

Developing biomimicry STEM activity by querying the relationship between structure and function in organisms

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ABSTRACT The theme that structure determines function is one of the most significant cornerstones in understanding natural sciences. On the other hand, recently revised science curriculum in Turkey has emphasized science and engineering practices to help students be able to converge science with the other disciplines by applying theory into practice and product; but there is not an emphasis on the repeating patterns and relationships between structure and function for natural and built systems at any grades. In order to close this gap, the main objective of this study is to develop an integrated biomimicry STEM activity about the unit of Living Things World at grade five. This paper reported on a case study of 21 fifth-grade students' gaining experiences about the engineering design process by mimicking a structure from the organisms to solve a human problem. Even more striking result is that students can manage to incorporate biomimicry into their design solutions by the way of complementary relationship between structure and function in organisms.

Keywords: *Biomimicry, Design, Function, STEM Education, Structure*

Organizmalarda bulunan yapı fonksiyon ilişkisi sorgulanarak biyomimikri STEM etkinliği geliştirilmesi

ÖZ Doğa bilimlerini anlamada en önemli mihenk taşlarından biri yapı fonksiyonu belirler temasıdır. Diğer taraftan Türkiye'de yakın zamanda revize edilen fen programında ise öğrencilerin feni diğer disiplinlerle bütünleştirerek teoriyi pratiğe ve ürüne dönüştürebilmelerine yardımcı olacak fen ve mühendislik uygulamalarına vurgu yapılırken; doğada ya da tasarlanmış dünyada tekrar eden örüntülere ve yapı ve işlev arasındaki ilişkilere herhangi bir sınıf düzeyinde vurgu yapılmamıştır. Bu açığı kapatmak için çalışmada, beşinci sınıf fen bilimleri dersi Canlılar Dünyası ünitesinde yapı ve fonksiyon ilişkisine dayanan bütünleştirilmiş biyomimikri STEM etkinliği geliştirmek amaçlanmıştır. Bu çalışma, 21 beşinci sınıf öğrencisinin insanlığa ait bir problemi çözmek için organizmalara ait bir yapıyı taklit ederek mühendislik tasarım süreci ile ilgili deneyimlerini aktaran bir durum çalışmasıdır. Çalışmanın çarpıcı bir sonucu ise, öğrencilerin organizmalardaki yapı ve fonksiyon arasındaki tamamlayıcı ilişki yoluyla biyomimikriyi tasarım çözümlerine dahil etmeyi başarabilmeleridir.

Anahtar Sözcükler: *Biyomimikri, Fonksiyon, STEM Eğitimi, Tasarım, Yapı*

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INTRODUCTION

The understanding of the relationship between structure and function has been recognized both as a crosscutting and disciplinary core concepts in the current reform document of *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (Framework)* (National Research Council [NRC], 2012). Amongst the seven crosscutting concepts as unifying themes across all the disciplines and grade levels, structure and function are defined as “the way in which an object or living thing is shaped and its substructure determine many of its properties and functions” (NRC, 2012, p. 84). The theme that structure determines function is one of the most significant cornerstones in understanding natural sciences. Structure is the way that an organism is shaped as a whole. Functions are the processes that help an organism to survive. The structure and function of an organism work complementarily in nature to meet the needs of the organism. Understanding these causal relationships between structure and function through the identification of mechanisms like behaviors in life sciences can be delineated by Structure–Behavior–Function (SBF) theory. The SBF theory makes it explicit how structure and function causally related with a bridge of behaviors/actions (Hmelo, Holton, & Kolodner, 2000; Hmelo-Silver, Marathe, & Liu, 2007). In this way, the SBF theory may account for coherent science learning in providing students to understand the purposes and processes of the structures to achieve their function (Hmelo-Silver et al., 2008). Also, when biological function is used in the same meaning as adaptation, it may account for understanding the origin of a structure’s function that emerged in the evolutionary process (Kohn, Underwood, & Cooper, 2018).

As related to the extent in which students understand the functions of structures by querying organisms or molecules in the natural world requires making causal inferences. This is a similar way by which “engineers make such inferences when examining structures in nature as inspirations for designs to meet people’s needs” (Next Generation Science Standards [NGSS] Lead States, 2013b, p.89). Engineers learn from studying nature; so they observe nature to get brilliant ideas for design solutions to solve human problems. This explains why technological tools we use in our daily life usually work in the same way as something in nature. As it can be seen that “the functioning of natural and built systems alike depends on the shapes and relationships of certain key parts as well as on the properties of the materials from which they are made” (NRC, 2012, p.96). Such scientific explanations of the relation between structure and function in natural systems can be further delineated by mimicking the translation of these observations into design solutions to solve human problems for STEM (Science, Technology, Engineering, and Mathematics) education. Therefore, understanding the purpose or mechanical function of structures in nature as a learning outcome in science courses should be considered in STEM education.

STEM education proposes an interdisciplinary integration of knowledge, skill, and beliefs relate to more than one STEM disciplines through the collaborative efforts of students and teachers (Çorlu, Capraro, & Capraro, 2014; Öner et al., 2014). To accomplish this goal, engineering and engineering design process-oriented integration for science teaching has been appreciated in the current reform documents (e.g., NRC, 2012) and related literature (e.g., Guzey, Thank, Wang, Roehrig, & Moore, 2014; Moore et al., 2014). Amongst the scope of Integrated Teaching Framework (ITP), which is considered as an effort for the pedagogical interpretation of STEM for Turkish context, the methodological integration means to use both the discipline and the methods of a particular field education in the teaching of other fields depending on the interests of teachers and students. The four main principles of integrated STEM education are defined as equity, relevance, interdisciplinarity and rigor (Aşık, Doğança Küçük, Helvacı & Çorlu, 2017). In parallel to this pedagogy as proposed by Aşık et al., (2017), the current study is an example for the use of the engineering design process or engineering-based learning in science classes.

Structure and Function as a Crosscutting and Core Concept

The *Framework* (NRC, 2012) defines crosscutting concepts as to “bridge disciplinary boundaries, having explanatory value throughout much of science and engineering” (p. 83). These concepts provide students useful lenses for recognizing similarities among disciplinary core ideas and practices in science and engineering. Thus, crosscutting concepts are common themes emerging across all science and engineering disciplines to help students better understand phenomena. As the NGSS document points out, there is no need to teach and assess these concepts as a separate vocabulary from practices or disciplinary context. Rather, the crosscutting concepts should be embedded in the science curriculum from beginning in the early grades of schooling and growing in complexity and sophistication across the grades (NGSS Lead States, 2013b).

The relationship between structure and function as a crosscutting concept can sometimes be essential to make causal inferences as a special case of cause and effect (NGSS Lead States, 2013b). Table 1 indicates that exploration of the relationship between structure and function should begin in the early grades and progress in complexity across the grades both as crosscutting and disciplinary core concepts. In early grades students can relate the shape and stability of structures for a variety of functions like a bridge’s diagonal brace or mechanical function such as wheels, axles, and gears. As students’ progress through the upper grades they are expected to improve from recognizing particular structures or substructures observed in the visible systems to a more complex, small scale, non- visible systems are related to their functions (NRC, 2012).

Table 1.

Progression of ideas for the structure and function both as a crosscutting concept and disciplinary core idea (Adapted from Duschl, 2012; NGSS Lead States, 2013b)

Grades	Structure and function as a crosscutting concept	Structure and function as a core idea in the life sciences
K-2	Examine relationships of structure and function in accessible and visible natural and human built systems.	All organisms have external parts that they use to perform daily functions.
3-5	Matter has a substructure that is related to properties of materials. Begin study of more complex systems by examining subsystems and the relationships of the parts to their functions.	Organisms have both internal and external macroscopic structures that allow for growth, survival, behavior, and reproduction.
6-8	Visualize, model, and apply understandings of structure and function to more complex and less easily observable systems and processes. The concept of matter having submicroscopic structures is related to properties of matter.	All living things are made up of cells. In organisms, cells work together to form tissues and organs that are specialized for particular body functions.
9-12	Apply the knowledge of structure and function when investigating unfamiliar phenomena; when building something or deciphering how a system works, begin with examining what it is made of and what shapes its parts take.	Systems of specialized cells within organisms help perform essential functions of life. Any one system in an organism is made up of numerous parts. Feedback mechanisms maintain an organism’s internal conditions within certain limits and mediate behaviors.

In this respect, understanding the structure and function as a topic for the life sciences should be emphasized as well. Bybee (2013) states the main goal of biology as to “develop explanations for functions based on structures and reciprocal-to explain the complementarity of structures and functions among an organism’s systems and subsystems” (p.26). Likewise, the life sciences (LS) in the *Framework* focus on patterns, processes, and relationships of living organisms. The first core idea ‘LS1: From molecules to organisms: Structures and processes’ addresses the characteristic structures of organisms to live, grow, respond to their environment, and reproduce. As the first subcomponent ‘LS1.A: Structure and function’ explains how the structures of organisms enable life’s functions by beginning from cells as the basic structural units to structural systems and subsystems of organisms that perform specialized functions (NRC, 2012). As it can be seen in Table 1, students at elementary grades are expected to investigate the relationships between the external and internal structures of organisms and their functions in growth, survival, behavior, and reproduction at the macroscale systems. Students in middle grades are expected to investigate explanations for the structure and function of cells as the basic units of life at microscale systems. Students at higher levels demonstrate

an understanding of how systems of cells function together to support the life processes, the hierarchical systems of organisms, and the role of specialized cells for maintenance and growth.

Why Teach Biomimicry?

The term biomimicry originates from Greek roots bios that means life and mimicry that means to imitate. Beyond its simple meaning of imitation of life, biomimicry is defined as “a creative form of technology that uses or imitates nature to improve human lives” (Hwang et al., 2015, p.5701). The origin of the term coined as biomimetics, bionics, bio-inspired design that are all used usually in the same meaning in the scientific literature. It has been considered as a new discipline of science starting from the book of Janine Benyus’s in 1997 titled “Biomimicry: Innovation Inspired by Nature”. In her book, biomimicry is defined as “a new science that studies nature’s models and then imitates or takes inspiration from these designs and processes to solve human problems e.g., a solar cell inspired by a leaf” (Benyus, 2002, p.0). In other words, biomimicry as an approach “seeks sustainable solutions to human challenges by emulating nature’s time-tested patterns and strategies” (Biomimicry Institute, 2010). According to Benyus (2002) billions of years of evolutionary process have given living organisms an amazing diversity of structures, shapes and their related functions to survive. Thus, learning from studying nature for perfection, accuracy and sustainability of natural mechanisms is the underlying philosophy of Benyus’s theory of biomimicry.

There are well known examples of biomimicry in the history of human industrialization like Leonardo da Vinci’s (1452–1519) work designed a “flying machine” by mimicking a bird and Wright brothers’ (1867–1948) airplane designed by mimicking the wings of eagles. Nowadays, transportation vehicles may become faster, more stable, and more aerodynamic but still nature gives inspiration like Japanese bullet train mimicking a kingfisher’s beak to reduce sonic boom and air resistance. It can be seen that biomimetic technology is applied in many different fields including material science, robotics, nanotechnology, product, design, innovation, inventions, systems design, architecture, agriculture, chemistry, medicine, communication and mechanics. One of the best known product examples of biomimicry is Velcro, a common hook-and-loop fastener, invented in 1948 by Swiss engineer George de Mestral who inspired from the fruit of the burr that sticks to his clothes and his dog’s fur while hiking (Hwang et al., 2015; Pauw, Kandachar, Karana, Peck, & Wever, 2010).

There are three levels to mimic a natural system as regard to the increasing complexity from the organism level, to behavior level and ecosystem level. Biomimicry at the organism level indicates the mimicry of a specified organism or a part from the whole organism. Biomimicry at the behavior level indicates the mimicry of behavior in a specified organism. Biomimicry at the ecosystem level indicates the mimicry of whole ecosystem. At each level biomimicry can take place as a form about how it looks, material about what it is made from, construction about how it is made, process about how it works, and function about what is the capability. For example, building that mimics termites in architecture is a good representative of three levels and their sub-dimensions. At the organism level the building looks like a termite. At the behavior level the building looks like such a termite mound that is made by termites. At the ecosystem level the building looks like an ecosystem such termites would live in (Aziz & El sherif, 2016).

While learning from studying nature there are two main approaches suggested for a biomimicry design process as indicated in Figure 1. Top-down approach or challenge to biology begins with an identified human need or problem and then looks intentionally into nature how organisms or ecosystems solve this problem for better design solutions. Conversely, bottom-up approach or biology to design begins by examining nature to identify a particular structure, behavior or function belongs to an organism or ecosystem for transmitting this bio-inspired design solution into a human problem (Aziz & El sherif, 2016).

