USE OF BIOMIMICRY IN INDUSTRIAL DESIGN EDUCATION IN TURKEY: THE CASE OF IZMIR UNIVERSITIES

A Thesis Submitted to
the Graduate School of Engineering and Science of
İzmir Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

in Industrial Design

by
Gamze AVCI

July 2019
İZMİR

We approve the thesis of **Gamze AVCI**

Examining Committee Members:

_____
Asst. Prof. Dr. Ayça Tunç COX
Department of Industrial Design, İzmir Institute of Technology

_____
Prof. Dr. Ahmet Nuri BAŞOĞLU
Department of Industrial Design, İzmir Institute of Technology

_____
Assoc. Prof. Dr. Güzden VARİNLİOĞLU
Department of Architecture, İzmir University of Economics

9 July 2019

_____
Asst. Prof. Dr. Ayça TUNÇ COX
Supervisor, Department of Industrial Design,
İzmir Institute of Technology

_____
Prof. Dr. Ahmet Nuri BAŞOĞLU
Head of the Department of Industrial Design

_____
Prof. Dr. Aysun SOFUOĞLU
Dean of the Graduate School
Engineering and Sciences

ACKNOWLEDGMENTS

I would first like to thank my thesis supervisor Assist. Prof. Dr. Ayça Tunç COX at the Department of Industrial Design at Izmir Institute of Technology for her quidance throughout the process. Whenever I ran into a trouble about my research or writing, she consistently supported, understood me, gave recommendations and directed me rightly.

I would like to thank my fellow friends Elvan Doğan Kumtepe, Nur Büyükyılmaz and Zeynep Aykul in the industrial design department for all their contributions and support from the beginning to the end of this long and challenging period and for all the nights and days we work with.

Also, I am gratefully indebted to my closest friends Tayfun Damla and Nigar Sezen Bal for endless support and very valuable comments on this thesis. This accomplishment would not have been possible without them.

Finally, I must extend my very profound gratitude to my parents for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis.

ABSTRACT

USE OF BIOMIMICRY IN INDUSTRIAL DESIGN EDUCATION IN TURKEY: THE CASE OF IZMIR UNIVERSITIES

From the viewpoint of industrial design, industrial design education and practice, and designer's responsibility, sustainable design has gained great importance to solve the crisis of sustainability the world has faced today. Besides sustainability, innovation is an important element or task in today's fast-changing economy. Thinking up new and fresh ideas to develop new products and services is a vital component for companies to stay competitive, provide financial benefits and to remain a successful business.

At this point, the concept of biomimicry offers industrial designers a great potential in solving complex human problems by providing sustainable innovation in both their education and professional life. Biomimicry, defined in many different ways, can be considered as a discipline, an approach, a strategy, a method, or a tool. More importantly, biomimicry is applicable.

This thesis aims to explore the state of biomimicry in Turkey and the world and to examine the awareness of students and academicians in industrial design education in Turkey. In this context, it first explains how the concept of biomimicry emerged, how it developed, its origins, its methodology, what it means and its relationships with sustainability and innovation. In addition, various examples and studies in the field of education and business regarding biomimicry as a discipline and as a practice have been given. Besides literature review, two surveys have been conducted with 10 industrial design instructors and 50 industrial design students to measure their awareness and to explain specifically how the concept of biomimicry has been conceived and applied in Turkey.

Keywords: Biomimicry, biomimetics, learning from nature, inspired by nature, industrial design education

ÖZET

TÜRKİYE'DE ENDÜSTRİYEL TASARIM EĞİTİMİNDE BİYOMİMİKRİNİN KULLANIMI: İZMİR ÜNİVERSİTELERİ ÖRNEĞİ

Endüstriyel tasarım, endüstriyel tasarım eğitimi ve uygulamaları ve tasarımcının sorumluluğu açısından bakıldığında, sürdürülebilir tasarım dünyanın bugün karşı karşıya olduğu sürdürülebilirlik krizini çözmede büyük önem kazanmıştır. Sürdürülebilirliğin yanı sıra, inovasyon da günümüzün hızla değişen ekonomisinde önemli bir unsur veya görevdir. Yeni ürün ve hizmetler geliştirmek için yeni ve taze fikirler düşünmek şirketlerin rekabetçi kalabilmesi, finansal fayda sağlayabilmesi ve başarılı bir işletme olarak kalabilmeri için hayati bir unsurdur.

Bu noktada, biyomimikri kavramı, endüstriyel tasarımcılara hem eğitim hem de mesleki yaşamlarında sürdürülebilir inovasyon sağlayarak karmaşık insan sorunlarını çözmede büyük bir potansiyel sunmaktadır. Farklı şekillerde tanımlanan biyomimikri, bir disiplin, bir yaklaşım, bir strateji, bir yöntem veya bir araç olarak düşünülebilir. Bu tanımların hepsinin geçerli olmasına ek olarak, biyomimikrinin uygulanabilir olması daha önemlidir.

Bu tez, Türkiye'de ve dünyadaki biyomimikri durumunu araştırmayı ve Türkiye'deki endüstriyel tasarım eğitimindeki öğrencilerin ve akademisyenlerin farkındalığını incelemeyi amaçlamaktadır. Bu bağlamda, biyomimikri kavramının nasıl ortaya çıktığını, nasıl geliştiğini, kökenlerini, metodolojisini, ne anlama geldiğini ve sürdürülebilirlik ve inovasyonla ilişkisini, bir disiplin olarak eğitim alanındaki ve bir pratik olarak iş alanındaki örneklerinin ve çalışmalarının neler olduğunu açıklamak için literatür taraması yapılmıştır. Literatür taramasının yanı sıra, bu tezin özellikle odak noktası olan biyomimikrinin Türkiye bağlamında nasıl tasarlandığını ve uygulandığını açıklamak için 10 endüstriyel tasarım akademisyeni ve 50 endüstriyel tasarım öğrencisi ile farkındalık çalışmaları yapılmıştır.

Anahtar Kelimeler: Biyomimikri, biyomimetik, doğadan öğrenmek, doğadan ilham almak, endüstriyel tasarım eğitimi

TABLE OF CONTENTS

LIST OF FIGURES

Figure **Page**

Figure **Page**

Figure **Page**

LIST OF TABLES

Table **Page**

CHAPTER 1

INTRODUCTION

1.1. Definition of Problem

Since the early days of human history, nature always has been used to design things, albeit unintentionally. The unconscious and simple use of nature has become more systematic and detailed through the time with the change of the world. Nature is still a source of inspiration in design to solve problems by various disciplines.

Through the history, the revolutions left many traces and made radical change in the world, some of the concepts now have very important place. Sustainability and innovation are two topics that continue to rise rapidly today. Especially, sustainability is very important considering the environmental and climatic crisis in the world. The concept of sustainability is becoming increasingly important all over the world.

From the viewpoint of industrial design, industrial design education and practice, and designer's responsibility, sustainable design has gained great importance to solve the crisis of sustainability the world has faced today. Besides sustainability, innovation is an important element or task in today's fast-changing economy. Thinking up new and fresh ideas to develop new products and services is a vital component for companies to stay competitive, provide financial benefits and to remain a succesful business.

In today's industrial design education and profession, it is a targeted principle to put forth innovative designs while providing sustainability in design by considering not only based on environment, also social and economic aspects. Considering the troublesome and difficult situations of today's world, industrial designers have a great role in taking some precautions in the field of design and being more responsible and conscious for the world.

