2009). About this issue, Biologist Janine Benyus gives a biomimetic example of airplanes' invention. She writes "We flew like a bird for the first time in 1903, and by 1914, we were dropping bombs from the sky" (Goss, 2009). Thus, biomimicry and other bio-approaches diverge at the intention of sustainability with a respect for nature.

3
Methods of Biomimcry in Design

Our environment is surrounded by human made design products. Even though design is associated with tangible objects, its decision process including the systems and the plans is important part of the design (Biomimicry Institute, 2015-a). For instance, there are many designed object in the kitchen of a house such as refrigerator, cupboard, dishwasher or bakery. Furthermore, there is an infrastructure in the design process of each product about how such a product works addition to the design of its physical attributes. Because of important roles of design decisions, the process of innovative design thinking related to design methods and tools has been gained importance in various areas including science, education, business and so on. Although they show diversity with regard to the application field, all design processes go through similar steps. Starting with research and understanding the design problem proceed with exploring and developing suitable solutions to test for the purpose of reaching a final product. The process of practice of biomimicry includes these basic phases, but it differentiates with its sustainable perspective among design approaches. In this section the systematic way of practice of biomimicry will be explained in the light of principles of nature's designs.

3.1 Principles in Nature's Designs

Nature has the best designs which operate systematically based on some rules. Biomimicry follows the main principles of nature by emulating its biological design ideas with the purpose of solving human problems. Benyus (1997) pays attention to the nature's sustainable methods in each example of biomimicry she gives in her book. Accordingly, she presents a list of 9 principles based on nature's laws or strategies.

- *Nature runs on sunlight*

Nature uses the power of sun as a source of energy. Its energy is renewable and available freely. For instance, the process of photosynthesis in plants is the main method of producing energy in nature. Mimicking the nature requires relying only on renewable energy sources for a sustainable life on earth rather than using nonrenewable ones which cause pollution (Althen, 2015).

- *Nature uses only the energy it needs.*

Nature uses energy efficiently without need of extra one. The energy sources it use are freely available, renewable and found locally such as sunlight by the process of photosynthesis, rising air currents, wind, minerals, organic materials and other nutrients. Organisms use low-energy processes by developing strategies to decrease the amount of energy they need (Biomimicry Institute, 2015-b). For example, emperor penguins develop the strategy of huddling together to keep their body temperature constant without needing extra energy to stay warm (Angel, 2015). As another example, the shell structure of abalone's can be given. These organisms have 200 times stronger shells which are out of minerals coming from the seawater at seawater temperature compared to the ceramics human make by using high heat and pressure (Biomimicry Institute, 2015-b). It is possible to model this principle of nature within a variety of forms. Even the establishment of a plant's production site and recycling facilities as close to each other in order to reduce the amount of energy that will be spent on transportation is a step towards energy efficiency. Thus, by imitating the designs and systems in nature, energy consumption can be optimized and technologies which provide efficient energy use can be developed.

- *Nature fits form to function.*

In nature, organisms have forms which serve specific functions. Their specified forms enable them to fulfill their functional requirements without needing extra material or energy. For example, when the structure of a tree is analyzed, it is seen that a tree has roots in the ground taking water and nutrients from the soil. It has many branches and leaves which enable it to increase its surface area to soak up the sunlight with the purpose of photosynthesizing (Althen, 2015). It is possible to observe nature's different types of designs which are related to the organisms' needs. For example, in nature there are many different kinds of wing shape or beak shape of the birds as related to the need of the birds in their habitats. Therefore, behind the forms of organisms, there is always a functional reason (Biomimicry Institute, 2015-b).

➢ *Nature recycles everything.*

In nature nothing is wasted. One organism's waste becomes others' source of food or materials. Even the body of organisms after they are died is not wasted, but they are decomposed by some organisms for the continuation of life. Thus, recycling everything is one of the main principles of nature (Biomimicry Institute, 2015-b). To clarify, the process of photosynthesis in plants can be given as an example to recycling. The leaves which are growing need a lot of energy from the tree, but at the same time, they produce this energy by the sunlight. They also transform carbon dioxide taken from outside to the oxygen which is the source of life on earth. However in winter, inadequate sunlight causes trees to drop their leaves onto the ground. Yet, this process has the purpose of protecting its root system from the cold and supporting the fungal cycle which in turn would help the tree grow by means of nourished soil (Biomimicry Institute, 2015-b). Therefore, in such closed- loop systems in which energy and matter are recycled and no waste is produced, each stage of the organisms' life has a role for the benefit of whole system.

➢ *Nature rewards cooperation*

One of the principles of nature is related to its ability to cooperate by creating different kinds of interactions with each other. This interaction can be mutual meaning organisms provide benefit from the relationship. There are many examples of such relationships among organisms in nature. As an example, pollination is necessary for the lifecycle of plants and at the same time pollinators like insects are fed with the nectar of plants in this way (Althen, 2015). Recycling in nature is also associated with this relationship. However the cooperation among organisms is so diverse that some interactions can be seen as dangerous for one organism like predation or parasitism (Biomimicry Institute, 2015-b). Yet, everything is so connected that all living organisms are dependent to each other and ecosystems in nature make possible to create interconnection webs of relationships in turn composing the life on earth. Therefore, organisms cannot survive in isolation from the others. The human built world also includes different kinds of interconnections which are part of complex systems. Knowledge and awareness of system interconnections can lead to optimize design solutions by also considering how such designs can fit within the earth context (Biomimicry Institute, 2015-c).

- *Nature banks on diversity*

Diversity is one of the rules of nature that ensures its survival. Over long periods of times, organisms on earth created diverse biological communities to pursue life within the limits and boundaries of nature. Also, genetic diversity determined the organisms' ability to adapt to the environmental changes (Biomimicry Institute, 2015-d). Although in nature competition and predation exist among species, from ecosystem perspective organisms support life of each other by providing food or material, so it is advantage for them to live together within diversity.

- *Nature demands local expertise*

Organisms can not to be considered independent from their local environments, because their survival is actually depend on their responses to the change of the environment. In other words, an ecosystem which organisms are included is affected by the local conditions in turn changing the organism's chance of survival. These changes can occur slowly within a particular location. Yet, if organisms take this change as an opportunity by managing the available resources, such species will have an advantage over others to survive and transfer their genes over generations. From a broad perspective, being responsive and attuned to local environmental changes adds contribution to the ability of organisms and ecosystems to flourish (Biomimicry Institute, 2015-b).

The mound of termites can be given as an example to the adaptive structures. Due to the fact that they have to protect the mound temperature as stable for them to survive, these creatures need fresh oxygen like human. They create their mounds about 2 to 3 meters above the ground acting as a ventilation system. Their construction looks like a technological mound. As the level of such gases is changed, the termites adjust the tunnels and the height of the mounds so that there is a temperature balance within the mound (Biomimicry Institute, 2015-b).

- *Nature curbs excesses from within*

Natural systems have a carrying capacity or a tipping point. When disequilibrium occurs, nature changes itself to create the balance again (Althen, 2015). Sometimes, nature can get rid of the excesses through some natural phenomenon. For example, ecosystems can renew and refresh because of wildfires. When wildfires are resulted by natural reasons in low intensity, this can be advantageous for the forests. It is one of the ways of nature to clear out the dead parts on floors. In this way important nutrients can also return to the soil. In addition, some plants need intense heat to germinate their seeds, so they trigger the fire with their leaves which include flammable resins. Without such level fire these plants could not transfer their genes (Johnson, 2018). Thus, under every circumstance, nature creates possibilities to allow regeneration by its rules.

- *Nature taps the power of limits*

All living organisms have limitations in terms of age, climate, resources or population. Everything in nature operates in a state of balance within a constant state of dynamism. Life has survived on the planet of earth with limited water, atmosphere and sunlight in different kinds of climate conditions. Nature has succeeded to thrive even in extreme conditions such as in deserts, poles, everglades or high plateaus by adapting to the boundaries of earth (Biomimicry Institute, 2015-d). The power of nature to tap the limits is based on its capacity to adapt by developing diverse forms for distinct environments.

Nature is a designer based on these fundamental principles. It operates the factory of earth on a regular basis compared to human production. It manufactures all kinds of designs at any moment in possible amounts. By taking power from renewable energy it avoids waste. It produces designs according to the purpose. When conditions change, it reviews and modifies its designs. It recycles the materials which have the ability to reuse. It continues to exist with minimum expense and maximum earnings.

These 9 principles of nature which Benyus identified teach us that the nature has the knowledge of how it can be lived sustainably in relationship with other organisms on earth. Biomimicry follows the fundamental principles of life like developing renewable energy sources, using energy efficiently, recycling, establishing relationships, and using environmentally friendly materials. The products and processes have been developed by following these principles enable us to be more compatible with the environment we live in.

3.2 The Use of Nature's Principles in Design

Biomimicry aims to produce innovative and sustainable design solutions inspired by nature's designs through integration of design and designers into the biomimicry process (Eryılmaz, 2015). The process of biomimicry is described by the design spirals to guide the designers. Designers whether they are from different disciplines such as engineering, architecture, industrial design or natural sciences can practice biomimicry by following the basic steps explained through these design spirals (Kuday, 2009). The biomimicry design process leads to integrate biomimicry into the design process by two main processes. These approaches are explained as follows (Macnab, 2012, p.210):

- **Challenge to Biology:** Identifying and defining the design problem and then exploring the nature for solutions (Figure 3.1).
- **Biology to Design:** Discovering and defining the strategies and behaviors of organisms in nature and then transforming that biological knowledge into the design project (Figure 3.4).

3.2.1 Challenge to Biology

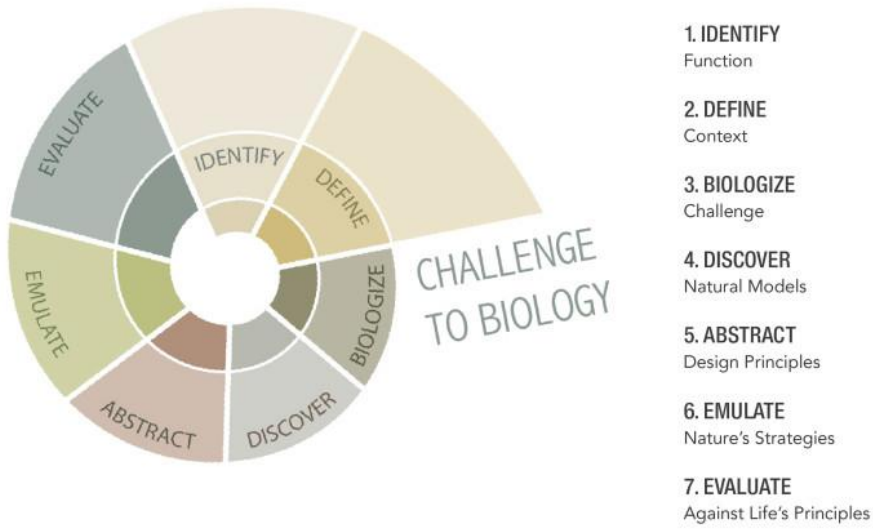


Figure 3. 1 Challange to Biology Spiral (reproduced from Macnab, 2012)

1. ***Identify:*** *Identifying the design problem based on human needs rather than simply stating what to design.*

The goal of this step is to identify the main and underlying design problem to be solved by stating what our design needs to do in what context. In this step, the purpose of the design is defined in terms of the intended function of the design. In other words, the question which needs to be answered is not about what we want to design, but it is related to what we want our design to do (Biomimicry Institute, 2015-e). In order to avoid jumping the statement about what to design in this step, "How might we…?" questions can be asked. For example a design question "How might we keep buildings cool in the summer?" can lead determining the function such as making people feel cooler instead of determining to design an air conditioner.

2. ***Define:*** *Defining the context and operating the parameters.*

After identifying the function, the context of the design is defined. For instance, parameters such as environmental conditions, social conditions, energy and material efficiently, ability to adapt to changing conditions are involved. Furthermore, sustainability goals based on nature's principles are defined in this step.

3. ***Biologize:*** *Analyzing the design problem in the context of biology to biologize the question; in other words, it is an approach to the design process in terms of nature's perspective.*

After identifying the design question, nature is asked for advice in this step. In other words, identified needs or functions in the design question are reframed in biological terms. In order to do that asking "How does nature…" questions can guide. For example: "How does nature take and solve this problem?", "What would nature not do in this situation?" To make it clear, if the design question is "How might we keep buildings cool in the summer?" the biologized question: "How does nature stay cool in hot conditions?" Asking variations of the question such as asking from opposite side is suggested. For instance, the same question can be reframed as "How does nature manage temperature in hot climates?"

4. ***Discover:*** *Researching the potential mechanisms in nature and identifying the strategies that perform specific functions related to our design problem.*

This step involves gathering information from different sources with the question "how does nature…" in mind as a guide. Different organisms, ecosystems and scales are discovered to find the functions and context related to the intended challenge. In order to that, going outside, getting close to the living organisms, observing their structures and behaviors, taking field notes and sketching observations are suggested. Reading the related scientific literature including different kinds of resources such as science news, journals and online databases like "AskNature" can also give ideas and inspiration. In addition, to ensure understanding of the biological details, the findings can be discussed with biologists, naturalists, and specialists in that field. At the end of this stage, the strategies of organisms which enable them to survive and success relevant to our design challenge are identified.

5. ***Abstract:*** *Studying the strategies and the functions of organisms which achieve success in nature to transform that biological knowledge into the design solutions.*

After identifying the key biological strategies, the biological strategies are translated into the design strategies in this step. Firstly, the key points related to biological strategy are determined and how that biological strategy works to perform a function is comprehended. Making a sketch to demonstrate the understanding of the mechanisms behind the biological strategy can help visualize and verbalize. Figure 3.2 shows the rabbit's strategy of having large ears radiating heat through networks of blood vessels on them.

Figure 3. 2 Diagram showing the rabbit's thermal strategy to regulate heat (Biomimicry Institute, 2015-f)

Then, rewriting the design strategy without using biological terms and redrawing the design strategy without showing the biological parts are suggested. Writing this type of statements and drawing the mechanical system or process behind the strategy via diagrams can make easy to translate the strategy into the design application. Figure 3.3 shows the mechanism of the rabbit's strategy via a diagram without referring biological features.

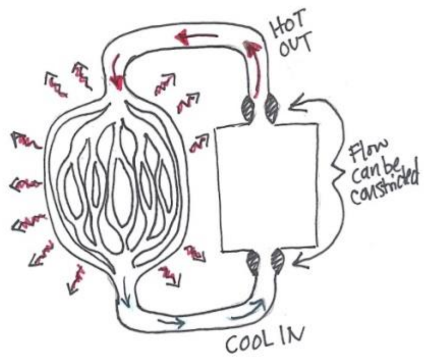


Figure 3. 3 The mechanism of the rabbit's strategy (Biomimicry Institute, 2015-f)

6. ***Emulate:*** *Learning from natural models, developing ideas and design solutions and applying those knowledge into the problems which human want to solve.*

This step is seen as the hearth of the biomimicry. The process of emulation requires capturing the key ideas, patterns and relationships among the strategies rather than absolutely copying the strategies of nature. Applying these lessons requires analyzing the design solution deeply in order to mimic the form, function or the ecosystem. In this stage, organizing the inspired strategies via visual tools, using techniques like brainstorming, mind-mapping, and sketching, revisiting the abstracted design strategies related to design question in previous steps are suggested.

7. ***Evaluate:*** *Assessing the design concept which is developed in the "Emulate" step in terms of how it solves the design challenge, how feasible and sustainable it is. Revisiting and refining the previous steps if needed.*

This step involves assessment of the biomimicry design process. Although it seems the last step in "Biomimicry Design Spiral", evaluation takes place during the design process. Activities like designing models, testing technologies, or creating prototypes can take place in evaluation step. In this stage, developing questions to test whether the design idea fits the principles of nature and to improve the design solution is important. In addition, questions about the future of the design such as the process of manufacture, packaging and transport can be evaluated in terms of sustainability.

As an example to the “challenge to biology” approach, the steps for the design of “Entropy Carpet” inspired by dead leaves accumulated on the forest is given in Table 3.1.

Table 3. 1 "Challange to Biology" steps for Entropy Carpet (Biomimicry Institute, 2016-a)

Challenge to Biology Steps	Instruction
Identify/Define	“How can we save the material and the labor in manufacturing carpet tiles?” “How might we create a carpet tile that is environmentally sustainable?”
Biologize	“How does nature make floor?”
Discover	Making observation in the forest and realizing the accumulated fallen leaves on the forest floor
Abstract	Different colors and shapes of the leaves create a harmony on the forest floor
Emulate	Designing relatively different carpet tiles which have similar colors and patterns, but that create uniformity when combined together
Evaluate	Evaluating its effectiveness with regard to sustainability (less waste, less labor in production and installation process, adaptive to changing conditions with its replaceable parts)

3.2.2 Biology to Design

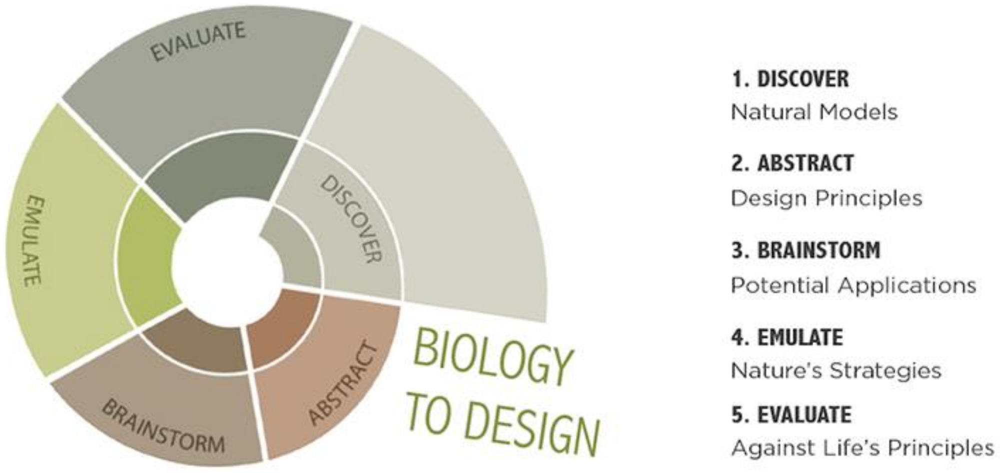


Figure 3. 4 Biology to Design Spiral (reproduced from Macnab, 2012)

1. **Discover:**

In this stage, organisms and ecosystems are discovered in a variety of ways such as making field observations, researching the scientific literature, exploring the databases like "AskNature" and talking with biologists or naturalists.

2. **Abstract:**

After discovering the nature's functions, the strategies whether they are forms, processes or systems of nature are decided. Then, for designers to understand, the determined strategy is translated into abstract expressions meaning that biologized strategies are reframed as design strategies.

3. **Brainstorming:**

In this step, designers together with field experts such as biologist and engineers brainstorm the potential design ideas as solution to the human problems.

4. **Emulate:**

This is the stage that nature's strategies are mimicked, so the design solutions which are determined through brainstorming are analyzed in detail. The sustainability principles of nature are involved into the design.

5. **Evaluate:**

Evaluation step requires evaluating the whole design process by comparing the developed design solutions to the life's principles. In addition, the future of the design solution is discussed and new questions are created to improve the present design.

As an example to the "biology to design" approach, the steps for the design of "ORNILUX Bird ProtectionGlass" inspired by spider web is given in Table 3.2.

Table 3. 2 "Biologt to Design" steps for ORNILUX Bird Protection Glass (Biomimicry Institute, 2016-b)

Biology to Design Steps	Instruction
Discover	Orb weaver spiders create their webs by using strands of silk which have UV reflective properties. Thanks to the bird's ability to see ultraviolet light, reflective webs prevent them from crashing into the webs
Abstract	Glass coating covered by ultraviolet reflective materials can prevent birds from striking windows and injuring or killing themselves
Brainstorm	Creating ideas about how to develop a product that would have the UV-reflective qualities similar to the spider webs.
Emulate	Analyzing and testing different types of coating and patterns lead to the development of patterned coating glass whose layers enhanced the reflective effect that is visible to birds, not to the human eye.
Evaluate	Evaluating its effectiveness in terms of life's principles such as sustainability.

4
Biomimicry in Science Education

4.1 The Aim of Science Education Program

The main aim of science education program is to educate all students as scientific literate individuals who have scientific knowledge about sciences and its applications and have abilities to use their knowledge in solving daily life problems, making informed decisions and taking responsible actions (MEB, 2018). Detailed information about the aim of science education is given in the following:

- Providing primary knowledge on astronomy, biology, physics, chemistry, earth and environmental science and engineering applications.
- Adopting scientific process skills and scientific research approach and finding solutions to the problems encountered in these areas in the process of discovering nature and understanding the relationship between human and environment.
- Enabling to recognize the interaction between individual, environment and society; developing awareness on the sustainable development related to society, economy and natural resources.
- Enabling to take responsibility for daily life problems and to use scientific process skills and other life skills about science in order to solve these problems.
- Developing career awareness and entrepreneurship skills related to science.
- Understanding how scientific knowledge is produced by scientists, what processes of this created knowledge go through and how to be used in new research.

- Raising interest and curiosity, developing attitudes about events occurring in nature and close environment.
- Creating awareness about the importance of safety in scientific studies.
- Developing the ability of reasoning, habits of scientific thinking and decision-making skills studying socio-scientific subjects.
- Ensuring the adoption of universal moral values, national and cultural values and scientific ethic principles.

4.2 The Importance of Biomimicry in Science Education

In order to design a sustainable future in 21st century, a broad perspective embracing different disciplines and research areas with collaboration and cooperation is required, so the process of education has been adapted based on the 21st century skills (Cortese, 2003). Accordingly, science education program includes various disciplines which are connected to each other such as natural and environmental sciences, mathematics, engineering and technology. Thus, it enables students to be able to interrelate among science, environment and society with awareness on sustainability (MEB, 2018).

In accordance with the objectives of science education, biomimicry offers a learning framework that brings various disciplines together to raise world citizens who are sensitive to the environment with conscious that they are a part of that nature. In other words, biomimicry does not only offer a comprehensive method to learn from the natural world heritage with the aim of solving human problems, but also plays a key role to educate young students to be positive agents who appreciate the natural world around them for shape this planet as sustainable. It is an interdisciplinary process involving the disciplines which can be supposed as disconnected such as nature and technology. It is accepted as a new way of understanding the relationship between natural world and the world of design and technology. That's why it has been taken place in education programs and universities worldwide (Benyus, 2014). Furthermore, biomimicry has many advantages from developing knowledge and skills to creating awareness and instilling values. In conclusion, integration of biomimicry into the science education is significant in terms of following arguments (Benyus, 2014):

- *Biomimicry offers an interdisciplinary framework for teaching a wide range of topics in science education including STEM/STEAM education and environmental literacy by connecting them to each other.*

Students are engaged with real life problems by following the biomimicry design process. While they were searching for solutions by looking at the nature or discovering the nature's strategies to transform them into the design project, they develop different kinds of knowledge and abilities in many fields involving science, technology, engineering, arts and mathematics. Furthermore, biomimicry is an effective way to promote environmental and ethical literacy by accepting the nature as a model, mentor and measure. In this way, the boundaries between the technological world and the natural world are broken in turn students learn to be able to look at the nature from a broad perspective.

- *Biomimicry can help teachers improve 21st century skills of students such as problem solving, decision making, creativity, analytical and critical thinking via design and project based activities.*

Biomimicry is an appropriate practice to be integrated into many topics in Science Education Programme such as biodiversity, energy transformations, human and environment, and especially engineering design process which was included in 2017 curriculum arrangement. Teaching these subjects with a biomimicry lens can enable students to develop scientific process skills, life skills, engineering and design skills together with a new perspective viewing the natural world.

- *It is an opportunity for children to appreciate the natural world that surrounds them and to awaken their feelings of connection with nature.*

Nowadays many children are deprived of discovering the nature's beauty and knowledge because they mostly live in modern societies spending their hours in front of a screen. Biomimicry takes the children outside to learn from the living systems in order to mend this broken relationship with nature. In fact, raising conscious generations caring about nature begins with instilling the love of nature.

At this point, biomimicry is an effective approach introducing children to nature by creating opportunities to love and respect the wisdom of nature.

- *When biomimicry is used as an inspirational method, it can lead students to develop a point of view so that they see design inspirations surrounding them and find creative ideas in every natural stimulus.*

Imparting this kind of view is so important that without experience with nature children may never realize the importance of their natural surroundings. How we view the nature also determines how we value it as well in turn affects the actions of people towards environmental issues. In other words, when students begin to see the natural world with curiosity and respect, they can perceive that nature is not just something for using but also something for learning from. Creating a sustainable world embodied in other living beings is only possible in our technological world when the shift in viewpoints of people takes place from learning about nature to learning from nature.

- *Biomimicry gives a hope for the future of the earth through its vision by encouraging students to volunteer in order to change the world in a sustainable way.*

Biomimicry attracts students' attention because its method is exciting and based on discovery feeding students' creativity and providing them with an active learning environment. Stories behind the examples of biomimicry and impressive examples of natural phenomena can raise students' enthusiasm to learn scientific subjects. In this way, students are motivated to explore the nature's ideas and to shape the world by developing 21st century skills such as problem solving, decision making and innovative thinking by the way of design based projects.

4.3 Core Concepts in Biomimicry Education

Biomimicry Institute provides an overview of core concepts to help understand and practice biomimicry by offering key ideas and suggestions. These important concepts summarizing the fundamental idea behind biomimicry and guiding educators in teaching biomimicry are explained in this section (Biomimicry Institute, 2017 & Benyus, 2014).

4.3.1 Teaching Approaches and Age Appropriateness

Biomimicry can be perceived so specialized or technical design approach, but like any other educational subject; its effectiveness on children is based on how it is introduced. Integration of biomimicry into science education can be oriented towards various goals considering learning objectives, time, or students' needs. For instance, creating awareness about nature's value, introducing multiple topics in science education, developing 21st century skills, and practicing engineering design process can be aimed together or separately. Whatever the students' age are, sharing biomimicry especially with the aim of instilling respect and love for nature is suggested (Benyus, 2014).