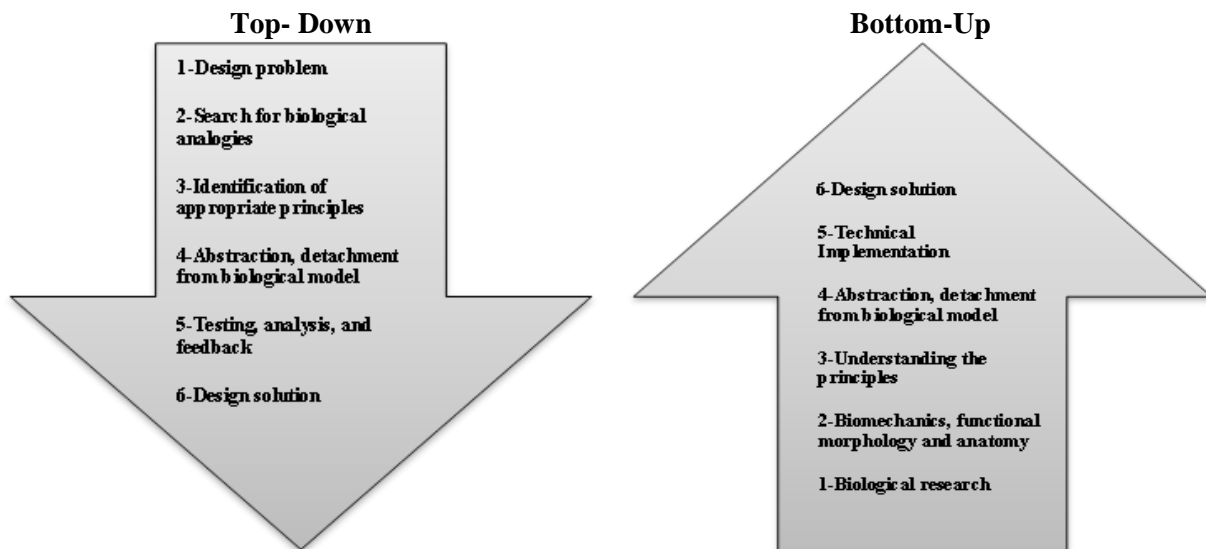


Figure 1. Biomimicry top-down and bottom-up approaches (Adapted from Aziz & El sherif, 2016)

It is inevitable that using nature as a model for sustainable design solutions has initiated the conceptualization of biomimicry in science education. Biomimicry can be viewed as a revolution in education by offering teachers a way to inspire students of all ages by blending life sciences, STEM, creative problem solving, design, and systems thinking (Biomimicry Institute, 2010). Teaching biomimicry in STEM education can provide a context by intersecting nature with science, technology, engineering and math. Consequently, being inspired by nature requires understanding how nature works by identifying various functional and environmental adaptation mechanisms of organisms and their sustainability in basic science courses at early stages.

Rationale for the Study

As proposed in the *Framework* when the students develop an understanding about the relationships between structure and function, they can apply this knowledge to learn an unfamiliar scientific phenomenon and solve how a system work as a critical element of successful engineering designs (NRC, 2012). Similarly, recently revised science curriculum in Turkey has emphasized science and engineering practices to help students be able to converge science with the other disciplines by applying theory into practice and product; but there is not an emphasis on the repeating patterns and the relationships between structure and function for natural and built systems at any grades (Ministry of National Education [MoNE], 2018). On the other hand, students are expected to classify living things according to their similarities and differences as microscopic organisms, fungi, plants, and animals within the context of the unit of Living Things World at grade five. In order to close this gap in science education, the main objective of this study is to develop integrated biomimicry STEM activity based on the relationship between structure and function in organisms both as an engineering design principle and core component of life sciences for fifth graders to achieve learning outcomes about the classification of living things. In the line with this main aim, the research questions are: (a) How students develop a deep understanding of structure and function about living things? (b) How students develop a deep understanding about the role of biomimicry in engineering design principles?

For this purpose the performance expectations related to the topic of structure and function in the life sciences from the NGSS were adapted to develop biomimicry STEM activity. NGSS Lead States (2013a) emphasizes biomimicry as a performance expectation linked to the structure and function as one of the main component ideas in the life sciences of the first grade numbered as 1-LS1-1 and fourth grade numbered as 4-LS1-1 as indicated in Figure 2. The Figure 2 displays examples of performance expectations for elementary school life sciences with supporting content from the foundation box which combines practices, core ideas and crosscutting concepts.

PERFORMANCE EXPECTATIONS		
Students who demonstrate understanding can:		
<p>4-LS1-1. Construct an argument that plants and animals have internal and external structures that function to support survival, growth, behavior, and reproduction. [Clarification Statement: Examples of structures could include thorns, stems, roots, colored petals, heart, stomach, lung, brain, and skin.] [Assessment Boundary: Assessment is limited to macroscopic structures within plant and animal systems.]</p> <p>1-LS1-1. Use materials to design a solution to a human problem by mimicking how plants and/or animals use their external parts to help them survive, grow, and meet their needs.* [Clarification Statement: Examples of human problems that can be solved by mimicking plant or animal solutions could include designing clothing or equipment to protect bicyclists by mimicking turtle shells, acorn shells, and animal scales; stabilizing structures by mimicking animal tails and roots on plants; keeping out intruders by mimicking thorns on branches and animal quills; and, detecting intruders by mimicking eyes and ears.]</p>		
Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
<p>Engaging in Argument from Evidence</p> <p>Engaging in argument from evidence in 3–5 builds on K–2 experiences and progresses to critiquing the scientific explanations or solutions proposed by peers by citing relevant evidence about the natural and designed world(s). (4-LS1-1)</p> <p>Construct an argument with evidence, data, and/or a model.</p> <p>Obtaining, Evaluating, and Communicating Information</p> <p>Obtaining, evaluating, and communicating information in K–2 builds on prior experiences and uses observations and texts to communicate new information.</p> <p>Read grade-appropriate texts and use media to obtain scientific information to determine patterns in and/or evidence about the natural world. (4-LS1-1)</p> <p>Constructing Explanations and Designing Solutions</p> <p>Constructing explanations and designing solutions in K–2 builds on prior experiences and progresses to the use of evidence and ideas in constructing evidence-based accounts of natural phenomena and designing solutions.</p> <p>Make observations (firsthand or from media) to construct an evidence-based account for natural phenomena. (4-LS1-1)</p> <p>Use materials to design a device that solves a specific problem or a solution to a specific problem. (1-LS1-1)</p>	<p>LS1.A: Structure and Function</p> <p>Plants and animals have both internal and external structures that serve various functions in growth, survival, behavior, and reproduction. (4-LS1-1)</p> <p>LS1.A: Structure and Function</p> <p>All organisms have external parts. Different animals use their body parts in different ways to see, hear, grasp objects, protect themselves, move from place to place, and seek, find, and take in food, water and air. Plants also have different parts (roots, stems, leaves, flowers, fruits) that help them survive and grow. (1-LS1-1)</p> <p>LS1.D: Information Processing</p> <p>Animals have body parts that capture and convey different kinds of information needed for growth and survival. Animals respond to these inputs with behaviors that help them survive. Plants also respond to some external inputs. (1-LS1-1)</p> <p>ETS1.A: Defining and Delimiting an Engineering Problem</p> <p>Asking questions, making observations, and gathering information are helpful in thinking about problems. (1-LS1-1)</p> <p>ETS1.B: Developing Possible Solutions</p> <p>Designs can be conveyed through sketches, drawings, or physical models. These representations are useful in communicating ideas for a problem's solutions to other people. (1-LS1-1)</p> <p>ETS1.C: Optimizing the Design Solution</p> <p>Because there is always more than one possible solution to a problem, it is useful to compare and test designs. (1-LS1-1)</p>	<p>Patterns</p> <p>Patterns in the natural and human designed world can be observed, used to describe phenomena, and used as evidence. (4-LS1-1)</p> <p>Structure and Function</p> <p>The shape and stability of structures of natural and designed objects are related to their function(s). (1-LS1-1)</p> <p>Systems and System Models</p> <p>A system can be described in terms of its components and their interactions. (4-LS1-1)</p> <p>-----</p> <p>Connections to Engineering, Technology, and Applications of Science</p> <p>Influence of Science, Engineering and Technology on Society and the Natural World</p> <p>Every human-made product is designed by applying some knowledge of the natural world and is built using materials derived from the natural world. (1-LS1-1)</p> <p>-----</p> <p>Connections to Nature of Science</p> <p>Scientific Knowledge is Based on Empirical Evidence</p> <p>Scientists look for patterns and order when making observations about the world. (4-LS1-1)</p> <p>Science is a human endeavor</p> <p>Science affects everyday life. (1-LS1-1)</p> <p>Most scientist and engineers work in teams. (1-LS1-1)</p>

* The performance expectations marked with an asterisk integrate traditional science content with engineering through a practice or disciplinary core idea.

Figure 2. The performance expectations for LS1: From molecules to organisms: Structures and processes (Adapted from NGSS Lead States, 2013a)

METHODOLOGY

This study employed a case study in which “the researcher develops an in depth analysis of a case, often a program, event, activity, process, or one or more individuals” (Creswell, 2014, p.13). The case involves students’ learning experiences by participating in the biomimicry STEM activity about organisms. The participants of the study were 10-11 years old 21 students (11 boys, 10 girls) attending 5th grade at the public lower secondary school in Antalya, Turkey. According to Yıldırım and Şimşek (2016), “if the researcher wants to introduce a new application or a novelty, he/she can identify them by determining one or more of the most typical among a series of case in which this application has been done or has innovativeness (p.120). For this purpose, the study group was determined in line with the typical case sampling which is one of the methods of purposeful sampling (Yıldırım & Şimşek, 2016) that emerged within the qualitative research tradition.

Biomimicry STEM activity worksheets, reflective open-ended questions, semi-structured interviews, rubrics were utilized in collecting data to evaluate the performances of the students and the effectiveness of the STEM activity. The data collection tools focused on obtaining the data in order to reveal how students develop a deep understanding of structure and function about living things and the role of biomimicry in engineering design principles. Students’ learning experiences, difficulties which were experienced and how they overcame these difficulties, likes and dislikes, what they learned and how they worked in a team were investigated.

The qualitative collected throughout students’ reflections about the engineering design process on open-ended questions and semi structured interviews, teacher’s observations and field notes and participant students’ portfolios were evaluated by descriptive analysis. The participant teacher’s observations and field notes were used to increase the verification by guiding students’ learning and behavior in the process. The abbreviations T for team, S for student and numbers were used to introduce the student’s team and the student member such that T4.S1 means 4th team 1st student.

Ethical Approval

The typical case sampling aims to describe and illustrate what is typical to those unfamiliar with the setting, not to make generalized statements about the experiences of all participants (Patton, 2014). Prior to the implementation of the research, the necessary permission was obtained according to board decision, dated 05/02/2019 and 2439445 numbered, from the Research Evaluation and Investigation Committee of the Antalya National Education Directorate. Written informed parental consent forms including options of opt-out and opt-in for their children’s participation in the research and collecting data from them were sent home to signature. The students were volunteer and had the signed parental consent forms involved in the study.

Description of Biomimicry STEM Activity

Biomimicry STEM activity provides students the learning opportunity to explore the relationship between structure and function in organisms both as an engineering design principle and a core component of life sciences for 5th graders in the unit of Living Things World. For this study some parts especially involving structure and function activities are described here in detailed. The activity consists of four main parts for science and engineering practices in parallel to the science standards as described below:

Part 1 – Asking Questions and Defining Problems. A scenario about biomimicry design task is given students (see Appendix 1) to introduce a problem or need for the engineering design task. After completing the next stages students consider how a human problem can be solved by mimicking a

structure from the organisms that has similar purpose for the engineering design process. Students then identify a human problem and develop their own design solutions inspired by organisms' adaptations.

Part 2 – Engaging in Argument from Evidence. It is expected that students get to know different kinds of organisms, determine the structures belonging to these organisms and explain how these structures help them to continue their lives by utilizing scientific resources or throughout their individual investigations. Using the scientific popular books like published by Scientific and Technological Research Council of Turkey (TUBITAK) titled “First Reading Series: Bees, Elephants, Spiders, Penguins, Bears, Owls, Caterpillars and Butterflies, Dogs, Trees etc.” would help students develop an understanding of how particular features help animals and plants to survive. Students then complete the worksheet of Structure and Function as individually given in Appendix 2 to keep the observed structures and their functions in different organisms from different resources. Teachers' use of science talk along within these texts can promote students to obtain scientific information in examining structures and inferring their functions. To reinforce and extend this understanding as a core idea of life sciences teachers can have students engage in constructing arguments that plants and animals have internal and external structures functioning to support survival, growth, behavior, and reproduction with evidence, data, and/or a model. Similarly, as a crosscutting concept of structure and function at this stage it is explicitly emphasized that “the structure or shape of an object or system is frequently related to use, operation, or function. Scientists infer function by referring to form and also explain form by referring to function” (Lederman, 2019).

Part 3 – Obtaining, evaluating, and communicating information. Designing Imaginary Organism activity is given students to enhance the understanding the organisms' adaptations in relation to structure and function. It is expected that students get to design their own imaginary organism within their groups by using the previously gathered data from the observation of organisms' particular structure and their function. They decide structures and their functions that the organisms need to survive by describing their adaptations on the worksheet of Imaginary Organism's Adaptations given in Appendix 3. After they identify their imaginary organisms' structures, feeding type, predators, habitat, physical and behavioral adaptations etc., they draw their imaginary organism on the worksheet of Drawing and Labelling the Imaginary Organism given in Appendix 4 by describing the traits and adaptations on it. By using the worksheet of Introducing Imaginary Organism given in Appendix 5 groups decide the scientific name and other characteristics to classify their organisms. They can also write a story or news about the investigation of their imaginary organism in the given part of Appendix 4. In order to introduce their organism for the rest of the class, groups make the model of their imaginary organism by depicting on one of their friends by using provided materials in the classroom. During the presentation of the model organisms of the groups, students would be asked to present what functions their organisms have and why they interpret particular structures in that way. Another way of presenting the model organisms would be audience students asked to infer what the function might be from the structure of organisms. Students can also be asked why they used particular materials for the structure that they infer. At this moment, it is an appropriate time to discuss the distinction between observation and inference. The structure would directly be observable using our senses, but its function is not directly observable (Lederman, 2019). During the presentations, the teacher evaluates the model organisms that each group has by using the Imaginary Organism Assessment Rubric (see Appendix 6).