At this point, the concept of biomimicry has a rich potential to help industrial designers solve complex human problems both in their educational and professional lives by offering sustainable innovation. There is a proliferation of the terms in the field such as "biomimicry" "biomimetics", "bionics", "bio-inspiration" and so on. They are often used interchangeably. Each concept is explained in detail and the term biomimicry is appropriated in the thesis. It is

defined in many ways such as learning from nature, ethics of sustainable development, new discipline of innovation, multidisciplinary design approach, or a new relationship with nature, can be considered as a discipline, an approach, a method, a tool, or a strategy, and so on. In addition to the validity of all these definitions, the more important is that biomimicry is applicable.

Seemingly, the concept of biomimicry, particulary in the Turkish context, does not have the significance it deserves. It is not incorporated into the industrial design education as much as it should have been. This thesis explores the condition of biomimicry in Turkey and the world to examine the awareness of students and academicians and as well as its inclusion in industrial design education in Turkey.

1.2. Research Objectives and Questions

This research draws together debates about biomimicry and the state of this concept in the field of industrial design education and in the business world in Turkey and abroad. Accordingly, the objectives of my thesis are to provide insight to the state of biomimicry in industrial design education and to examine students' as well as academicians' awareness of the concept of biomimicry.

In this context, the main questions to be asked in order to achieve the objectives are as follows:

How recognized is biomimicry in industrial design education (in Izmir)?

To what extent is biomimicry applied in industrial design education?

How students and academicians react to the concept of biomimicry?

What is the level of awareness of students and academicians regarding the concepts?

Is there any knowledge transfer from academicians to students in industrial design education at universities?

How do academicians address the concept?

1.3. Research Methodology

Within the scope of the study, first of all, literature review is conducted to explore and explain how the concept of biomimicry emerged, how it developed, its origins, its methodology, what it means and its relationship with sustainability and innovation. Addressing how biomimicry is applied in industrial design in education and proffesional area is important for the scope of the research. It specifically focuses on how it is conceived and applied in the Turkish context. To this end, a survey is conducted with students and academicians from three universities in İzmir with an industrial design department. The results of the survey allows for an insightful analysis of the state of biomimicry in industrial design education.

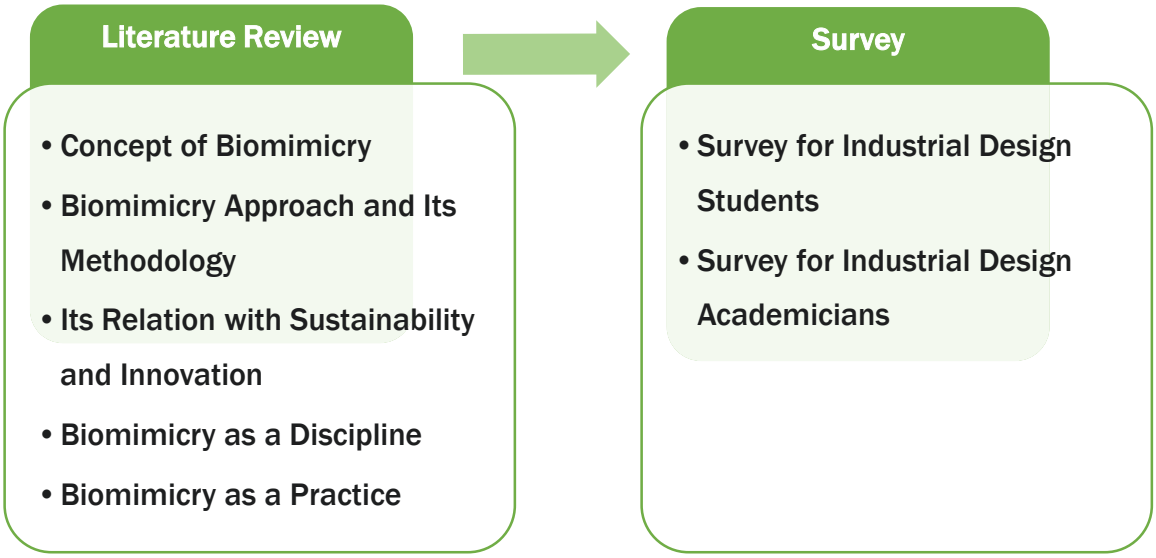

Figure 1.1. Research methodology of the thesis

1.4. Structure of the Thesis

This thesis includes five chapters:

Chapter 1 provides a brief introduction to the thesis by stating the problem definition, the objectives, research questions of the study, the research methodology and the structure of the thesis.

Chapter 2 includes the literature review adressing the revolutions of the world and their impacts, presenting the biomimicry notion and approach, its origins, its methodology, its relationship with sustainability and innovation.

Chapter 3 explores the state of biomimicry in the world and in Turkey by refering to biomimicry examples, studies and developments in the academia and in the industry.

Chapter 4 presents the analysis of the survey conducted to investigate biomimicry awareness and usage in industrial design education in Turkey.

Chapter 5 concludes the thesis with a summary of the study and the surveys' findings by revisiting the research questions.

CHAPTER 2

ADVENT AND DEVELOPMENT OF BIOMIMICRY

2.1. Revolutions and Their Impacts

To better understand the ever-increasing importance of biomimicry, why people want to establish a bond with nature again, and why some concepts have become important, one needs to understand the revolutions that paved the way for today's lifestyles, and their long-lasting effects. There are many important revolutions that have taken place in the history which had profound socio-cultural, environmental, technological, political and economic impacts on societies.