There are some circumstances to be considered for planning an age appropriate biomimicry education such as an appropriate vocabulary, level of complexity and relevance to student life. The definition of biomimicry is suggested to be introduced together with examples which captivate students' attention. For younger students using simple language avoiding the use of confusing terms can help them understand the essence of biomimicry. Progression of complexity is also suggested while introducing the examples of biomimicry. For instance, starting with an example "Velcro" is considered appropriate for almost each level of students because of its interesting story and visual resemblance to the inspiring organism. Therefore, this type of simple example can be chosen for both younger and older students. Besides, increasing the complexity in more abstract ways is an appropriate method for older students.

4.3.2 Function and Strategy

Biological function and strategy are described as the core concepts for the practice of biomimicry, so firstly understanding the concept of function and strategy is suggested (Benyus, 2014). Function is the most important element in the biomimicry design process because the presence of function differentiates biomimicry from other designs called with bio-terms. That is to say, biomimicry is based on learning from the role played by organisms to meet specific functions rather than simply copying the visual qualities of living things. While function can also be defined as the purpose or activity of something, strategy is the characteristics, mechanisms or process of organisms to survive and perform a particular function. In other words, organisms use biological strategies to fulfill functional needs.

For instance, while a hard shell of a snail's body is a strategy the organism has, the protection from predators to survive is the function accomplished related to this strategy. Studying the functions associated with the biological strategies leads to the creation of technological product ideas such as design of a bike helmet as for the example of the snail (Biomimicry Institute, 2015-e).

For younger students the concept of strategy can be connected with the structures of organisms to make comprehension easy. On the other side, function can be defined as the purpose or advantage of having these structures. When students link the structures of organisms to the advantages of having such structures, they can understand the relationship between strategy and function.

4.3.3 Systems Thinking

"Systems thinking" is an important concept to understand the viewpoint of biomimicry. Systems consist of various interacting parts like the structural organization of the body arranged in a special way from cells to organism. Similarly all organisms in nature are connected and they cannot survive in isolation from the other living things. Understanding the relationship between interacting parts and thinking about the whole system is essential to practice biomimicry with a broad perspective. For students to develop problem solving skills, they need to learn to see the big picture constituted from interacting pieces. While searching for solutions to the problems of the world, the nature has the answer with its excellent systems. For example in natural ecosystems, no waste is produced because each material is reused and recycled among other organisms in the system. Therefore, the clues and inspiration about how to live sustainable and how to innovate technology systems in human society underlie the wisdom of nature. In terms of biomimicry education, engaging students in conversations about the natural interaction among the living organisms, discussing cause and effect relationships and encouraging them to analyze their design with respect to the resource flow with a systems view are suggested (Benyus, 2014).

4.3.4 Patterns in Nature

One of the characteristics of nature is that it arranges itself in patterns at every scale from micro to macro level. It is possible to observe patterns of nature as shape, structure, color, arrangement or repeating events and relationships. Identifying patterns in nature requires having improved observation skill, so even noticing the nature's patterns is important in science and engineering. After the recognition of patterns, questions arise about the explanation of their existence. At this point, answering such questions is resulted by progress in science and engineering designs. Thus, in teaching biomimicry design process, introducing the natural patterns can lead students to understand organizational strategies presented by living things in order to solve functional problems (Benyus, 2014). Consequently, creating opportunities for students to notice patterns in nature such as size, shape, color and arrangement is suggested in biomimicry education.

5
Literature Review

Biomimicry is an approach applying nature's time tested strategies to solve human problems. Establishment of biomimicry approach brings a new perspective to the nature that is to say nature is perceived as a teacher (Benyus, 2014). Since the knowledge of nature rooted in 3.8 billion years of its history as recognized in scientific area, biomimicry has been taken place in many sectors such as technology, architecture, industrial design, health, medicine and accordingly education (Benyus, 1997). Because of the fact that innovation inspired by nature is a serious attempt for the sustainability of our planet, the potential of biomimicry in terms of its clever solutions and design ideas has been accepted as a leading approach for enhancing the world by several organizations, companies, and research groups.

As a result of understanding and accepting biomimicry as a new way of observation and design, biomimicry has been taken place in education adapted to universities and education programs worldwide (Benyus, 2014). The most important movement in the incorporation of biomimicry into the formal education and informal spaces is the foundation of Biomimicry Institute in 2006 by Janine Benyus who introduced biomimicry in order to teach, practice and spread it (The Biomimicry Institute, n.d.). Biomimicry Institute offers resources for educators and education organizations as well as learning opportunities for individuals. With regard to the resources for educators, the Biomimicry Institute provides free curriculum and resources as a framework for educators to teach biomimicry with STEM approach based on NGSS (Next Generation Science Standards). "Biomimicry Global Design Challenge" for university educators and "Youth Design Challenge" for middle and high school students offer project based competition to design bio inspired solutions for the critical environmental issues of the world. The

Biomimicry Education Network (BEN) also serves as a platform enabling educators who are interested in teaching biomimicry to share their ideas and experiences with other biomimicry educators all over the world. Regarding the offerings for education organizations, Biomimicry Institute provides instructional design services and workshops by collaborating associated organizations to develop curricula programs, museum exhibits and more. In addition, the institute builds academic partnerships to make biomimicry as a particular degree or certificate program in academic institutions. The institute especially places emphasis on spreading the nature's design ideas and solutions for people to learn and inspire. That's why a free online tool called "Ask Nature" is created in order to give learning opportunities for individuals. Its name comes from the fundamental thought behind biomimicry which is that the nature has already solved the problems which human face today.

Through many curricular programs, multiple organizations and worldwide education networks, biomimicry has been shaping the education with new standards integrating engineering and design activities within each level of education. While some education programs particularly incorporate biomimicry into their curriculum, some programs integrate it into their existing curricula. On the other hand, although there has been ever- increasing attempts to introduce and implement biomimicry into the education, review of the literature regarding biomimicry shows that the research conducted about biomimicry mostly is related to the industrial design and architecture.

One of the research in the area of industrial design is about the use of natural analogy in design (Boğa, 2013). The natural analogy has different names based on the field it is used such as biomimicry, biomimetics, bionics or bio inspired design. Accordingly, in design it is named as biomimicry. In this research "natural analogy" is preferred to call, because it is one of the types of design methods taught in the department of industrial product design. This study aims to understand the reasons behind the unwillingness of industrial design students to apply natural analogy in their design projects and explore reflections of using natural analogy on the design process. Students' reluctance was thought to be result of the inadequate knowledge on biomimicry and how to use it. Accordingly, a workshop was organized for first grade industrial design students to inform and provide experience about biomimicry and they were given a questionnaire to evaluate their views. At the end of the study, practicing biomimicry was found as complicated compared to understanding the nature's principles. That's why students mostly tended to mimic nature's physical form as a source of inspiration instead of using nature with the aim of solving problems. Eventually, a certain level of biology knowledge and the ability to interpret it had been seen as necessary in order to establish a comprehensive analogy with nature. In conclusion, using biomimicry in a design project with a systematical method in related courses involving Biology knowledge in the design curricula was suggested in order to increase its effective and accurate utilization by the researcher.

Another research in the area of industrial design named "Biomimetic Design and Methodology in the Content of Industrial Product Design" aims to investigate the methods of learning from nature for industrial product design, to discuss the future of these approaches together with their contribution by examining the concepts related to the industrial product design and biology (Yıldız, 2012). In this research, beside the informational part about the content, interviews were carried out with Prof. Dr. Orhan Küçüker, Biomimicry Institute instructor Zeynep Arhon and biologist Özlem Şorlu for detailed information about biomimicry such as the definition and methodology of it, the relationship of biomimicry with industrial product design and sustainability. A survey was done with Professional industrial designers to evaluate their views about biomimetic designs. Finally a case study was conducted with 8 master students from different disciplines to understand the incorporation of biomimetic methodology into the industrial product design by using the "challenge to biology" approach. In the interviews, it was concluded that the biomimicry approach required cooperation among different disciplines. Otherwise, it was thought difficult to go beyond copying only the physical shape of nature with aesthetics concerns. The views of biomimicry experts was consistent with the result of the survey which showed that participants inspired by nature in their design at the formal level. They stated they had difficulty in reaching information about the nature's process and mechanism. In conclusion, it can be said that inspiration from nature has been taking place since the emergence of this discipline in the industrial product design, but the integration of nature's technic into the industrial design by consulting biology with an interdisciplinary approach is a new approach getting importance day by day.

“Biomimicry for Sustainability” is an example of educational project about the integration of biomimicry into the industrial design education (Bakırlıoğlu, 2012). This research was conducted with the purpose of examining the biomimicry approach for sustainability and analyzing its outcomes in terms of challenges that industrial students face during the project, advantages and disadvantages of this integration as well as the instructors’ view on that. The tool named “Biomimicry Sketch Analysis” (BSA) was developed and applied to the 3rd year industrial design students for the idea generation in the biomimicry design process which was based on the “biology to design” approach. BSA involves both research (observation and analysis stages) and idea generation (transfer stage) phases. The main research stages consist of three parts that are biomimicry application in product design process, analysis of projects and semi-structured interviews to explore the insights of students and instructors. Analysis of results revealed that BSA tool created awareness towards biomimicry and sustainability. In terms of the challenges, inadequate knowledge on biomimicry approach and its incorporation into the design process, lack of time for observation and transferring process of observed strategies to the design solutions were determined. The most challenging exercise was stated as the emulation stage in which ideas and solutions were developed based on natural inspirations. With regard to the views of students about the individual versus group work, students thought that the working individually in biomimicry design process was more reasonable, but working partly in groups during observation and analysis stages to discuss and share opinions could help better comprehension. Consequently, researchers suggest that the integration of BSA exercise for the idea generation stage is effective in connecting research and idea generation stage for sustainable design solutions. Although this is a short-time educational project, it can be concluded that it has a pioneering role utilizing biomimicry approach in industrial design education.

Biomimicry is not only be integrated into the disciplines such as engineering, architecture or design, but it can also be integrated to different disciplines by functioning as a bridge to teach assorted topics. For example; in one research, biomimicry exercise was integrated into the field of paleontology in order help students discover connections among biodiversity, form and function and species conservation during Earth's Sixth Extinction (Soja, 2014). In this research, filed based, paleontology-focused learning exercise in which students were actively learning about biodiversity was performed. Students got opportunity to describe structure and function of organisms based on the fossil records to reveal about past mass extinction on the earth. During the exercise, they worked like a scientists and developed skills to observe and make inference about organisms. Finally they were engaged with bio- inspired thinking for design solutions with the purpose of solving human problems with a sustainable way. The outcomes of the research demonstrated that biomimicry exercise based on student's data which they collected, analyzed and synthesized improved their critical and innovative thinking skills. More importantly, such lessons enable students to gain valuable insights into the significance of biodiversity and their effects on environmental change for the future of our planet so that they can become an active agents to change the world with a sustainable design solutions.

Regarding the integration of biomimicry into the education, one study about the biomimicry as a solution based approach to the environmental science curriculum for high school students was conducted (Staples, 2005). The aim of the study was to review the literature to introduce the importance of the biomimicry and lead to think about nature inspired solutions to human needs and environmental problems. Because there have not been many attempts to integrate biomimicry into the education curriculum, the researcher created a website for educators to use as a resource and suggested lesson plans which include thinking exercises and open ended problems in line with high school environmental curriculum.

In terms of higher education there is one study about the significance and place of biomimicry data in physics education (Ersanli, 2016). This study is based on the idea that no matter in which field of education, the way to increase motivation is matching the knowledge with its models in nature beside understanding the place and significance of that knowledge in life. Because of the fact that students have difficulty in establishing relationship between physics and the real life, the study aims to raise students' awareness for the importance of physics education, to improve their scientific literacy skills and to increase their motivation by making students knowledgeable about biomimicry involving the mechanisms and the products inspired by nature related to the physics. Thus, the study offers educators a recommendation to teach physics by relating them to life through a biomimicry lens.

In the literature, regarding biomimicry in elementary science education, it is seen that the nature inspired thinking and designing are related to the STEM approach and engineering design process. Nowadays, science, technology, engineering, and mathematics (STEM) disciplines have taken on ever increasing importance to educate individuals equipped with 21st century skills. The purpose of STEM education is not only educate individuals who have knowledge about the core concepts of science and engineering but also have skills such as creative thinking, problem solving, communication and working collaboratively (Isabelle, 2017).

Accordingly, science education strengthened with STEM approach aims to educate students as creative, productive, inventive, problem solver, design oriented, proficient at using engineering and scientific methods together as well as to engage them in the pursuit of STEM careers. With regard to STEM approach, actions have been taken by USA with an increasing importance and demand. The actions of USA especially were come to the light with the established curriculums called National Science Education Standards (NSES) in 1996 and in particular the Next Generation Science Standards (NGSS) in 2012 for K-12 science education in United States schools (Bybee, 2014).

The NGSS were developed related to STEM education under the name of engineering design from pre-school to Grade 5 and under the name of engineering, technology and science applications in secondary and high school. Compared to the previous state standards, NGSS has a three dimensional science approaches which are called as science and engineering practices, disciplinary core ideas, and crosscutting concepts to create a cohesive understanding of science over time (Bybee, 2014).

Several organizations implemented the NGSS including the National Science Teachers Association (NSTA) which is the largest organization of science teachers in the world as taking the role of leadership in science teaching and learning. Members of NSTA are the subscriber to the journal of Science and Children (S&C) that includes articles about implemented lesson plans which are prepared based on NSTA in order to provide inspiration and ideas for educators and researchers. In this journal, it is possible to see the examples of studies integrating biomimicry into the science education.

One of the outstanding studies incorporated biomimicry into the existing fourth-grade science unit on structure and function based on NGSS (Ethington, Stark & Walker, 2016). The purpose of the study was to explore how living things help people solve the problems encountered in their lives. The lesson consisting of two parts named structure and function of ants and biomimicry was designed based on the engineering design process that creates a model for solution to the problems. The first part of the lesson which aimed to teach structure and function of organisms included three stages. First stage included outdoor investigation of local ant populations. In this stage, students observed the numbers and behaviors of ants at different locations in the schoolyard and took notes to discuss later. In the second stage, students placed ants in a container and observed their structure with a small hand lens to understand how the structures of ants support their survival. After the detailed observation process, they inferred that ants had a variety of structures with specific functions such as legs for walking, antennae for sensing, jaws for eating and grips on their feet for holding. Next, students measured ant adhesion at different surfaces which were plastic as smooth and sandpaper as rough by using a protractor and then, they recorded their data. At the end of this stage, students found that ants could better hold onto the rough surface than the smooth surface thanks to the grips on their feet which enabled them to climb. The third stage was about solving problems. Teachers guided students to think about the ways animals survive and which structures they have functioning to help them survive in their environment. After students were engaged with structure and function unit, in the second part of the lesson, they were introduced biomimicry as a model scientist and engineers use to solve problems in life. Students were presented about various interesting examples of biomimicry. Afterwards, they were asked to determine a problem and a biological champion which is a plant or animal that can accomplish this task thanks to a special structure and its function. The design process followed the identification of biological champions and establishing clear connections between structure and function. During the design process students created ideas to solve their problems by looking at the structures of their biological champion. They drew their nature inspired solutions on a sheet in an organized way. At the final stage, students created three dimensional, representative models of their design idea by using assorted materials. At the end of the modeling process, students shared their models and explained their design process. The teachers stated that they observed how each student was actively and eagerly engaged throughout the lesson. Students' biomimicry experiences gave teachers the hope that students could look at the organisms they encountered after this lesson as a biological champion.

Another article is about the integration of engineering design inspired by nature into the STEM curriculum. In this article, a final lesson of seven-day STEM and literacy unit which uses engineering in an interdisciplinary and meaningful way is described (Moore, Strnat & Tank, 2015). In the lesson, 4th grade students were engaged in an engineering design unit with the purpose of designing a water storage and collection device for the people of Popa Island in Panama. Accordingly, students were informed how engineers could use nature as inspiration for solving problems and the concept of biomimicry was introduced together with different examples. After students developed the idea of taking inspiration from nature for engineering, they explored the content in terms of plant adaptations. Students analyzed the physical structures of plants as adapted to their biomes. Once the connection between features of the plants and their adaptations were established, students were engaged with the engineering design challenge. With the guidance of their teachers, students used the engineering design process. Firstly, they identified the problem of water shortage and its significance that was the problem they were trying to solve. Then, they brainstormed their ideas based on inspiration taken by plant adaptations within groups and decided which design solutions they could use. After they created their water storage design inspired by plants, they tested their design like engineers do. When they thought their design needed a chance or improvement, they redesigned it. Finally, they evaluated and shared their design by explaining their design process. In conclusion, the teacher shared its positive thoughts about the attitudes and design considerations of students during the engineering design process.

Taking into consideration of the research conducted about biomimicry from industrial product design to the different levels of education, it is remarkable that there has been comprehensive research in the area of industrial design on biomimicry conducted to examine the biomimicry approach, to analyze its outcomes, to evaluate the views of students and instructors on this approach as well as to create awareness on biomimicry and sustainability (Boğa, 2013; Bakırlıoğlu, 2012 & Yıldız, 2012). On the other hand, when the studies integrating biomimicry into the education are examined, it is seen that there is limited number of studies (Ersanli, 2016; Soja, 2014 & Staples, 2005). In addition, although these studies introduced the importance place of biomimicry in education, their methods and outcomes do not have enough explanation to allow educators practicing biomimicry in their lessons. In terms of science education, there are studies integrating biomimicry into the science curriculum based on STEM approach (Moore, & Strnat, Tank, 2015; Ethington, Stark, & Walker, 2016). However, these studies have not been scientifically examined in terms of their results. Therefore, the literature is lacking with regard to scientifically conducted research about the integration of biomimicry into elementary science education especially for Turkey.

Regarding the Turkish science education program, biomimicry is not involved as a scientific subject and in the literature any study was not found implementing biomimicry into primary science education. However, regarding the engineering applications, some progress was made in the curriculum. Since the STEM education approach has been gained significance all around the world, Turkish science curriculum changed in order to integrate STEM into the science education in 2017. Within the context of STEM, “engineering applications” was included as a separate unit at the last unit of each grade from 4^{th} through 5^{th} grade (MEB, 2017). This new curriculum firstly was applied in 5^{th} grades. In this unit students were engaged with “engineering design process” to solve a daily life problem for three weeks. However; in 2018, the curriculum has been revised with the consideration that STEM education should be included in the curriculum as a whole encompassing each unit instead of a separated one. Thus the unit of “Engineering Applications” was removed. Instead, the theme “Science, Engineering and Entrepreneurship Practices” is included in the 2018 science curriculum (MEB, 2018). According to this new curriculum, students are expected to make applications through the instructions in the section of “Science, Engineering and Innovation Applications” as part of the education process and present their projects in the science festival at the end of the year.

Because of the fact that biomimicry is closely related to engineering design, integration of STEM into the Turkish science curriculum through engineering applications is an important development. In fact, in the 2017 science curriculum in which the “engineering applications” was introduced as a separate unit in 5^{th} grades, the 5^{th} grade official science textbook included a topic about the invention of Velcro to gain attention to the engineering design (2017, p. 268). In this story, students were implicitly introduced the concept of nature inspired design before practicing engineering design. Nonetheless, biomimicry does not have a special place in science education as a branch of science. At this point, the present research aims to examine the biomimicry approach in science education and its outcomes in terms of implementation into science education through “Biomimicry Teaching Approach”.

6
Methodology

6.1 Research Design

In the present study, action research approach as the qualitative research method was utilized. Action research is described as a self-reflective research practice including the ongoing process of planning, acting, observing and reflecting (McNiff, 2010). Action research conducted by a teacher is also called as "classroom research" (Hopkins, 2008). The classroom research process is similar to regular teaching activity of teachers, but the difference stems from that the classroom research is more systematic, reflective and reachable by public compared to the classroom activity (Zeni, 1998). Classroom research is practiced by teachers with the purpose of understanding and improving the quality of teaching practice and learning activities. In other words, purposeful action with educational intent has positive impact on both teaching practices of teachers and learning experience of students (Vula, 2013, McNiff, J.& Whitehead, J, 2009). For example, carrying out a research in their own classrooms enables teachers to take responsibility of their actions and creating a classroom environment as more dynamic and energetic (Hopkins, 2008). It enables the researcher teacher to be able to see from the students' eyes in order to understand the students' progress by focusing on the process rather than only focusing the product (Bryman, 2004). Also, because the researcher is the teacher of the classroom, he or she is capable of facing with challenging situations during the teaching process (Zeichner 2003).

Through this method, teachers can deeply understand the effects of their actions as a researcher and improve their teaching based on these experiences, so the ongoing learning experience of teachers is resulted by improved learning of students by the way of developing teachers' work. In conclusion, action research is not only an opportunity for teachers to develop themselves professionally and personally but also to develop education in terms of curriculum, school performance and educational policies (Vula, 2013). Accordingly, the present research can be classified as an action research which was implemented by the science teacher during the 5th grade science lessons in a public school.

6.1.1 Biomimicry Teaching Approach

"Biomimicry Teaching Approach" is created by the researcher as a model to integrate biomimicry into primary science education. The approach proposed by the researcher consists of 3 parts as follows:

- **Part 1:** *Teaching structure and function of organisms.*

The aim of the first part of the lesson is enabling students to make relationship between biological strategies of organisms and their functions to facilitate understanding and practicing biomimicry.

- **Part 2:** *Introducing Biomimicry with various examples.*

The second part of the lesson aims to introduce the science of "biomimicry" to students through various examples.

- **Part 3:** *Biomimicry Design Model*

The aim of third part of the lesson is to enable students to perform biomimicry by creating their own designs based on "Biomimicry Design Model".

(The implementation process of "Biomimicry Design Model" will be explained in detail in the procedure section.)

6.1.1.1 Biomimicry Design Model

The diagram of Biomimicry Design Model is created by the researcher to represent the circular flow of the Biomimicry Design Model for primary school students as seen in Figure 6.1. The explanations about the stages of the design process are given in Table 6.1. The overall diagram is inspired by the clover plant to symbolize nature. Curved arrows in the diagram represent the continuity in design process. Arrows from the "design" stage imply that the new observation, discovery or idea can lead to redesign process.

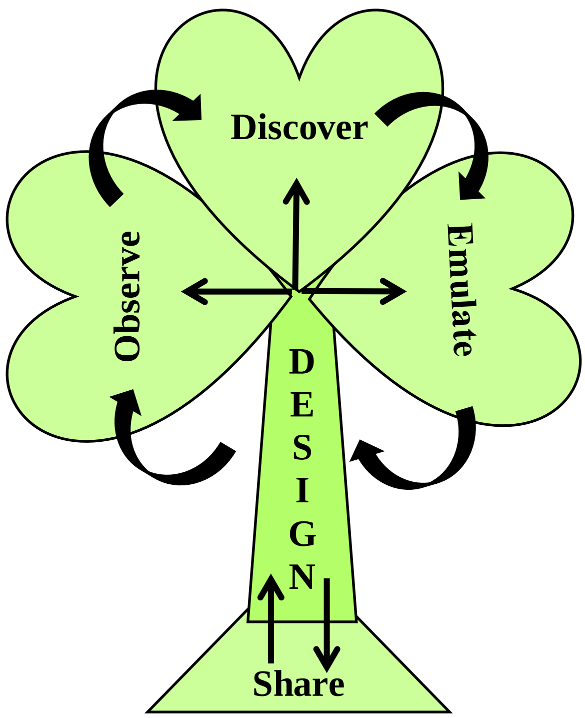


Figure 6. 1 Biomimicry Design Model

Table 6. 1 Stages of Biomimicry Design Model

Stages of the Biomimicry Design Model	Explanation of the Stages
Observe	Students make observation from different sources such as photographs, videos, and nature itself in order to be familiarized with organisms.
Discover	Students make connection between strategy and function of organisms which they observe.
Emulate	Students are inspired by the organisms they chose in order to find technological design ideas.
Design	Students create their design inspired by living things through drawing and creating 3-dimensional models of them.
Share	Students share their design ideas through their models with other students.

The Biomimicry Design Model for primary school students is rearranged based on the “Biology to Design Spiral”. The reason why the method of “biology to design” is referenced is that this method leads students to discover the organisms surrounding them and gives opportunity to see the nature from a design perspective.

The proposed “Biomimicry Design Model” has similar stages with the “Biology to Design Spiral” (Macnab, 2012). Table 6.2 shows the stages of the first model (Biology to Design Spiral) and the stages of the second model (Biomimicry Design Model) with regard to each other.

Table 6. 2 Biology to Design Spiral and Biomimicry Design Model

Stages of Biology to Design Spiral (Proposed by Biomimicry Institute)	Stages of Biomimicry Design Model (proposed in the present study)
Discover	**Observe**
	Discover
Abstract	**Emulate**
Brainstorm	
Emulate	**Design**
Evaluate	**Share**

The “discover” stage of the first model falls into the “observe” and the “discover” stage of the second model regarding that both focus on the discovering nature’s strategies and functions through observation and researching. However, the second model includes the “observe” stage separately, because for primary school students observation is an important scientific skill needed to develop. Beginning with observation is suggested in the second model as the first stage. For this model, organisms' strategies and functions are explored based on the observations in the discover stage.

The "abstract" and "brainstorm" stages of the first model corresponds the "emulate" stage of the second model. Abstraction can be difficult for younger students because it requires higher level thinking. That's why it is not included in the second model. However, brainstorming can take place in the "emulate" stage of the second model in which students produce design ideas related to the strategies they identify in the "discover" stage.

The "Emulate" stage of the first model is related to the "design" stage of the second model. Students create two or three dimensional model of their design ideas in the "design" stage of the second model compared to the first model in which the "emulate" stage includes the idea generation and the design activity together.

Finally, the "evaluate" stage of the first model falls into the "share" stage of the second model. In the second model, evaluation is not included as a separate stage like the first one. When evaluation is required, students can review and redesign their models during the whole design process according to this model. After the final design is prepared, students share their design models with other students.