Part 4 – Constructing Explanations and Designing Solutions. Students are introduced with the great design task through a scenario given at first that defines biomimicry and how bioengineers inspire nature to develop new ideas for innovations. Using the scientific knowledge and models learned in the previous steps in which students make such observations about animals and plants' adaptations for survival, growth and meeting their needs, they can translate this information in a larger study to design a solution to a human need. In reverse relation, students would be asked to give examples by identifying and comparing designed objects related to natural shapes and structures. This investigation provides students to connect how observations of the natural world aid human survival. Then, they are asked to identify a human problem to develop a possible solution by using biomimicry which may be

an imitation of the relation between structure and function that belongs to organisms. As bioengineers students draw their prototype design solutions and describe how their design solutions solve the human problem on the worksheet of Great Design Task Draft Drawing given in Appendix 7. After deciding on the best design solution, students are supplied with materials to design a prototype model that solves a specific problem or a solution to a specific problem. In the last step students test, evaluate and analyze their design solutions within their groups to improve their model. Once the process is completed, groups present their biomimicry models in respect to the relations between the design and inspirations from the natural world by providing an analysis of the design process. During the presentations, the teacher evaluates the biomimicry models that each group has by using the Biomimicry Design Task Assessment Rubric (see Appendix 8).

Implication Steps of Biomimicry STEM Activity

Biomimicry STEM activity was planned to cover all the outcomes about the classification of living things within a larger dissertation study based on engineering design based unit phases (Wendell et al., 2010) and eight step engineering design process of Massachusetts Department of Education (2006). The study was conducted for twelve hours during the science lessons at the first term of the school year of 2018-2019 by the second author of this research. The activity was started with the identification of the need or the problem. During the two-lesson hour, students identified the human need or problem which was given in the scenario. They described the criteria and constraints. After identification of the needs/problem, they were researching the need/ problem in the second step. In this phase, students investigated the scientific knowledge needed for solving the problem phase. During the four-lesson hour, the scientific knowledge collected from books and mini activity, imaginary organism activity implemented to understand structure and functions in nature. Collected scientific knowledge was used for developing possible solutions in the step three. During the one-lesson hour, students developed solutions individually in their team for the one-hour lesson. They explained their solution proposals by using criteria and constraints. The developed possible solutions were discussed in their team in order to choose the best solution proposal. In the step of selecting the best possible solution, students used a decision-making matrix to decide the best one by using criteria and constraints during the one-lesson hour. The chosen solution by the team used for constructing a model/prototype in the step five. In this period, students developed their models in the two-lesson hour. Developed models were tested/controlled by using a checklist according to the criteria and constraints in the step of test and evaluate the solution after then they presented their models in the phase of communicate the solution during the one-lesson hour. In the last step of redesign, each team improved its solutions regarding the feedback from teacher and students during the one-lesson hour.

Description of Performance Assessment Rubrics

The Imaginary Organism Assessment Rubric (see Appendix 6) was developed for assessing the models that students developed to describe their imaginary organisms' adaptations based on the mechanism between structure and function on the range of 0 and 24 points. The first sub-dimension of the rubric titled Developing and Using Models indicates the progression of students from level 0 to 3 for developing an accurate model in terms of drawing, description and identification of their imaginary organisms. The second sub-dimension of the rubric titled Structure and Function indicates the progression of students from level 0 to 3 for accurately explaining the relation between proposed structure and function that an imaginary organism has for each adaptation.

The Biomimicry Design Task Assessment Rubric (see Appendix 8) was developed for assessing the prototype biomimicry models that students developed to solve a human problem as regards to eight categories that indicates the progression of students from level 0 to 3 providing analysis of the engineering design process on the range of 0 and 48 points. The categories of the rubric developed based on the engineering design steps of Massachusetts Science and Technology/Engineering Curriculum Framework (Massachusetts Department of Education, 2006) in order to assess students' achievement on engineering design steps.

Description of Evaluation Form

Biomimicry STEM Activity Reflective Evaluation Form (see Appendix 9) consists of open-ended questions to realize students' perceptions and opinions about the whole process of engineering design task. The form was applied for all the students of 21 at the end of the study. Six students were interviewed with the similar questions because of their short or unclear answers.

FINDINGS

Findings on the Imaginary Organism Assessment Rubric

Through the science activities as performance expectations, students are expected to query the structures of organisms and relate their functions, create an imaginary organism, and communicate the way of thinking by drawing, labeling, and explaining. Students developed an imaginary model organism by describing the traits and adaptations on it as well as by describing its scientific group and scientific name. The drawings and created imaginary organisms that each group developed are displayed in Appendix 10. The Imaginary Organism Assessment Rubric was used for assessing students' science learning through the worksheets completed during the whole process and created imaginary model organisms' adaptations. After each group presented their imaginary model organism, the teacher completed the rubric. The Table 2 indicates the overall score that each group gets for their imaginary model organism. As regard to the table each team has average high score that indicates students' understanding the role of the structure-function relationship in organisms' adaptations. When the presented imaginary organisms were considered, students were able to describe their organisms' structures, feeding type, predators, and habitat, physical and behavioral adaptations.

Table 2.
Imaginary organism assessment rubric scores

Dimension	Criteria	Team 1	Team 2	Team 3	Team 4	Team 5	Team 6
Developing and using models	Name and classification	3	3	2	3	2	1
	Drawings	2	2	2	3	2	3
	Description	3	3	3	3	3	3
	Nutrition	3	3	2	3	3	3
	Defending from predators	2	3	2	3	3	3
Structure and Function	Communication	2	2	3	3	2	3
	Mating	0	3	2	2	3	3
	Habitat	2	3	3	3	3	3
Total Score	.../24	17	22	19	23	21	22

Findings on the Biomimicry Design Task Assessment Rubric

Through the engineering design activities as performance expectations, students are expected to describe how they would adapt an organism's structure to solve a human problem. Appendix 11 displays the sample drawings of great designs for the biomimicry models that each group proposed to solve a human problem. The biomimicry models that each group developed are displayed in Appendix 12. The Biomimicry Design Task Assessment Rubric was used to evaluate the students' prototype biomimicry models at eight categories. After each team presented their biomimicry designs to the class, the teacher completed the rubric. Table 3 indicates the scores for eight categories and for overall that each group has for their biomimicry model. The students' scores on the categories of 'Identify the need or the problem' including identifying constraint and criteria and 'Research the need or the problem' are lower than other steps of the engineering design process. Although all groups have the lowest score in identifying and research the problem, they seem to develop an understanding about engineering design as a whole process. When the developed biomimicry models were considered, they

were able to reflect the complementary relationship between structure and function in relation to the behaviors of organism in their design solutions for a human problem. The Team 1's biomimicry model named as fishing-net aims to help people fish inspired from pelican's beak. The Team 2's biomimicry model named as non-slip socks aims to prevent people from slipping inspired from gecko's toe pads. The Team 3's biomimicry model named as trap aims to help people hunt inspired from Venus flytrap. The Team 4's biomimicry model named as bat's ear headset aims to help deaf people hear or use in sound insulation inspired from bat's ears. The Team 5's biomimicry model named as hook aims to help people carry out heavy things inspired from falcon's claw. The Team 6's biomimicry model named as sew-burry aims to help people plant seed easily inspired from chicken's beak.

Table 3.
The biomimicry design task assessment rubric scores

Engineering Design Process	Criteria	Team 1	Team 2	Team 3	Team 4	Team 5	Team 6
Identify the need or the problem	Identification of need/problem	2	1	2	2	3	2
	Identification criteria and constraints	1	1	1	1	1	2
	Identifying the information needed to solve the need / problem	1	1	2	2	1	1
Research the need or the problem	Identifying how the information obtained will be used to solve a human needs / problem	1	1	2	1	1	2
	Suggestion of solution for needs / problem	1	1	3	2	1	3
Develop possible solution(s)	Drawing blueprint for solution proposal	2	2	2	2	2	3
	Determining the pros and cons of solution proposals 11	1	1	2	2	2	3
	Explanation of the reasons (positive /negative aspects, criteria and constraints) of the selection the best proposal	1	1	2	2	2	2
Select the best solution(s)	Building a model / prototype for the solution proposal	2	2	3	3	2	3
	Using the materials that meet the criteria and constraints for the model / prototype	3	3	3	3	3	2
Test and evaluate the solution(s)	Testing how the model or prototype solves the problem/need	1	2	3	3	2	3
	Explanation of the test results using a scientific language	1	2	3	2	2	2
	Explaining how designs can solve human needs / problems	2	2	3	2	2	3
Communicate the solution(s)	Determining the structures of living things in their designs and how they are used in their functions	1	2	3	2	2	3
	Describing the required improvements for their design	2	2	3	2	2	2
	Improving designs according to the data and evaluations obtained as a result of testing and sharing solutions	1	2	3	2	1	2
Total Score	.../48	23	26	40	33	29	38

Findings on the Reflective Evaluation Form

The prominent findings on the examination of the students' reflection by applying open-ended questions and semi-structured interviews about the activity are summarized under the four themes as following; *challenges, team working, learning in activity, and likes and dislikes*. The students expressed that they faced with the challenges while building their model/prototype (n=11) and team working such as indecisions (n=4) and disputes (n=2) within the team (n=9), and the selection of the best solution (n=3). Students usually expressed difficulties while practicing the mechanism in their model. For example, one of the students reported that *"the mechanism inside our design that is the point we had difficulty choosing which material to use"* (T6.S4). As an example for group challenges T1.S6 reported that *"We had a lot of difficulty because each design solution was very good"* Similarly, T2.S2 reported that *"We could not make a decision in the team."* Another student member in the same group explained the reason for the problems that they had faced in the group work as *"Because we*

have a lot of ideas in our mind. Which one we should apply? Which one is more beautiful? Which one works well? So, we had some confusion in the group” (T2.S1).

On the other hand, they explained how they overcome the challenges while working within team members including collaborating, brainstorming, generating new ideas, discussing, helping each other and finding a solution together (n=11). For example, T3.S3 stated that “*Two friends in our group did not work well at the first. They were working as if they had been in another group. It frustrated me. We could not work well. But we had an agreement with them. After agreement we would work together harder.*” Besides they expressed that using different materials (n=1), by trying (n=1), planning study (n=1), using criteria (n=1) and working without giving up (n=1) helps them to cope with the challenges. In the probing interview about how they cope with an unstable condition T4.S1 reported that “*We were in trouble while choosing the best solution. We used the criteria and constraints to choose the best solution.*”

Students were also asked how they worked as a team in the separate question. Although the students mainly explained they work in a harmony as a team with cooperation and helping with each other (n=15), some of them explained they could not work in a team because of struggling with team members and failing to decide together (n=6) in parallel to the statements in the theme of the challenges. The students’ answers indicates that they work in a harmony in their group are as follows. T3.S4 stated that “*We were debating, but we worked very well.*” Similarly, T5.S1 reported that “*We worked very well in our team. Only we had a trouble while choosing which structure of the animal we used to design task.*” According to the teachers’ field notes, only in two groups there were serious disputes in team working. Even though six students stated that they could not work as a team only two students wanted to change their group.

The students in the theme of learning in the activity pointed that they learnt about the engineering including how engineers work and nature of engineering (n=6), structure and function in organisms (n=9), working in a team (n=3), scientific inquiry (n=3), building a model/prototype (n=3), knowledge about the living things (n=1), importance of doing research (n=1), decision making (n=1), finding imperfection in design (n=1), understanding project (n=1) and entrepreneurship (n=1). For example, T3.S2 stated that “*We used structure and function in order to find a solution for human needs. Engineers use biomimicry as we use.*” Similarly, T1.S2 stated that “*We learned species of living things, engineering and entrepreneurship.*” The students indicated that their skills to learn science and scientific inquiry in obtaining scientific knowledge developed. For example, T2.S2 reported that “*We learned structures of the animals from TUBITAK books. There was a worksheet that we were used for writing what we learn from the book. Using that knowledge, for example Gecko’s structure and function we inspired to design not-slip socks.*” Also, students reported that they learned working in the team. As an example, T2.S1 reported that “*We learned how we can make a decision together and working together.*”

About the themes of likes versus dislikes about the activity the findings indicated that students liked everything in the activity (n=17), the design task and building model/prototype (n=6), learning about animals (n=5), team working (n=2), and brainstorming (n=2). Overall, the students seem to have positive perceptions towards the activity. The collected data by using semi-structured interview supports this finding. For example, one of students (T3.S1) stated that “*This activity is both fun and instructive.*” Another student (T3.S2) pointed that “*The idea of the design task was very beautiful. To bring the life the idea made us very happy.*” Although majority of the students’ answers indicated that they like every section in the activity, few of them stated unfavorable sections of the activity including difficulties on some parts of worksheet (n=1), building a design solution (n=1) and drawing of the model/prototype (n=1). Examination of the students’ respond in the theme of suggestions for implementation of the activity indicates that the majority of students did not to change anything (n=15). On the other hand, few students wanted to change such as their team (n=2), design task (n=2) and writing task (n=1). For example, T1.S2 stated that “*The design task was very hard. It would be*

better if it would be easier.” Another student T2.S2 reported that *“I would like to change my team members.”*

DISCUSSION AND CONCLUSION

In achieving science goals, students were expected to make observations and conduct investigations to build an understanding of animal behaviors and adaptations. Overall, the students expressed positive science experiences and they were able to identify the structure and its function properly for coherent science learning. In deepening their understanding about nature, the imaginary organism activity it is an effective and fun way to display the relationship between structures and function in organisms for 5th graders. In the similar line, Keçeci, Alan, and Kırbağ Zengin (2017) emphasized the role of inquiry learning to help students integrate STEM disciplines by involving them actively and enjoyable in the science learning process. Another study by Tekerek and Tekerek (2018) supported that instructional materials developed by integrating different disciplines provide an efficient teaching and learning tool.