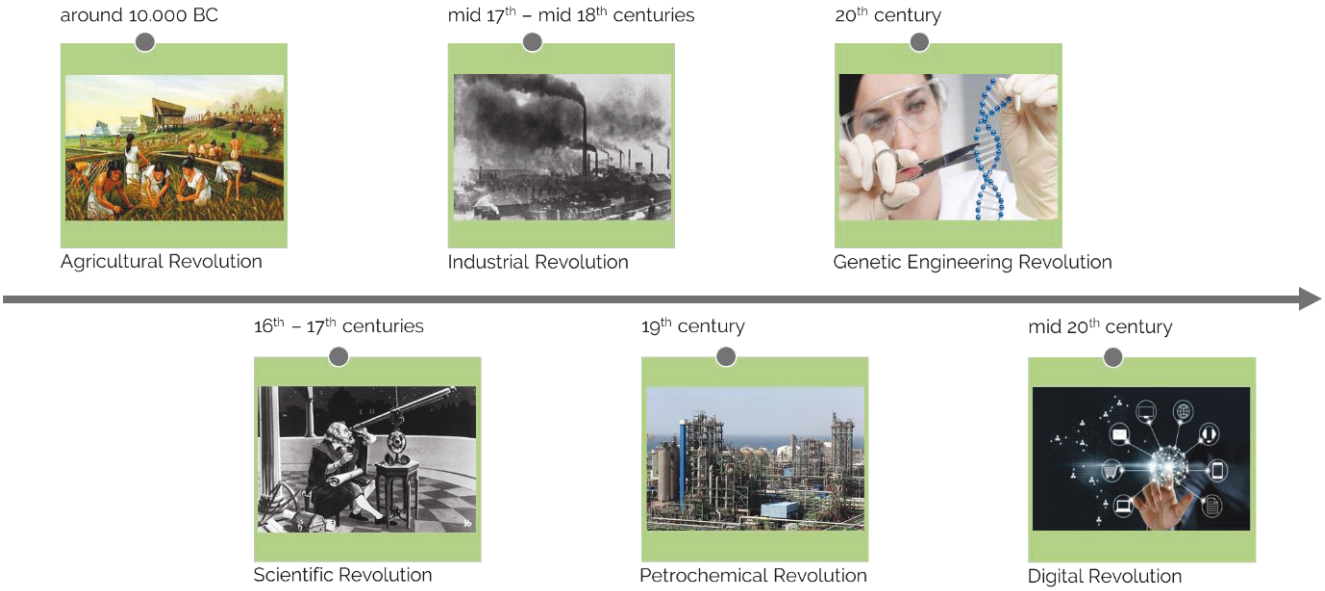

Figure 2.1. Timeline of revolutions

As claimed by Benyus (1997, p.5), imitating biological forebears appears completely reasonable, yet humankind has been going counter to this for a long time. Ten thousand years ago, this conflict began with the Agricultural Revolution. It gained momentum with the Scientific Revolution and later assumed dominance with the Industrial Revolution. These were followed by the Petrochemical and Genetic Engineering Revolutions, which broke connections

between man and the Earth (Benyus 1997, p.5) and the world is now in the era of the Digital Revolution (Figure 2.1). Among those two played a very important role in the transformation of people's socio-cultural, economic and environmental life and led to fundamental differentiations; one being the agricultural revolution, and the other industrial revolution.

2.1.1. Agricultural Revolution

Agricultural revolution, which is also known as Neolithic Revolution following the Palaeolithic era, occurred approximately around 10,000 BC. It was a period whereby human beings started production, agriculture, trading and took control of food resources. In short, thanks to these achievements, transition occurred from hunting to animal husbandry, from gathering to agriculture and farming. An agricultural society replaced primitive societies with the connecting of people to land and the concomitant emergence of small settlements. Settled lifestyle spread and became permanent as a result of production and domestication. Small village settlements developed. As Zıllıoğlu and Güvenç point out (1993), urbanization is usually associated with the Industrial Revolution, but the fundamentals of urbanization are indeed based on Agricultural Revolution. Small village settlements occurred during the Agricultural Revolution produced surplus products and began to engage in non-agricultural activities. This gave rise to the creation of towns and cities by communities that did not have to produce food to live. Also, factors such as regular family life, regularity of food supplies and going away from the dangers of hunting due to settled life led to population growth and the extension of human life (Zıllıoğlu and Güvenç 1993, p.50,52). Human relations got more complicated and concepts and values such as ownership, wealth, power, hegemony and hierarchy became common in social life (Nair 2009, p.310), (Aygün and Mutlu 2006, p.3). Such concepts and values, which did not exist in the earlier societies, brought a major change in the structure and mind-set of the new society (Aygün and Mutlu 2006, p.3).

Aygün and Mutlu indicates (2006) that above mentioned concepts and values affected and changed the perception of nature and world in an unprecedented manner. Social structure faced a major change. Individual ownership based on property ownership, hierarchy and domination caused deterioration of equality. People were unable to share resources equally. Possessive words such as "my" and "mine" replaced formerly used 'our' and people began to desire to rule over and own nature. Consequently, when unity and intimacy among people broke

down for reasons such as authority, division of labour and specialization, the relationship between man and nature was also affected. As a result, the famous binary contradiction human versus nature, which can be addressed as the primary source of ecological problems that still exist today, started (Aygün and Mutlu 2006, p.8).

With these, people began to see nature as an asset to be dominated. Unlike previous societies, people turned their backs on nature. In other words, social problems caused by social changes resulted in a shift in the perception of and attitudes towards nature. From then onwards, people constantly moved away from nature because of social problems (Aygün and Mutlu 2006, p.3,7,8).

2.1.2. Scientific Revolution

The Agricultural Revolution was followed by the Scientific Revolution which created significant transformations in societies across the world. However, it should be noted here that, unlike political revolutions, social, cultural and intellectual revolutions prove to be difficult to identify. The Scientific Revolution in Western Europe was one of those debates among historians as to when the revolution started, and ended and who were indeed the pioneers of this revolution sustain. Nevertheless, its impacts on peoples were far greater than any political revolution.

The Scientific Revolution was a period roughly between the sixteenth and seventeenth century; then occurred the numerous outstanding intellectual achievements and innovations in various fields such as European astronomy, physical science, natural philosophy and medicine (Harman 2013, p.1). It is mostly agreed that the period central in the history of science since it heralded the emergence of ‘modern science’. Canonical set of subjects such as astronomy, physics, mathematics, anatomy, physiology, and chemistry were explored by some influential individuals such as Copernicus, Tycho, Kepler, Galileo, Vesalius, Harvey, Descartes, Boyle, and Newton (Osler 2000, p.3).

New attitudes to the natural world were proposed about 1700. All of these new attitudes completely conflicted with the traditional conception of nature. For example; at first, it was thought that the earth was immobile and the centre of the cosmos. It was the general opinion that the central earth was embraced by the cosmos like the layers of an onion. Cosmos was a structure composed of crystal spheres. Also, nature was regarded as a living organism linked

by a web of hidden active powers. However, with the Scientific Revolution, the conception and expression of the universe changed. The earth was no longer at the centre of the universe. Now it was orbiting around the sun in the universe designed as a mechanical structure. Unknowns of nature started to be investigated through experimentation and mathematical analysis (Harman 2013, p.1).

This major shift led to a broader cultural transformation. The emergence of natural science, the acquisition of natural knowledge and the prospect of the control of nature opened up new horizons and caused agitation, confusion and excitement in the general public. Some people were excited by these new discoveries and knowledge while others were terrified of what they did not know and what it could do to their role in society. According to Herbert Butterfield, the Scientific Revolution was "the most important event in European history since the rise of Christianity". It was both "a cultural phenomenon" and "a revolution in scientific method and cosmology" (Harman 2013, p.1,2). Society began to give value and trust in the investigation of nature and its control owing to the intellectual transformation. Thus, steps toward the understanding and development of the importance of science were taken in modern society (Harman 2013, p.1,2).

The seventeenth century and its society were characterized by optimism and hopes about the potential for human advancement and by the cultural values associated with the pursuit of natural knowledge. People hoped that techniques in industry and agriculture would improve through science. Also, values of technological development, intellectual enlightenment and the glorification of divine wisdom in creating the world were stated by science (Harman 2013, p.2).

The conception of the cosmos and of man's place in nature changed with these important shifts. As new thoughts and beliefs began to emerge, they became menace to traditional assumptions. For example, society believed that man was unique in the universe and the cosmos had been created for the benefit of man. However, these beliefs began to be denied when people accepted that the universe was mechanic and there might be other worlds in infinite space. People began to believe less in traditional beliefs such as astrology, witchcraft and magical healing. On the other hand, the "belief in the potential of man to achieve scientific mastery of the natural world by means of technical innovation" was growing (Harman 2013, p.3). An essential key to the development of the mankind was completely provided by natural knowledge (Harman 2013, p.2,3).