6.2 Participants

"Biomimicry Teaching Approach" that is developed for primary school students was applied in a 5th grade classroom that the researcher teaches. The classroom consists of 19 students at 5th grade, 10 students are male and 9 students are female. The school is a public school in Gaziantep located in a district which residents have low socioeconomic status. In addition, none of the children in the classroom have never met the concept of biomimicry earlier.

6.3 Procedure

"Biomimicry Teaching Approach" was proposed in order to integrate biomimicry into primary science education. The approach consisting of three parts which are prepared in a lesson plan format for educators to use is given in Table 6.3. Assessment activities are included at the end of the 1st and 2nd part of the model in order to evaluate students' prerequisite learning for the design stage. In the following sections the process of "Biomimicry Teaching Approach" is explained in detail.

Table 6. 3 Biomimicry Teaching Approach

1st Part	**2nd Part**	**3rd Part**
Presentation "Exploring the Nature"	Presentation " Biomimicry"	"Biomimicry Design Model" ➢ Observe ➢ Discover ➢ Emulate ➢ Design ➢ Share
Assessment Activity "Structures and Functions of Organisms"	Assessment Activity "Nature & Technology Matching Card Game"	

6.3.1 The First Part of the Biomimicry Teaching Approach

6.3.1.1 Presentation of 1st Part: Exploring the Nature

The aim of the first part of the biomimicry lessons is enabling students to make relationship between biological strategies of organisms and their functions in order to provide a basis for the concept of biomimicry. At the end of this part, students are expected to be able to

- observe different kinds of organisms.
- explain the structural characteristics of observed organisms.
- describe how the structural characteristics of organisms can provide advantages for them.
- make relationship between structure and function of organisms.

Biological strategy and function are described as core concepts in order to use biomimicry in the design process. Strategy expresses the characteristics, mechanisms or processes which organisms have in order to survive and perform a particular function. Function in general is defined as the purpose or activity of something. Within the context of biology, it refers to the role that organisms play through the strategies they have. Organisms use their own strategies to fulfill their biological functions. For instance, if a polar bear's fur is a strategy the organism has, then the insulation or conservation of heat is the function accomplished related to this strategy. Studying the functions linked to biological strategies leads to the development of ideas on technological issues such as design of insulated clothes or buildings in the example of polar bear.

In this research the concept of strategy was associated with the structures of organisms in order to facilitate understanding of biomimicry in the elementary level, because primary school students can analyze the organisms' strategies stemming from observed structures of organisms. On the other hand, function was defined as the purpose or advantage of having these structures.

In the first part of the lesson, students were expected to make observation and realize the structures of organisms and make connection with related functions by looking at the pictures and videos of various organisms via power point presentation. 10 different organisms were presented in a student-centered classroom environment. Organisms were selected from those who have distinctive and interesting features for elementary students. Among 10 organisms, 9 were chosen from animals, 1 was chosen from plants. The reason why almost all organisms were selected from animals is that moving objects might be more attractive, and it might be easier for children to recognize the properties such organisms possess. In addition selected organisms were thought to be able to lead design ideas for the last part of the lesson.

The steps in the first part of the lesson for each organism are given in Table 6.4.

Table 6. 4 Steps in the first part of the Biomimicry Teaching Approach

Teacher	Students
➢ shows a photo or video about the organism.	➢ observe the given organism.
➢ asks: "What kind of structures does this organism has?"	➢ share their observations.

➢ asks students to make relationship between structure and function of organisms: "What's the purpose of the organism to have this structure?" or "What is the advantage/benefit of organism to have this structure?	➢ share their explanations.
➢ evaluates students' answer and summarizes their ideas.	➢ ponder on the evaluation of the teacher and ask questions if there are any.

The information about the examples in the presentation was given in Table 6.5. In fact, there were many interesting features of organisms that was included in the presentation. These characteristics were discussed with students who had pre-knowledge and experiences.

Table 6. 5 Information about the examples of the organisms in the first presentation

	Organism	Structure	Function	Other Information
1	Penguin	They have wing-like flippers.	It provides better and easier swimming	
		They have short fur and among these feathers there are small pores enclosing the air.	It makes the penguin feathers waterproof, so keeps it warm.	
		Their body are tapered at both ends	They can slide easily on the ice	
2	Cat	They have claws on their paws.	They allow the cats to climb, dig, attack and defend themselves.	
		Their tongue has tiny spines that all point in the same direction.	It makes them clean when they groom.	
3	Venus's	The plant has a trap-like	The trap prevents	

	Flytrap	structure at the end s of their leaves	the insect to run away by shutting.	
		Inside each trap there are 6 hair- like structures.	They give information the plant by triggering when there is an insect inside.	
4	Flying Dragon	They have folds of skin along the sides of their body which acts as wings when they are opened.	It allows them to glide through the air.	The strategy of the flying dragon and flying squirrel are associated with the concept of air friction which students learn in the science lesson.
		They have long and slender tails.	It enables to steer themselves.	
5	Flying Squirrel	They have a specialized membrane on both sides of their body that acts like a parachute.	It enables them to leap to a target tree by gliding.	
		They have broad, long and fluffy tails	It enables to steer and break themselves when they glide.	
6	Hummingbird	They have long beak like a needle.	They can reach and get the nectar from tubular flowers.	
		The wing structure of hummingbirds is different than the other birds. They don't flap their wings; they rotate them in an oval pattern like drawing number 8.	They enable them to fly forward, backward, hover and even upside down. *They can* flap their wings between 50 and 200 times per second.	
7	Owl	Their feathers are serrated like a comb.	They can fly silently.	The strategy of owl are compared by hawk and dove by watching an experiment testing their flight.
8	Chameleon	They can move their eyes separately from each other.	This provides visual field of 360 degrees	

			They can see different directions at the same time.	
		They have long and sticky tongue.	To catch insects easily.	
		They can change the color of their skins.	To expresses their emotions and to be camouflaged.	
		They have crystal structure on nanoscale in their skins.	They can change the color of their skin by changing the direction of these crystals.	
9	Blood Squirting Lizard	They shoot blood from their eyes.	They defense themselves from predators that attack them.	
10	Puffer fish	They have large number of spins on their bodies They inflates their body and make it three times larger	They defense themselves when they are threatened.	

6.3.1.2 Assessment of 1st Part: Structures and Functions of Organism

In the assessment part students were given opportunity to apply their knowledge about the relationship between the structure and function of different kinds of organisms on a worksheet. Selected organisms were included as examples due to the same reasons as the presentation of the first lesson (Table 6.6).

Table 6. 6 Examples of the organisms in the first assessment

Organisms			
1	Giraffe	**6**	Glass-winged Butterfly
2	Sailfish	**7**	Polar Beer
3	Elephant	**8**	Dragonfly
4	Ostrich	**9**	Red Eyed Tree Frog
5	Turtle	**10**	Ross

6.3.2 The Second Part of the Biomimicry Teaching Approach

6.3.2.1 Presentation of 2nd Part: Biomimicry

The aim of the second part of the lesson is to introduce biomimicry to students via various examples. At the end of this part students are expected to be able to

- define the science of biomimicry.
- explain the examples of biomimicry.
- create their ideas based on the examples of biomimicry.
- make connection between biological organisms and possible technological applications.

Teaching biomimicry to younger students requires planning age-appropriate education. In order to make understanding easy for elementary students, it is important to choose simple vocabulary and simple examples which students can relate to. Beside choosing familiar examples to students, introducing examples which have a visual similarity between inspirational organism and the technological application may be a good starting point for students who will meet biomimicry for the first time. In this research biomimicry examples were selected by taking into consideration these situations.

In the second part of the lesson, firstly students were introduced the definition of biomimicry. Then, they were engaged with different examples of biomimicry. The examples were chosen from both microstructures of the organisms such as lotus leaves or gecko feet and larger physical structures which can be seen with naked eye such as flippers of humpback whales or beak of kingfishers. 8 different organisms were presented as the examples of application in biomimicry. The first example was chosen as "Velcro" which was suggested as an appropriate initial biomimicry example for almost all level of students. The others were also selected from well-known examples of biomimicry considering the level of complexity and interest for primary students. Numerically 5 organism from animals and 3 organisms from plants were presented. Detailed information and the stories behind the examples were shared in Table 6.7. The general steps in the second part of the lesson as follows:

Table 6. 7 Steps in the second part of the Biomimicry Teaching Approach

Teacher	Students
➢ asks students to make observation of the given organism in real life or via videos or photographs.	➢ observe the given organism.
➢ asks questions to help them reveal the structure and function of organisms similar to the first part of the lesson: "What kind of structures does this organism has?" "What is the advantage/benefit of organism to have this structure?"	➢ share their explanations.
➢ asks what kind of invention could be designed by inspiring the given organism.	➢ share their ideas.
➢ explains the technological innovation inspired by the organism.	➢ listen to the teacher and ask questions if there are any.
➢ asks design ideas of students "What would you design as you are inspired by this organism?"	➢ share their design ideas.

The steps in the second part of the lesson were not certain and identical for each example. The flood of lesson was determined according to the nature of the organism and the related technological application. For instance, when it was possible to observe the organism in real life, students were given opportunity to explore their structure by touching or observing. The invention process in some examples was storified to catch students' attention. All biomimicry examples presented in this step were explained in detail in Appendix A. To provide an example, one of the most cited examples of biomimicry called Velcro was given as follows (Table 6.8):

Table 6. 8 Examples of organisms in the second presentation

	Nature	Technology
1	Burdock burrs	Velcro
2	Humpback Whale	Tubercle Technology
3	Kingfisher/Penguin/Owl	Shinkansen Bullet Train
4	Lotus Plant	Lotus Effect
5	Maple Seed	Drone
6	Pangolin	Backpack
7	Woodpecker	Hammer
8	Gecko	Bandage

Burdock burrs- Velcro

Invention of Velcro dates back to a hike of Swiss engineer George de Mestral with his dog in 1941. When they back home, Mestral realized that plants named burdock burrs stick to his dog's fur. Then he observed the structure of the plant closely via microscope. When looked closely he noticed the tiny hooks which allow them to attach to rough surfaces such as the clothes and furs. Influenced by the wonderful characteristic of the burdock burrs, a design idea came to the Mestral' mind as. The product inspired by this plant had two surfaces that interlock.

After years of investigation for the appropriate material and the device, he succeeded to invent the product which he named "Velcro", also known as "hook and loop". While the Mestral's invention could not get the attention that it deserved at the beginning in the shoe company, Mestral's perseverance enabled his invention to be recognized by space agency NASA. Finally the use of Velcro in equipment's of NASA enabled Velcro to achieve its reputation and expand itself in many areas of life. Today its products are still used all around the world.

6.3.2.2 Assessment of 2nd Part: "Nature & Technology" Matching Card Game

In the assessment part students were expected to apply their knowledge about biomimicry through a matching card game. The game aimed students to see different kinds of technological designs inspired by nature and to realize the association between nature and technology in a classroom environment in which students discuss their ideas.

The nature- technology matching card game consists of 20 examples from nature and 20 examples from the related application in technology as seen in Table 6.9. Examples of structure based designs (9) and function based designs (11) were selected as relative to each other in terms of number. It was not easy to distinguish the characteristics of each organism and the design included in the game. Also, not all the design examples could be classified as a representation of biomimicry from each aspect. The reason of the diversity among examples was to create opportunity to discuss the different applications of nature inspired design and principles of biomimicry.

Throughout the game students worked in groups to match the cards. They were encouraged to discuss their ideas before reaching the final decision. After the game finished, groups shared their results with the class. For each example students were asked to share their thinking process. When the groups matched the different cards, their viewpoints were discussed together. Because it was possible to design many diverse products by taking inspiration from one organism, all ideas of students were appreciated by giving the message that this was not a competition game.

Table 6. 9 Examples of organisms in the second assessment

	Nature	**Technology**	**Source of Inspiration**
1	Forest floor	Carpet	Function
2	Spider web	Bird Protection Glass	Function

3	Termite mound	Air-conditioning	Function
4	Cat eyes	Road marker	Function
5	Dolphin	Concorde	Structure
6	Morpho butterfly	Structural color	Function
7	Cat fish	Aerospace plane	Structure
8	Dragonfly wings	The Munich Olympic Stadium	Structure
9	Snowshoe rabbits hind feet	Snowshoes	Structure
10	Leaf photosynthesis	Solar Ivy	Function
11	Darkling beetles	Fog harvesting system	Function
12	Hawk	Spirited Stealth Bomber	Structure
13	Boxfish	Car (Mercedes Benz)	Structure
14	Dragonfly	Helicopter	Structure
15	Dandelion	Parachute	Structure
16	Dolphin	Swimming fins	Function
17	Kangaroo	Kangaroo bag	Function
18	Eucalyptus	Street Lamb	Function
19	Cat tongue	Tongue brush	Structure
20	Sunflower	Solar panel	Function

6.3.3 The Third Part of the Biomimicry Teaching Approach: "Biomimicry Design Model"

The aim of third part of the lesson is enabling students to perform biomimicry by creating their own designs based on Biomimicry Design Model. The model consists of 5 steps: observe, discover, emulate, design and share.

- **Observe:** In this stage, students observed organisms which they chose through different sources such as photographs, videos, and the organism itself in order to be familiarized with organisms.
- **Discover:** Students established relationship between structures and function of organisms which they observed. The questions: "What kind of physical structures does this organism has?" and "What is the advantage/benefit of organism to have this structure?" guided them.
- **Emulate:** Students took inspiration from the organisms they discovered in order to create technological design ideas. They brainstormed their ideas with others. While some of them decided to work together, some preferred to work individually on a design project.
- **Design:** In this stage, students worked on a design project about the organism they decided to emulate. They were given a worksheet to record during the design process. The worksheet consists of two pages. First page includes the parts to take notes of the data gathered in the discover stage together with the name and the picture of the emulated organism. The second page is as a blank page for students to draw their design. After students completed these steps they made a three dimensional model of their designs. At this stage students were also given simple materials such as cartoon, colored pencils, scissors, glue and more to decorate their design. The created models did not function like the drawn design. In fact, they were only a three dimensional prototype representing their design idea.
- **Share:** Finally, students shared their design ideas together with the three dimensional model of their designs at the end of the design process. The

teacher takes notes of the students' explanations during the "share" stage. The steps in the third part of the lesson as follows (Table 6.10):

Table 6. 10 Steps in the third part of the Biomimicry Teaching Approach

Teacher	Students
➢ asks students to choose an organism to observe.	➢ choose an organism to observe. ➢ write the name of it on worksheet ➢ paint a picture of it or stick a photo of it on worksheet.
➢ asks students to explore the structure and function of the chosen organism.	➢ write the structure and function of the organism on the worksheet.
➢ asks what kind of invention could be designed by inspiring the chosen organism.	➢ create design ideas emulated by the living organisms they explored.
➢ asks them to draw their design ideas and create a three dimensional model of their designs.	➢ draw their design ideas on worksheet. ➢ create their model by using simple materials.
➢ asks them to present their design to the class by explaining the design process and features of the design.	➢ share their models by explaining their designs and the design process.

6.4 Data Analysis

6.4.1 Student Designs

Students created their designs ideas and design models in the last part of the biomimicry lesson and presented them to the whole class. Students' explanations while they were presenting their designs were summarized in order to make them understandable. Designs firstly were organized in terms of the number of students included in each design, the subject of the design and the inspirational organism. Secondly, designs were analyzed with respect to the reference point and the methods used by the students. Taking into account all of these, results were discussed.

6.4.1.1 Analysis of Student Designs with regard to the Reference Point

The source of information for the inspired organism and the source of design ideas were organized under 2 groups according to the reference of the design as "presentation" and "student". The explanation underlying the categorization was made in the result section in detail.

6.4.1.2 Analysis of Student Designs with regard to the Biomimicry

Students' designs were divided into three categories as "form based", "structure based" and "function based" in order to analyze them in detail. The categorization is based on a research that aimed at revealing the ideas of industrial design students about natural analogy which is closely related to biomimicry (Boğa, 2013). Although the titles were kept the same as the referenced research, they were rearranged in terms of meaning to some degree. The categorization in the present study based on Boğa's research is summarized with criteria in Table 6.11. Students' designs were divided into three categories based on these criteria. In the following sections these categories are explained with the examples from both referenced and the present study.

Table 6. 11 The categorisation criteria of students' designs

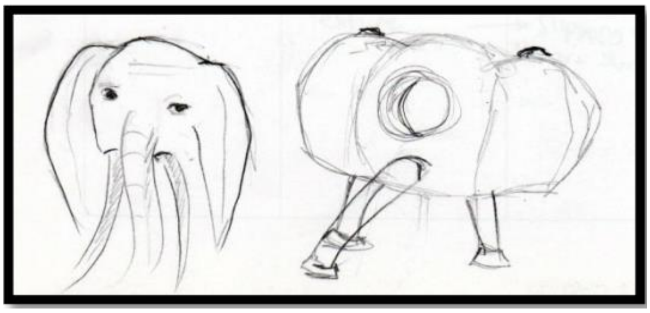
Form-Based Design	Structure-Based Design	Function-Based Design
➢ The organism's shape is simply imitated as a whole or a part ➢ There is a physical similarity between the inspired organism and the design ➢ The design does not imitate the function that the form of the organism serves ➢ There is not a relationship between the function of the design and the function of the organism's form	➢ The structure of the organism is mimicked ➢ The function is achieved due to the structure of the organism ➢ The design imitates the structure of the organism in order to function like the structure of the organism ➢ The relationship is established between the function of the design and the function of the organism's structure	➢ The function of the organism is mimicked ➢ The function is not achieved due to the structure of the organism ➢ The design imitates the different mechanisms of the organism to function like the organism ➢ The relationship is not established between the function of the design and the structure of the organism.

In order to ensure the trustworthiness of the analysis of data, the views of the advisor who is a professor at science education department and two science education experts were taken. Firstly, they were informed by the concept of biomimicry. Then, the referenced study (Boğa, 2013) was introduced to compare with the present study. In the classification process of the students' designs in terms of biomimicry based on the referenced study, the viewers worked together. For some designs different categories were offered by the viewers. Categorization was formed when a consensus was reached among them. The detailed information about the categorization is given together with the examples from both referenced study and the present study in the following sections.

➢ Form-Based Design

Both in the referenced study and the present study, the "form based" implies the same meaning. In the form based designs, the participants chose the inspired organism just because of its form without considering the function that form serves. In other words, participants simply imitates the organism' shape as a whole or a part. This type of imitation is not included in the scope of biomimicry, but can be evaluated as "biomorphism" meaning "look like" nature and shows the students 'ability to observe and relate the physical similarity between the natural forms and technology. To clarify one example from both referenced and the present study are given comparatively (Table 6.12).

Table 6. 12 Form based design in referenced and present study

Referenced Study-Form Based Design (Boğa, 2013)	
	This tripod design for camera mimics the form of elephant.
Present Study - Form Based Design	
	The students were inspired by the form of the peacock bird and upupa epopos and designed the handheld fan.

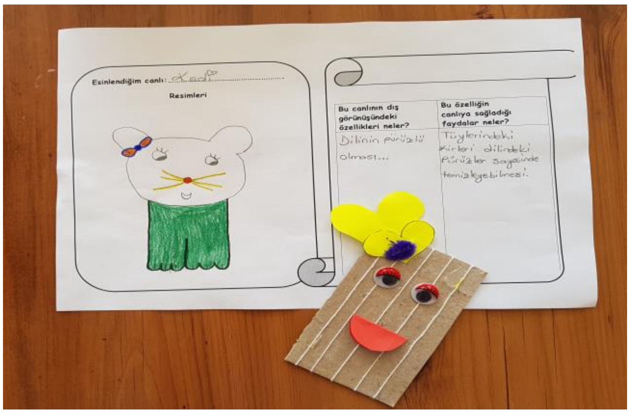
As can be seen in Table 6.12, in the referenced study one industrial design student mimicked the physical form of the elephant in a tripod design. In the present study the students designed handheld fans inspired by the peacock bird and upupa epopos. In the tripod design the shape of the elephant was simply imitated as a whole. Similarly, in the handheld fan design the shape of the feathers of the peacock bird was imitated as a part. These designs do not imitate the function that the form of the organisms serves. Because only the physical similarity was focused without considering the function, the function of the design and the organism's form are not related to each other. For example, peacock birds spread their feathers to attract a mate so, the wing structure of the peacock bird functions as attraction compared to the handheld fan which functions as cooling. That is why, these kind of designs are categorized as "form based design" according to the criteria in Table 6.11.

- **Structure-Based Design**

In the referenced research the structure based designs implies again that the design reflects the form of the organism, not the function. However, in the present study, the structure based designs mimic the structure of the organism to serve the function. For example there is not a relationship between structure of the cone and the dish drainer in terms of function in the referenced study (Boğa, 2013), but the cleaning tool was inspired by the cat's tongue in order it to function like the cat tongue in the present study. Table 6.13 shows design examples produced in the referenced and the present study related to each other.

Table 6. 13 Structure based design in referenced and present study

Referenced Study- Structure Based Design (Boğa, 2013)	
	This dish drainer was designed by mimicking the structure of the cone.

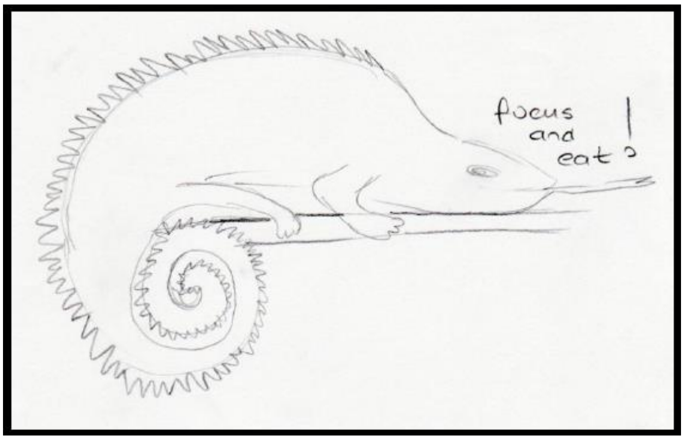
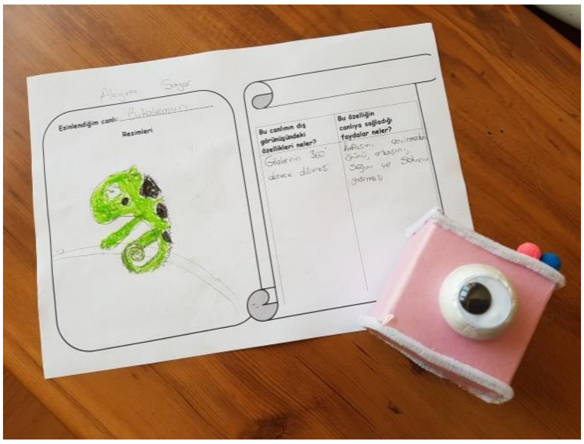
Present Study - Structure Based Design	
	The student mimicked the rough structure of the cat's tongue to design a cleaning tool.

When the student's design in the present study was analyzed in terms of criteria in Table 6.11 it was seen that the student mimicked the rough structure of the cat tongue in order it to function in the same way with the organism. Cats can clean themselves with their special tongues. Similarly the student's design functions as cleaning due to its rough surface. Because the student related the function of her design with the structure of the organism, this design was included in "structure based design".

- **Function- Based Design**

Both the referenced research and the present research, the inspired organism is mimicked due to its function. For example, in the referenced study, a participant mimicked the function of the chameleon tongue besides the design was physically the same as the chameleon form. On the other hand, in the present study one student designed a camera having the mobility like the chameleon eye. Overall, the designs whose primary objective is mimicking the function are categorized under the group of "function based design". Table 6.14 shows comparative examples from both studies.

Table 6. 14 Function based design in referenced and present study

Referenced Study- Function Based Design (Boğa, 2013)	
	The camera was designed by mimicking the focusing mechanism of the chameleon tongue.
Present Study – Function Based Design	
	The student designed a camera by mimicking the mechanism of the chameleon eye. The lens of the camera can move right and left like the chameleon's eyes.

In the light of the criteria in Table 6.11 the student's camera design inspired by the chameleon eye is categorized as "function based design" because it was intended to function to turn its lens like the chameleon eye. The student focused on the eye mechanism of the chameleon without relating this function with the eye structure of the organism. As can be seen in this design example, designs in which the function is not achieved due to the structure of the organism are included in "function based design".

7
Results and Discussion

7.1 Results

The students' designs created in the last part of the "Biomimicry Teaching Approach" were organized to analyze in terms of general outcomes, the source of information for the inspired organism and the design idea, and the level of biomimicry in the following sections.

7.1.1 General Results

Firstly the students' design ideas and models created through "Biomimicry Design Model" were organized regarding the number of created designs, the choice of students as individual or group work for each design, the number of students involved in each design, the subject of the designs and the inspired organisms. These general results were given in Table 7.1.

According to the general results which can be seen in Table 7.1, 19 students attended all biomimicry lessons and each of them was engaged in a design project. In total 24 designs were created by students. Almost all students preferred to work individually. Of the 24 designs, only 3 were made by students who preferred group work. 2 students (Students 1-6) who worked in groups wanted to design another model individually. Some students (Student 1-7-9) were so enthusiastic that they created 3 different designs.