The results on the biomimicry design task assessment rubric indicate that students can describe how they would adapt the organism's structure to solve the human problem for the engineering design process. But, the students' scores on the first steps of identifying a need or problem including determining criteria and constraints and what they need to know about scientific knowledge to realize their design task are lower than other steps of the engineering design process. Likewise, Karakaya, Yantırı, Yılmaz, and Yılmaz (2019) in their study with primary students emphasized shortage of time, materials and information as the problems in the realization of STEM activities. Students' struggles while identifying constraints and criteria were also realized on written documents such that they mixed them and used interchangeably.

The qualitative data obtained from students' responses to reflective open-ended questions and transcribed interviews also confirm these findings such that level of students' literacy about structure and function, perception of the engineering and understanding engineering design process were improved. Related with the engineering design process they gained mainly an ability to build a model/prototype. These outcomes are consistent with many studies in attempt to further development of students engineering design process skills and understanding engineering throughout STEM implications (Baran, Canbazoglu-Bilici, & Mesutoğlu, 2015; Duban, Aydoğdu, & Kolsuz, 2018; Ergün & Külekçi, 2019; Özcan & Koca, 2019). Even more striking result is that students can manage to incorporate biomimicry into their design solutions by the way of the complementary relationship between structure and function in organisms. Structure-function model to translate biomimicry into bio-inspired design solutions has been pointed in growing large body of the design based educational literature (Cohen, Reich, & Greenberg, 2014; Hmelo et al., 2000; Stevens, De Vries, Bos, & Koprina, 2019).

As a result of the examining the further findings on the qualitative data we can conclude that they had challenges most with working in a team due to the conflicts and building model/prototype for engineering design process. The challenges may stem from background of the students. It can be seen that it is inevitable for students to face these difficulties because they may have experienced STEM activity and teamwork for the first time in their educational lives. Examining the related literature in the similar context usually support this finding. For example, Özcan and Koca (2019) stated the problems faced with engineering design process as troubles in utilizing the technology, troubles in putting the designs into practice and not respecting the ideas in the group. Similarly, Karakaya et al., (2019) reported as the most revealed problem by the students as the designing and implementing.

The current study also revealed that even the students' answers pointed that working in a team was challenging, they coped with these challenges by working in a harmony as a team. Another supporting idea is that only two students wanted to change their teams when they were asked what you would like

to change in this study. It can be interpreted that they were learning in the process how to work effectively with their peers in the team. As it is supposed to be they discussed each design solution regarding pros and cons by considering criteria and constrains. This gave them an opportunity to see weakness versus strengths of their design solutions. This finding is consistent with the previous STEM studies in which collaboration has been emerged as prominent 21st century skills that students acquired through the design process (Bolatlı & Korucu, 2018; Karakaya et al., 2019; Özcan & Koca, 2019; Özçelik & Akgündüz, 2018).

Based on the overall findings of the study, it can be concluded that the biomimicry STEM activity provides student actively involved in science and engineering practices. Students were defined the problem, collected data about living things by reading scientific books or watching documentaries or observing living things, collected and interpreted data, developed models, explained their design solutions by using scientific knowledge, and communicating ideas and their findings with their peers. As a core result of the study, biomimicry STEM activity provided students conceptualize the adaptations of living things based on the relationship between structure and function while experiencing the engineering design process. That's why, biomimicry should be considered precisely in science teaching curriculum in terms of providing an opportunity to integrate interdisciplinary STEM into the classroom environment (Gardner, 2012; Pauls, 2017; Yakışan & Velioğlu, 2019; Yıldırım, 2019).

Taking consideration advantage of the features of biomimicry in STEM education can provide a unique learning opportunity for students to understand both scientific concepts and engineering design principles. Moreover, using the relationship between structure and function is an effective way to understand biomimicry and engage students as a bioengineer into engineering design process because of the natural connections between natural and designed world. So, much more research should be needed to explore biomimicry strategies to inspire students in solving human made problems for more sustainable future.

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APPENDIX 1

Biomimicry Design Task

Nature has been an inspiration for art, design, and innovation for a long time. For example, the wing structure of birds was a guide for humankind who had dreamt of flight and led Wright brothers to invent the plane. The science that brings solutions to problems by mimicking the models and systems in nature or different characteristics of living things is called Biomimicry. Today, applications of biomimicry are used in various fields such as science, technology, art, architecture, artificial intelligence, nanotechnology, robotics, industry, military research, and transportation. A biomimicry company is looking for solutions to human problems by using the characteristics of living things. Company officials in need of new ideas in this field are organizing a competition. As a biomimicry expert, you are expected to solve one of humanity problems by mimicking how plants and animals use their internal and external structures to grow, survive, and meet all their other needs.

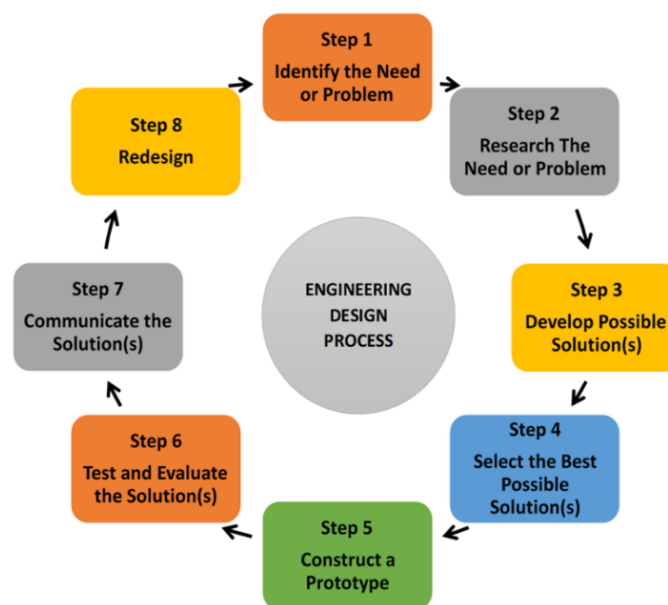
To this end, you and your team are expected to observe the structures of living things, collect information about the functions of these structures, and then develop a design to solve a human problem using the complementary relationship between structure and function in organisms. Once you have completed your design, you will present your work to a board of scientists and engineers. In your presentation, you will explain how you created your design by describing the structure of the living thing you have determined and the function of this structure, and how you used these to solve humanity's problems. The specifications of the competition are given below:

Specifications of the competition

- 1) Your design must be created by mimicking at least one structure belonging to the organism.
- 2) Your design must address at least one of human problems.
- 3) No harmful substances should be used in your design.
- 4) You can use all kinds of materials in your design, especially recycled materials.

**Through direct observation, watching documentaries or reading scientific books such as publications by TUBITAK, you will determine which organism you will use in your design, the structures belonging to the organism and how they use these structures to survive based on evidence. You can also use other resources (webpages, available printed resources).

You will use the following engineering cycle while performing your design task;



APPENDIX 2

Structure and Function Worksheet

Name-Surname:

Summarize the structures that help the survival of organisms you have found in your research and their functions in the table below.

The source you collected the information	Name of the organism	Structure belonging to the organism and its characteristics	Function of the structure	Benefits of this function for the organism	Which humanity problem you can solve by using the characteristic of this structure?

APPENDIX 3

Imaginary Organism's Adaptations

Name of your Team:

Think of an imaginary organism with your teammates. You can use the structures and functions of different organisms each of you learned in the first stage while deciding the characteristics of the imaginary organism. Explain the structures you have chosen for your imaginary organism, the functions of these structures and their benefits to the organism using the table below.

Explanations Structures	Name and characteristic of the structure (wing, tail, mouth, teeth, root, leaf, trunk, eye, etc.)	Function of the structure	Explain why you chose this structure (What kind of benefit this structure provides for the survival of your organism?)
What external structures will your imaginary organism have?			
What internal structures will your imaginary organism have?			
What structures will your imaginary organism have to find and eat its food?			
What structures will your imaginary organism have to protect itself from its enemies?			
What structures will your imaginary organism have to communicate with its friends and offspring?			
What structures will your imaginary organism will have to find a mate?			
You can also add...			

APPENDIX 4

Drawing and Labeling the Imaginary Organism

Name of your Team:

Draw the picture of your organism you have imagined. While drawing your picture, be sure to label the structures of the organism you have imagined in detail.



Scientific name of your imaginary organism:

Write a story or news that introduces your imaginary organism to the world of science:

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APPENDIX 5

Introducing Imaginary Organism

Name of your Team:

You will introduce your imaginary organism to the world of science. To do this, you will form the following species tag. In this tag, you can mention the structures and characteristics of your organism, the group its scientifically belong, habitat, nest, food sources, enemies, etc.

<p>Scientific name of our organism: (It must be a Latin name called binomial nomenclature consisting of two names. The first name defines <i>genus</i> and the second a name defines <i>species</i>. The entire name is italicized (e.g., <i>Homo sapiens</i>) and abbreviated by the first letter of the genus name capitalized (e.g., <i>H. sapiens</i>).</p>	
<p>The scientific group our organism belongs: Specify whether it is a plant, an animal, a microscopic organism or fungi. If it is a plant, is it vascular or nonvascular? If it is an animal, is it vertebrate or invertebrate? If it is vertebrate, is it a mammal, a fish, a frog, a reptile or a bird? If it is invertebrate, is it an insect, a spider, a worm, a snail, etc.? If it can be in multiple groups, specify.</p>	
<p>Body parts of our organism have: (Tail, wing, trunk, mouth, beak, leaf, root, legs, ears, etc.)</p>	
<p>The habitat of our organism lives: (Desert, sea, forest, poles, etc.)</p>	
<p>The nest and its characteristics of our organism:</p>	
<p>The nutrient sources of our organism:</p>	
<p>The dangers awaiting our organism:</p>	
<p>The strongest feature of our organism:</p>	
<p>The weakest feature of our organism:</p>	

APPENDIX 6

Imaginary Organism Assessment Rubric

Name of Team:

Dimension	Criteria	Imaginary Organism Assessment Rubric			
		0	1	2	3
Developing and using models	Name and classification of organism	No evidence of the name or classification of the organism	The organism is named but not classified.	The organism is classified but not named.	The organism is named and classified
	Drawing and labeling	No evidence of drawing of the organism	Drawing of the organism is unclear and lack of finer details.	Drawing of the organism is clear but lack of finer details.	Drawing of the organism is clear and has finer details.
	Description	No evidence of description of the organism	Description of the organism does not match the drawing.	Description of the organism does not exactly match the drawing.	Description of the organism matches the drawing.
Structure and function	Nutrition	No evidence of relation between structure and function	The organism cannot consume nutrients with its modelled structures.	The organism hardly consumes nutrients with its modelled structures.	The organism consumes nutrients easily with its modelled structures.
	Defending from predators	No evidence of relation between structure and function	The organism cannot protect itself from its predators with its modelled structures.	The organism hardly protects itself from its predators with its modelled structures.	The organism can protect itself easily from its predators with its modelled structures.
	Communication	No evidence of relation between structure and function	The organism cannot communicate with its modelled structures.	The organism can hardly communicate with its modelled structures.	The organism can communicate easily with its modelled structures.
	Mating	No evidence of relation between structure and function	The organism cannot find a mate with its modelled structures.	The organism hardly finds a mate with its modelled structures.	The organism can find a mate easily with its modelled structures.
	Habitat	No evidence of relation between structure and function	The organism cannot survive with its modelled structures in its habitat.	The organism hardly survives with its modelled structures in its habitat.	The organism can survive easily with its modelled structures in its habitat.
Total Score	.../24				

APPENDIX 7

Great Design Task Draft Drawing

Name of your Team:

At the beginning of the unit, read the great design task you were given again. You will apply the scientific knowledge you have learned up to this stage on your great designing task. Answer the following questions and draw the sketch of the design you have made with your team below.

While creating your design, which organisms did you use the structure and the function of?