In the seventeenth century, notable intellectual tensions arose between the revealed wisdom of Christianity and the natural knowledge of the philosophers. Before the Scientific

Revolution, theology was queen of all the sciences. However, this status, authority and dominance over other forms of knowledge came under re-evaluation because of the radical shift in man's conception of the cosmos. Claims of the pursuit of natural knowledge and Christian doctrine were in fact mostly compatible with each other and even the rational investigation of nature, which was God's design, held an important place in Christianity. The scientific movement of the seventeenth century declared the independence and integrity of the methods and theories of science. It was simultaneously stating that understanding God's intentions more completely would be possible with the study of nature by human reason (Harman 2013, p.3).

To sum up, the early modern society, Western view of the universe and humanity's place within it changed forever through the philosophical, religious, and cultural effects of the Scientific Revolution. The scientists and philosophers of the Scientific Revolution did not follow blindly accepted facts which the world and society was based on. They all challenged traditional views of the world. Thus, empiricism and scepticism which were new ways of thinking came to the fore. The idea that finding real truth could only be possible by observation and experimentation gradually spread. The modern scientific method of observation, hypothesis, experimentation, analysis and conclusion were developed and clarified in this period. As a result of increased knowledge, there was a challenge against the foundations of the revealed truths of the Christian church. The scientific revolution encouraged people to think for themselves, analyse society and reconsider previous beliefs about the world. The sense of individualism and the basic belief in equal rights were stimulated as a result of ideas born during this period. People began to question the rights of politicians and religious leaders to rule and to influence the thoughts and behaviours of them. Concepts of human beings' natural rights to life, liberty, property and freedom of speech were discussed and questioned. The modern world as we know it started to form as a result of this revolution.

2.1.3. Industrial Revolution

One of the most important milestones for the history of humanity is certainly the Industrial Revolution. It had an impact on all areas of life; political, economic, social and environmental. All countries and societies of the world, especially in Europe, were deeply influenced by it (Güzel 2014, p.158).

There were lots of important developments that paved the way for the Industrial Revolution. Advent of the Industrial Revolution was possible owing to many ideas and concepts such as freedom, equality, democracy, the republic and the human rights that were formed during the French Revolution and its precedent the Enlightenment (Güzel 2014, p.158).

The Industrial Revolution, which began in the mid-1700s and lasted into the mid-1800s, caused a permanent and profound transformation with worldwide effects. In general, the Industrial Revolution refers to a transition from the production based on human and animal power to the production based on machine power (Güzel 2014, p.158). Before the Industrial Revolution, life was mostly based on only agriculture, animal husbandry and trade by having simple tools and animal. With this revolution, machinery and factories appeared and an industrial society was formed (Edwards 2005, Introduction, para.8).

The technological breakthroughs such as James Watt's improved steam engine (1769), Edmund Cartwright's power loom (1783) and Eli Whitney's cotton gin (1793) can be given among the identifiers of the Industrial Revolution. The limits of human and animal power were exceeded with all these developments and innovations, and everything began to change. Factories were built and mass production started. Railways were paved. Transportation services were improved and travel became easier (Brynjolfsson and McAfee 2014, p.15). Productivity in the coal mines, the use of electricity, the gasoline engine and factory-based production methods, and the economic infrastructure of nation states were improved (Edwards 2005, Introduction, para.13). In other words, the path to modern life was opened thanks to these developments and innovations (Brynjolfssonn and McAfee 2014, p.15). Impact of production on many industries and economic growth began in those times had long-lasting effects (Edwards 2005, Introduction, para.17). Accordingly, these situations brought on the changes in social, economic, political and environmental aspects of everyday life. Social structure began to change with the increasing power of the bourgeoisie. In the field of economy, two different groups within the continuous struggle with each other for survival emerged. One fought for labour, one fought for capital. The remarkable transition from agriculture to industry and on the resultant decline in the values of humanity resulted in many social problems. Parallel to these developments, new factories were established where the settlements was more intense and new mine shafts were opened. Thus, migration began from rural areas to cities, because people wanted to live a more comfortable life by earning more money. This situation led to an urbanization and increase in population in the cities. Population growth caused formation of new settlements in city surroundings called suburbs. Subsequently, socio-cultural differences

between the city centre and its peripheries emerged. This situation gave rise to the creation of social problems. Inequalities between classes visibly increased and this brought many sub-problems such as poverty, unemployment and crime (Güzel 2014, p.158).

2.1.4. Petrochemical Revolution

The twentieth century was the age of oil. Petroleum with particularly in the form of crude oil and its refined products completely dominated the past century and shaped it. The modern industry was born when engineers and entrepreneurs started searching and drilling intentionally for petroleum in the 19th century. Petroleum became the centre of modern industrial society and an important strategic geopolitical target for nations. In the twenty first century, it is still a part of daily life. Petroleum is used both as the energy source and as raw material for the production of chemical and synthetic materials. Petroleum in the form of natural gas is quite important in the production of fertilizers, pesticides, cultivation, or transport. Petroleum and energy are still major basis/fundamental things that play a role in the construction of the entire structure of modern society (Vassiliou 2009, p.1).

In addition to its usefulness as an energy source, petroleum has also changed the world with its petrochemicals. The new synthetic materials including plastics, synthetic fibres, synthetic rubber, explosives, pesticides, and many others were obtained from petroleum (Vassiliou 2009, p.5). The advent of petrochemical-based polymer technologies and products brought about the most significant upheaval in the twentieth-century chemical industry (Chandler 2009, p.22). In the 20th century, petrochemistry developed. By the 1920s and 1930s, we began to hear of petrochemical products. In the 1920s, an interest in polymer based synthetic materials such as bakelite, celluloid, and cellulose acetate arised. In the 1930s, outstanding technological advances and notable new synthetic materials were presented especially by the efforts of Du Pont, Dow, and Union Carbide (Chandler 2009, p.23). They were used in World War II (Vassiliou 2009, p.5). Unforseen demands of World War II were also a precursor of Petrochemical Revolution (Chandler 2009, p.23). By the 1950s, widely abundant and inexpensive plastics spread throughout society. Subsequently, the petrochemical revolution accelerated (Vassiliou 2009, p.5). Modern society gave a lot of importance to synthetic and plastic solutions through petrochemical revolution following the World War II. Over time, crucial parts of people's lives were based on petrochemicals. Nowadays, petrochemicals

continue playing a crucial role in modern societies. For example, the foods, the household products and the homes and so on - that is to say, almost many outputs of modern industry are based on petrochemical products. These are chemical products made from fossil fuels such as petroleum (crude oil), coal, and natural gas. Various materials and products in many industries and in other fields such as agriculture, communication, and transportation have been produced thanks to petrochemicals. For instance, half of the main structure of one of the latest modern aircraft, the Boeing 787 Dreamliner, is made of modern synthetic materials. Furthermore, most of the tools on which we depend for our daily lives are obtained from petrochemicals. Cars, computers, cell phones, children's toys, pesticides, fertilizers, household cleaning products, and pharmaceutical drugs are just some of these tools. The discovery of petrolum/oil marked the beginning of an era. Civilization found the source of life and the face of the world has changed in a very short period of time with that discovery. Riding horse-drawn carriages progressed toward driving automobiles, using planes and even landing on the moon. Plants and animals that are embedded in the earth's crust, are exposed to intense heat and pressure for a long time. They undergo anaerobic decomposition with time, so that fossil fuels are formed. Today these fossil fuels that are still the primary source to meet the energy needs of humanity, are the basis of petrochemicals. Considering the swift global consumption of petroleum, it should be known that these sources are finite (Shukla and Shukla 2012).