Table 7. 1 Students' designs

Design No	Individual /Group	Student No	Subject of the Design	Inspired Organism/s
Design 1	Group	Student 1 Student 2	Hand-held Fan	Peacock Bird and Upupa Epopos
Design 2	Group	Student 3 Student 4	Sticky Gloves	Gecko
Design 3	Group	Student 5 Student 6	Pelerine	Flying Squirrel
Design 4	Individual	Student 7	Coat Rack	Giraffe
Design 5	Individual	Student 8	Camera with a Moving Eye (Lens)	Chameleon
Design 6	Individual	Student 9	Liquid Soap Dish	Horned Lizard
Design 7	Individual	Student 6	Rocket	Owl
Design 8	Individual	Student 10	Rocket	Maple Seed
Design 9	Individual	Student 11	Jump Jump Shoes	Rabbit
Design 10	Individual	Student 12	Airplane	Kingfisher
Design 11	Individual	Student 13	Car Headlight (Luminous Mustache)	Cat
Design 12	Individual	Student 9	Helmet	Turtle
Design 13	Individual	Student 1	Digging Tool	Mole
Design 14	Individual	Student 14	Luminous Hat	Luminous Fish
Design 15	Individual	Student 15	Aircraft (Flying Frill)	Owl
Design 16	Individual	Student 7	Window Glass	Glass Winged Butterfly
Design 17	Individual	Student 7	Quilt	Polar Bear
Design 18	Individual	Student 16	Fur-Fruit Collecting Tool-Clamp	Giraffe
Design 19	Individual	Student 17	Flagpole	Hummingbird
Design 20	Individual	Student 1	Washing Machine	Ant
Design 21	Individual	Student 18	Flying Bicycle	Butterfly
Design 22	Individual	Student 19	Comb	Cat
Design 23	Individual	Student 7	Cleaning Brush	Cat
Design 24	Individual	Student 9	Drone-like Letter Carrier	Glass Winged Butterfly

7.1.2 The Source of Information for the Inspired Organisms and the Design Idea

The source of information for the inspired organism and the source of design ideas were organized under two groups as "presentation" and "student" (Table 7.2). When students chose an organism which they observed in the lesson, the source was defined as "presentation". When they chose an organism which was not mentioned in the lesson, then the source was defined as "student". The same classification was made for the design idea. When students' design idea was the same as one of the examples in the lesson, the source of the design idea was defined as "presentation". When their design was different or original, it was defined as "student".

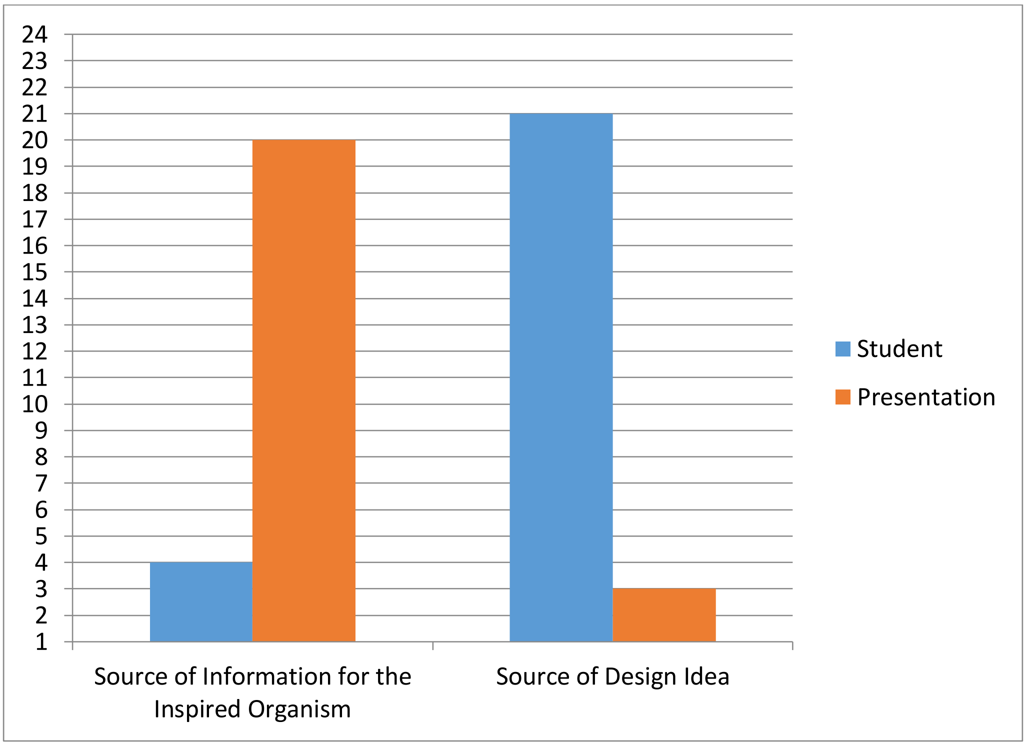


Figure 7. 1 Reference of students

As seen in Figure 7.1, the source of information for the inspired organism was resulted in "presentation" for majority of the designs (20 of 24). Because the students observed and analyzed the characteristics of organisms which had the potential to be inspired in the presentations lately, they were expected to choose the organisms they saw in the lesson as an inspiration.

In fact, what is surprising is that almost all designs were based on students' ideas. Only 3 design ideas from 24 were the same as the biomimicry examples in the presentation. This shows that majority of the students were willing to design their models by using their imagination and ideas.

For detailed analysis, student designs were categorized as “A”, “B”, and “C”. The results of this categorization were summarized in Table 7.2. In addition, Table 7.3 shows the overall results of students’ designs with regard to the source of information for the inspired organism and the design idea.

Table 7. 2 Detailed analysis of students' designs

Category	The source of information about the inspired organism	The source of design idea
A (4)	Student	Student
B (17)	Presentation	Student
C (3)	Presentation	Presentation

Table 7. 3 Overall results of designs with regard to the students' references

	Category	Subject of the Design	Inspired Organism/s	The source of information	The source of design idea
Design 1	A	Hand-held Fan	Peacock Bird and Upupa Epopos	Student	Student
Design 2	C	Sticky Gloves	Gecko	Presentation	Presentation
Design 3	B	Pelerine	Flying Squirrel	Presentation	Student
Design 4	B	Coat Rack	Giraffe	Presentation	Student
Design 5	B	Camera with a Moving Eye (Lens)	Chameleon	Presentation	Student
Design 6	B	Liquid Soap Dish	Horned Lizard	Presentation	Student
Design 7	B	Rocket	Owl	Presentation	Student
Design 8	B	Rocket	Maple Seed	Presentation	Student

Design 9	B	Jump Jump Shoes	Rabbit	Presentation	Student
Design 10	B	Airplane	Kingfisher	Presentation	Student
Design 11	B	Car Headlight	Cat	Presentation	Student
Design 12	B	Helmet	Turtle	Presentation	Student
Design 13	A	Digging Tool	Mole	Student	Student
Design 14	A	Luminous Hat	Luminous Fish	Student	Student
Design 15	B	Aircraft	Owl	Presentation	Student
Design 16	B	Window Glass	Glass Winged Butterfly	Presentation	Student
Design 17	B	Quilt	Polar Bear	Presentation	Student
Design 18	B	Fur-Fruit Collecting Tool-Clamp	Giraffe	Presentation	Student
Design 19	B	Flagpole	Hummingbird	Presentation	Student
Design 20	A	Washing Machine	Ant	Student	Student
Design 21	B	Flying Bicycle	Butterfly	Student	Student
Design 22	C	Comb	Cat	Presentation	Presentation
Design 23	C	Cleaning Brush	Cat	Presentation	Presentation
Design 24	B	Drone-like Letter Carrier	Glass Winged Butterfly	Presentation	Student

When the designs were analyzed in detail in terms of their reference, it was seen that only 4 designs were included in category A. Inspired organisms and the design ideas in this category were different from the presented examples in biomimicry lessons. However, the originality in chose of organism and the design idea do not mean that these designs are included in the same group regarding biomimicry. For example; in the design of hand-held fan inspired by the peacock, only physical form of the organism plays role in inspiration compared to design of digging tool inspired by the mole that the function is taken into consideration in the design process.

Nonetheless, it can be considered as a positive outcome that students at primary level tried to apply their knowledge about biomimicry to a different organism they chose.

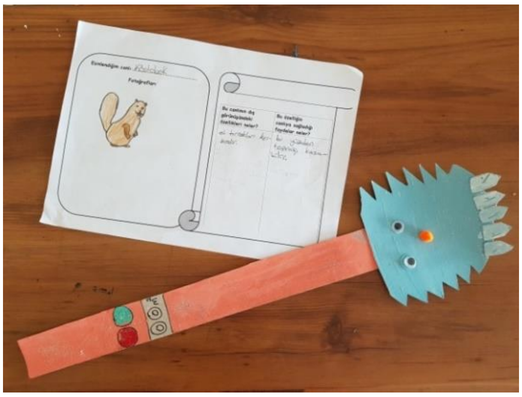
Digging tool inspired by the mole (Function Based)	Hand-held fan inspired by peacock and upupo epopos (Form Based)
	

Figure 7. 2 Examples from Category A

Designs in category "B" are based on students' ideas inspired by the organisms presented in biomimicry lessons. The organisms and the designs in the presentation led students to rethink, rearrange, and recreate the presented design ideas. Some students used their knowledge gained through the lessons in order to create a different design. In other words they worked on the same strategy presented in the lesson with the aim of creating their own design. For example, one student designed an airplane inspired by the kingfisher compared to the design example of Shinkansen train inspired by the kingfisher as seen in Figure 7.3.

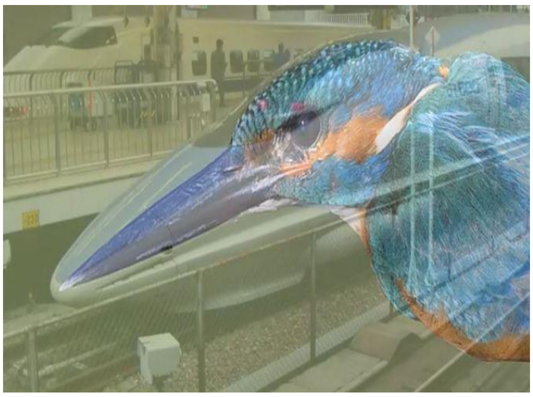
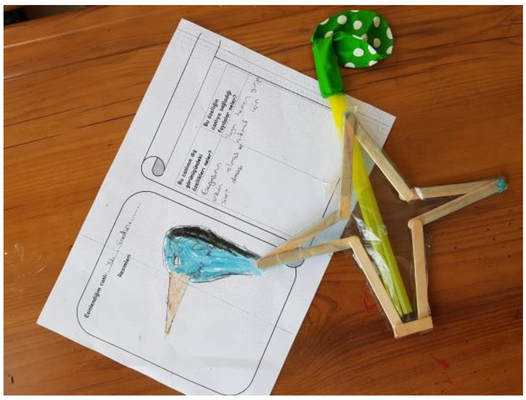
Shinkansen Train Inspired by Kingfisher	Airplane Inspired by Kingfisher
	

Figure 7. 3 Examples from Category B-1

Another recreation method impressed by the presentation is the emulating the same function performed by different organism. For instance one student designed a helmet inspired by the turtle similar to the helmet design inspired by the woodpecker that was presented in the lesson (Figure 7.4).

Helmet Inspired by Woodpecker	Helmet Inspired by Turtle
	

Figure 7. 4 Examples from Category B-2

Because students observed and analyzed the characteristics of the various organisms through the lesson via presentation and they were encouraged to create alternative design ideas about the given organisms, it is an expected result that they took a familiar organism as an inspiration. That's why majority of the students' designs are included in this category.

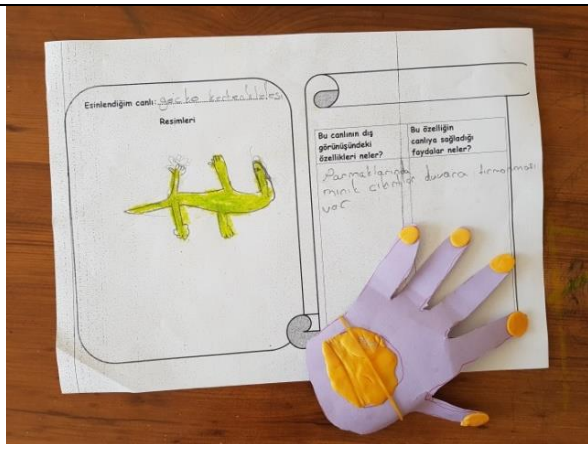
Gecko Inspired Gloves	Gecko Inspired Gloves
	

Figure 7. 5 Examples from Category C

Category C includes the same design idea with the design examples in the presentation. Only a few of the students' designs (3 of 24) were included under this category. These students stated that they wanted to reproduce the same design in the presentation because they were impressed by the given organism and the design idea. Gecko inspired gloves can be given as the example for this category as seen in Figure 7.5.

7.1.3 Student Designs with regard to Biomimicry

Students designs are categorized under three categories which are "form based", "structure based", and "function based". Students' designs are organized in tables and brief explanation about each design is given in Appendix B. The overall results were summarized in Table 7.4 with regard to the frequency. Two design models from each category are provided below in the following tables.

Table 7. 4 The number of student designs with regard to biomimicry

Form Based Designs	5
Structure Based Designs	10
Function Based Designs	9

7.1.3.1 Form Based Designs

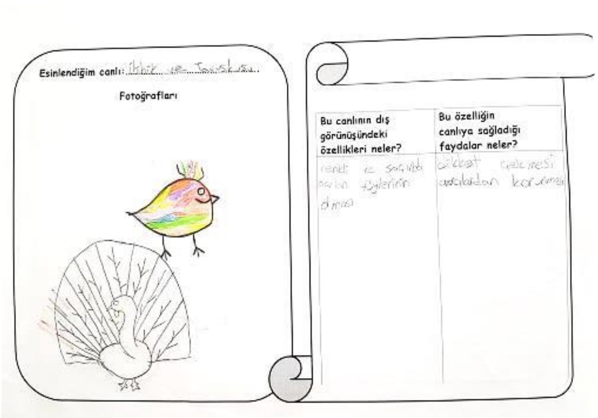
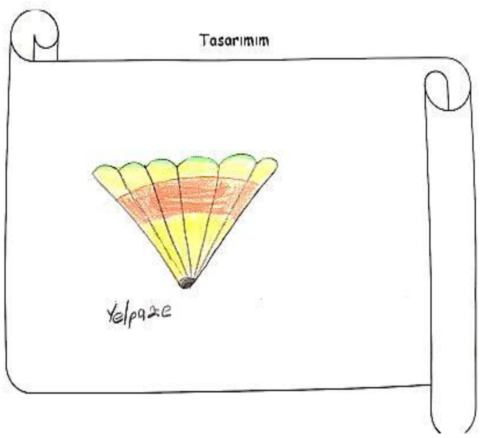
5 designs of 24 are included in the form-based designs (Table 7.5). Because the form based designs only visually resemble the inspired organism rather than focusing on the function, the result that low number of designs is included in this category can be evaluated as a positive outcome in terms of biomimicry. It is an indication that majority of students showed an appropriate approach in applying biomimicry. However, the 5 designs included in this category represent the students' interest in imitating the visual form of nature to reshape or reinterpret the existing designs.

Table 7. 5 Form-based designs

	Design No	The Subject of the Design	Inspired Organism/s
FORM BASED DESIGNS	Design 1	Hand-held Fan	Peacock Bird and Upupa Epopos
	Design 4	Coat Rack	Giraffe
	Design 6	Liquid Soap Dish	Horned Lizard
	Design 19	Flagpole	Hummingbird
	Design 21	Flying Bicycle	Butterfly

Design 1: Two students worked together to design a hand-held fan inspired by two organisms, peacock and upupo epopos (Table 7.6). The hair structure of upupo and wing structure of peacock function as attraction compared to the hand-held fan which functions as cooling. The fan design imitates the physical form of the organisms, not the function. Therefore it is categorized as "form- based".

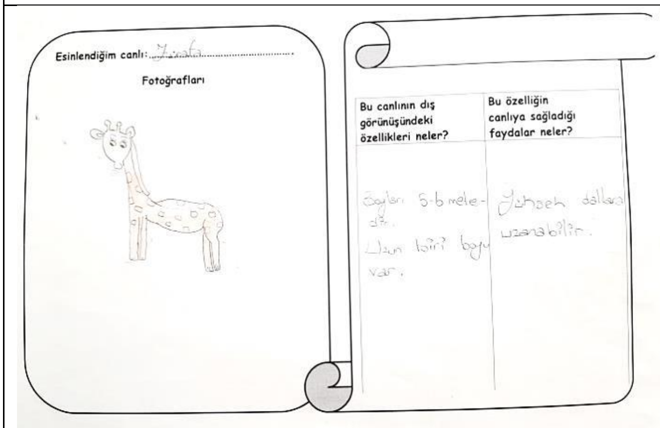
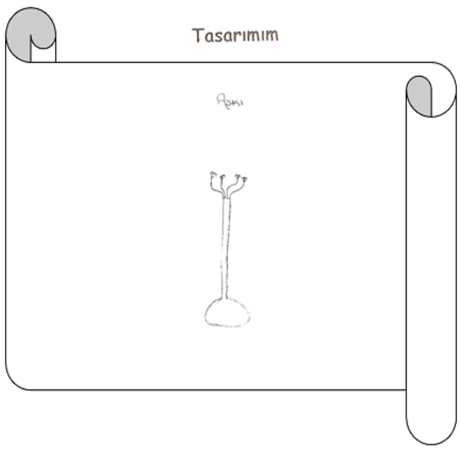
Table 7. 6 Example to form-based designs-1

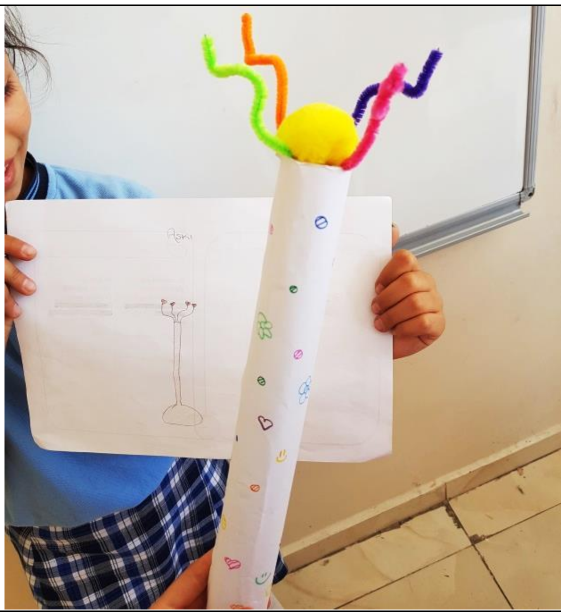
<table>
<tr><th>Peacock and upupo epopos</th><th>Hand-held fan</th></tr>
<tr><td>
</td><td>
</td></tr>
</table>

Model	Presentation
 	• The hair of the bird looks like fan. • The peacock opens its wings like a fan. • Inspired by these two organisms, we designed a fan. • The peacock and upupo epopos attract attention with these features and are protected from hunters. • Our design is for cooling.

Design 4: A student inspired by the giraffe to design a coat rack (Table 7.7). She mimicked the form of the giraffe's upper part considering the length and horns of it. The organism and the design do not share the same function except sharing the similar long shape, so the student's design is included in the form-based design category.

Table 7. 7 Example to form-based designs-2

Giraffe	Coat Rack
 	

Model	Presentation
	• Giraffes have long necks, so they can reach high branches. • I made a coat rack design inspired by giraffes. • The length of the coat rack resembles the neck of the giraffe, and the edge of it resembles the horns of the giraffe.

7.1.3.2 Structure Based Designs

Designs of 10 students are included in the structure-based designs (Table 7.8). From 10 designs, 8 of them are created as 3 dimensional models. Students mimicked the structure of organisms to design a model which focuses on the function of that structure in accordance with the biomimicry.

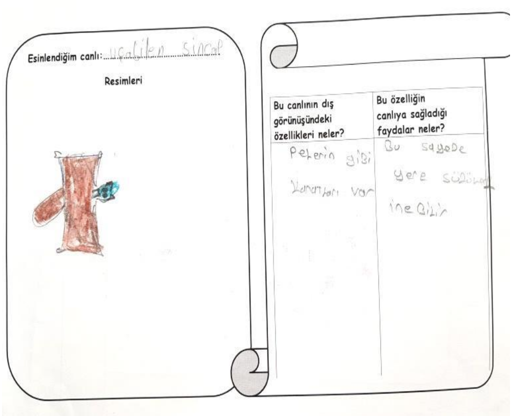
Table 7. 8 Structure-based designs

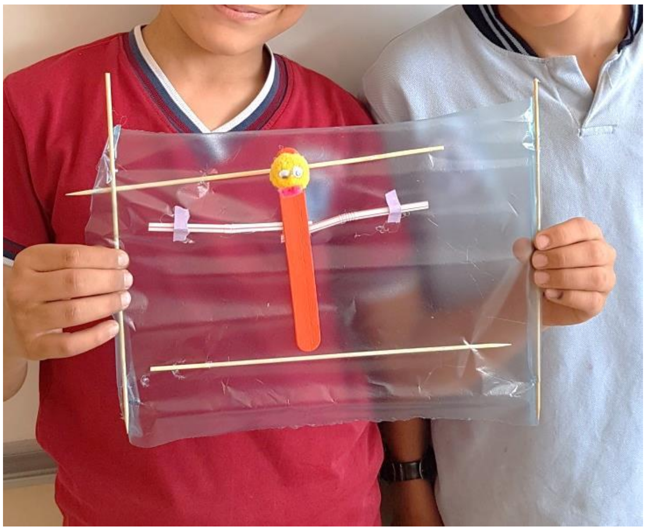
STRUCTURE BASED DESIGNS	Design No	The Subject of the Design	Inspired Design/s
	Design 3	Pelerine	Flying Squirrel
	Design 7	Rocket	Owl
	Design 8	Rocket	Maple Seed
	Design 10	Airplane	Kingfisher

	Design 12	Helmet	Turtle
	Design 13	Digging Tool	Mole
	Design 15	Aircraft (Flying Frill)	Owl
	Design 16	Window Glass	Glass Winged Butterfly
	Design 22	Comb	Cat
	Design 23	Cleaning Brush	Cat

Design 3: Wings-like structure of flying squirrel gave inspiration two students to design a pelerine which can be worn to be able to fly (Table 7.9). Students imitate the structure of the flying squirrel to be able to function like it. That's why it is grouped as structure based biomimicry.

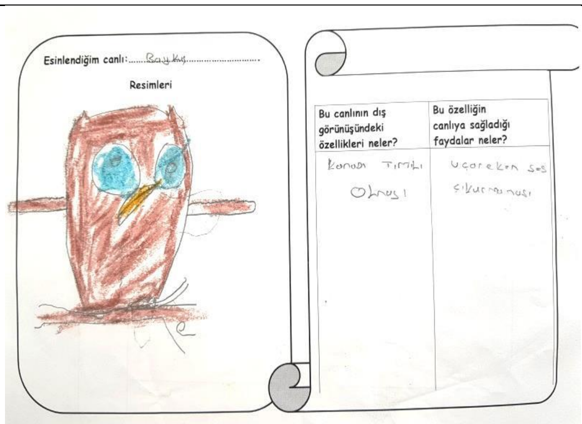
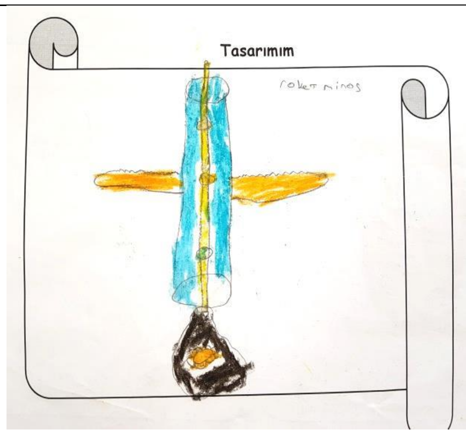
Table 7. 9 Example to structure-based designs-1

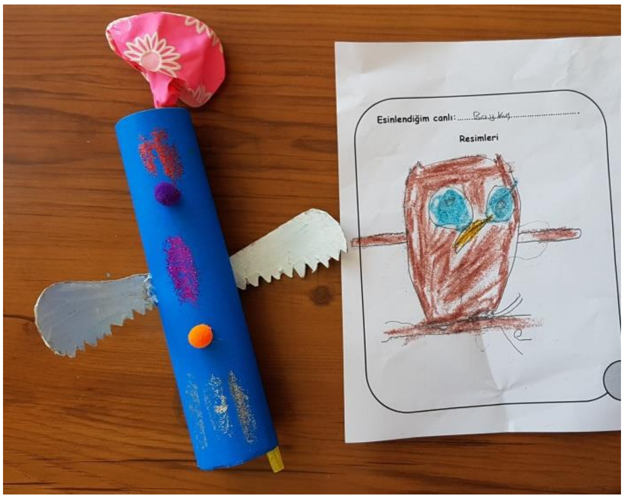
Flying Squirrel	**Pelerine**
	
Model	**Presentation**

	• The flying squirrel has wings like a pelerine. • It can glide while landing. • We designed a pelerine inspired by it. • This pelerine will have a part to wear our arms. • Our design is like a toy for now. If it is worked on it, the real and the larger one can be designed just as Hezarfen Ahmet Çelebi made.

Design 7: A student designed a rocket whose wings are terrated like the wings of the owls (Table 7.10). The reason why it was designed in this structure is to make it fly quietly like the owls. Therefore it is a structure based design.

Table 7. 10 Example to structure-based designs-2

Owl	**Rocket**
	
Model	**Presentation**

	• The wings of the owls are serrated, so they do not make noise when flying. • I am inspired by my rocket design in making the wings serrated. • I ran my rocket by balloon power. • It did not move well, because the pipet was thin.

7.1.3.3 Function Based Designs

9 designs were included in the category of function-based designs (Table 7.11). From 9 design ideas, 5 of them are created as 3 dimensional models. Common thread to all designs in "function based" category is that the starting point is the "function". Some students realized the function served by the structure of organisms; some of them only took the idea of function and put it in a different way.