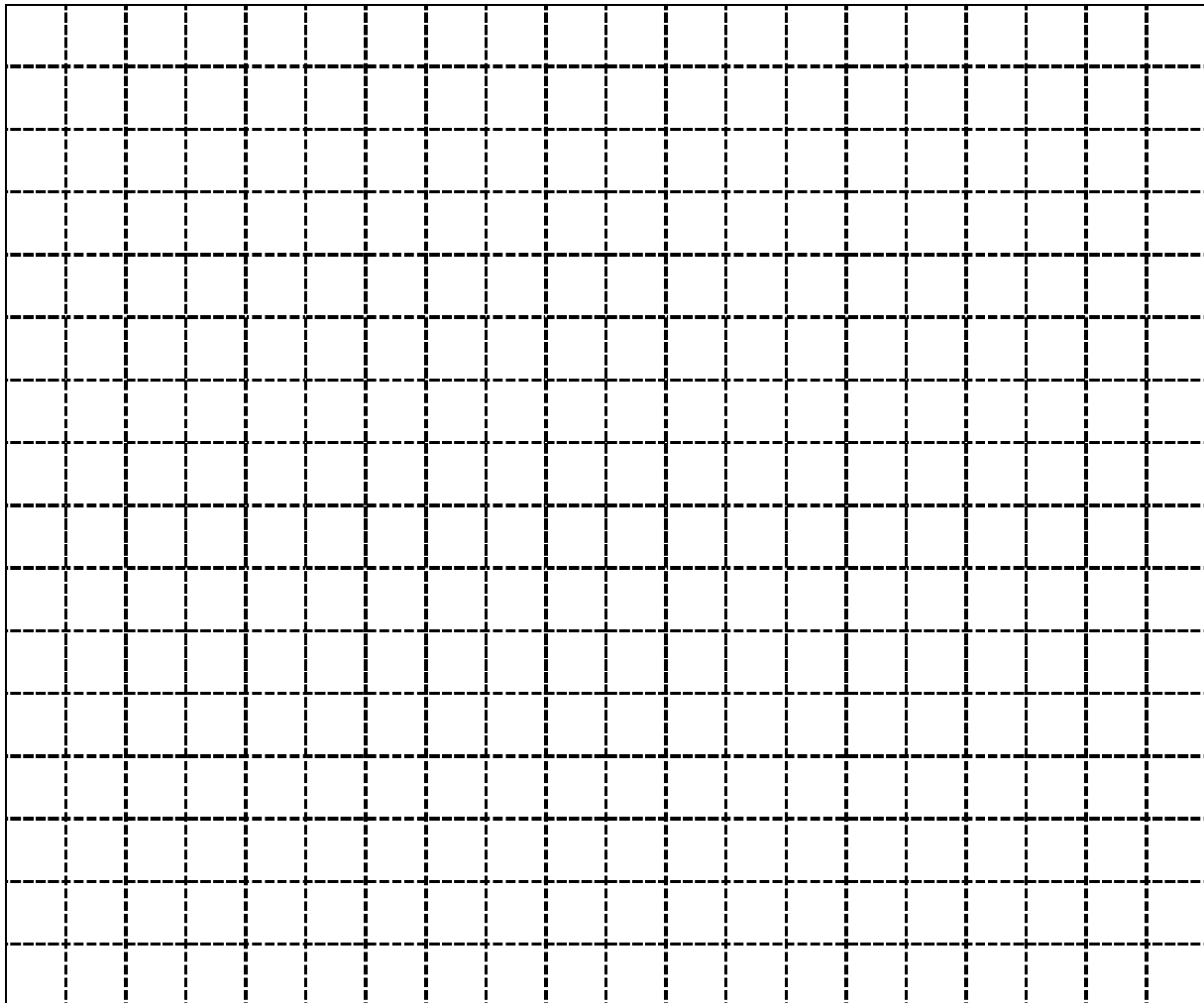
.....

What human problem will your design solve, and how?

.....

Which materials will you use in which part of your design?

.....



APPENDIX 8

Biomimicry Design Task Assessment Rubric

Engineering Design Process Steps	0	1	2	3
Identify the need/problem	The need/problem was not identified.	The need/problem was defined superficially.	The need/problem was identified.	The need/problem was identified clearly with all details.
	The criteria and constraints were not identified.	Some of the criteria and constraints were identified.	Most of the criteria and constraints were identified.	All the criteria and constraints were identified.
Research the need or the problem	The information needed for the solution of the need/problem was not determined.	Some of the information needed for the solution of the need/problem was defined.	Most of the information needed for the solution of the need/problem was defined.	All the information needed for the solution of the need/problem was defined.
	It was not defined how the collected information would be used to solve the need/problem.	It was superficially defined how the collected information would be used to solve the need/problem.	It was defined how the collected information would be used to solve the need/problem.	It was clearly defined in detail on how the collected information would be used to solve the need/problem.
Develop possible solution(s)	No solution was proposed for the need/problem.	The proposed solution for the need/problem was met the some of the criteria and constraints.	The proposed solution for the need/problem was met most of the criteria and constraints.	The proposed solution for the need/problem was met the all the criteria and constraints.
	No blueprint drawn for proposed solution.	The blueprint was reflected the solution proposal superficially.	The blueprint was reflected the solution proposal.	The blueprint was reflected the solution proposal in detail.
Select the best solution(s)	The pros and cons of proposed solutions were not defined.	Some of the pros and cons of proposed solutions were defined.	Most of the pros and cons of proposed solutions were defined.	All the pros and cons of proposed solutions were defined with details.
	Whether the chosen solution meets the criteria and constraints were not explained.	Some of the reasons for the chosen solution were explained.	Most of the reasons for the chosen solution were explained.	All the reasons for the chosen solution were explained with details.
Construct a prototype	A model/prototype for the solution proposal was not created.	A partially appropriate model/prototype for the solution proposal was created.	An appropriate model/prototype for the solution proposal was created.	A completely appropriate model/prototype for the solution proposal was created.
	The materials that meet the criteria and restrictions for the model/prototype were not used.	The materials that meet part of the criteria and restrictions for the model/prototype were used.	The materials that meet most of the criteria and restrictions for the model/prototype were used.	The materials that meet all the criteria and restrictions for the model/prototype were used.
Test and evaluate the solution(s)	It was not tested how the model/prototype solves the need/problem.	The model/prototype was tested how it would solve the need / problem. Test results were not analyzed.	The model/prototype was tested how it would solve the need/problem. Part of the test results were analyzed	The model/prototype was tested how it would solve the need/problem. All the test results were analyzed completely.
	The data related to the test results were not explained by using scientific language.	Part of the data related to the test results were partly explained by using scientific language.	Most of the data related to the test results were explained by using scientific language.	All the data related to the test results were explained by using scientific language completely with details.
Communicate the solution(s)	It was not explained how the designs would solve the need/problem.	It was partly explained how the designs would solve the need/problem.	It was explained how the designs would solve the need/problem.	It was explained completely how the designs would solve the need/problem with details.
	The structure/structures belonging to living things and how the functions of these structures are utilized were not identified.	The structure/structures belonging to living things and how the functions of these structures are utilized were partly identified.	The structure /structures belonging to living things and how the functions of these structures are utilized were identified.	The structure /structures belonging to living things and how the functions of these structures are utilized were completely identified with details.
Redesign	The need of improvement for designs was not identified.	The need of improvement for design was partly identified.	The need of improvement for design was identified.	The need of improvement for design was identified with details.
	The design was not improved in the light of the data and feedbacks from the test results and the communication of the solutions.	The design was partly improved in the light of the data and feedbacks from the test results and the communication of the solutions.	The design was improved in the light of the data and feedbacks from the test results and the communication of the solutions.	The design was optimally improved in the light of the data and feedbacks from the test results and the communication of the solutions.
Total Score	.../48			

APPENDIX 9

Biomimicry STEM Activity Reflective Evaluation Form

Write your answers to the following questions in the gaps. You can add drawings to explain. You can use the backside of the paper or a separate paper for your drawings.

1. What kind of difficulties did you face when designing your model / prototype?

.....
.....

2. How did you overcome these difficulties?

.....
.....

3. What did you learn in this activity?

.....
.....

4. What did you do to improve your model/prototype?

.....
.....

5. What did you like in this activity?

.....
.....

6. What did you dislike in this activity?

.....
.....

7. Explain how did you work as a team?


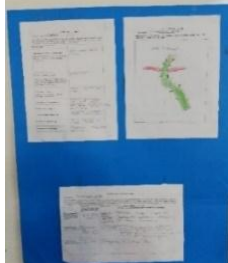



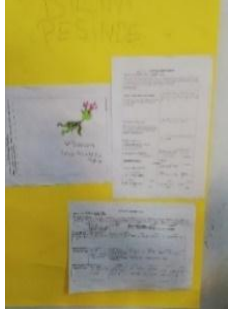

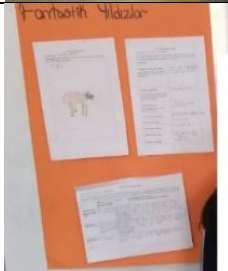




.....
.....

8. What would you like to change in this activity?

.....
.....

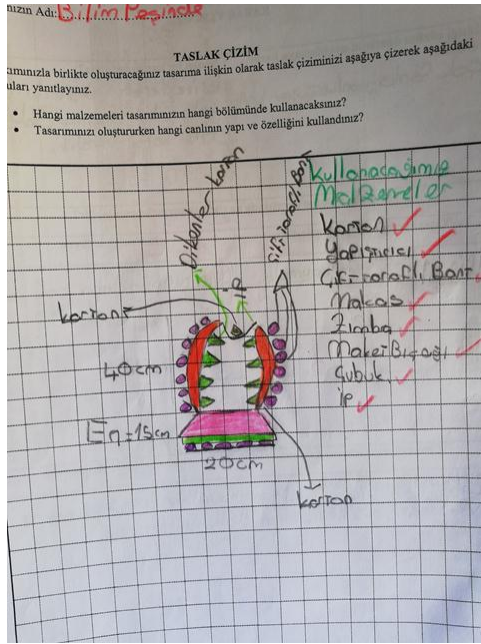
APPENDIX 10

Drawings and Created Imaginary Organisms

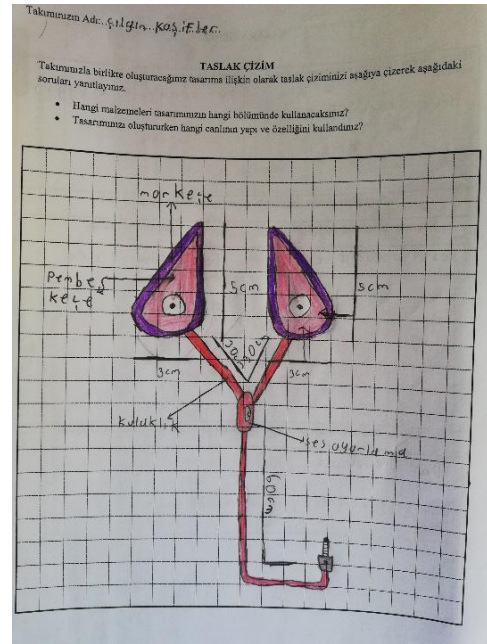
	Introducing the imaginary organism	Modelling the imaginary organism	Presentation of the imaginary organism
Team 1	<p>The flying reptile belongs to reptiles and birds in taxonomy. It has got a tail, wings, a mouth, and legs. It lives in rain forest, nested in shrubs, crawls on the ground and can fly. It has sticky legs like Gecko's pads. It fishes for feeding. The strongest features are poisoned thorn and eyes to help for defending from its predators. The weakest feature is walking slowly. It can hear with sensitive ears and communicate by howling. Its beautiful eyes and mouth, and the capabilities to build a nest can help him to find a mate.</p>		
Team 2	<p>The lion-headed cheetah belongs to mammals in taxonomy. It has a tail, a mouth, a nose, ears, and legs. It has fur to keep itself warm and breathes with lungs. It lives in desert and nested on trees, and hunts for feeding. The strongest features are sharp teeth, paws and legs for hunting and defending from its predators. The greatest danger is human for it. It can communicate using by olfactory ability. This ability also helps to find a mate.</p>		
Team 3	<p>The laying mammal, Babacan has a tail, a mouth, horns, teeth, paws, ears, and black speckles. It is a vertebrate with thick bones. It has a hairy body and thick layer of fat that help for defending its predators. It lives in the forest, and nests in a cave placed on top of the hill. It eats fish and meat. Hunters and its kind of species are hazardous for Babacan's life. While the strongest structures are its poisoned teeth, camouflage, and horns, having a long tail is the weakest. Having eye-catching colors and the feature of changing the colors help him find a mate.</p>		
Team 4	<p>Ulti-bear is an amphibian. It has mouth, lungs and gills, ears, legs, teeth, paws and eyes. Thanks to its lungs and gills, it can breathe in the sea and overland. It is a carnivore and lives in the forest. Its predator is falcon. Its paws and teeth help for defending. The thick fur helps to keep him from the cold weather. The stronger part is gecko eyes so it can see everything. The weakest characteristic is being a coward. Having a beautiful voice helps him find a mate.</p>		
Team 5	<p>Tekakdomeji is a reptile and carnivore. It has got big eyes to see better and hunt, and shred to its prey with sharp teeth. It has got a big shell to be protected by its predators. It lives in a forest and nested in a tree cavity. The strongest structure is its poisoned thorns and the weakest is toenails. The poisoned thorns help to protect its life. Also, it can run fast with its long legs. Tekakdomeji howls like a wolf for communication. With its interesting semblance, it can find a mate easily.</p>		
Team 6	<p>The Red Head belongs to one than more groups in taxonomy. It lives in the forest and nested in a cool place. It has got paws like wolves, and poisoned teeth like bats for hunting. It can change its colors like chameleons and it has got strong shells like a turtle, and flexible spine like a snake. The stronger structures are paws and poisoned teeth, the weakest is its tail. The fishes are its prey. The carnivores are its enemies. The Red Head communicates by barking like dogs. It looks fancy so, it can find a mate.</p>		