With the Petrochemical Revolution, the world may have made great progress in social and economic terms, but the products and petrochemicals given to us by the petrochemical industry have also badly affected people and the world in many respects.

It is a fact that the petrochemical industry has provided us with a wide range of useful products and novel materials, but it is also true that petrochemicals and their derivatives have greatly damaged the health of the living beings and the earth's ecosystem. With more advanced research and advanced tools we have today, we are able to measure the dangerous and toxic effects of the petrochemical revolution on human physiology and the environment (Shukla and Shukla 2012). Human life and the environment are being negatively affected by the continuous release of petrochemicals to the ground, air, and water. From the perspective of human physiology, "since petrochemicals can be absorbed through the skin or might be ingested, they can accumulate in human tissues and organs such as the brain and liver and can cause brain, nerve and liver damage, birth defects, cancer, asthma, hormonal disorders, and allergies." (Shukla and Shukla 2012). For example, it is claimed that by the name of bisphenol A (BPA), which is used in the manufacture of many plastic-based products and epoxy resins, has an

estrogenic effect on humans and has a potential role in disrupting the normal balance of other hormones such as the thyroid. Moreover, BPA, which is also used in the construction of plastic baby bottles, can affect the normal development of the baby by accumulating in certain tissues of the baby (Shukla and Shukla 2012).

As succintly put by Saçlı (2009, p.4), the second largest movement that substantially changed human life in terms of environment followed the discovery and subsequent itensive use of fossil fuels. Coal, oil, natural gas that are used as the main energy sources of modern industrial age are fossil fuels. There is already a danger of depletion of fossil fuel resources in the world. Because the developed world has encouraged consumption, not protection, the end result is a tremendous increase in the use of the world's limited resources and widespread pollution (Saçlı 2009, p.100). Many chemicals such as detergents, insecticides and herbicides, plastics, synthetic materials and their toxic wastes are products of petrochemical industry and all these damage the environment (Saçlı 2009, p.8). In brief, the petrochemical industry is seen as the number one culprit of the environmental destruction.

The impact of the petrochemical industry on the economy should not be overlooked either. As Saçlı (2009, p.9) explains, the market value of synthetic products is lower than that of agricultural products, and therefore, it creates an unfair competition which has become stronger over the years. Furthermore, small farmers who are tied to traditional farming methods have been defeated and removed from the economic system due to the agriculture industry that is controlled by big companies. For instance, a high yielding seed industry is developed through biotechnology. These industrial breakthroughs were presented as revolutionary innovations at first, but afterwards they have become controversial as their damage to the ecosystem became clearer. Also, as mentioned earlier, coal, oil and natural gas dominated as energy sources in the 19th and 20th centuries. Over time, only hydroelectric and nuclear power plants have been offered as an alternative to these, but these alternatives have either fallen into spontaneous regressions over time or there have been economic and environmental debates regarding their use. As a result, the world is still dependent on oil and its by-products in terms of economy (Saçlı 2009, p.100).

2.1.5. Genetic Engineering Revolution

The beginning of the Genetic Engineering Revolution dates back to 1953 when Francis Crick and James Watson revealed the structure of DNA. Along with that, mankind now has the opportunity to play with "the blueprint of life itself" even if it was rather unsystematic to begin with. For example, the clonening of a sheep called Dolly was an incredibly large development, but scientists have made hundreds of unsuccessful attempts to make it happen. As another example, a gene can be transferred from a fish into a strawberry plant to create a frost-resistant fruit, but it is not known what effect this genetic play will have on things like other genes and the organism's life span (Morgan 2003, p.88). The studies and developments in this area continued rapidly during the 1970s. According to the brief history of the genetic engineering mentioned in the book of "*Genetic Engineering: A Reference Handbook*" (Vine 2006, p.2,3), research has gained momentum as recombinant DNA technology has been discovered and used. Vine describes (2006, p.23) this technology as follows:

> "Recombinant DNA technology is a variety of enzymatic and chemical procedures used to manipulate DNA in the test tube to form selected combinations of sequences. By these techniques, genes can be added to or removed from the genome of a cell, or existing genes can be modified in some way. The process of changing the genetic complement of a cell or a whole organism by this process has come to be known as genetic engineering."

There were now genetic engineers who could rearrange the DNA code according to their own wishes and purposes and a new era, genetic engineering has begun (Vine 2006, p.1,2). Many new things were chemically discovered and made before genetic engineering. Now all these new things have begun to be made biologically (Vine 2006). As Patra and Andrew pointed out (2015, p.1), genetic engineering based mainly on science, and technology has been developed to prevent the spread of a variety of emerging diseases resulting from genetic mutation. For example, cystic fibrosis, diabetes, and some other diseases are being tried to combat by changing the way genomes are formed through genetic engineering. Also, illnesses in unborn or born children can be detected with genetic screening and they can be tried to treat, so it can be clearly seen that genetic engineering has a potential to improve the quality of life and provide a longer life. Genetic engineering has not been limitted to human health, its applications have been very broad. These applications are biomanufacturing, agriculture,

industry, bioremediation, medicine and health, gene therapy, pharmacogenomics, DNA and the law, biological warfare and bioterrorism (Vine 2006).

Genetic engineering has been a development that divides people's ideas into two. Some have fully supported this development and some have completely disagreed with it because of the effects and controversial issues surrounding it. As Vine (2006, p.1,2) explains, from a positive perspective, this new area was a way to produce raw materials for industry, developing food, finding new medicines, preventing pollution, recycling wastes and finding long-lasting treatments for inherited diseases by modifying bacteria, yeasts, plants and animals. According to others, genetic engineering dragged the human race into and destroyed the natural order of the world. The world's ecosystem has deteriorated, uncontrolled spreading microorganisms provided resistance to antibiotics, and these new diseases have caused problems, and the sanctity of life has been degenerated.

In addition, as noted in Uzogara's review (2000, p.179),

> "Some of the specific fears expressed by opponents of GM technology include alteration in nutritional quality of foods, potential toxicity, and possible antibiotic resistance from GM crops, potential allergenicity and carcinogenicity from consuming GM foods. In addition, some more general concerns include environmental pollution, unintentional gene transfer to wild plants, possible creation of new viruses and toxins, limited access to seeds due to patenting of GM food plants, threat to crop genetic diversity, religious, cultural and ethical concerns, as well as fear of the unknown."

At first, people were concerned about the use of recombinant DNA technology because genetic engineering and its technologies had just emerged. There was no recognition, and there were questions in people's minds about whether it was safe to use or not. Afterwards, concerns about the impacts of the application of this technology have continued to raise. For example, the environmental impacts of the increasingly common genetically modified organisms have become a matter of big debate from the past to the present. The debates later turned towards the social impacts of what can be done with the use of genetic engineering technology. There was now knowledge and ability to manipulate genes in societies. The issue of how those who have this power will use this technology and how to control it made the world anxious. Genetic engineering, which was once a scientific issue, has now become a social problem. Ethics was the other important aspect. The impression that genetic engineers are "playing God" worried people immensely. Thus, the lack of knowledge about its actual effects and using human genes

in non-human organisms to create new forms of life have become major topics of debate (Patra and Andrew 2015, p.2). Another concern has been the economic impacts of genetic engineering technology. New industries were born as a result of genetic engineering, and these have created economic changes (Vine 2006, p.4,5). In sum, there are potential health and environmental, agricultural and economical risks regarding this field and technology despite its potential to carry humanity far ahead.