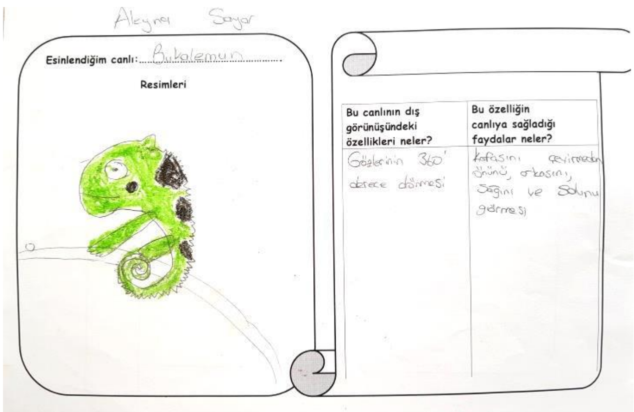
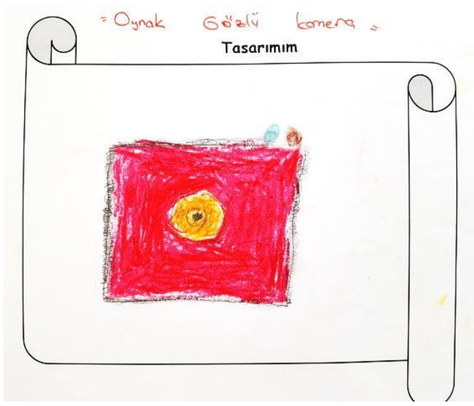
Table 7. 11 Function-based designs

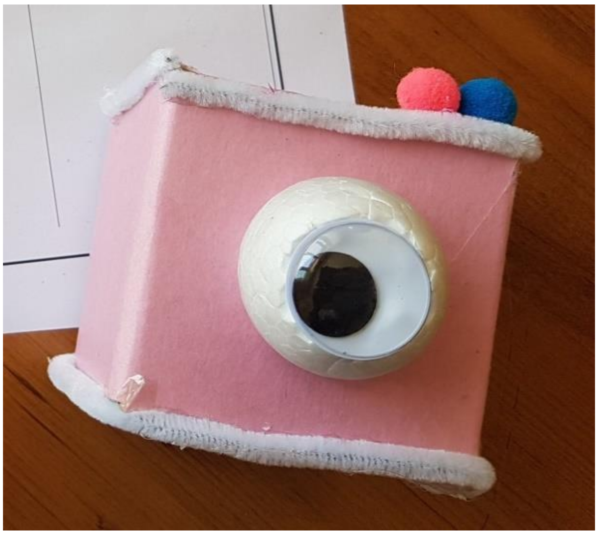
	Design No	The Subject of the Design	Inspired Organism/s
FUNCTION BASED DESIGNS	Design 2	Sticky Gloves	Gecko
	Design 5	Camera with a Moving Eye (Lens)	Chameleon
	Design 9	Jump Jump Shoes	Rabbit

	Design 11	Car Headlight (Luminous Mustache)	Cat
	Design 14	Luminous Hat	Luminous Fish
	Design 17	Quilt	Polar Bear
	Design 18	Fur-Fruit Collecting Tool-Clamp	Giraffe
	Design 20	Washing Machine	Ant
	Design 24	Drone-like Letter Carrier	Glass Winged Butterfly

Design 5: Camera with a moving a car is the design of a student who inspired by the chameleon's characteristic of eyes (Table 7.12). Her design is intended to function to turn its lens like the chameleon eye. Because the function is which student focused in her design, it is included in a function based designs.

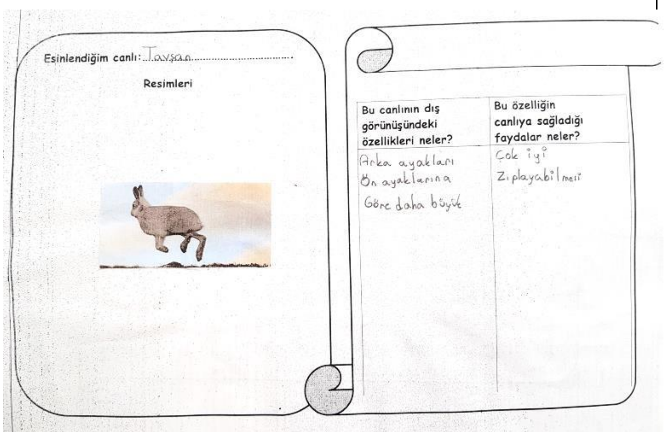
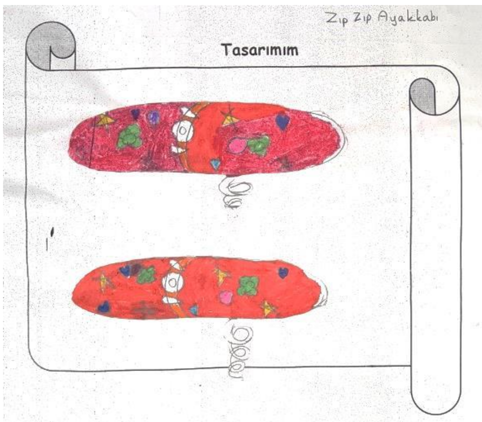
Table 7. 12 Example to function-based designs-1

Chameleon	Camera with a moving eye(lens)
	

Model	Presentation
	• Chameleons can turn their eyes 360 degrees. So they can see their front, back, right, and left without turning their head. • I designed a camera with a moving eye inspired by chameleon. • This camera can take a video of its right and left because it can turn. • It has buttons on it for adjustment.

Design 9: One student designed a shoe which has a mechanism to jump by inspiring the rabbits (Table 7.13). Although student used the similar feet structure with rabbit, she achieved the jumping strategy with a different mechanism than rabbit. That's why the "jump jump design" is accepted as a function based design.

Table 7. 13 Example to function-based designs-2

Rabbit	Jump jump shoes
	

Model	Presentation
	• The hind legs of the rabbits are bigger than their front legs. They can jump very well • I designed shoes inspired by the rabbits' feet • I imitated the shape of the rabbit feet and I put a spiral wire underneath to make it jump like a rabbit.

7.2 Discussion

In this section, the implications of integrating biomimicry into science education and the ways students engaged in biomimicry are discussed related to the literature. Firstly, the general results were discussed in terms of students' choice as individual or group work with the place of teamwork in design process. Secondly, the students' designs were analyzed with respect to their reference points about the inspired organism and the design idea as "presentation" or "student". Finally the categorized designs as "form-based", "structure-based", and "function-based" in terms of biomimicry was discussed in consideration of research in related literature.

Regarding the preference of students about individual versus group work during the biomimicry design process, it was observed that nearly all students wanted to design their models individually. Only 3 of the 24 designs were made with group work. This result is consistent with the findings of the research which was conducted by industrial design students who found individual work as reasonable compared to the group work (Bakırlıoğlu, 2012). However, these students stated that working in groups to discuss and share opinions could help comprehension process during the observation and analysis stage. Similarly, in this research students mostly worked individually in the design part; but before the design process, group work and brainstorming during the biomimicry lessons could have helped students produce several design ideas related to the presented organisms. Actually, working with cooperation and collaboration is also important in the engineering design process which has a specific stage for it called "brainstorming" (Hailey, C. E. & Householder, D. L., 2012). Because biomimicry is a design process involving the engineering abilities, working together can help students to produce multifunctional design ideas.

It can also be said that teamwork, collaboration and communication are effective in enhancing creativity (Hailey, C. E. & Householder, D. L., 2012).. In relation to that, the examples of industry show that innovation and teamwork are highly interrelated (Barak & Goffer, 2002). Therefore in order to integrate creativity into the biomimicry design process, students need encouragement to share and discuss their design ideas together in a learning environment where creativity will emerge naturally.

Creativity also goes hand with knowledge and motivation (Campbell, Jane & Webster, 2006). In terms of the relationship between creativity and knowledge one study showed that students who took structured lessons about the recycling developed creative design ideas and integrated those ideas into their designs when they were asked to design recycling devices. In addition, providing resources or ideas such as pictures or illustrations to exemplify and guide students was found inspirational for the design phase. Accordingly, in biomimicry design process, knowledge has a significant place to create design ideas appropriate to the principles of biomimicry.

When there is inadequate knowledge about biology and biomimicry, inspiration is limited by only the form of the nature. The findings of the research conducted by Boğa (2013), Bakırlıoğlu (2012) and Yıldız (2012) are consistent with this claim. Boğa (2013) states that for creative solutions students need wider database to consult. When there is lack of biology knowledge, it is difficult to analyze and incorporate the nature's lessons into the design process, thereby decreasing the creativity in their designs.

Inadequacy in biology knowledge can also cause to decrease motivation to practice biomimicry as the industrial students in Boğa's study (2013) who were not willing to use natural analogy in their projects because of their lack of knowledge. Students' attitude toward a subject also affects the analytical and deeper thinking which are needed to discover and understand the mechanism in nature. Therefore there is need encouraging and supporting environment to enhance creativity in the design process.

Accordingly, throughout the biomimicry lessons in the present research, the researcher teacher observed that the students were so interested with observing and exploring the living organisms. The students were surprised when they learned how technological ideas came from the organisms in nature. Especially the storified examples caught their attention. After they have a certain level of knowledge about the living organisms and the concept of biomimicry with a variety of examples, they were motivated to create their own biomimicry designs through Biomimicry Design Model.

In the light of above information, when the students' designs were analyzed with respect to their reference points, it was seen that students tended to emulate the organisms they observed during the presentation without copying the same design idea. For the majority of the designs (20 of 24) the source of information for the inspired organism was the presented examples during the biomimicry lessons. This was an expected result in terms of students' choice because they analyzed these organisms to learn about them and take inspiration, so this became their knowledge about nature to practice in biomimicry design stage. In fact, what was unexpected is that the source of the design idea of 21 designs in 24 came from the students. This shows the students' motivation to create their own designs based on their imagination. Therefore, when the effect of knowledge and motivation on creativity was considered, it can be said that biomimicry design process contributes the students' creativity in an environment where students are motivated with provided knowledge and materials appropriate to their age and interests.

Finally, with regard to biomimcry, the students' designs were organized under three categories as "form-based", "structure-based", and "function-based". Because of the fact that the "Biomimicry Teaching Approach" was introduced to the 5th grade students, the presented examples were related to the physical forms and special structures of organisms. Even though the students focused on the physical characteristics of the organisms in their designs, majority of them did not make the mistake of copying the organisms without considering the functional purposes. In 19 of 24 designs the function was taken into consideration. This is a positive outcome regarding the integration of biomimicry into primary science education. Related to this finding, a case study conducted by master students at industrial design education revealed that participants used biomimicry in their designs at the formal level (Bakırlıoğlu, 2012). Another research in the field of industrial product design also showed students' tendency to mimic nature's physical forms (Boğa, 2013). Thus, going beyond copying the physical shape of the nature was found difficult even for university students studying the industrial design product. Not only the industrial design students but also the professional industrial designers in Turkey stated they they had difficulty to reach the biological mechanism of the nature, so the visual impression in their designs went beyond the functionality (Yıldız, 2012).

Taking into account these findings, the fact that 5th grade students tried to make different designs by taking inspiration from an organism in nature and considering the function behind the physical structure of the organism shows that the most of the students can practice biomimicry appropriately in elementary level. In fact, the most of the students' designs created with functional purposes were inspired by an organism presented during the biomimicry lessons. This can imply that students at this age level need to discover the organisms in nature with the guidance of the teacher in order to practice biomimicry in accordance with its principles.

In addition, similar design examples to the students' ideas inspired by living things were found in the literature on biomimicry. The relevant examples are explained below.

The idea of flying pelerine design was produced by two students taking inspiration from flying squirrel. These students stated they would develop their idea on a real model in the future. Even though they have not heard before, there is a sports called wing-suit flying which takes back over a hundred year. Wing-suit flying is experienced by a special squirrel-like suit that allows gliding through the air. The similarity between the wing-suit and the 5th grade students 'design model can be seen in Figure 7.6.

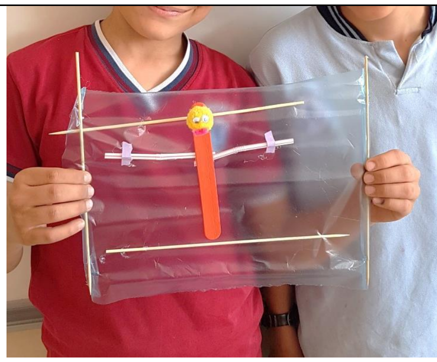
Wing-suit	**Student Design: Flying pelerine inspired by flying squirrel**
	

Figure 7. 6 Wing-suit and flying pelerine

Another relationship was established by a student whose idea was to design a car headlight inspired by the cats' eye. She realized the connection between the cat's eye and the car reflector and created a model she named "limunous mustache". She emulated the physical shape of the cat to emphasize its source of inspiration (Figure 7.7). Although the student could not understand the mechanism of cats' eye and the car headlight, she built its design based on the function that both glow in the dark. In fact, at the back of their eyes cats have a special layer of tissue reflecting the light entering their eyes. Mimicking this mechanism, Percy Shaw took the patent of his invention called "catseye" roadstud in 1935 ("Reflective Roadstuds Ltd," n.d., para. 11). The student's idea of emulating the cat's eye by focusing on the function of illumination without considering the underlying mechanism shows that a few students at 5th grade can practice biomimicry without copying only the physical shape of the organism though at the superficial level.

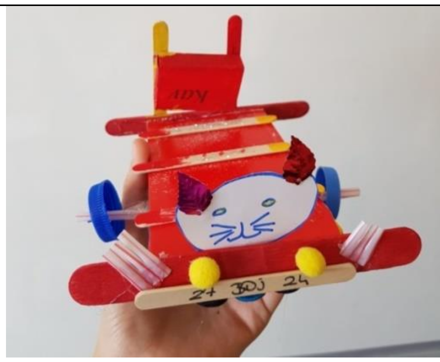
Percy Shaw's design: "Catseye" Roadstud	**5th grade student design: Car headlight inspired by cats' eye**
	

Figure 7. 7 Student designs inspired by cat eyes

When the 5th grade students' design ideas were compared with the studies of industrial design students, some similarities were found. For example, in Boğa's research (2013) a design idea was produced in the workshop with the industrial product design students about natural analogy is the same as the the design idea of a 5th grade student in this research. Both mimicked the special characteristic of chameleon eyes which have a 360 degree vision. The industrial design student placed two camera lenses to have this feature while the 5th grade student attached one moving eye for the same function. Their design models can be compared in Figure 7.8.

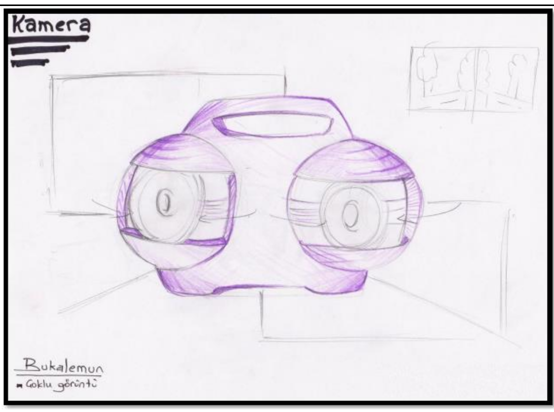
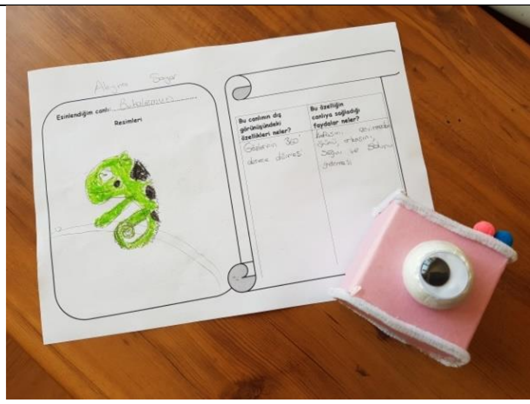
The camera design of a student at industrial product design inspired by the chameleon (Boğa, 2013)	**The camera design of a 5th grade student inspired by the chameleon**
	

Figure 7. 8 The camera designs inspired by chameleon

Another example to the same design idea created by an industrial product design student and a 5th grade student is the helmet design inspired by the turtle shell. The protective function of the shell structure was considered in both designs. The sketch of the industrial design student in Özdoğan's research (2015) and the three dimensional model of the 5th grade student's design were given in Figure 7.9.

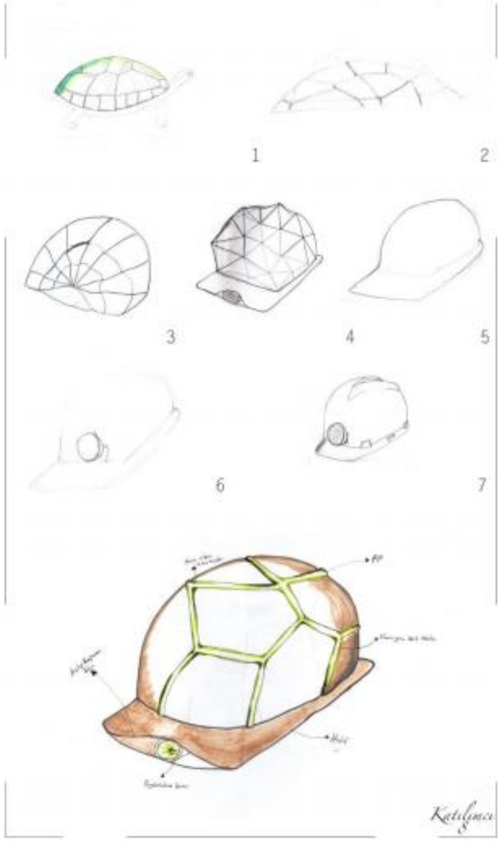
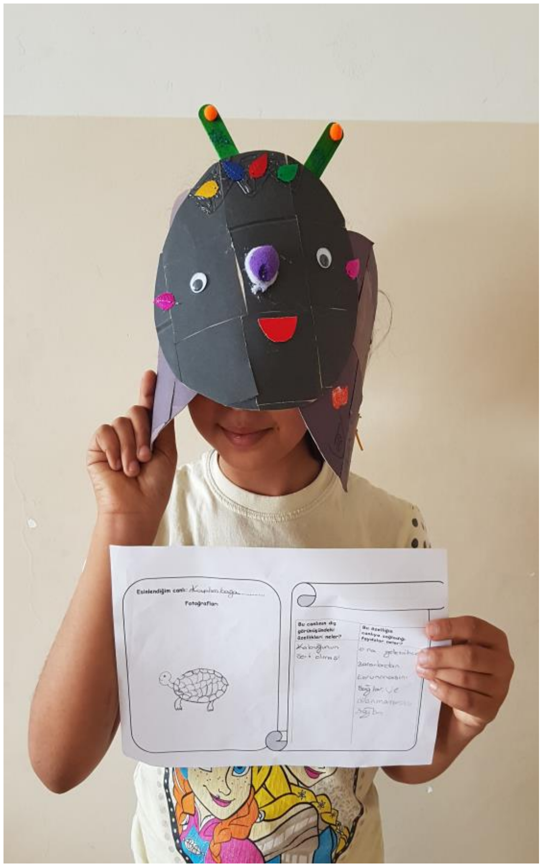
The helmet design of a student at industrial product design inspired by the turtle (Özdoğan, 2015).	**The helmet design of a 5th grade student inspired by the turtle.**
	

Figure 7. 9 Helmet designs inspired by turtle

In addition, the same design idea was given as an example to functional biomimicry in a research investigating the relation between design and biomimicry (Kuday, 2009). Figure 7.10 shows the representation of this relationship in both studies.

Design example to functional biomimicry inspired by the turtle (Kuday, 2009)
 
5th grade student's helmet design inspired by the turtle


Figure 7. 10 Design examples inspired by turtle

There are also other similarities in terms of the design examples in the Kuday's study (2009) and the present research. For instance, the hand-held fan inspired by the peacock was categorized as form based biomimicry in both research. Figure 7.11 shows them comparatively.

Design example to form based biomimicry inspired by the peacock (Kuday, 2009)

5th grade student's hand-held design inspired by the peacock.

Figure 7. 11 Design examples inspired by peacock

Although it was not known whether some products people use today were designed by mimicking the organisms in nature, those with similar characteristics were exemplified in relation to one another in Kuday's research (2009). The relationship between the moon claw and the rake is one of the given examples. Similarly, one of the design ideas of 5th grade students was a digging tool inspired by the mole as seen in Figure 7.12.

Design example involving the biomimicry concept inspired by the moon claw (Kuday, 2009).

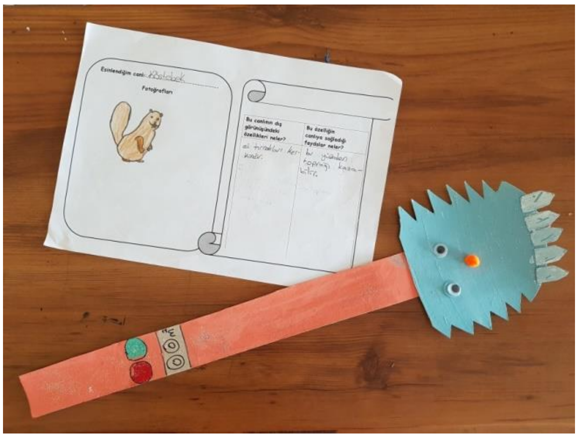
5th grade student's digging tool design inspired by the mole.


Figure 7. 12 Design examples inspired by animal claw

Taking into account all of these, it can be seen that the 5th grade students can create design ideas as the same or similar to the ones in the literature. This shows how applicable design ideas primary school students can produce inspired by the nature when they are given opportunity to practice biomimicry through "Biomimicry Teaching Approach".

7.3 Conclusion

In this study, biomimicry was integrated into science education with a teaching approach within design model proposed by the researcher. Firstly, the students were presented with different kinds of organisms to help them understand the relationship between structure and function. Secondly, they were introduced the concept of biomimicry with a wide variety of examples. At the end of each part of the lesson, students were evaluated with assessment activities to prepare them for the design activity. Finally students were engaged with the "Biomimicry Design Model" in which they used their knowledge and abilities like observation, analyzing and creativity. In this stage the students discovered the structures and functions of organisms they observed. Then, inspired by these organisms they produced design ideas and models. Within this context, the outcomes of "Biomimicry Teaching Approach" through "Biomimicry Design Model" were examined.

The results showed that during the biomimicry lessons and design process, students were actively engaged, shared ideas and created models based on their final design idea. Their preference in terms of group work versus individual working was on the side of individual working for the majority of the students. In total 24 designs were created by the students at the end of the design process. Some students created more than one design, so the number of designs (24) was higher than the number of students (19). It can be said that biomimicry teaching approach motivates students to create more designs by contributing their creativity.

Analysis of students' designs with respect to their reference point revealed that while the source of information for the inspired organism was resulted in "presentation" for majority of the designs (20 of 24), the source of design idea was resulted in "student" for almost all designs (21 of 24). In other words, students generally produced their own design ideas by emulating the organisms which were presented throughout the biomimicry lessons. Because students were introduced with organisms having potential to inspire via presentation, it was expected them to get inspired by these organisms. Students' attempt to create their own design ideas without copying the same in the presentation is also an indication of their motivation to put their creativity into the design process. Regarding these findings, it can be concluded that the more organisms we introduce to the students, the more ideas they can produce.

Regarding the categorization of the designs, form based designs were in low number compared to the structure and function based designs. Also, the number of structure and function based designs were almost the same. While some students were inspired by the organisms' structures, some focused on their functional characteristics to emulate. This is a positive outcome showing that majority of the students understood the fundamental idea behind biomimicry. In this context, according to the research even the industrial design students tended to copy organisms' physical shape (Boğa, 2013 & Bakırlıoğlu, 2012). Thus 5th grade students' attempt to create different design ideas by considering the underlying function indicates that they can practice biomimicry appropriately in elementary level through biomimicry design model.

In addition, some of the design ideas and models students created were similar to the biomimicry examples in literature such as flying pelerine, hand held fan, helmet, digging tool and car headlight. Therefore, it can show that primary school students can produce applicable design ideas when they are given opportunity to practice biomimicry via biomimicry teaching approach.

7.4 Recommendations

The integration of biomimicry into science education is a new approach to teach. Although there are organizations studying to teach, practice and spread biomimicry worldwide, the literature about this topic is lacking in terms of science education research. That's why the present research offers a framework for educators to integrate biomimicry into their science lessons. The design ideas of 5th grade students showed that the Biomimicry Teaching Approach developed for primary school students can lead students to learn and practice biomimicry. However, in the present research there were some limitations in terms of observational process and the educational supplies. All the biomimicry lessons took place in the classroom environment. In fact, if the students had the chance to make field observation in nature, they could have made more discoveries about living organisms and created more distinctive design ideas. For example, observing the burdock burrs in their natural habitat and discovering their special attaching mechanisms through a microscope like the Gerorge de Mestral did or exploring the Lotus plant's hydrophobicity by making experiments on it can be an effective way to introduce biomimicry examples. In the present research, the researcher could only reach the maple seeds. The enthusiasm and excitement that the students exhibited while watching the maple seeds turning like a helicopter were like to support this claim. Therefore, outdoor observation to explore the nature is suggested within the bounds of possibility in order to practice biomimicry efficiently.

The fact that the organisms inspiring the students were mostly involved in the presentation can imply that the students' knowledge and experience about the living organisms are limited. Because the knowledge and experience lead to the design ideas, students need to explore more organisms and learn from the designs in nature. Thus, for students to establish relationship between nature and technological design, teachers are responsible to create rich learning environments encouraging students' curiosity and desire as well as engaging them in exploring their ideas by providing the required materials.

When it comes to the design products, it is seen that the 3-D models the students created were only for the purpose of presenting their idea, so they did not have the functional characteristics. At this point, in the design process of biomimicry design model students can be provided with suitable materials to create more realistic models, so students can evaluate their design in terms of the relationship between structure and function based on the experimental tests.

This research is expected as an inspiration for further research about biomimicry teaching approach in elementary level. Because of the fact that biomimicry is related to several disciplines from natural sciences to engineering and technology, the effects of biomimicry education on different variables are needed to find out in order to understand its significance in education.

Further research can be carried out to implement biomimicry into primary science education based on the "challenge to biology" method different than the present research which used "biology to design" method. The "challenge to biology" method is also in accordance with the STEM approach in which students are engaged with real life problems through connection between the learning disciplines of science, technology, engineering and mathematics. The innovation that would come with the integration of biomimicry into the STEM disiplines is looking at the nature for searching solutions to daily life problems because according to biomimicry, nature has already solved the problems people face. In this context, the effect of Biomimicry education on learning in STEM disciplines should be studied in further research.