APPENDIX 11

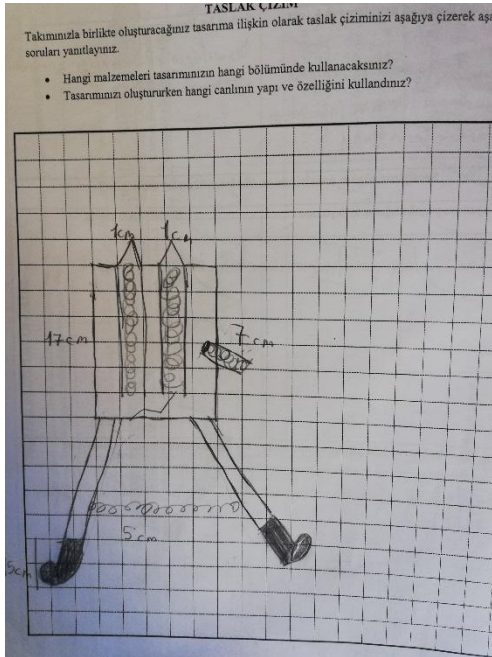
Sample Drawings of Great Design



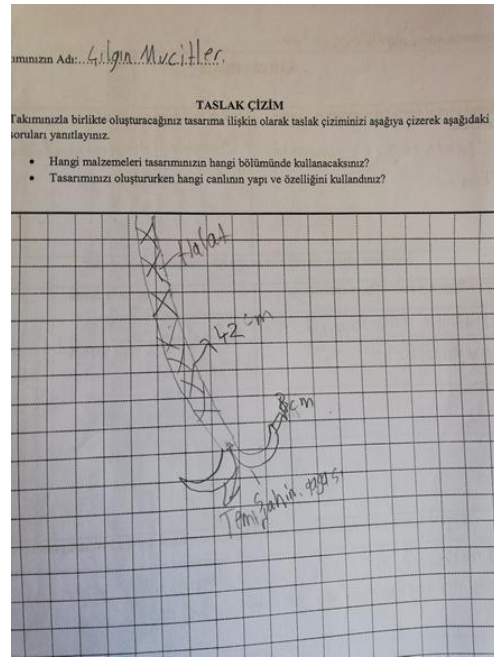
Team 3
Blueprint of the Trap



Team 4
Blueprint of the Bat's Ear Headset









Team 5
Blueprint of the Sew-burly



Team 5
Blueprint of the Hook

APPENDIX 12

Developed Biomimicry Models

Team	The model	The name of the organism used in the design	Structure of the organism	Function of the structure	What kind of human problems solved by your design?	How it works?	What improvement needs in your design?
Team 1 Fishing-net		Pelican	Beak	Scooping - up fish with its large shape.	To help people fish.	Water drains from the holes and fishes remain in the net.	The drainage holes for water were too small. It needs to be larger.
Team 2 Non-slip socks		Gecko	Toe-pads	Climbing on surfaces without slipping or falling down.	To prevent people from slipping and falling.	Sipped silicone prevents slipping.	The slip-proof material under the stocking was thick. It needs to be thinner.
Team 3 Trap		Venus Flytrap	Leaves	Catching the bugs and flies	To help people hunt	When the animal steps on the trap, two leaves are closed.	Need to expand the rim of model
Team 4 Bat's Ear Headset		Bat	Ears	Seeing with ears	To enable deaf people, hear and for sound insulation.	It sends sound waves to human brain.	Size of the headset
Team 5 Hook		Falcon	Claws	Hunting their prey and carry out.	To help people carry heavy things	The load can be hung on the hook and people hold in high.	
Team 6 Sew-burly		Chicken	Beak	Fighting and protecting, Breaking grass and digging the soil.	To help people plant seed easily	The one of chicken's beak digs the hole and another puts the seed and closes the hole.	In our model the beak did not looks like a chicken beak.

TÜRKÇE GENİŞLETİLMİŞ ÖZET

Doğa bilimlerini anlamada en önemli mihenk taşlarından biri ‘yapı fonksiyonu belirler’ temasıdır. Ulusal Araştırma Konseyi (National Research Council [NRC], 2012) tarafından geliştirilen *K-12 Fen Eğitimi Çerçevesi: Uygulamalar, Kesişen Kavramlar ve Öz Fikirler* reform belgesinde, yapı ve işlev arasındaki ilişki bilim ve mühendislik uygulamaları yoluyla hem kesişen hem de disiplin temel kavramları olarak kabul edilmektedir. Tüm disiplinlerde ve sınıf seviyelerinde temaları birleştiren kesişen kavramlar arasında yer alan yapı ve işlev “bir nesnenin ya da canlının oluşma biçimi ve alt bileşenleri, özelliklerini ve fonksiyonunu belirler” şeklinde tanımlanmaktadır (NRC, 2012, s. 84). Bu çerçevede fizik ve yaşam bilimlerindeki disiplin temel fikirlerinin ana bileşenleri olarak ise yapı ve işlev, sırasıyla ‘Maddenin yapısı ve özellikleri’ ve ‘Yapı ve işlev’ içeriğinde yer almaktadır. Diğer taraftan ülkemizde yakın zamanda revize edilen fen programında ise öğrencilerin feni diğer disiplinlerle bütünleştirerek teoriyi pratiğe ve ürüne dönüştürebilmelerine yardımcı olacak fen ve mühendislik uygulamalarına vurgu yapılırken; doğada ya da tasarlanmış dünyada tekrar eden örüntülere ve yapı ve işlev arasındaki ilişkilere herhangi bir sınıf düzeyinde vurgu yapılmamıştır.

Doğa uzun zamandır sanat, tasarım ve yenilik için bir ilham kaynağı olmuştur. Örneğin, uçma hayali kuran insanoğluna kuşların kanat yapıları en büyük yol gösterici olmuş ve bu sayede Wright kardeşler uçağı icat etmişlerdir. Benyus'a (2002) göre milyarlarca yıllık evrimsel süreç, organizmalara canlılıklarını sürdürebilmeleri için inanılmaz çeşitlilikte yapılar, şekiller ve bunlarla ilgili işlevler kazandırmıştır. Bu nedenle, yapı ve fonksiyon arasındaki ilişkiyi anlamak mühendislik tasarımları ve özellikle de biyomimikri tasarımları için kritik bir öneme sahiptir (Cohen, Reich ve Greenberg, 2014). Biyomimikri “doğanın zaman içinde test edilmiş kalıplarını ve stratejilerini taklit ederek insanların sorunlarına sürdürülebilir çözümler arayan yenilikçi bir yaklaşımdır” (Biomimicry Institute, 2010).

Öğrencilerin doğal dünyadaki organizmaları sorgulayarak yapıların işlevlerini ne ölçüde anladıklarıyla ilgili olarak nedensel çıkarımlar yapmaları gerekir. Bu, “mühendislerin doğadaki yapıları insanların ihtiyaçlarını karşılayacak tasarımlar için ilham kaynağı olarak incelerken böyle çıkarımlar yapmalarına” benzer bir yöntemdir (Yeni Nesil Fen Standartları [NGSS] Lead States, 2013b, s.89). Mühendisler doğayı inceleyerek öğrenirler. Bu yüzden yeni tasarım çözümleri için daha mükemmel fikirler elde etmek için doğayı gözlemlerler. Bu durum, günlük yaşamımızda kullandığımız birçok teknolojik aracın neden doğadaki bir mekanizma ile aynı şekilde çalıştığını açıklar. “Doğal ve insan yapımı sistemlerin benzer şekilde işleyişinin, bazı kilit parçaların şekillerine ve ilişkilerine bağlı olduğu kadar üretildikleri malzemelerin özelliklerine de bağlı olduğu” görülebilir (NRC, 2012, s.96). Bu nedenle, doğadaki yapıların amacının veya mekanik fonksiyonunun fen bilgisi derslerinde bir öğrenme çıktısı olarak anlaşılması STEM eğitiminde önemsenmelidir.

STEM eğitiminde biyomimikrinin özelliklerinden yararlanmak, öğrencilere hem bilimsel kavramları hem de mühendislik tasarım ilkelerini anlamalarında eşsiz bir öğrenme fırsatı sunmaktadır. Yapı ve fonksiyon arasındaki ilişkiyi kullanarak biyomimikriyi anlamak, doğal ve insanoğlu tarafından inşaa edilen dünya arasındaki bağlantılar nedeniyle öğrencileri bir biyomühendis olarak mühendislik tasarımına dahil etmenin etkili bir yoludur. Bu çalışma, beşinci sınıf fen bilimleri dersi Canlılar Dünyası ünitesinde yapı ve fonksiyon ilişkisine dayanan biyomimikri STEM etkinliği geliştirmeyi amaçlamaktadır. Çalışmada durum çalışması yöntemi kullanılmış, sosyo ekonomik düzeyi düşük bir devlet ortaokulunda 12 ders boyunca 21 öğrenci ile yürütülmüştür. STEM uygulamaları kapsamında öğrencilerden günlük yaşamdan bir problem belirleyerek canlılara ait yapı ve işlev arasındaki ilişkinin bir taklidi olabilecek biyomimikriyi kullanarak olası bir tasarım çözümü geliştirmeleri istenmiştir. Veriler, açık-uçlu sorular, yarı yapılandırılmış görüşmeler ve mühendislik sürecinin değerlendirilmesi için rubrik kullanılarak toplanmıştır.

Bu çalışmada, öğrencilerin tasarladığı biyomimikri modellerine dayalı veriler, tasarım ve doğal dünyadan alınan ilham arasındaki ilişkilere dayalı olarak tasarım sürecinin bir analizi şeklinde sunulmuştur. Öğrencilerin geliştirdikleri biyomimikri modelleri göz önüne alındığında, öğrencilerin bir organizmayla ilgili yapı ve fonksiyon arasındaki tamamlayıcı ilişki yoluyla biyomimikriyi bir insanlık problemine yönelik tasarım çözümlerine yansıtmayı başardıklarını göstermektedir. Sonuç olarak, biyomimikri STEM etkinlikleri öğrencilerin mühendislik tasarım süreciyle ilgili deneyimler yaşarken canlıların adaptasyonlarını, yapı ve fonksiyon ilişkisine dayalı olarak daha iyi kavramsallaştırmalarını sağlamıştır. Öğrenciler biyomimikri tasarım sürecinde bazı zorluklar yaşamalarına rağmen, çoğu tasarım görevi ve model/prototip yapma dahil olmak üzere etkinlikle ilgili her şeyi beğendiklerini ifade etmişlerdir.

Doğanın sürdürülebilir tasarım çözümleri için bir model olarak kullanılması fen eğitiminde biyomimikrinin kavramsallaştırılmasını kaçınılmaz kılmaktadır. Biyomimikri, öğretmenlere yaşam bilimleri, STEM, yaratıcı problem çözme, tasarım ve sistem düşüncesini harmanlayarak her yaşta öğrencilere ilham verecek bir yol sunarak, eğitimde bir devrim olarak görülebilir (Biomimicry Institute, 2010). Biyomimikri, disiplinlerarası STEM'i sınıf ortamına entegre etme fırsatı sağlaması açısından fen bilgisi öğretim programında yer almalıdır. STEM eğitiminde biyomimikriyi öğretmek doğayı; bilim, teknoloji, mühendislik ve matematikle kesiştirerek bütünleşik bir bağlam sağlayacaktır. Daha sürdürülebilir bir gelecek için, insan kaynaklı sorunların çözümünde öğrencilere ilham verecek biyomimikri stratejilerini öğretmek için daha fazla araştırmaya ihtiyaç vardır.

EK 1

Biyomimikri Tasarım Görevi

Doğa uzun zamandır sanat, tasarım ve yenilik için bir ilham kaynağı olmuştur. Örneğin, uçma hayali kuran insanoğluna kuşların kanat yapıları en büyük yol gösterici olmuş ve bu sayede Wright kardeşler uçağı icat etmişlerdir. İnsanların ihtiyaç duyduğu problemlere doğadaki modelleri, sistemleri ya da canlılara ait farklı özellikleri taklit ederek tasarım çözümleri geliştiren bilim dalına Biyomimikri adı verilir. Biyomimikri uygulamaları günümüzde bilim, teknoloji, sanat, mimari, yapay zekâ, nanoteknoloji, robotik, endüstri, askeri araştırmalar, ulaşım gibi birçok alanda kullanılmaktadır.

Bir biyomimikri şirketi canlıların özelliklerini kullanarak insanların sorunlarına çözüm aramaktadır. Bu alanda yeni fikirlere ihtiyaç duyan şirket yetkilileri bir yarışma düzenler. Bir biyomimikri uzmanı olarak sizden beklenen; bitkilerin ve hayvanların sahip oldukları iç ve dış yapılarını büyütmek, hayatta kalmak ve diğer tüm ihtiyaçlarını karşılamak için nasıl kullandıklarını taklit ederek insanlığın bir problemi için çözüm üretmenizdir.

Bu amaçla sizlerden takımınızla birlikte canlıların sahip oldukları yapıları gözlemlemeniz, bu yapıların işlevlerine ilişkin bilgi toplamanız sonra bu yapıları ve işlevleri kullanarak insanların bir problemini çözmek için tasarım yapmanız beklenmektedir.

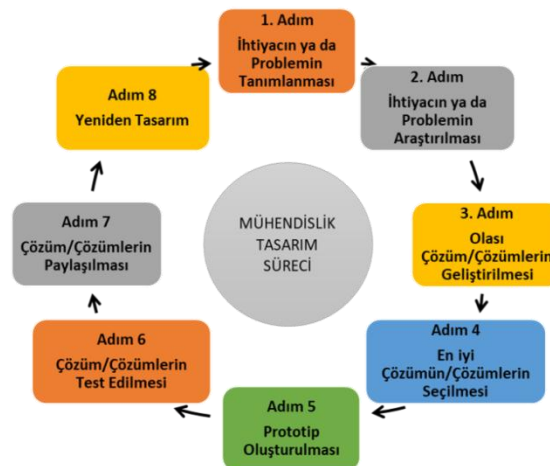
Tasarımınızı tamamladıktan sonra yaptığınız çalışmayı bilim insanları ve mühendislerden oluşan bir kurula sunacaksınız. Sunumunuzda canlıya ait yapı ve bu yapının işlevini açıklayarak tasarımınızı nasıl oluşturduğunuzu, bunları insanların sorunlarını çözmek için nasıl kullandığınızı açıklayacaksınız. Yarışma şartnamesi aşağıda verilmiştir:

Yarışma Şartnamesi

- 1- Tasarımınız bir canlıya ait en az bir yapının işlevini taklit ederek oluşturulmalıdır.
- 2- Tasarımınız insanların sorunlarından en az bir tanesine çözüm getirmelidir.
- 3- Tasarımınızda insan sağlığına zararlı madde kullanılmamalıdır.
- 4- Tasarımınızda geri dönüşüm malzemeleri başta olmak üzere her türlü malzemeyi kullanabilirsiniz.