2.2. Notion of Biomimicry and Its Origins

Janine Benyus, biologist and the American pioneer of "biomimicry" discipline, documented and integrated her findings about biomimicry on the book "*Biomimicry – Innovation Inspired by Nature*" (1997). In her definition, biomimicry is a "new science that studies nature's models and then imitates or takes inspiration from these designs and processes to solve human problems" (Benyus 1997). As Benyus (2011, p.2) further described, biomimicry is "learning from and then emulating natural forms, processes, and ecosystems to create more sustainable designs. Biomimicry is studying a leaf to invent a better solar cell, or a coral reef to make a more resilient company". The main idea in this view is that nature has already solved many of the the problems of people. Nature has already had the solutions of problems such as energy, food production, climate control, benign chemistry, transportation, collaboration, and more (Benyus 2011, p.2). Biomimicry is a deep and extensive field that can be applied to find a solution to technical and social challenges at any scale. For this, as Janine Benyus (2011, p.2) points out, "biomimicry is a discipline of design, a discipline, a problem-solving method, an ethic of sustainability, a movement, a stand against nature, a new way of seeing and valuing biodiversity". Biomimicry proposes the study of nature from a systems point of view, in which all elements are interdependent. "Biomimicry is an evolving discipline that studies nature's 'best ideas' and then imitates these designs and processes to solve human problems. Studying a leaf to invent a better solar cell is an example" (Flint 2013, p.111). Biomimicry with its motto "innovation inspired by nature", aims to create products, processes, and policies or in other words, new ways of living. They are well adapted to life on earth over the long haul (Flint 2013).

Word of biomimicry is etymologically based on a combination of the Greek roots; In Greek, bios means life and mimesis means imitate. When the term biomimicry first appeared

in scientific literature in 1962 and its usage was increased over time especially among scientists working on the field of material science in the 1980s (Pawlyn 2011, p.2). However, this term showed its actual emergence three decades later after the 1960's in the book of Janine Benyus as mentioned above. In this book, biomimicry was a term informing a new era of design with its enormous potential (Benyus 1997). Biomimicry in 1962 was a general term including the terms "cybernetics" and "bionic" (Volstad and Boks 2008, p.2). In the beginning, definiton for biomimicry was "referred to all kinds of imitation of one form of life by another one", while the definition of bionics was "…an attempt to understand sufficiently well the tricks that nature actually uses to solve her problems." (Bensaude-Vincent, Arribart, Bouligand, and Sanchez 2002, p.1). That is to say, it is understood that the definition of term bionics at that time is more or less closer to the definition of term biomimicry has been used by material science since the 1980s. "Biomimetics" frequently and, "bionics" less frequently, was used by some researches at the time (Pawlyn 2011, p.2). Biomimicry later became a preferred term through Janine Benyus (1997). As Pawlyn (2011, p.2) has pointed out, there has been a huge swell in interest in biomimicry over the last decade thanks to individuals in the fields such as biological-sciences writer Janine Benyus, Professor of Biology Steven Vogel and Professor of Biomimetics Julian Vincent. They and other individuals have written extensively on this subject. According to Julian Vincent, biomimicry is "the abstraction of good design from nature", while it is "the conscious emulation of nature's genius" according to Janine Benyus (Pawlyn 2011, p.2).

Although Benyus comes to the fore with an ecologically motivating view of biomimicry, today's interest in biomimicry is not limited to it. Today, one of the crucial reasons of the rapid increase in interest in biomimicry is that human beings can analyze nature for the first time in humanbeings' history. It now has its brainpower and tools to learn from the 3.8 billion years of research and development of nature. Besides, in order to realize biomimicry successfully, professionals from many different fields have been brought together and the necessary networks have been created for them to work together. The potential that biomimicry has is enormous. In order to support this, Julian Vincent (2001, p.3), professor of biomimetics at the University of Bath, suggests that: "...at present there is only a 10 percent overlap between biology and technology in terms of the mechanisms used." (as cited Volstad and Boks 2008).

Many studies have shown that biomimicry is still not fully understood or confused term. According to Benyus (2011, p.6), in order to understand what biomimicry is, it is first to understand what it is not. People actually do different things when they think that they understand and practice biomimicry correctly. Since the emergence of biomimicry, there have

already been some terms and notions that are almost synonymous and analogous to biomimicry, which are worth investigating. Even if briefly, these needed to be rewieved to better understand biomimicry through its different definitions and views to distinguish the difference from other bio-inspired approaches; in short, to understand what biomimicry is and what is not and to better understand why this very term is preferred in this thesis is necessary.

There are many notions such as “biomimetics”, “bionic”, “biognosis” and “bionic creativity engineering” which are more or less synonymous with biomimicry, and also disciplines such as “biomechanics” and “biophysics” which are bordered on biomimics (Volstad and Boks 2008, p.2). There are many ways to use nature in design. Natural analogy, which is frequently used to combine nature and design, also has many different forms of application. The use of natural analogy in different fields creates different names such as ‘biomimetics’, ‘bionic’, ‘biomimicry’, ‘bio-inspiration’. In fact, all of these terms have almost the same meaning: copied, adapted or converted from nature (Vincent 2007, p.8). Firstly, in order to eliminate the confusion about what biomimicry is, it should be stated that the terms mentioned above biomimicry and biomimetics are basically synonymous. Biomimetics depending on the the practical use of mechanisms and functions of biological science in engineering, design, chemistry, electronics and so on, is a relatively young study. Julian Vincent (2007) takes biomimetics synonymous with “biomimesis”, “biomimicry”, “bionics”, “biognosis”, “biologically inspired design” and similar words and phrases. Biomimetics was first coined by Otto Schmitt. If his doctoral thesis is exemplified, Otto made an effort to complete to produce a physical device that mimicked the electrical movement of a nerve (Vincent 2007, p.8). The difference between biomimicry and biomimetic was defined frankly by Reed, Klumb, Koobatian and Viney (2009, p.1572) as: In addition to the same meaning, biomimicry is a design process; biomimetic is the field of study in which that design process is applied. Term of biomimicry is often preferred in design, and term of biomimetic is mostly preferred in engineering (Boga-Akyol and Timur-Ogut 2016, p.21). The single notable difference between the terms biomimetic and biomimicry is that biomimetic can sometimes be applied to fields of endeavour, such as military technology, while the term biomimicry is particularly used when focusing on developing sustainable solutions (Pawlyn 2011, p.2). Secondly, the other related word bionics was coined by Jack Steele of the US Air Force in 1960. The term put forward in a meeting at Wright-Patterson Air Force Base in Dayton, Ohio is “the science of systems which have some function copied from nature, or which represent characteristics of natural systems or their analogues” (Vincent 2007, p.8). There are some terms

quite different from the biomimicry that need to be clarified; “bio-utilisation”, “bio-assisted”, and “biophilia”. Bio-utilisation is related to direct use of nature for beneficial purposes. For example, planting in and around buildings can be given to produce evaporative cooling (Pawlyn 2011, p.2). Benyus (2011, p.6) explains that “Bio-utilization entails harvesting a product or producer, e.g. cutting wood for floors or wildcrafting medicinal plants. It is also distinctly different than bio-assisted technologies, which involve domesticating an organism to accomplish a function, e.g. bacterial purification of water or cows bred to produce milk.” Biomimicry refers to nature and takes ideas from it; they look at an organisms, a physical blueprint such as the structure of a lotus plant that forces back dust and dirt particles, a process step in a chemical reaction such as in the case of creating artificial photosynthesis to apprehend and store energy from sunlight, or an ecosystem principle such as nutrient cycle already used in industrial symbiosis, and borrow ideas from them. The original remains always in nature so that others can be inspired (Benyus 2011, as cited in Petrig 2013, p.8). Biophilia popularized by Biologist E.O. Wilson argues that there is an instinctive bond between humans and other living organisms (Pawlyn 2011, p.2).