Regarding the STEM education, engineering design process can also be modified to integrate biomimicry concept. In the brainstorming section of engineering design, the solution can be sought in nature as a part of the biomimicry process. Also, students should be encouraged to work and create ideas together.

Biomimicry design process can improve 21st century skills of students depending upon the design approach, so the effect of biomimicry education on students' creativity, problem solving, and decision making should be investigated.

Biomimicry teaching apparaoach gives message to students that the nature is like a teacher with full of ideas and waits to be discovered, not to be used. Hence biomimicry has a huge potential to increase students' awareness on nature surrounding them. Accordingly, the influence of biomimicry on environmental attitude might be another topic to be studied in future research.

In conclusion, even though the "Biomimicry Teaching Approach" was designed according to the level of primary school students, the present research was limited to 5th grade students. Therefore the implications of integrating biomimicry into science education are required to be investigated for other grades.

References

Althen, A. (2015). *The nature of LEED: How natural laws inspire and inform green building.* Retrieved from https://www.usgbc.org/articles/nature-leed-how-natural-laws-inspire-and-inform-green-building

Akter, S., Arslan, H. B., and Şimşek, M. (2017). *5. Sınıf fen bilimleri ders kitabı: Fen ve mühendislik uygulamaları/Uygulamalı bilim.* (M. Taş, A. E. Bozdoğan and A. Tekbıyık, Eds.). Ankara: MEB.

AskNature. (2016-a). *Wing surface self-cleans.* Retrieved from https://asknature.org/strategy/wing-surface-self-cleans/

AskNature. (2016-b). *Surface allows self-cleaning.* Retrieved from https://asknature.org/strategy/surface-allows-self-cleaning/

AskNature. (2016-c). *Scales provide flexible, strong protection.* Retrieved from https://asknature.org/strategy/scales-provide-flexible-strong-protection/

AskNature. (2016-d). *Pangolin backpack.* Retrieved from https://asknature.org/idea/pangolin-backpack/

AskNature, (2016-e). *Skull protects brain from impact.* Retrieved from https://asknature.org/strategy/skull-protects-brain-from-impact/

AskNature. (2019). *Edge of seed creates vortex lift to increase dispersion.* Retrieved from https://asknature.org/strategy/edge-of-seed-creates-vortex-lift-to-increase-dispersion/

Aziz, M. S. (2016). Biomimicry as an approach for bio-inspired structure with the aid of computation. *Alexandria Engineering Journal*, *55*(1), 707-714.

Bakırlıoğlı, Y. (2012). *Biomimicry for sustainability: An educational project in sustainable product design.* (Master's Thesis), Retrieved from Higher Education Council (YOK) National Thesis Center Database. (Accession No. 313756)

Barak, M., and Goffer, N. (2002). Fostering systematic innovative thinking and problem solving: Lessons education can learn from industry. *International Journal of Technology and Design Education*, *12*(3), 227-247.

Barthlott, W., and Neinhuis, C. (1997). Purity of the sacred lotus, or escape from contamination in biological surfaces. *Planta*, *202*(1), 1-8.

Bartholomew, S. R., Strimel, G. J., and Yoshikawa, E.(2017). Designing the technological world through biomimicry. *Children's Technology and Engineering*, *21*(4), 18–22.

Benyus, J. M. (1997). *Biomimicry: Innovation inspired by nature.* New York: HarperCollins Publishers.

Benyus, J. M. (2014). A Biomimicry Primer. In Baumeister, D., Tocke, R., Dwyer, J., Ritter, S. and Benyus, J. (Eds), *Biomimicry resource handbook: a seed bank of best practices* (pp.7-15). Missoula, Montana: Biomimicry 3.8.

Bernett, A. (2015, January 17). *Biomimicry, bioutilization, biomorphism: The Opportunities of bioinspired design.* Retrieved from https:/ww.terrapinbrightgreen.com/blog/2015/01/biomimicry-bioutilization-biomorphism/

Biomimicry Institute. (2015-a). *Biomimicry toolbox: What is design?* Retrieved from https://toolbox.biomimicry.org/introduction/design/

Biomimicry Institute. (2015-b). *Biomimicry toolbox: Nature's unifying patterns.* Retrieved from https://toolbox.biomimicry.org/core-concepts/natures-unifying-patterns/

Biomimicry Institute. (2015-c). *Biomimicry toolbox:The systems view.* Retrieved from https://toolbox.biomimicry.org/core-concepts/systems/

Biomimicry Institute. (2015-d). *Biomimicry toolbox: Earth's operating systems.* Retrieved from https://toolbox.biomimicry.org/core-concepts/earths-operating-system/

Biomimicry Institute. (2015-e). *Biomimicry toobox: Function and strategy.* Retrieved from https://toolbox.biomimicry.org/core-concepts/function-and-strategy/

Biomimicry Institute. (2015-f). *Biomimicry toobox: Abstract Design Strategies. https://toolbox.biomimicry.org/methods/abstract/*

Biomimicry Institute. (2016-a). *Biomimicry case study: Entropy non-directional carpet tiles*. Retrieved from http://toolbox.biomimicry.org/wp-content/uploads/2016/03/CS_Interface_TBI_Toolbox-2.pdf

Biomimicry Institute. (2016-b). *Biomimicry case study: ORNILUX Bird Protection Glass.* Retrieved from http://www.ornilux.com/Attachments/CaseStudy_Ornilux_MASTER.pdf

Biomimicry Institute. (2017). *Sharing biomimicry with young people: An orientation for K-12 teachers.* Retrieved from https://asknature.org/resource/sharing-biomimicry-with-young-people/

Boğa, M. (2013). *Tasarımda doğal analoji: Endüstri ürünleri tasarımı öğrencilerinin yaklaşımı üzerine bir çalışma.* (Master's Thesis), Retrieved from Higher Education Council (YOK) National Thesis Center Database. (Accession No. 350654)

Brusic, S. A. (2013). Designed by nature inspired by nature. *Children's Technology and Engineering, 18*(1), 18–21.

Bryman, A. (2004). *Social research methods*. New York: Oxford University Press

Bybee, R. W. (2014). NGSS and the next generation of science teachers. *Journal of science teacher education*, *25*(2), 211-221.

Campbell, C., Jane, B., and Webster, A. (2006). Enhancing the creative process for learning in primary technology education. *International Journal of Technology and Design Education*, *16*(3), 221-235.

Christensen, D. L., Cutkosky, M. R., Eason, E. V., and Hawkes, E. W. (2015). Human climbing with efficiently scaled gecko-inspired dry adhesives. *Journal of The Royal Society Interface*, *12*(102). https://doi.org/10.1098/rsif.2014.0675

Cortese, A. D. (2003). The critical role of higher education in creating a sustainable future. *Planning for Higher Education*, *31*(3), 15-22.

DeLuca, D. (2014, March 28). *Bio-inspired buzzwords: biomimicry and biomimetics, biomimicry for creative innovation.* Retrieved from http://businessinspiredbynature.com/bio-inspired-buzzwords-biomimicry-biomimetics/

De, M. G. (1955). *U.S. Patent No. 2,717,437*. Washington, DC: U.S. Patent and Trademark Office.

Ersanli, C. C. (2016). *The significance and place of biomimicry data in physics education.* 5th International Vocational Schools Symposium (pp. 583-590).

Eryılmaz, H. (2015). Biyomimikri ve Ergonomi: Tasarimda Doğadan Yenilikçi İlham. *Mühendislik Bilimleri ve Tasarım Dergisi*, *3*(3), 469-474.

Ethington, R. L., Stark, A. Y., and Walker, C. (2016). Who Is Your Champion?. *Science and Children*, *53*(9), 39.

Fish, F. E., Howle, L. E., Murray, M. M and Weber, P. W. (2011). The tubercles on humpback whales' flippers: Application of bio-inspired technology. *Integrative and Comparative Biology*, *51*(1), 203–213.

Fisch, M. (2017). The nature of biomimicry: Toward a novel technological culture. *Science, Technology, & Human Values*, *42*(5), 795-821.

Goss, J. (2009). *Biomimicry: Looking to nature for design solutions* (Doctoral dissertation). Retrieved from ProQuest Dissertations & Theses Global Database. (Accession No. 503430610)

Hailey, C. E. and Householder, D. L. (2012). *Incorporating engineering design challenges into STEM courses.* National Center for Engineering and Technology Education. Retrieved from https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1164&context=ncete_publications

Hopkins, D. (2008). *A teacher's guide to classroom research*. New York: Open University press.

Isabelle, A. D. (2017). STEM is elementary: Challenges faced by elementary teachers in the era of the next generation science standards. *The Educational Forum, 81*(1), 83-91. https://doi.org/10.1080/00131725.2016.1242678

Johnson, S. (2018) Advantages and disadvantages of fire. Retrieved from https://sciencing.com/advantages-disadvantages-fire-8160003.html

Knowles, E. (Ed.). (2001). *The oxford dictionary of quotations.* New York: Oxford University Press.

Kuday, I. (2009). *Examination of the term biomimicry as a supporting factor in design process.* (Master's thesis), Retrieved from Higher Education Council (YOK) National Thesis Center Database. (Accession No. 256612)

Lodato, F. (2005). The nature of design. *Design Management Review*, *16*(1), 56-61.

Macnab, M. (2012). *Design by nature: using universal forms and principles in design*. Berkeley, CA: New Riders.

Mara, Wil. (2012). *From cats' eyes to... reflectors.* U.S: Charry Lake Publishing.

McKeag, T. (2012) Auspicious forms: Designing the Sanyo Shinkansen 500-Series Bullet Train. *Zygote Quarterly*, *2*, 12-35.

McNiff, J. and Whitehead, J (2009). *You and your action research project*. New York: Routledge.

McNiff, J. (2010). *Action research for professional development: Concise advice for new action researchers.* Dorset: September books.

MEB (2017). *Fen Bilimleri Dersi Ogretim Programi (İlkokul ve Ortaokul 3, 4, 5, 6, 7 ve 8. Siniflar).* Ankara: Talim ve Terbiye Kurulu Başkanlığı Yayınları.

MEB (2018). *Fen Bilimleri Dersi Ogretim Programi (İlkokul ve Ortaokul 3, 4, 5, 6, 7 ve 8. Siniflar).* Ankara: Talim ve Terbiye Kurulu Başkanlığı Yayınları.

Messina, A., Reina, G., Rossi, C., and Savino, S. (2015). Performance of Greek–Roman Artillery. *Arms & Armour*, *12*(1), 67-89.

Moore, T., Strnat, M. and Tank, K. (2015). Nature as Inspiration. *Science and Children*, *53*(2), 72–78.

Özdoğan, M. (2015). *Bioprocess: A proposal of systematic method for design process inspired by nature and its application.* (Master's Thesis), Retrieved from Higher Education Council (YOK) National Thesis Center Database. (Accession No. 425735)

Peters, A. (2012). A stronger bike helmet, made of cardboard and inspired by a woodpecker. Retrieved from https://www.good.is/articles/a-stronger-bike-helmet-made-of-cardboard-and-inspired-by-a-woodpecker

Reflecting Roadstuds Ltd. (n.d). Retrieved from http://www.percyshawcatseyes.com/history

Rossin, K. J. (2010). Biomimicry: nature's design process versus the designer's process. *WIT Transactions on Ecology and the Environment*, *138*, 559-570. doi:10.2495/DN100501

Satterfield, B., Jameson, S. and Youngren, H. (2009). *Design of the SAMARAI monowing rotorcraft nano air vehicle*. Paper presented at the American Helicopter Society 65th Annual Forum, Texas: Grapevine.

Soja, C. M. (2014). A field-based biomimicry exercise helps students discover connections among biodiversity, form and function, and species conservation during earth's sixth extinction. *Journal of Geoscience Education*, *62*(4), 679-690.

Staples, H. (2005). The Integration of Biomimicry as a Solution-Oriented Approach to the Environmental Science Curriculum for High School Students. *Online Submission.* Retrieved from https://files.eric.ed.gov/fulltext/ED490541.pdf

The Biomimicry Institute. (n.d.). Retrieved from https://biomimicry.org/

Tytell, E. (2004). Humpbacks' bumpy flippers. *Journal of Experimental Biology, 207*(21), 4-4.

Vula, E. (2013). 1st *Action research as a form of teacher professional development.* Albania International Conference on Education (pp. 634-644).

Yanik, M. F. (2009). Towards gecko-feet-inspired bandages. *Trends in biotechnology*, *27*(1), 1-2.

Yıldız, H. (2012). *Biomimetic design and methodology in the content of industrial product design.* (Master's thesis), Retrieved from ITU Academic Open Archieve. (Accession No. 422747)

Zeichner, K. M. (2003). Teacher research as professional development for P–12 educators in the USA [1]. *Educational action research*, *11*(2), 301-326.

Zeni, J. (1998). A guide to ethical issues and action research. *Educational action research*, *6*(1), 9-19.

A
Biomimicry Examples

Burdock burrs- Velcro

Invention of Velcro dates back to a hike of Swiss engineer George de Mestral with his dog in 1941. When they back home, Mestral realized that plants named burdock burrs stick to his dog's fur. Then he observed the structure of the plant closely via microscope. When looked closely he noticed the tiny hooks which allow them to attach to rough surfaces such as the clothes and furs. Influenced by the wonderful characteristic of burdock burrs, a design idea came to the Mestral's mind. The product inspired by this plant had to be have two surfaces that interlock.

After years of investigation for the appropriate material and the device, he succeeded to invent the product which he named "Velcro", also known as "hook and loop" (U.S. Patent No. 2,717,437, 1955). While the Mestral's invention could not get the attention that it deserved at the beginning in shoe company, Mestral's perseverance enabled his invention to be recognized by space agency NASA. Finally the use of Velcro in equipments of NASA enabled Velcro to achieve its reputation and expand itself in many areas of life. Today its products are still used all around the world.

Humpback Whale- Tubercle Technology

Humpback whales can undertake acrobatic underwater maneuvers despite the fact that they are almost 50 feet long and 40 tons. Their secret is that they have bumps or tubercles across the leading edges of their flippers. When the water or air flows over the bumps on the flippers, they break up into many turbulent vortices leading easy lift of the body. The characteristic of the humpback whales was recognized by a scientist who is Dr. Frank Fish while he was shopping at a gift store. When he noticed a humpback whale sculpture, he thought that sculptor made a mistake in shaping the flippers of the whale. His thought was stem from the his pre-knowledge about the airfoils and hydrofoils whose leading edge were believed had to be smooth and streamlined. After this event, he set out an experiment on wind tunnel by working with his collaborators to reveal the answers. The experiment was designed to test and compare the performance of the airfoil which has the smooth shape with another airfoil which has bumps on its leading edge. The results of the experiment showed that the addition of bumps or tubercles to the airfoil increased lift (6%) and decreased the drag (32%) together with energy efficiency and reduction in sound (Tytell, 2004). These results lead the company called WhalePower to apply this principle to the design of wind turbines and all sorts of fans.

Kingfisher/Penguin/Owl- Shinkansen Bullet Train

The Shinkansen is the network of high- speed "bullet trains" manufactured by Japan Railway Groups. The first Shinkansen was built by Japan in 1964. The speed of this train can be up to 300 km/h (Mckeag, 2012). The first problem Shinkansen faced was not due to his speed but to the noise the speed had caused. The problem was detected in the pantographs which had role in receiving electricity from the overhead wires. The one who solved the problem was "Eiji Nakatsu" who was the engineer and the director of this Shinkansen series. The story of how Nakatsu solved the problem was based on a serious of inspirations. While Nakatsu was searching solutions to this challenge, he attended a lecture of "Seiichi Yajima" who was an aircraft design engineer. Yajima was also interested with birds and a member of the Wild Bird Society of Japan. Nakatsu learned the effect of studying the functions and structures of birds on the aircraft technology in the lecture. He also learned that owls could fly silently thanks to their "serration feathers" which broke the larger air vortexes into small ones. Inspired by this fact, he worked with an engineer team to analyze the owl's silent flying mechanism and applied this principle to the main part of the pantograph. They became successful on reducing the noise level at the end of 4 years of effort. In addition to this improvement, the base of the pantograph was reshaped like "Adelie" penguin which could swim easily by lowering the resistance thanks to its body shape.

The new design of pantographs allowed them to be less affected by air resistance and to work more efficient. However, the train had another challenge. Whenever the train passed through the tunnel the sonic boom problem occurred due to the difference in air pressure between inside and the outside of the tunnel. Nakatsu once again looked at the nature to find out if there was an organism that could manage the sudden changes in resistance. Then he found “the kingfisher” which could dive from the air (low pressure) into the water (high pressure) without splashing. He thought that the beak structure of king fisher could be the reason and studied to test this idea. The analysis of different nose designs showed that the ideal beak shape for the purpose of managing pressure was almost the same as the kingfisher’s beak. As a result, new series of Shinkansen was designed by reshaping the nose of the trains by mimicking the kingfisher’s beak, so not only sonic bomb effect was reduced, but also the trains could become faster, powerful, quitter and energy efficient.

Lotus Plant- Lotus Effect

Although lotus plants can live dirty waters, they can stay dry and dirt-free. They can clean themselves without using any chemical or expending any energy. This characteristic of these plants were detected by Wilhelm Barthlott who was a German botanist in 1977. He revealed the secret of self- cleaning property of these plants by investigating them under the electron microscope. He realized that lotus plants had rough structure including micro and nano scale bumps on their leaves that give them superhydophobicity. When dirty particles contact with water droplets on the leaf, they stick to the droplets. Then, the water rolls of the plant by carrying the dirt along with it similar to a ball rolling on the carpet (Barthlott & Neinhuis, 1997).

It is known as the lotus effect due to the discovery of hydrophobicity on the lotus plant, the same self-cleaning ability is observed by some insects with large wings such as butterflies, moths and dragonflies (AskNature, 2016-a).

The microstructural principle of these organisms to stay dry and clean can be applied to different areas of life such as textiles, paints and various artificial surfaces (Barthlott & Neinhuis, 1997). The well-known application of the lotus plant mechanism is "Lotusan" coating as the name implies. Lotusan facade paints have the self-cleaning effect by inspiring the lotus plant's microstructure. The facades clean themselves after the rainfall (AskNature, 2016-b).

Maple Seed- Drone

Maple trees have wing-like seeds which give them the advantage of spinning like a helicopter while falling to the ground. Seeds move slowly as they swirl, so the wind can carry them to distances. The researchers revealed that maple seeds create tornado like vortices at the leading edge of the seeds. This leading-edge vortices cause the air pressure to be low over the upper surface of the seed resulting in lift against the gravity (AskNature, 2019).

An aerospace company named Locked Martin developed a device called "the SAMARAI" inspiring by maple seeds' aerodynamic structure (Satterfield, Jameson & Youngren, 2009). This model is a single winged helicopter about a foot long operated as a drone. Beside a small camera, it has two moving parts which one is a small fan providing the motor power and the other one is a wing allowing controlling the movement of the vehicle. Thanks to these parts, they have managed to direct the flying camera. While flying, SAMARAI spins around in a circle like the maple seed, so it can obtain video at 360 degree view.

Pangolin- Backpack

Pangolin is a mammalian who has an armor consisting of tough overlapping scales. Although Pangolins do not have teeth and they move slowly, they can protect themselves by changing the position of their body. When in danger, they roll like a ball by tucking their head into their stomach (AskNature, 2016-c). This strategy of the pangolins became an inspiration to a backpack design. The pangolin backpack is a pack which has overlapping scales as the pangolin. It is also durable and has magnets instead of zippers (AskNature, 2016-d).

Woodpecker- Hammer

Species of woodpeckers strike their beat into tree trunks almost 12.000 times per day at 6-7 m/s speed but they experience no brain damage thanks to their skeletal structure. Otherwise, the force stemming from high speed pecking would cause physical and neurological trauma. Thanks to the spongy bones in their skull and the anatomy of their beak the force due to striking is reduced before reaching the brain so they can protect themselves (AskNature, 2016-e).

An industrial designer named Anirudha Surabhi was inspired by woodpecker in order to design a stronger helmet. His interest in creating helmet was based on a bike accident he experienced. Although he was using an expensive helmet, it was not enough to protect him, so he examined the anatomy of the woodpecker for inspiration. He mimicked the spongy structure of the bird and found the suitable material after trying 150 different kinds. Eventually he created a helmet which tree times stronger than a standard one (Peters, 2012).

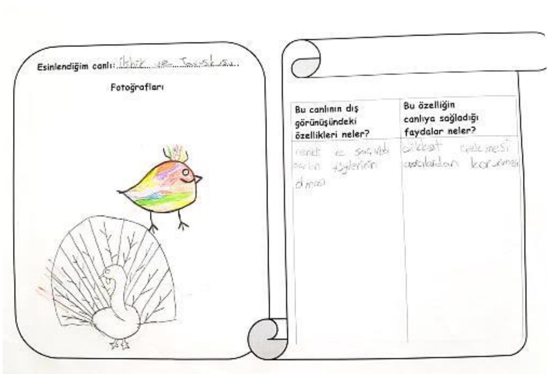
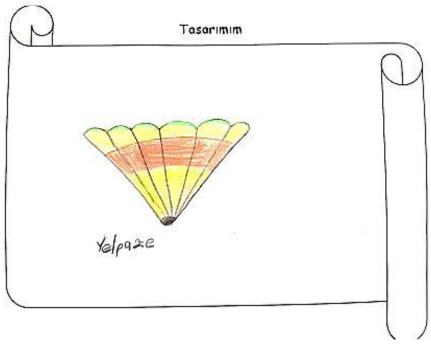
Gecko- Bandage

Geckos are reptiles which can adhere to even smooth surfaces and climb vertical walls because the surface of their feet are covered by millions of micro hairs that create an adhesive force between their toe pads and the surface. Scientists have studied this characteristic of geckos in order to understand the mechanism and to apply it for developing materials which function like geckos' feet. By inspiring Gecko, a team of scientists from MIT (Massachusetts Institute of Technology) have developed such a bandage that is strong and elastic mimicking the nano technology in gecko feet (Yanik, 2009). The gecko inspired materials could be used in surgeries, help robots to climb vertical walls and even lead to the development of gloves which enable to climb walls like a superman (Christensen, Cutkosky, Eason, & Hawles, 2015).

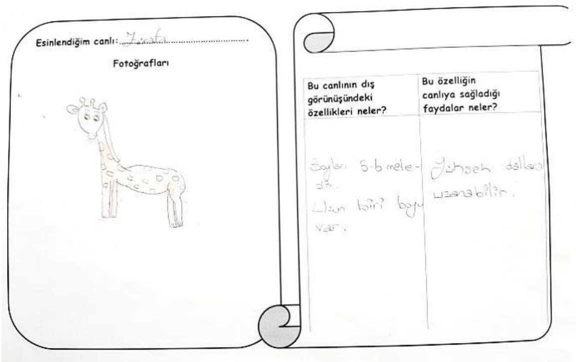
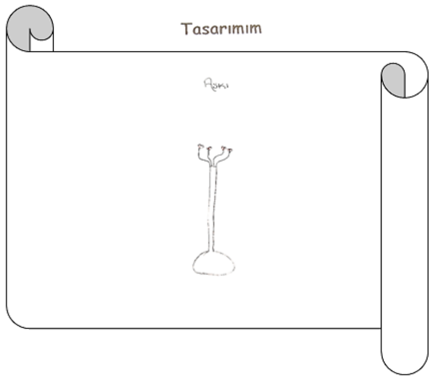
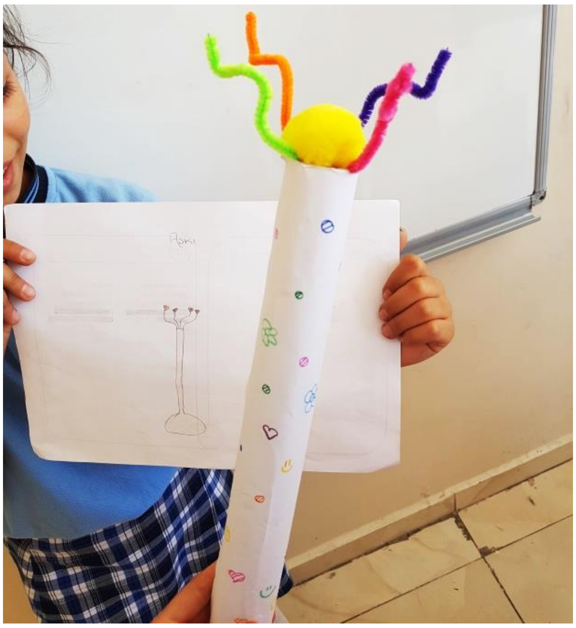
B
Students' Designs

Form Based Designs

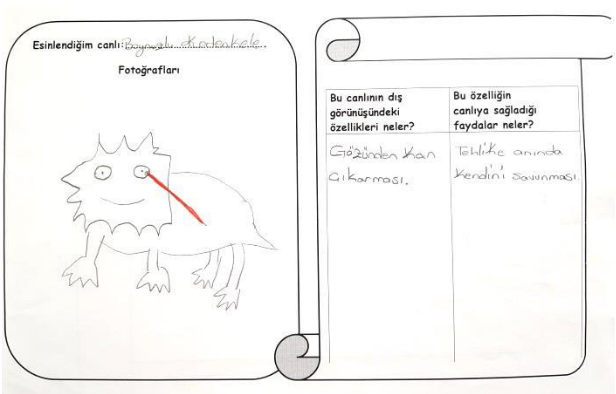
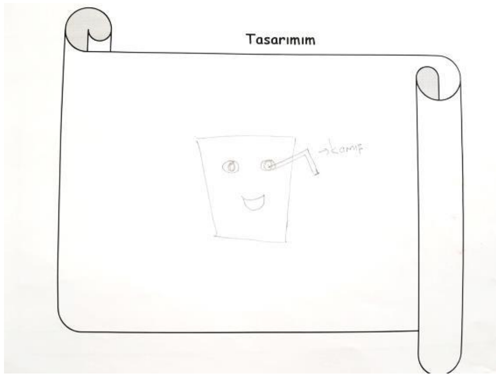
Design 1: Two students worked together to design a hand-held fan inspired by two organisms, peacock and upupo epopos. The hair structure of upupo and wing structure of peacock function as attraction compared to the hand-held fan which functions as cooling. The fan design imitates the physical form of the organisms, not the function. Therefore it is categorized as "form- based".