**Tasarımınızda doğrudan gözlemleyerek ya da izlediğiniz belgesellerden, TÜBİTAK yayınları gibi okuduğunuz bilimsel kitaplardan canlıları, canlılara ait yapıları ve canlıların bu yapıları hayatta kalmak için nasıl kullandıklarını kanıta dayalı olarak belirleyeceksiniz. Bununla birlikte diğer kaynaklardan da (çevrimiçi sayfalar, ulaşabileceğiniz basılı kaynaklar) yararlanabilirsiniz.

Tasarım görevinizi gerçekleştirirken aşağıdaki mühendislik döngüsünü kullanacaksınız;



EK 3

Hayali Canlının Adaptasyonları

Takımınızın Adı:

Takım arkadaşlarınızla birlikte hayali bir canlı düşünün. Hayali canlının sahip olacağı özelliklere karar verirken her birinizin birinci aşamada bilgi sahibi olduğu farklı canlılara ait yapılar ve bu yapıların işlevlerini kullanabilirsiniz. Hayali canlınız için seçtiğiniz yapıları, yapıların işlevlerini ve canlıya sağladığı yararları aşağıdaki tabloyu kullanarak açıklayınız.

Açıklamalar Yapılar	Yapının adı ve özelliği (Kanat, kuyruk, ağız, dişler, kök, yaprak, hortum, göz, vb.)	Yapının işlevi	Neden bu yapıyı seçtiğinizi açıklayınız? (Bu yapı canlınızın hayatta kalmaması için ne tür bir yarar sağlayacak?)
Canlınız hangi dış yapılara sahip olacak?			
Canlınız hangi iç yapılara sahip olacak?			
Canlınız besinlerini bulmak ve yemek için hangi yapılara sahip olacak?			
Canlınız düşmanlarından korunmak için hangi yapılara sahip olacak?			
Canlınız arkadaşlarıyla ve yavrularıyla haberleşmek için hangi yapılara sahip olacak?			
Canlınız eş bulmak için hangi yapılara sahip olacak?			
Siz de ekleyebilirsiniz...			

EK 4

Hayali Canlının Çizimi ve Etiketlenmesi

Takımınızın Adı:

Hayal ettiğiniz canlının resmini çiziniz. Resminizi çizerken hayal ettiğiniz canlıya ait yapıları detaylı olarak göstermeye dikkat ediniz.

Canlınızın bilimsel adı:

Canlınızı bilim dünyasına tanıtan bir hikâye ya da haber yazınız:

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EK 5

Hayali Canlınızı Tanıtınız

Takımınızın Adı:

Hayali canlınızı bilim dünyasına tanıtacaksınız. Bunun için aşağıdaki tür künyesini oluşturacaksınız. Bu künyede genel olarak canlınızın sahip olduğu yapılar ve özellikleri; bu özellikleri dikkate alarak bilimsel olarak ait olduğu grup, yaşam alanı, yuvası, besin kaynakları, düşmanları vb. yer verebilirsiniz.

Canlınızın bilimsel adı: (İki isimden oluşan ikili isimlendirme adı verilen Latince bir isim olmalıdır. İlk isim <i>cinsi</i> , ikinci isim ise <i>tür</i> olarak tanımlanır. İsmi tamamı italik yazılmalıdır (ör., <i>Homo sapiens</i>) ve cins adının ilk harfi büyük büyük yazılarak kısaltılmalıdır (ör., <i>H. sapiens</i>).	
Canlınızın ait olduğu grup: Bitki-hayvan- mikroskobik canlı- mantar mı olduğunu belirtiniz. Bitki ise çiçekli/çiçeksiz hayvan ise omurgalı/omurgasız mı? Omurgalı canlı ise memeli-balık-kurbağa-sürüngen-kuş mu? Omurgasız canlı ise böcek-örümcek-solucan-salyangoz vb. mi? ya da birden çok gruba girebilir şeklinde özellikleriyle tanımlayınız.	
Canlınızın sahip olduğu vücut kısımları: (Kuyruk, kanat, hortum, ağız, gaga, yaprak, kök, bacaklar, kulaklar vb. şeklinde özellikleriyle tanımlayınız)	
Canlınızın yaşadığı yer: (Çöl/deniz/orman/kutuplar vb. şeklinde özellikleriyle tanımlayınız.)	
Canlınızın yuvası ve özellikleri:	
Canlınızın besin kaynağı:	
Canlınızı bekleyen tehlikeler:	
Canlınızın en güçlü özelliği:	
Canlınızın en zayıf özelliği:	

EK 6

Hayali Canlı Değerlendirme Rubriği

Takım Adı:

Boyut	Kriter	Hayali Canlı Değerlendirme Rubriği			
		0	1	2	3
Model geliştirme ve kullanma	Canlının adlandırılması ve sınıflandırılması	Canlı adlandırılmamış ve sınıflandırılmamıştır.	Canlı adlandırılmıştır fakat sınıflandırılmamıştır.	Canlı sınıflandırılmış fakat adlandırılmamıştır.	Canlı adlandırılmış ve sınıflandırılmıştır.
	Çizim ve etiketleme	Canlı çizilmemiştir.	Canlının çizimi net değildir ve ince detaylar eksiktir.	Canlının çizimi nettir fakat ince detaylar eksiktir.	Canlının çizimi nettir ve ince detaylara sahiptir.
	Betimleme	Canlı betimlenmemiştir.	Canlının betimlemesi ile çizim ile uyumuyor.	Canlının betimlemesi ile çizimi tam olarak uyumuyor.	Canlının betimlemesi ile çizimi ile uyuyor.
Yapı ve İşlev	Beslenme	Yapı ve işlev arasında bir ilişki yoktur.	Canlı modellenen yapılarıyla besin tüketemez.	Canlı modellenen yapılarıyla güçlükle besin tüketebilir.	Canlı modellenen yapılarıyla kolayca besin tüketebilir.
	Düşmanlardan korunma	Yapı ve işlev arasında bir ilişki yoktur.	Canlı modellenen yapılarıyla avcılarından korunamaz.	Canlı modellenen yapılarıyla avcılarından güçlükle korunabilir.	Canlı modellenen yapılarıyla kolayca korunabilir.
	Haberleşme	Yapı ve işlev arasında bir ilişki yoktur.	Canlı modellenen yapılarıyla haberleşemez.	Canlı modellenen yapılarıyla güçlükle haberleşebilir.	Canlı modellenen yapılarıyla kolayca haberleşebilir.
	Eş bulma	Yapı ve işlev arasında bir ilişki yoktur.	Canlı modellenen yapılarıyla eş bulamaz.	Canlı modellenen yapılarıyla güçlükle eş bulabilir.	Canlı modellenen yapılarıyla kolayca eş bulabilir.
	Yaşam alanı	Yapı ve işlev arasında bir ilişki yoktur.	Canlı modellenen yapılarıyla yaşam alanında hayatta kalamaz.	Canlı modellenen yapılarıyla yaşam alanında güçlükle hayatta kalabilir.	Canlı modellenen yapılarıyla yaşam alanında kolayca hayatta kalabilir.
Toplam Puan	.../24				

EK 8

Biyomimikri Tasarım Görevi Değerlendirme Rubriği

Mühendislik Tasarım Süreci	0	1	2	3
Problemin ya da İhtiyacın Tanımlanması	İhtiyaç/problem tanımlanmamış.	İhtiyaç/problem yüzeysel olarak tanımlanmış.	İhtiyaç/problem tanımlanmış.	İhtiyaç/problem tüm detaylarıyla açıkça tanımlanmış.
	Kriterler ve kısıtlamalar tanımlanmamış.	Kriter ve kısıtlamaların bir kısmı tanımlanmış.	Kriter ve kısıtlamaların çoğunluğunu tanımlanmış.	Kriterler ve kısıtlamaların tamamı tanımlanmış.
Problemin ya da İhtiyacın Araştırılması	İhtiyaç/problemin çözümüne yönelik gereksinim duyulan bilgi belirlenmemiş.	İhtiyaç/problemin çözümüne yönelik gereksinim duyulan bilginin bir kısmı belirlenmiş.	İhtiyaç/problemin çözümüne yönelik gereksinim duyulan bilginin çoğunluğu belirlenmiş.	İhtiyaç/problemin çözümüne yönelik gereksinim duyulan bilginin tamamı belirlenmiş.
	Elde edilen bilginin insanların ihtiyacını/problemlerini çözmek için nasıl kullanılacağı belirlenmemiş.	Elde edilen bilginin insanların ihtiyacını / problemlerini çözmek için nasıl kullanılacağı yüzeysel olarak belirlenmemiş.	Elde edilen bilginin insanların ihtiyacını/problemlerini çözmek için nasıl kullanılacağı belirlenmiş.	Elde edilen bilginin insanların ihtiyacını/problemlerini çözmek için nasıl kullanılacağı tüm detaylarıyla açıkça belirlenmemiş.
Olası Çözümlerin Geliştirilmesi	İhtiyaç/problemin giderilmesine yönelik çözüm önerisi sunulmamış.	İhtiyaç/problemin giderilmesine yönelik sunulan çözüm önerisi kriterler ve kısıtlamaların bir kısmı karşılanmış.	İhtiyaç/problemin giderilmesine yönelik sunulan çözüm önerisi kriterler ve kısıtlamaların çoğunluğu karşılanmış.	İhtiyaç/problemin giderilmesine yönelik sunulan çözüm önerisi kriterler ve kısıtlamaların tamamı eksiksiz karşılanmış.
	Çözüm önerisine yönelik taslak çizilmemiş.	Taslak çizim çözüm önerisini yüzeysel olarak yansıtmış.	Taslak çizim çözüm önerisini yansıtmış.	Taslak çizim çözüm önerisini tüm detaylarıyla yansıtmış.
En İyi Çözümlerin Seçilmesi	Çözüm önerilerinin olumlu ve olumsuz yönleri tanımlanmamış.	Çözüm önerilerinin olumlu ve olumsuz yönlerini yüzeysel olarak tanımlanmış.	Çözüm önerilerinin olumlu ve olumsuz yönlerini çoğunlukla tanımlanmış.	Çözüm önerilerinin olumlu ve olumsuz yönleri tam ve eksiksiz olarak tanımlanmış.
	Seçilen çözümün kriterleri ve kısıtlamaları karşılayıp karşılamadığı açıklanmamış.	Seçilen çözüm için gerekçelerin bir kısmı açıklanmış.	Seçilen çözüm için gerekçelerin çoğunluğu açıklanmış.	Seçilen çözüm için gerekçelerin tamamı detaylarıyla açıklanmış.
Prototip Oluşturulması	Çözüm önerisine yönelik bir model / prototip oluşturulmamış.	Çözüm önerisine yönelik kısmen uygun bir model / prototip oluşturulmuş.	Çözüm önerisine yönelik uygun bir model / prototip oluşturulmuş.	Çözüm önerisine yönelik tamamen uygun bir model/prototip oluşturulmuş.
	Model/ prototip için kriter ve kısıtlamaları karşılayan malzeme kullanılmamış.	Model/ prototip için kriter ve kısıtlamaları kısmen karşılayan malzeme kullanılmış.	Model/ prototip için kriter ve kısıtlamaların çoğunluğunu karşılayan malzeme kullanılmış.	Model/ prototip için kriter ve kısıtlamaların tamamını karşılayan malzeme kullanılmış.
Çözümlerin test edilmesi ve değerlendirilmesi	Model/ prototipin ihtiyacı/ problemi nasıl çözeceği test edilmemiş.	Model/ prototipin ihtiyacı / problemi nasıl çözeceği test edilmiş. Test sonuçları analiz edilmemiş.	Model/ prototipin ihtiyacı / problemi nasıl çözeceği test edilmiş. Test sonuçları kısmen analiz edilmiş.	Model/prototipin ihtiyacı/ problemi nasıl çözeceği test edilmiş. Test sonuçlarının tamamı analiz edilmiş.
	Test sonuçlarına ilişkin veriler bilimsel bir dil kullanılarak açıklanmamış.	Test sonuçlarına ilişkin verilerin bir kısmı bilimsel bir dil kullanılarak açıklanmış.	Test sonuçlarına ilişkin verilerin çoğunluğu bilimsel bir dil kullanılarak açıklanmış.	Test sonuçlarına ilişkin verilerin tamamı bilimsel bir dil kullanılarak detaylarıyla açıklanmış.
Çözümlerin Paylaşılması	Tasarımların ihtiyacı/ problemi nasıl çözeceği açıklanmamış.	Tasarımların ihtiyacı/ problemi nasıl çözeceği kısmen açıklanmış.	Tasarımların ihtiyacı/ problemi nasıl çözeceği açıklanmış.	Tasarımların ihtiyacı/ problemi nasıl çözeceği tam ve eksiksiz açıklanmış.
	Canlı/canlılara ait yapı/yapılar ve bu yapıların fonksiyonlarından ne şekilde yararlandığı belirtilmemiş.	Canlı/canlılara ait yapı/yapılar ve bu yapıların fonksiyonlarından ne şekilde yararlandığı kısmen belirtilmiş.	Canlı/canlılara ait yapı/yapılar ve bu yapıların fonksiyonlarından ne şekilde yararlandığı belirtilmiş.	Canlı/canlılara ait yapı/yapılar ve bu yapıların fonksiyonlarından ne şekilde yararlandığı tam ve detaylarıyla belirtilmiş.
Yeniden Tasarım	Tasarım için gerekli iyileştirmeler tanımlanmamış.	Tasarım için gerekli iyileştirmeler kısmen tanımlanmış.	Tasarım için gerekli iyileştirmeler tanımlanmış.	Tasarım için gerekli iyileştirmeler detaylarıyla tanımlanmış.
	Çözümlerin test edilmesi ve paylaşılması sonucunda elde edilen veriler ve geri bildirimler doğrultusunda tasarımlar iyileştirilmemiş.	Çözümlerin test edilmesi ve paylaşılması sonucunda elde edilen veriler ve geri bildirimler doğrultusunda tasarımlar kısmen iyileştirilmiş.	Çözümlerin test edilmesi ve paylaşılması sonucunda elde edilen veriler ve geri bildirimler doğrultusunda tasarımlar iyileştirilmiş.	Çözümlerin test edilmesi ve paylaşılması sonucunda elde edilen veriler ve geri bildirimler doğrultusunda tasarımlar en iyi şekilde iyileştirilmiş.
Toplam Puan	.../48			

EK 9

Biyomimikri STEM Etkinliği Öğrenci Yansıtıcı Değerlendirme Formu

Aşağıdaki soruları boşluklara cevaplayınız. Açıklamak için çizim ekleyebilirsiniz. Bunun için kâğıdın arka yüzünü veya ayrı bir kâğıt kullanabilirsiniz.