Tables are presented in a Biomimicry Primer (2011) and in the Biomimicry Resource Handbook (Baumeister 2014). These tables show and distinguish between practices that do not fit well into the web of life and even destroy this web of life. Mal-adapted innovations encompass a niche or higher level construct such as ecology or biomass. They are extinct or contribute to the depletion of other species. Well-adapted innovations have a suitable cyclic structure (Appelman, Bosch, Brenk, Groeneweg, Holzapfel and Velde 2017, p.5). Another major significant aspect is the differences between well-adapted and mal-adapted practices. Mal-adapted practices are not life-friendly and sustainable, because they only handle and mimicks the form. (Benyus 2011, as cited in Petrig 2013, p.8). If so, the following new table (Table 2.1) of combination of these two tables can be used to describe and classify the practices in this developing field. If so, the following new table of combination of these two tables can be used to describe and classify these terms and explain their differences from biomimicry.

When biomimicry and the bio-inspiration approaches are compared, the common point of both approaches is that they want to learn from nature. Additionly, it should be mentioned here that ethos, (re)connect, and emulate; the three conceptual cornerstones underlying biomimicry distinguishes biomimicry from other bio-inspired approaches. When the essential elements come together, the bio-inspired design becomes biomimicry (Baumeister 2012, as cited in Rovalo 2017). These will be discussed in detail in other sections.

Table 2.1. How Does Biomimicry Differ from Other Bio-Approaches (Benyus 2011, Baumeister 2014)

BIO-MIMICKED (emulate the producer)	**BIO-UTILIZED (acquire the product or producer)**	**BIO-ASSISTED (domesticate the producer)**	**ADAPTATION or FIT**
Mimicking form, process and ecosystem. o Water-based chemistry o Mimicry of spider's manufacturing process o Bio-bricks (growing bricks with minerals water and bacteria)	o Sustainable harvest o Organic agriculture o Agro forestry o Snake skin to heal burned skin	o Natural breeding o Natural breeding to maximixe silk production o Mycorhizae to support growth and improve soil conditions o Trained dogs to support physically challenged people	Fit Well-adapted
Mimicking form alone; heat, beat and treat processes. o Nylon and kevlar manufacturing o Shinkansen bullet-train o Fasto elephant trunk	o Unsustainable harvest o Over-harvesting of silkworm silk o Over fishing o Carbon-based agriculture	o Transgenics o Splicing "silk" gene into goats to produce silk proteins in milk o Test animals for the cosmetics industry	Unfit Mal-adapted

It can be argued that nature is not a new concept. From early human history, nature has found voice in every level of the design process. Artists, architects and engineers have influenced nature throughout the centuries. Natural shapes, patterns, structures, construction principles and techniques have been used in many ways and forms. History is full of examples of these approaches integrating the relationship of nature and design (Ritu Vasu 2013).

The use of nature in design is a very old act that has been carried out since the history of mankind. Since the beginning of the relationship between people and artificial things, they have always looked at the nature. (Boga-Akyol and Timur-Ogut 2016, p.21). There are many examples demonstrating how old an idea biomimicry is. For example, although unproven, it is

believed that human-made domes were probably inspired by the form of eggs (Pawlyn 2011, p.5). Although the term biomimicry began to be heard only a few decades ago, human beings have actually been learning from nature and copying it for thousands of years. Our ancestors observed and mimicked the hunting strategies of predators in the wild. Features of scales in fish and reptiles to build body armor and the geometric proportions of nature in art and architecture were mimicked (Brennan 2015, p.440). Biology is a phenomenon that has inspired design since prehistoric man. Spears were made of the teeth of animals. The effective sneak-and-pounce hunting technique of large predators was mimicked. The new one is the development of a methodological framework while trying to transform these biological strategies into design innovations (Kennedy, Fecheyr-Lippens, Hsiung, Niewiarowski and Kolodziej 2015, p.66). What is new today is that the imitation of nature becomes more systematic and elaborate, because the techniques used to imitate nature have changed with the developments in technology (Boga-Akyol and Timur-Ogut 2016, p.21). Being always ahead of his contemporaries, Leonardo da Vinci was obviously a pioneer in this regard thanks to his foresightedness. He observed and worked on birds flying; as a result, he designed some machines. Nevertheless, he could not achieved to fly (Vincent 2007, p.9). A new alternative for the production of paper instead of using cotton and linen fibres was thrown out by the French entomologist Réne-Antoine Réamur around 1719. His suggestion was to use wood pulp as wasps do in nature. Also, Sir George Cayley did a study on the naval architecture for developing ship hulls with lower coefficients of drag in 1809. Therefore, he searched the streamlined form of dolphins and trout (Pawlyn 2011, p.5).

Since designers have been trying to meet an increased demand for sustainable products, biomimicry has developed incredibly in the last 15 years. As a result, it is possible to find many contemporary examples of it such as:

> "...the invention of Velcro around 1948, ...the Mercedes biomimetic concept car is inspired by the surprisingly streamlined and roomy boxfish, olympic swimsuits based on shark skin, and new types of drill designed after a wood wasp's ovipositor have all delivered a superior product by learning from the functions delivered by adaptations in natural organisms." (Pawlyn 2011, p.5)

As Pawlyn (2011, p.5) points out, biomimicry has been used primarily in building design until today and this use is very limited. For example, termite mounds and spider webs, which are frequently quoted and cited in researches as examples, can be mentioned. In recent years, biomimicry has developed very rapidly in other areas. One of these areas is industrial

design. In recent years, biomimicry has developed very rapidly in other fields such as industrial design and medicine.

Hollington (2007, p.35) argues that biomimetic is a technique, not related to appearance and style. A product can be designed as a zoomorphic but this is not necessary. Hollington (2007, p.35) exemplifies British-born design chief Jonathan Ive's works at Apple. Today's fashion is a kind of post-Bauhaus minimalism. For Apple's design language, it looks like a sharp and machine-like, but thanks to its simplicity and the elaborate use of materials, its designs become humane and friendly. The hard-edged and minimal phone can be equipped with many innovations if it is designed with a biomimetic/biomimicry approach. That is why it is important for designers to understand that biomimicrin does not necessarily affect the appearance and style of a product, even if it is capable.

2.3. Biomimicry Approach: Its Methodology

In biomimicry, nature is seen as a source of ideas rather than a source of goods. In the industrial culture of the world people living this is now a new way of viewing and a new way of valuing other organisms. As biomimicry is practiced by more people and people realize what can be learned living systems, the claim of the biodiversity conservation begins to occur spontaneously (Benyus 2011, p. 7).

All in all, if people want to consciously emulate nature's genius, the natural world is dealt with consciously and scientifically. In biomimicry, people look at nature as model, measure and mentor. This is the *biomimicry approach*. Flint (2013) explains this in detail:

1. Nature as a model:

Studying nature's models and emulating these forms, process, systems, and strategies to solve human problems belongs to a new science, biomimicry. Achieving sustainability can be given as an example. The Biomimicry Guild and its collaborators have developed a practical design tool. It is the Biomimicry Design Spiral and it is for using nature as model.