Peacock and upupo epopos	Hand-held fan
	
Model	**Presentation**
	➢ The hair of the bird looks like fan. ➢ The peacock opens its wings like a fan. ➢ Inspired by these two organisms, we designed a fan. ➢ The peacock and upupo epopos attract attention with these features and are protected from hunters. ➢ Our design is for cooling.

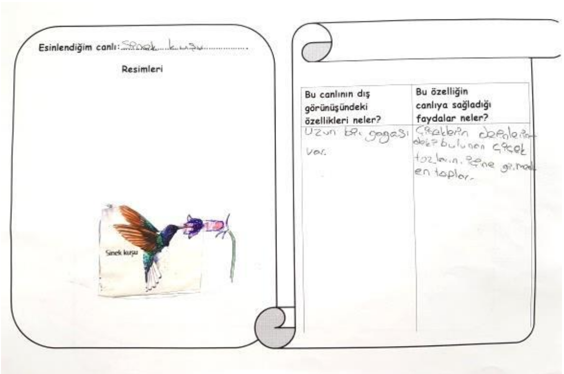
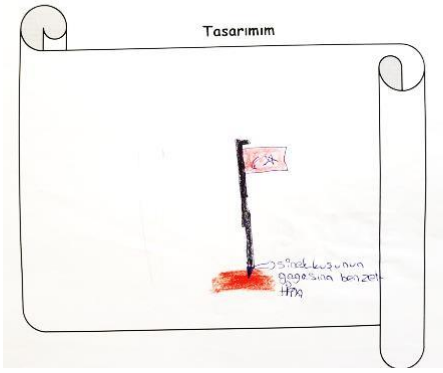
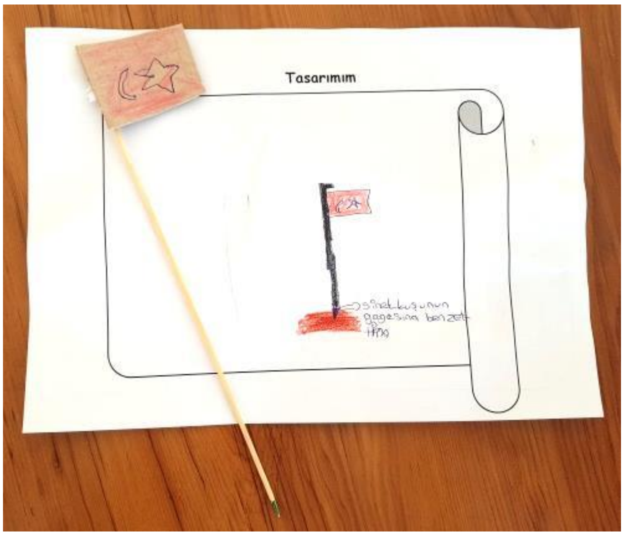
Design 4: A student inspired by the giraffe to design a coat rack. She mimicked the form of the giraffe's upper part considering the length and horns of it. The organism and the design do not share the same function except sharing the similar long shape, so the student's design is included in the form-based design category.

Giraffe	**Coat Rack**
	
Model	**Presentation**
	➢ Giraffes have long necks, so they can reach high branches. ➢ I made a coat rack design inspired by giraffes. ➢ The length of the coat rack resembles the neck of the giraffe, and the edge of it resembles the horns of the giraffe.

Design 6: A student redesigned the form of liquid soap dish by imitating the defense mechanism of horned lizards. Instead of squirting soap from the top of the soap dish, it squirts from the eye which is designed as a part of decoration to make it look like a horned lizard face. Hence, the design is form-based.

Horned Lizard	**Liquid Soap Dish**
	
Model	**Presentation**
	➢ Horned lizard squirts blood from his eyes to defense itself when in danger. ➢ I am inspired by it to make soap dish which squirts water when pressed. ➢ I placed the pipette in the eye to make it look like a horned lizard.

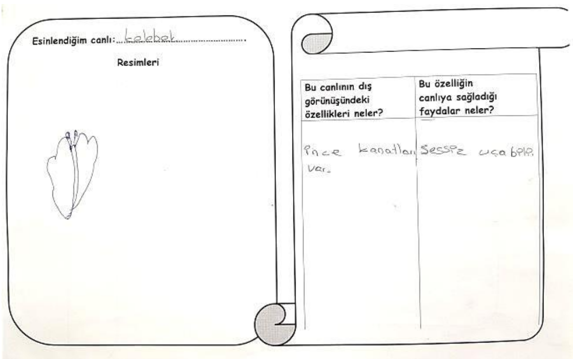
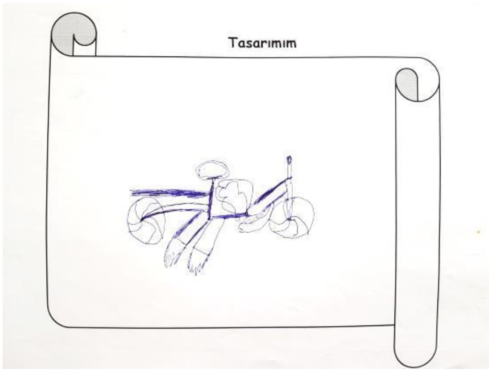
Design 19: In this design, the bottom of the flag pole is shaped by mimicking the long beak of hummingbird. Because the function does not play role in shaping the pole, the design is taken into the scope of form based.

<table>
<tr><th>Hummingbird</th><th>Flagpole</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><th>Model</th><th>Presentation</th></tr>
<tr><td>
</td><td>

- Hummingbirds have long beaks. They can reach the nectar in tubular flowers.
- I designed a flagpole inspired by these birds' beak.
- I imitated the beak of hummingbirds to design the bottom of the flag pole.

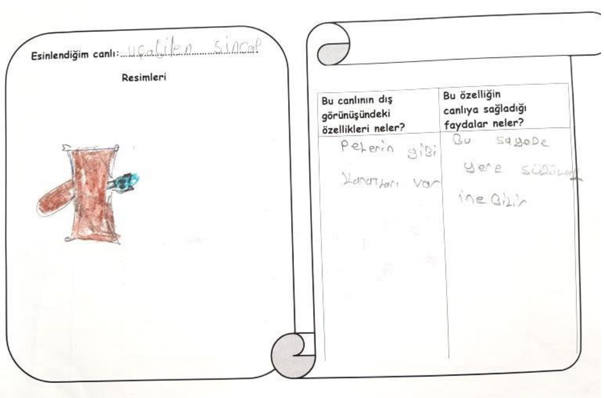
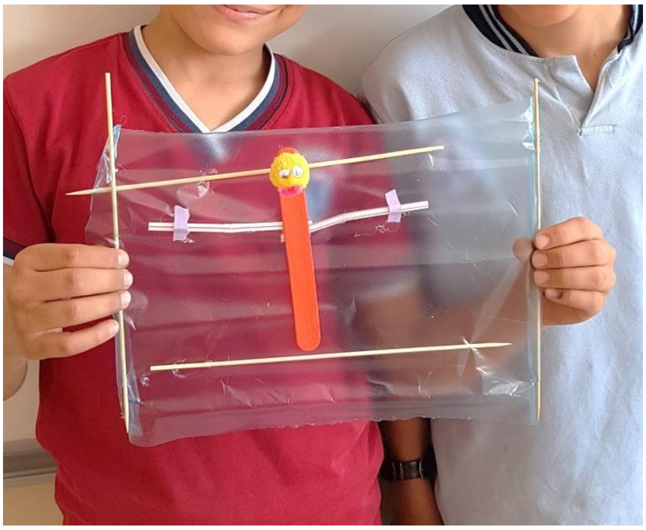
</td></tr>
</table>

Design 21: The student imitated the shape of the butterfly wings in designing his flying bike. Although he mentions the characteristics of butterfly wing as becoming thin and flying quietly, he does not relate them with his design, so the design is categorized as form based.

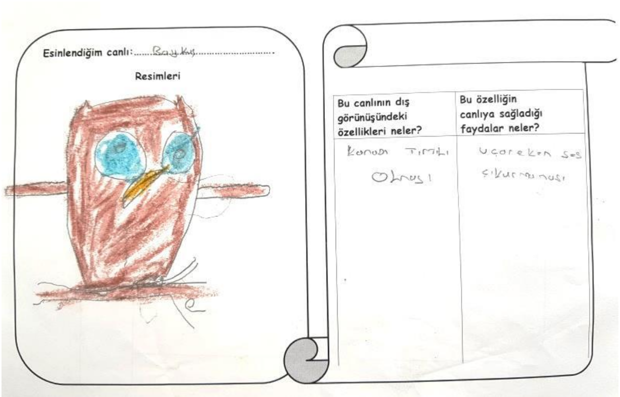
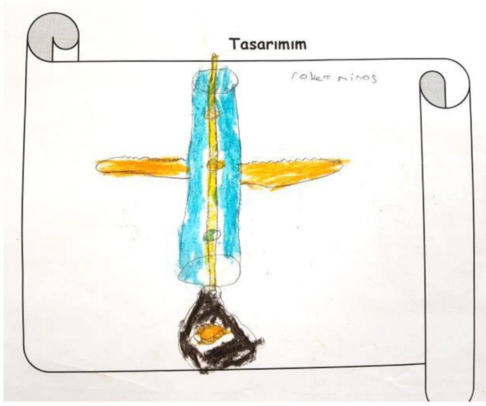
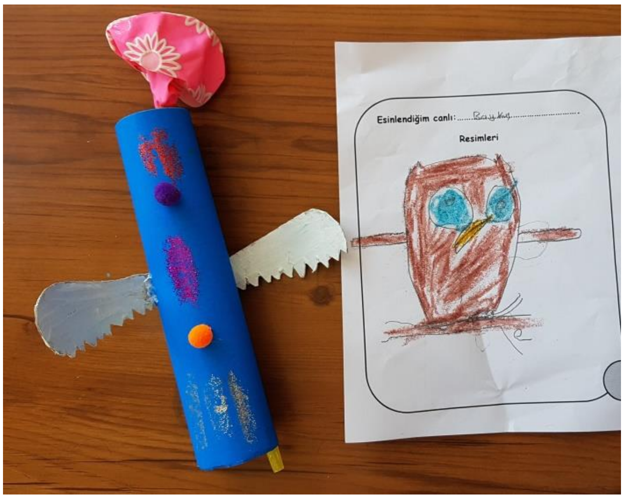
Butterfly	Flying Bicycle
	
Model	**Presentation**
	➢ I designed a flying bike. ➢ I designed a flying bicycle by mimicking the shape of the butterfly wing.

Structure Based Designs

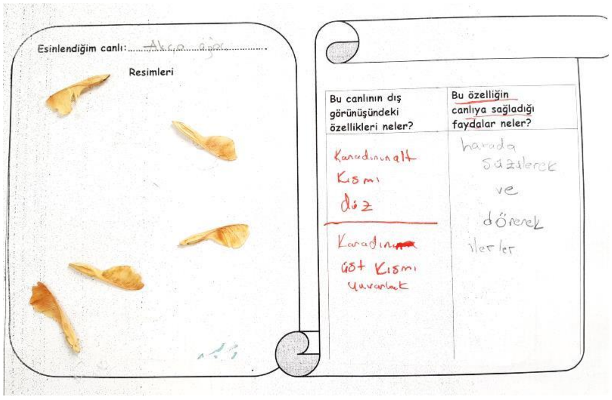
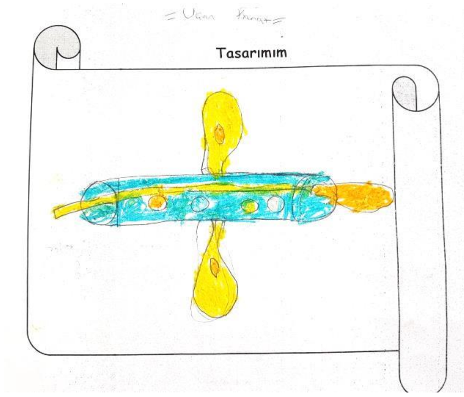
Design 3: Wings-like structure of flying squirrel gave inspiration two students to design a pelerine which can be worn to be able to fly. Students imitate the structure of the flying squirrel to be able to function like it. That's why it is grouped as structure based biomimicry.

Flying Squirrel	Pelerine
	
Model	**Presentation**
	➢ The flying squirrel has wings like a pelerine. ➢ It can glide while landing. ➢ We designed a pelerine inspired by it. ➢ This pelerine will have a part to wear our arms. ➢ Our design is like a toy for now. If it is worked on it, the real and the larger one can be designed just as Hezarfen Ahmet Çelebi made.

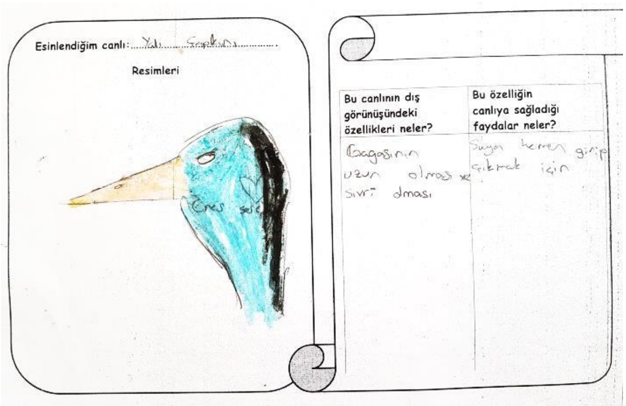
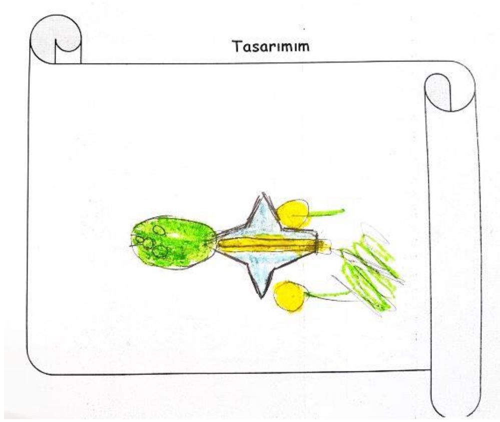
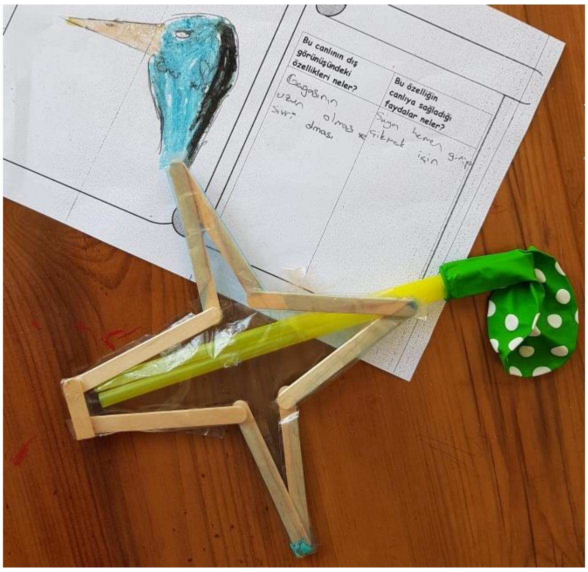
Design 7: A student designed a rocket whose wings are terrated like the wings of the owls. The reason why it was designed in this structure is to make it fly quietly like the owls. Therefore, it is a structure based design.

Owl	**Rocket**
	
Model	**Presentation**
	➢ The wings of the owls are serrated, so they do not make noise when flying. ➢ I am inspired by my rocket design in making the wings serrated. ➢ I ran my rocket by balloon power. ➢ It did not move well, because the pipet was thin.

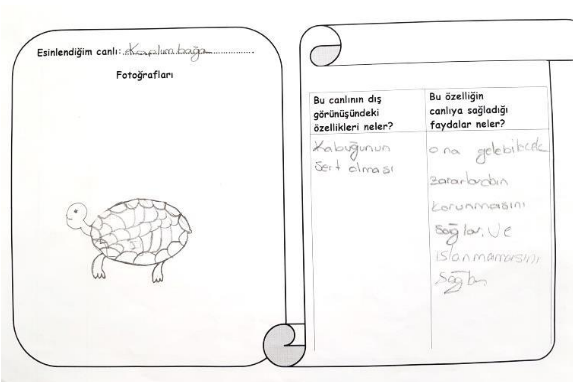
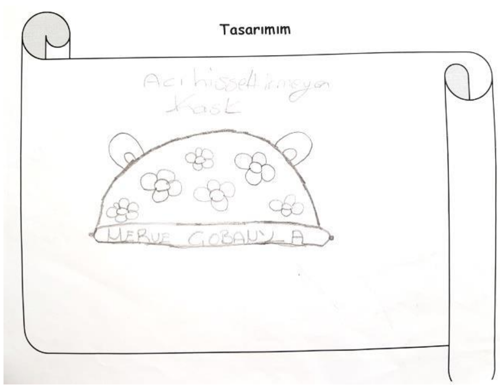
Design 8: The structure of maple seeds resembles the wing. A student designed the wing of her rocket model by imitating the structure of maple seeds. Her aim is to enable her rocket to fly easily due to this structure, so it is included in structure based design.

Maple Seed	Rocket
	
Model	**Presentation**
	➢ The shape of maple seeds is similar to the wing. The lower part is straight and the upper part is round. They move in the air by gliding and spinning. ➢ In my rocket design I make the wings like the maple seed, so the it could fly more easily. ➢ I moved my rocket with balloon power by blowing air by pipette. ➢ We did experiments with the other rocket which has serrated wings, but the balloon power was not enough to move the rocket.

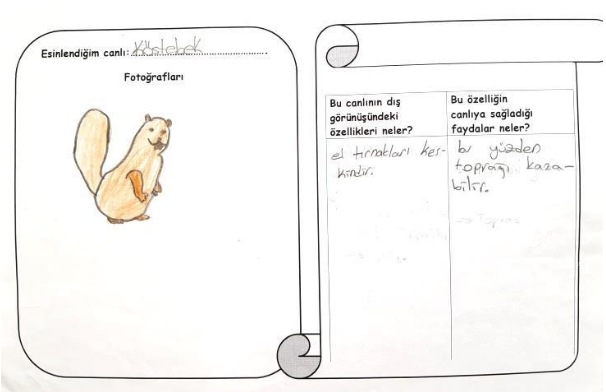
Design 10: A student mimicked the beak structure of the kingfisher in order his design to move quickly. The intended function is provided with this form like when the kingfisher dives. Thus, it is an example of structure based biomimicry.

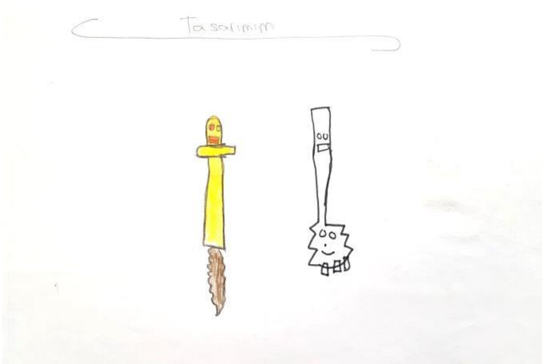
<table>
<tr><th>Kingfisher</th><th>Airplane</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><th>Model</th><th>Presentation</th></tr>
<tr><td></td><td>
➢ The beak of the kingfisher is long and sharp, so it can instantly take a dip. It can move fast.
➢ My design is an airplane. I imitated the beak of the king fisher to design the front of the plane.
➢ I enabled it to move by adding balloons to the front.
➢ I intend to develop this design in the future</td></tr>
</table>

Design 12: The function of the shell of the turtle is to protect it from danger. A student mimicked the structure of the turtle shell to design a helmet. Her design reached the same protection function with turtle by having a similar structure to the shell. Primarily the student mimicked the structure of the shell and the function followed it. Therefore the helmet design is classified as "structured based."

Turtle	**Helmet**
	
Model	**Presentation**
	➢ The shell of the turtle is hard. This ensures that it will be protected from harm and will not get wet. ➢ I designed a helmet inspired by his shell. ➢ This helmet will be as tough as a turtle shell and will not make feel pain.

Design 13: The structure of the moles' fingernails serves the function of digging soil well. That's why a student's design of digging tool inspired by the moles is an example of structure based design.

<table>
<tr><th>Mole</th><th>Digging Tool</th></tr>
<tr><td>


</td><td>


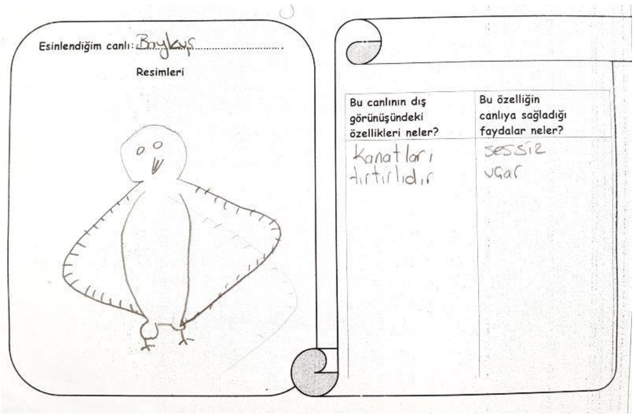
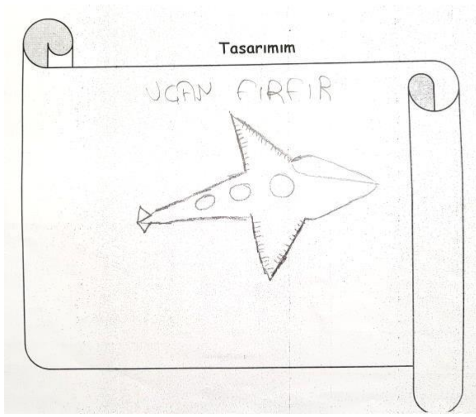
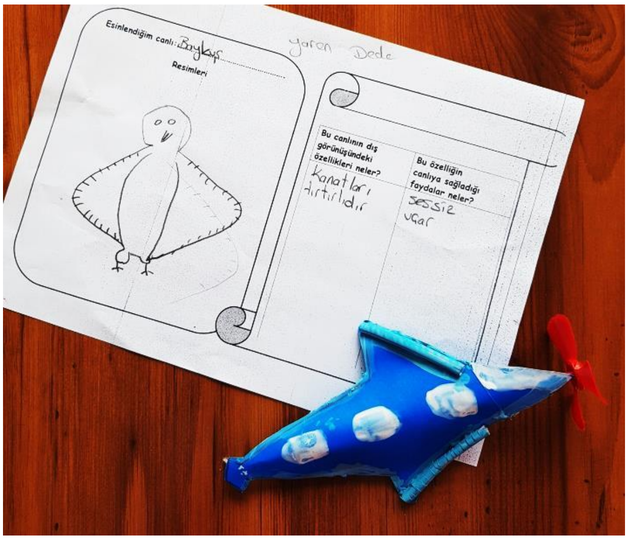
</td></tr>
<tr><th>Model</th><th>Presentation</th></tr>
<tr><td>

</td><td>

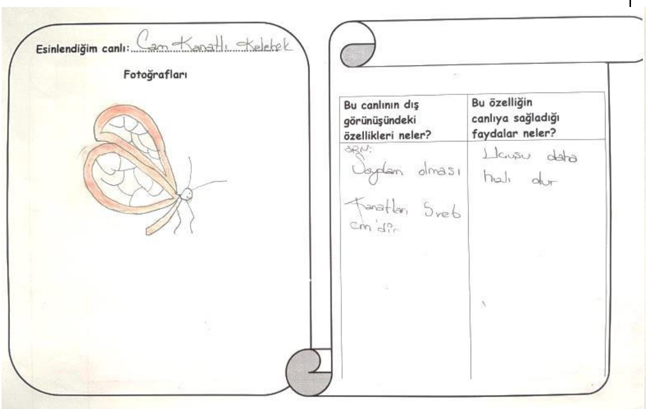
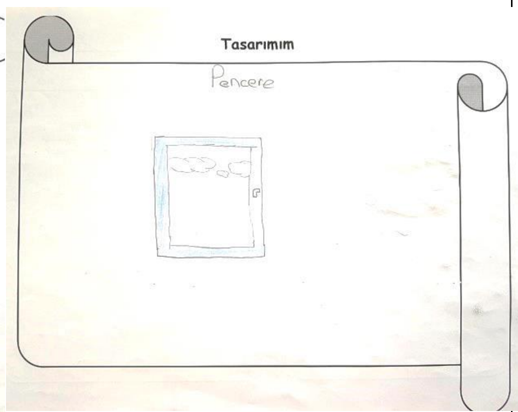
- The mole's fingernails are sharp, so they can dig the soil.
- I designed a digging tool by taking inspiration from the claw of the mole.
- The tip of the digging tool will have hard protrusions like the mole claw.

</td></tr>
</table>

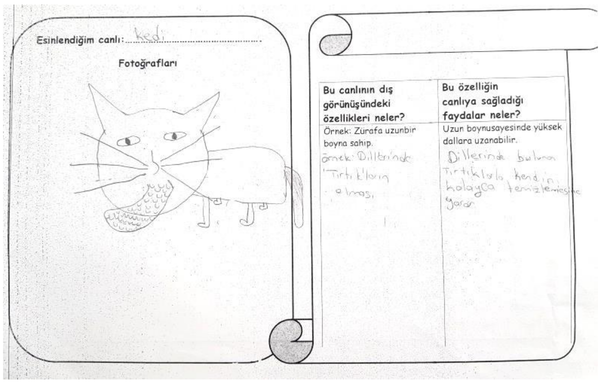
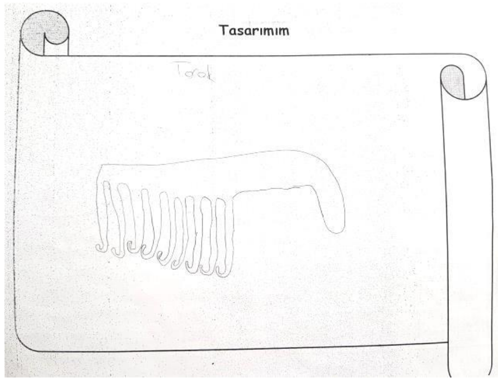
Design 15: The silent flight characteristic of owls inspired another student to design the wings of an aircraft. The air craft design with serrated wings also is included in structure based design like the similar previous biomimicry example.