1. Modelinizi/prototipinizi tasarlarken ne tür zorluklarla karşılaştınız?

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2. Bu zorlukların üstesinden nasıl geldiniz?

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3. Çalışmada neler öğrendiniz?

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4. Modelinizi/prototipinizi iyileştirmek için neler yaptınız?

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5. Bu çalışmada neleri sevdiniz?

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6. Bu çalışmada neleri sevmediniz?

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7. Bir takım olarak nasıl çalıştığınızı açıklayınız?

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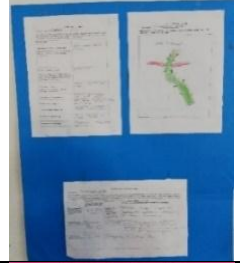





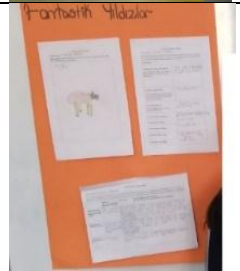




8. Bu çalışmada neleri değiştirmek isterdiniz?

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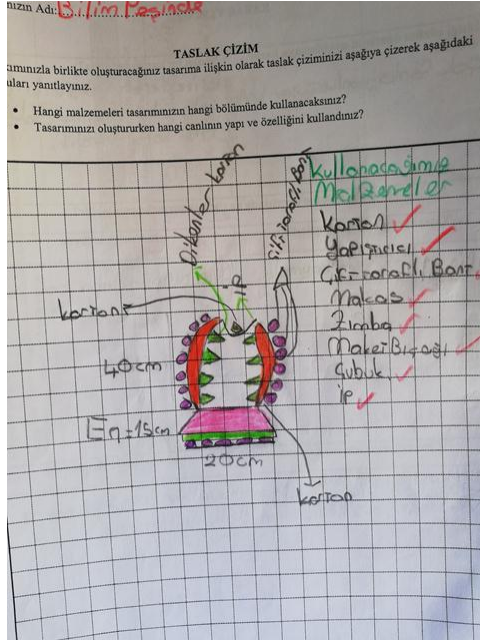
EK 10

Çizimler ve Oluşturulan Hayali Canlılar

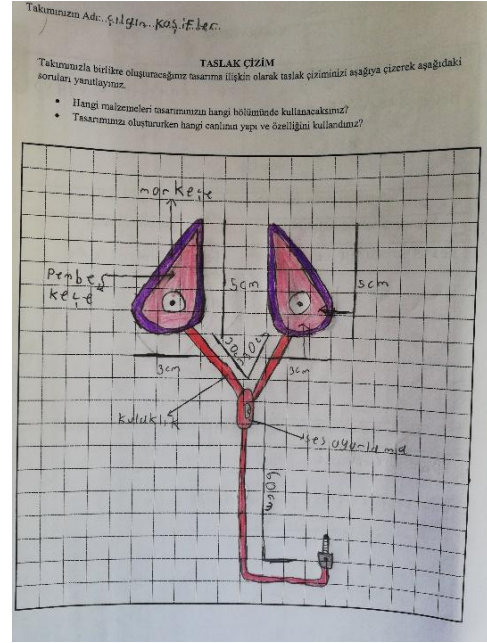
	Hayali organizmanın tanıtılması	Hayali organizmanın modellenmesi	Hayali organizmanın tanıtımı
Takım 1	<p>Uçan sürüngen sürüngenler ve kuşlar sınıfındadır. Kuyruğu, kanatları, ağzı ve bacakları vardır. Yağmur ormanlarında yaşar, çalılıklara yuva yapar, yerde sürünür ve uçabilir. Geko'nun ayakları gibi yapışkan ayakları vardır. Beslenmek için avlanır. En güçlü özellikleri zehirli dikenleri ve gözleri, avcılarından korunmasına yardımcı olur. En zayıf özelliği yavaş yürümesidir. Hassas kulaklarla duyabilir ve uluyarak iletişim kurabilir. Güzel gözleri, ağzı ve yuva yapabilmeleri, uçan sürüngenin eş bulmasına yardımcı olabilir.</p>		
Takım 2	<p>Aslan başlı çita memeliler sınıfındadır. Kuyruğu, ağzı, burnu, kulakları ve bacakları vardır. Kendini sıcak tutmak için kürkü ve nefes almak için akciğerleri vardır. Çölde yaşar, ağaçların üzerinde yuva yapar ve beslenmek için avlanır. Avlanmak ve avcılarından korunmak için en güçlü özellikleri keskin dişleri, pençeleri ve bacaklarıdır. En büyük tehlike onlar için insandır. Koku alma kabiliyeti ile iletişim kurar. Bu yetenek ve bir eş bulmasına da yardım eder.</p>		
Takım 3	<p>Yumurtlayan memeli Babacan'ın kuyruğu, ağzı, boynuzu, dişleri, pençeleri, kulakları ve kara benekleri vardır. Kalın kemikli bir omurgalıdır. Kılıklı bir vücuda ve yırtıcı hayvanlardan korumaya yardımcı olan kalın bir yağ tabakasına sahiptir. Babacan ormanda yaşar ve tepenin üzerindeki bir mağaraya yuvasını yapar. Balık ve et yer. Avcılar ve kendi türü Babacan'ın hayatı için tehlikelidir. Babacan'ın en güçlü yapıları zehirli dişleriyken, uzun kuyrukları olan kamuflaj ve boynuzları en zayıf yapılarıdır. Göz alıcı renklere ve renk değiştirme özelliklerine sahip olmak Babacan'ın eş bulmasını sağlar.</p>		
Takım 4	<p>Ülti-ay-ı iki yaşamlıdır. Ağzı, ciğerleri, solungaçları, kulakları, bacakları, dişleri, pençeleri ve gözleri vardır. Ciğerleri ve solungaçları sayesinde denizde ve karada nefes alabilir. Etçildir ve ormanda yaşar. Avcısı şahindir. Pençeleri ve dişleri savunmaya yardımcı olur. Kalın kürk, onu soğuk havalardan uzak tutmaya yardımcı olur. Daha güçlü olan kısmı Geko gözleridir. Bu sayede her şeyi görebilir. En zayıf özelliği korkak olmasıdır. Güzel bir sese sahip olması eş bulmasına yardımcı olur.</p>		
Takım 5	<p>Tekadomeji sürüngen ve etoburdur. Daha iyi görmek ve avlamak için büyük gözleri vardır ve keskin dişleriyle avını parçalar. Avcılarından korunmak için büyük bir kabuğu vardır. Tekadomeji ormanda ağaç kovuğunun içinde yaşar. Tekadomeji'nin en güçlü yapısı zehirli dikenleridir, en zayıf yapısı da ayak tırnaklarıdır. Zehirli dikenler yaşamını korumasına yardımcı olur. Ayrıca, uzun bacakları sayesinde hızlı koşabilir. Tekadomeji iletişim için kurt gibi ulur. İlginç görüşüyle ile kolayca bir eş bulabilir.</p>		
Takım 6	<p>Kızıl kafa, birden fazla grupta sınıflandırılabilir. Ormanda yaşar ve serin bir yerde yuvasını yapar. Kurt gibi pençeleri ve avlanmak için yarasa gibi zehirli dişleri vardır. Bukalemun gibi renk değiştirebilir ve kaplumbağa gibi güçlü kabuğu ve bir yılan gibi esnek omurgası vardır. En güçlü yapıları pençeleri ve zehirli dişlerdir, en zayıf ise kuyruğudur. Balıkları avlarlar. Etçiller düşmanlarıdır. Kızıl Kafa, köpekler gibi havlayarak iletişim kurar. Süslü görünüşü sayesinde eş bulabilir.</p>		

EK 11

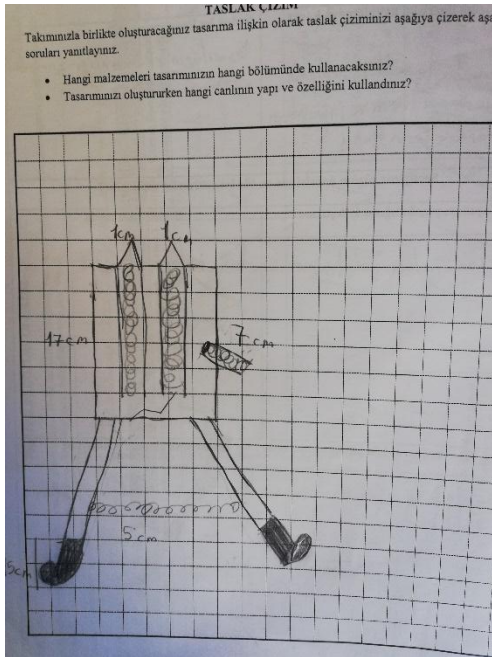
Büyük Tasarım Görevine Ait Taslak Çizimler



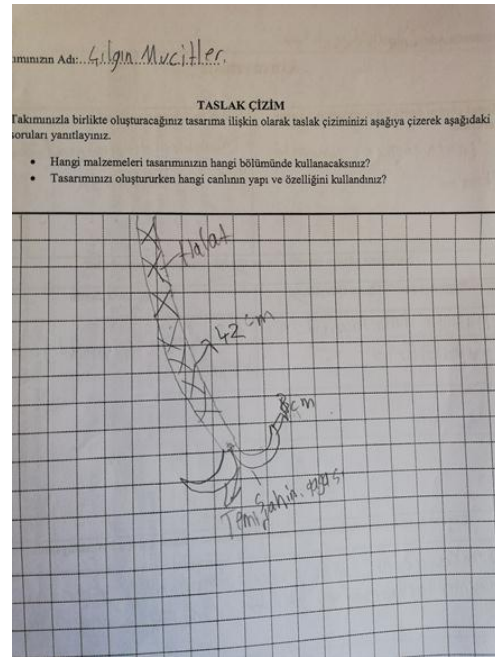
Takım 3
Tuzak Taslak Çizimi



Takım 4
Yarasa Kulağından Kulaklık Taslak Çizimi







Takım 5
Diker-Gömer Taslak Çizimi



Takım 5
Kanca Taslak Çizimi

EK 12

Geliştirilen Biyomimikri Modelleri

Takım	Model	Tasarımda kullanılan canlının adı	Canlıya ait yapı	Yapının fonksiyonu	Tasarımınız ne tür insan problemini çözdü?	Nasıl çalışıyor?	Tasarımınızın ne tür iyileştirmelere ihtiyacı var?
Takım 1 Balık yakalama filesi		Pelikan	Gaga	Geniş şekliyle balıkları yakalar.	İnsanlara balık avlamaları için yardım etmek	Sular delikler-den akar ve balıklar içeride kalır.	Su için boşaltma delikleri çok küçüktü. Daha büyük olması gerekiyor.
Takım 2 Kaymaz Çorap		Geko	Ayaklar	Düşmeden ve kaymadan tırmanır.	İnsanları kaymaktan ve düşmekten korumak.	Sürülen silikon kaymayı önler.	Çorap altındaki kaymaya dayanıklı malzeme kalındı. Daha ince olması gerekir.
Takım 3 Tuzak		Sinekkapan Bitkisi	Yaprak	Böcekleri ve sinekleri yakalar.	İnsanlara avlanmaları için yardım etmek.	Hayvanlar adımını tuzağa atınca yapraklar kapanır.	Modelin kenarını genişletmek gerekiyor.
Takım 4 Yarasa Kulağından Kulaklık		Yarasa	Kulak	Kulakları ile görür.	Duyamayan insanların duymalarını sağlamak. Ayrıca ses yalıtımı için kullanılabilir	Ses dalgalarını insan beynine gönderir.	Kulaklığın boyutu
Takım 5 Kanca		Şahin	Pençe	Avlarını avlar ve taşır.	İnsanlara ağır şeyleri taşımaları için yardım etmek.	Yük kancaya asılabilir ve insanlar yükü yüksekte tutarlar.	
Takım 6 Diker-Gömer		Tavuk	Gaga	Kavga etme ve korunma. Otları yolar ve çukur açar.	İnsanların kolayca tohum dikmelerini sağlamak.	Tavuğun gagasından biri deliği kazar, diğeri tohumu koyar ve deliği kapatır.	Bizim modelimizde gaga tavuk gagasına benzemiyordu