Owl	Aircraft (Flying Frill)
	
Model	**Presentation**
	➢ The wings of the owls are serrated, so they can fly silently. ➢ I was inspired by my aircraft design, making the wings serrated.

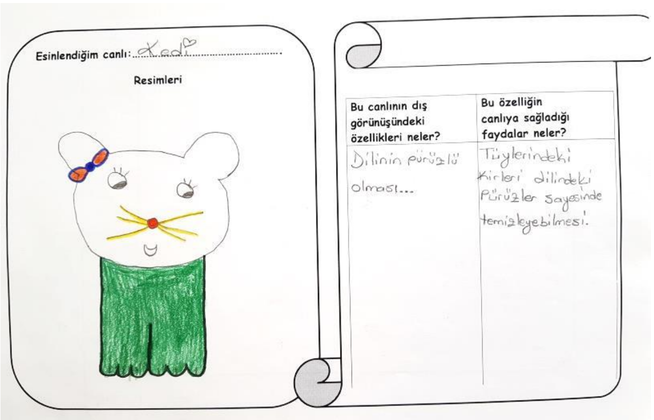
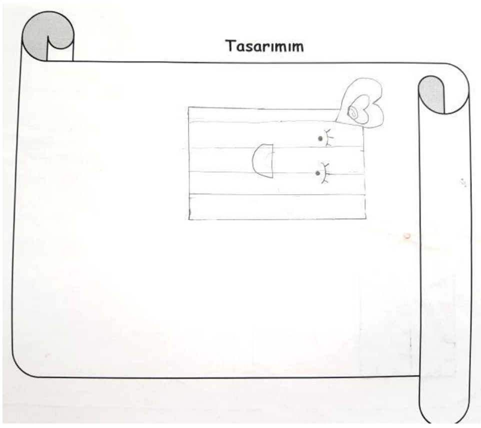
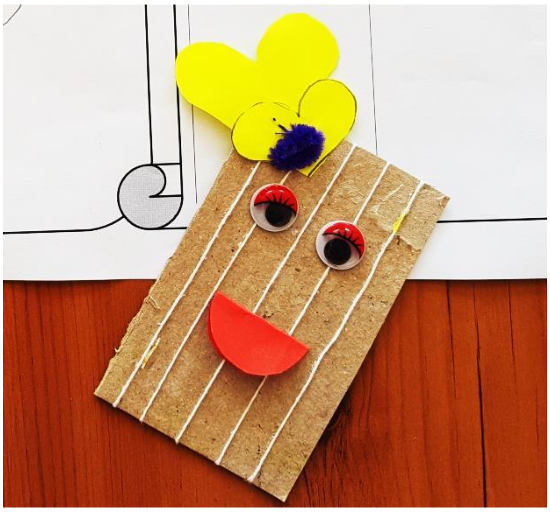
Design 16: One student inspired the wing characteristic of glass winged butterflies to design a window. Her design mimics the structure of butterfly wing in order to get the advantage of it. However, the function of such glass is not clearly considered by the student. Because the structure is included in design process, it is accepted in the group of the structure-based designs.

Glass Winged Butterfly	**Window Glass**
	
Model	**Presentation**
The students did not make the model of her design.	➢ The glass winged butterfly's wings are transparent like the glass, so they can fly easily. ➢ I designed a window glass inspired by the wings of the butterfly.

Design 22: The rough structure of the cats' tongue and its function in cleaning got the attention of two students. This one is a comb model mimicking the structure of the cat tongue to make combing the hair easy. The student inspired by the spines on the tongue of the cat by making the comb's teeth curled. It is an example of structure based biomimicry.

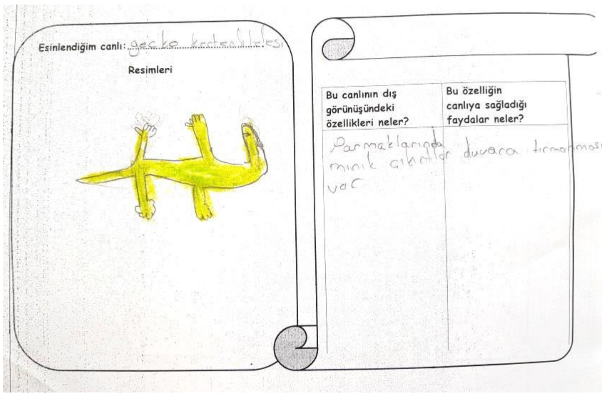
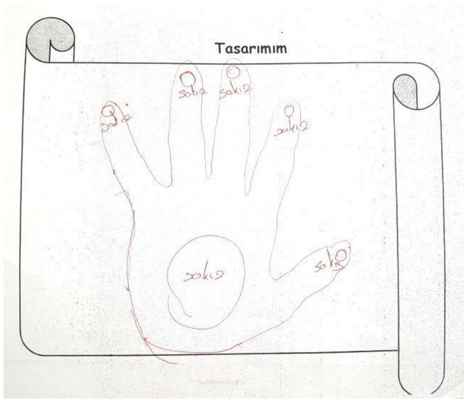
<table>
<tr><th>Cat</th><th>Comb</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><th>Model</th><th>Presentation</th></tr>
<tr><td>The students did not make the model of her design.</td><td>➢ My design is a comb.
➢ I made the comb's teeth curled like the spines on tongue of the cat.</td></tr>
</table>

Design 23: One more student inspired the curling characteristic of the cat tongue. Her design is a cleaning tool which has a rough surface like the cat tongue. The same function was aimed with a similar structure, so the design is included in structure based design.

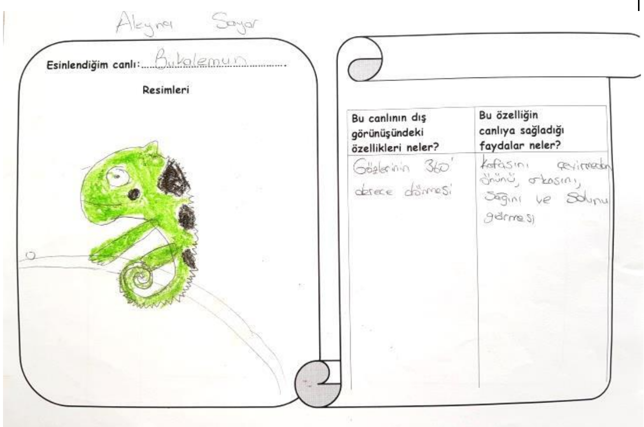
Cat	**Cleaning Brush**
	
Model	**Presentation**
	➢ Tongue of the cats is rough. Cats can remove the dirt on their feathers when they groom by using their rough tongue. ➢ I designed a cleaning brush. It has a rough surface like the cat tongue.

Function Based Designs

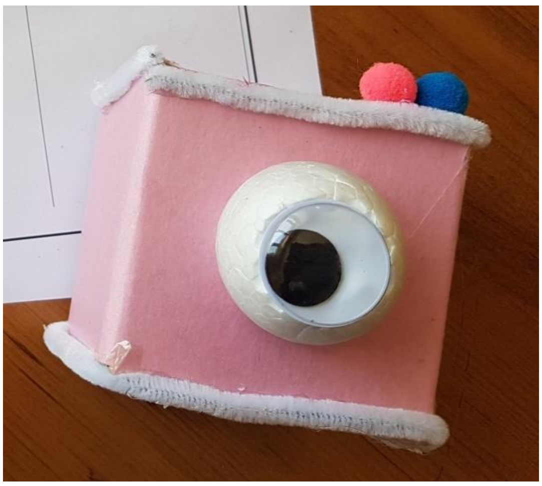
Design 2: Two students inspired by the characteristics of gecko feet which enable them to climb the walls. They intend to design a sticky glove that mimics the function of gecko feet. However they did not achieved this function by imitating the gecko's nano strategy. Students found their own solution to get the similar result. Therefore their design is categorized as "function based".

Gecko	Sticky Gloves
	
Model	**Presentation**
	➢ Geckos can climb the walls thanks to the bumps on their feet. ➢ We designed a sticky glove inspired by the feet of the Gecko lizard. ➢ We stacked gum on the glove to make it sticky. ➢ We tested our design but it could not carry us. We need to use stronger adhesive.

Design 5: Camera with a moving eye is the design of a student who inspired by the chameleon's characteristic of eyes. Her design is intended to function to turn its lens like the chameleon eye. Because the function is which student focused in her design, it is included in a function based designs.

<table>
<tr><th>Chameleon</th><th>Camera with a moving eye(lens)</th></tr>
<tr><td>


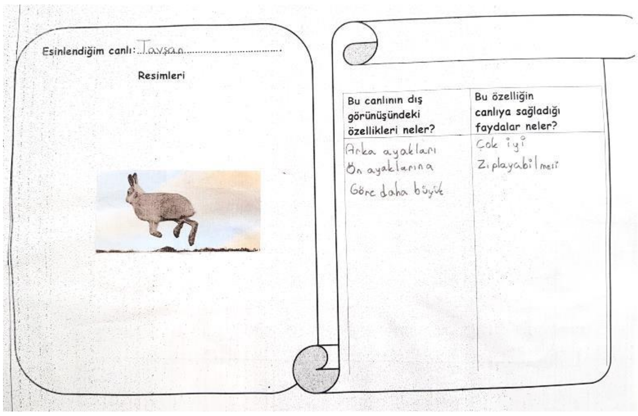
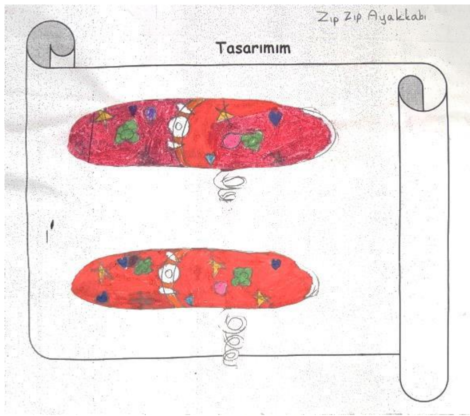
</td><td>


</td></tr>
<tr><th>Model</th><th>Presentation</th></tr>
<tr><td>

</td><td>

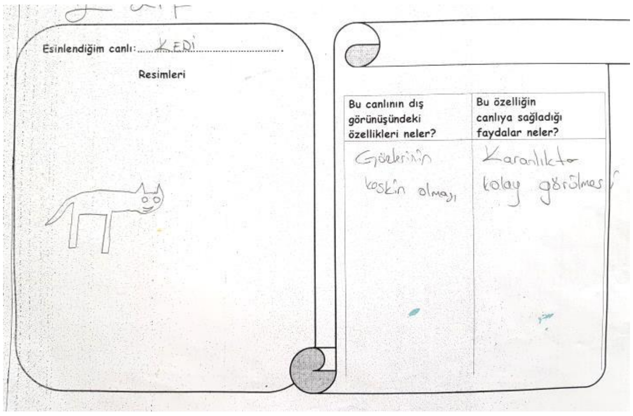
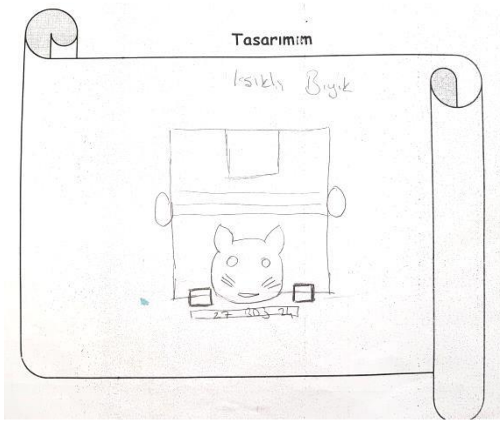
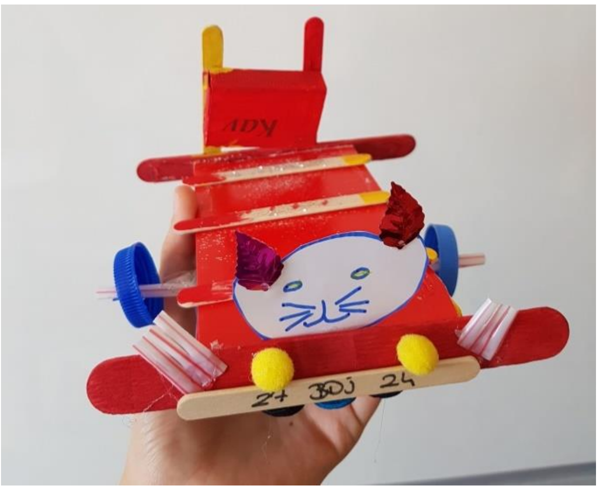
Chameleons can turn their eyes 360 degrees. So they can see their front, back, right, and left without turning their head.
I designed a camera with a moving eye inspired by chameleon.
This camera can take a video of its right and left because it can turn.
It has buttons on it for adjustment.

</td></tr>
</table>

Design 9: One student designed a shoe which has a mechanism to jump by inspiring the rabbits. Although student used the similar feet structure with rabbit, she achieved the jumping strategy with a different mechanism than rabbit. That’s why the “jump jump design” is accepted as a function based design.

Rabbit	Jump jump shoes
	
Model	**Presentation**
	➢ The hind legs of the rabbits are bigger than their front legs. They can jump very well ➢ I designed shoes inspired by the rabbits' feet ➢ I imitated the shape of the rabbit feet and I put a spiral wire underneath to make it jump like a rabbit.

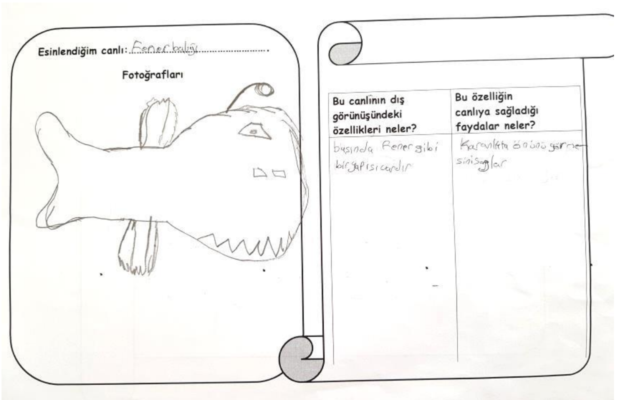
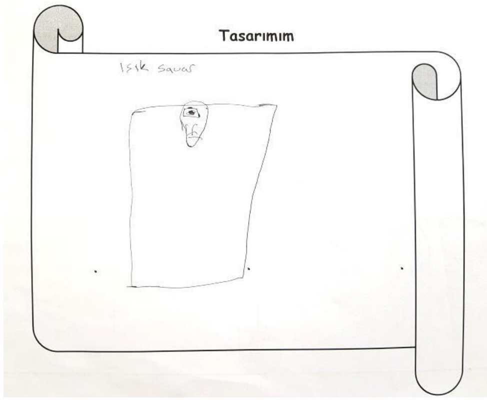
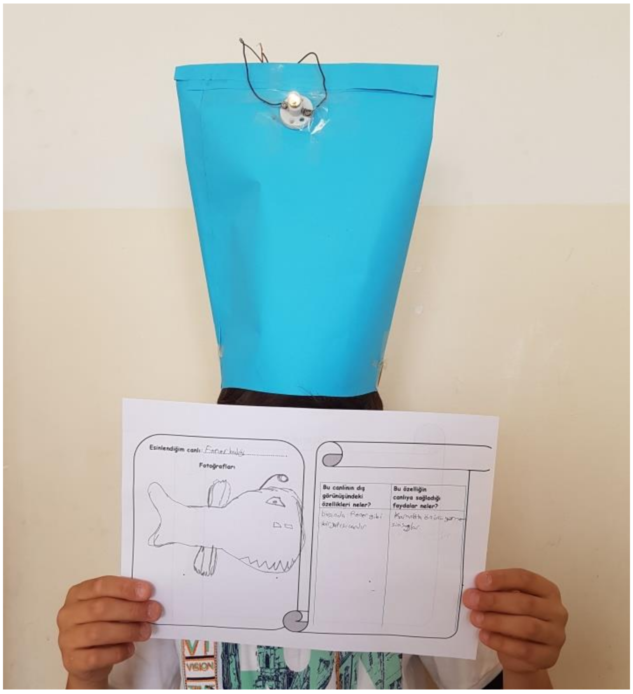
Design 11: Cat's eyes can glow in the dark. One student associated the cat eye with car headlight. In spite of the fact that student intend to shape the form of her design similar to cat body, she chose the cat as an inspirational organism because of its lighting function, so it is a function based design.

<table>
<tr><th>Cat</th><th>Car Headlight (Luminous Mustache)</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><th>Model</th><th>Presentation</th></tr>
<tr><td>
</td><td>

- Eyes of the cats have sharp vision and they can easily see in the dark.
- Inspired by the cat eyes, I designed a car headlight.
- I also shaped the car similar to the cat face. In the dark it will shine like the cat eye.

</td></tr>
</table>

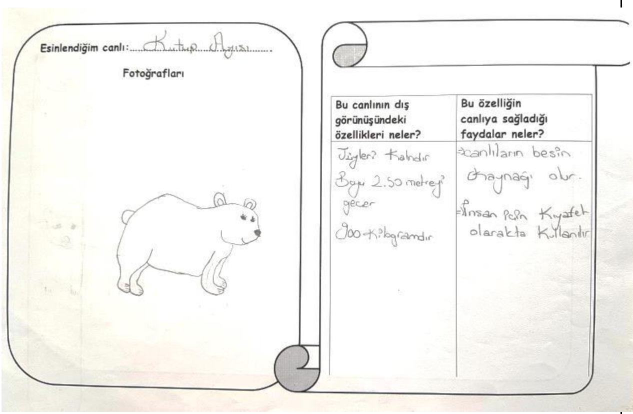
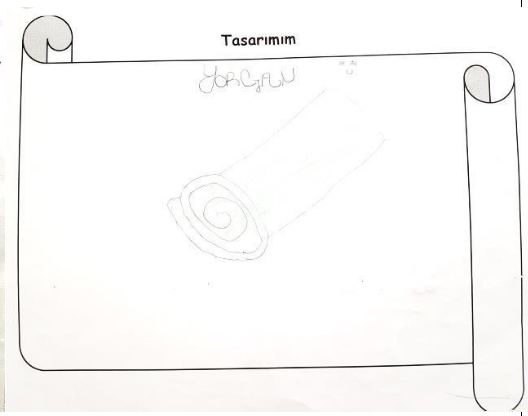
Design 14: The luminous hat is designed by a student who mimicked the the function of a structure which luminous fish has on its head. Because the function plays role in the design idea, it is categorized under the function based design.

<table>
<tr><th>Luminous fish</th><th>Luminous hat</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><th>Model</th><th>Presentation</th></tr>
<tr><td></td><td>

Luminous fish has a structure on their head functioning like the lamp. That's why it is called luminous fish. Thanks to this structure, they can see in the dark under the deep see.
I designed a hat which has a lamb on it.

</td></tr>
</table>

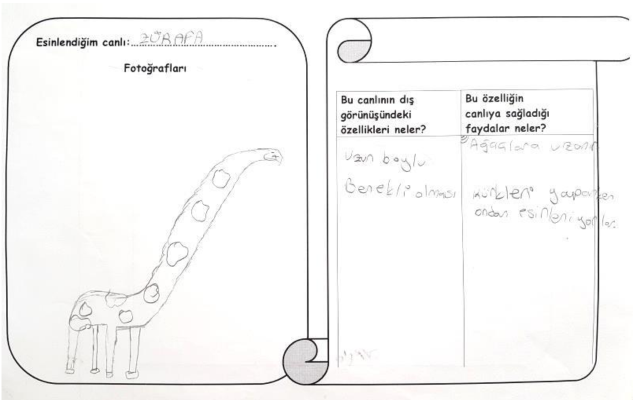
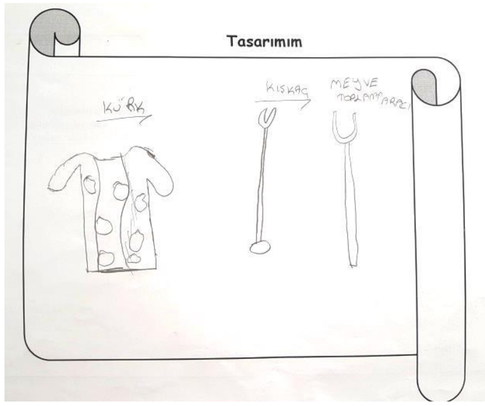
Design 17: One student associated the polar beer's fur with quilt. She focused on the function, keeping warm, in her design. Although she writes that the polar bears fur can be used as clothes, she clarified by explaining that she meant the same function can be applied. Therefore, the design is accepted as function based design.

<table>
<tr><th>Polar Bear</th><th>Quilt</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><th>Model</th><th>Presentation</th></tr>
<tr><td>The student did not make the model of her design.</td><td>

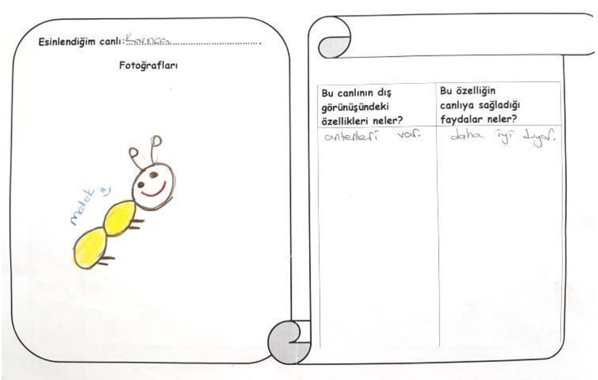
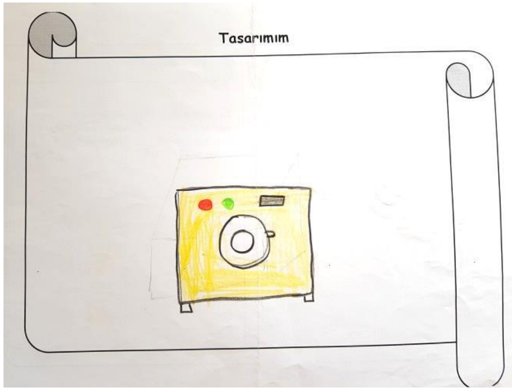
Polar bears have a thick coat covered by fur.
My design is a quilt. The quilt also keeps people warm like the polar bears' fur
It can be designed as clothes for human by inspiring polar bears' fur.

</td></tr>
</table>

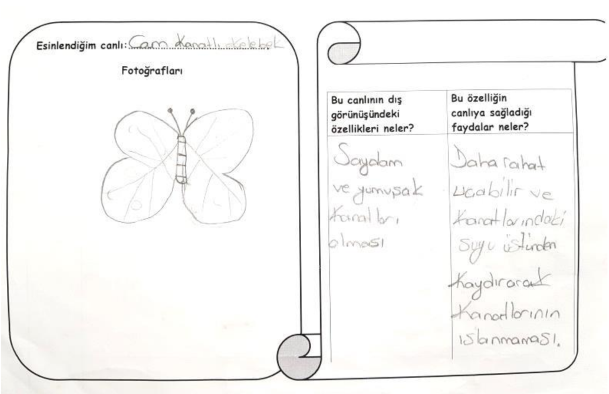
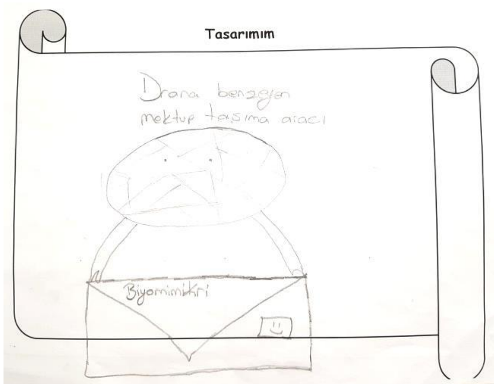
Design 18: One student proposed three different design ideas inspired by giraffe. His design focused on the function that giraffes serve which are keeping warm and reaching inaccessible high places. The function point makes it to be included in function based design.

Giraffe	**Fur-Fruit Collecting Tool-Clamp**
	
Model	**Presentation**
The students did not make the model of his designs	➢ The neck of the giraffes is long and it is spotted. They can reach high branches of trees. ➢ I designed three different things inspired by the giraffe. ➢ One is a coat fur design. This fur has spots on it, and soft structure like giraffes. ➢ The other one is a grabber which is long like the giraffe neck. ➢ The last one is a fruit picking tool. It can be used to reach inaccessible places.

Design 20: This one is the only design which function plays role without any association to form or structure of the ant organism. Student presented a design idea which needs to be studied. Her design is accepted as function based design.

Ant	**Washing Machine**
	
Model	**Presentation**
The student did not make the model of her design.	➢ The ants can move quietly. ➢ A washing machine which works quietly can be designed by mimicking this feature of the ants.

Design 24: An interesting design was presented by a student who inspired glass winged butterfly. The design of the student is similar to butterfly as a form. It has a flying characteristic like the butterfly. Also, it has a glass structure which is made of a material similar to the butterfly wing. Student mimicked the organism from various perspectives. Taken all together, student intention of designing a flying machine which is durable and light highlights the function, so it is included in function-base design.

Glass Winged Butterfly	Drone-like Letter Carrier
	
Model	**Presentation**
The student did not make the model of her design.	➢ The wings of the glass winged butterflies are transparent and soft. They can fly easily and can remove the water on their wings by sliding it. ➢ My design is a letter-moving tool. ➢ My vehicle is powered by solar energy and can be charged immediately in the sun. It is made of light and durable glass similar to glass-winged butterfly. It is also waterproof.

Publications from the thesis

Contact Information: mervecoban92@gmail.com

Conference Papers

1. Çoban, M. (2019). *Integration of biomimicry into science education*. Paper presented at 1st International Symposium on Education and Change, Medipol University, İstanbul.