Macnab (2012, p.210) mentions about The Biomimicry Design Spiral in her book, "*Design by Nature: Using universal forms and primciples in design*." The Biomimicry Design Spiral describes the biomimicry process of consulting life's genius and serves as a guide to help innovators use biological processes that took the natural world for inspiration. The processes can then be evaluated to make sure that the final design mimics nature at all levels which are

form, process and ecosystem. Biomimicry as a tool can be used by innovators from various areas such as engineering, management, design, architecture, business etc. to create more sustainable and enduring designs. They can use these spirals to guide the design process, or to incorporate them into existing design processes.

Macnab (2012, p.210) continues by saying that this process has the reiterative nature, so spirals are used to emphasize this – that is, one challenge is solved and after it is evaluated how well it meets life's principles, thereafter another challenge often arises, and the design process begins anew. According to the literature, biomimicry as a design process can be summarized in two basic segments of design spirals. These are Biology to Design and Challenge to Biology (Figure 2.2).

The first approach is identified as the indirect method. It is informed by Nature. In this approach, the biologist or ecologist are responsible for the identification of a biological feature and its potential applicability to human design. When working with the Biology to Design Spiral, a designer or student first observes the strategies and adaptations in nature and then considers how to apply that biological knowledge as a directive for a design project. It has a disadvantage from a designer's point of view, because the designer has no control over the design parameters from the beginning of the process. This method provides potential to contribute to human design in unprecedented ways, although it requires strong cross-disciplinary collaborations. The second approach is labeled as the direct method. It requires a designer to formulate a design problem and a biologist to find a related design solution in nature. When working with the Challenge to Biology Spiral, a designer or student first identify a design problem and then explore the natural world for solutions to that challenge. In this case, the initial objectives of the design are controlled by the designer. On the other hand, human design can remain surface oriented, if the designer makes the scientific research without an in-depth understanding of the topic or not to make a good translation of biological knowledge into design. In either case, strategies that are related to natural principles and processes are used by designers (Macnab 2012, p.210).

Benyus (2011) proposes that nature can not be taken only as a model to learn from life's genius. Besides, nature should be considered as a measure and a mentor. Benyus (2011, p.7) considers the following questions to be asked: "What nature should do here (nature as a model), what nature does not do here (nature as a measure) and why or why not? (nature as your mentor)."

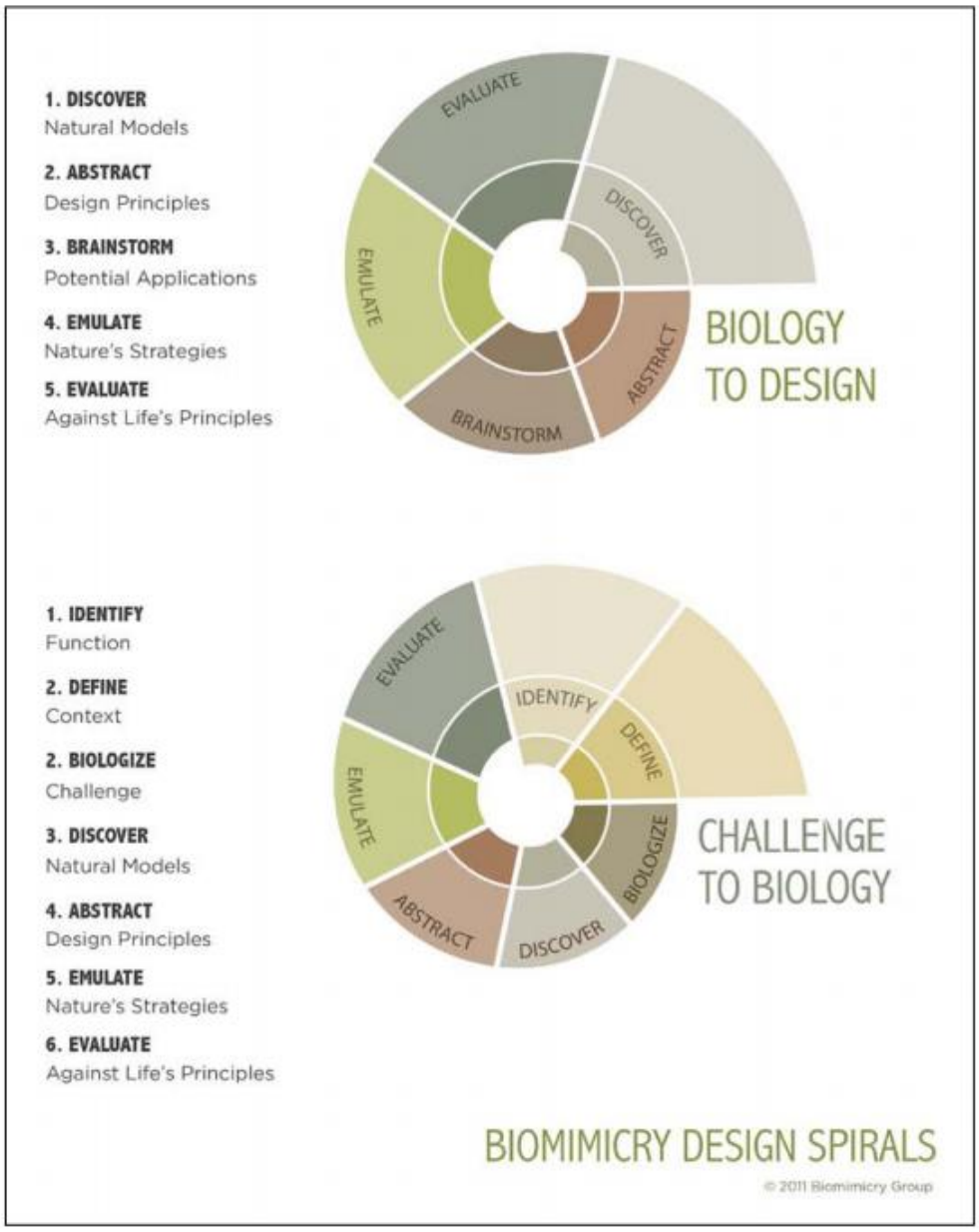

Figure 2.2. The Biomimicry Design Spirals showing approaches to applying nature's solutions to specific design problems (Source: Macnab 2011, p.211)

2. Nature as a measure:

Biomimicry uses an ecological standard, because it judges the sustainability of our innovations. Nature has learned what works and what lasts after 3.8 billion years of evolution. Life's Principles (Figure 2.3) provides taking the nature as measure and it is embedded in the evaluation step of the Biomimicry Design Spiral. Life's Principles constitute a framework and a filter through which designer tests solutions against nature's attributes. Life's Principles includes the nine laws of nature. Janine Benyus considers that this is an essential tool for measuring sustainability.

Figure 2.3. Life's Principles framework (Source: Bakırlıoğlu 2012, p.23)

3. Nature as a mentor:

Biomimicry is considered as a new way of viewing and valuing nature. It is based not on what we can extract from the natural world, but what we can learn from it.

Biomimicry also proposes another tool called Asknature.org:

> It is a "tool proposed considering the challenges towards incorporating the biology knowledge. It is a free, open-source project, built as an online inspiration source for natural systems and organisms. It aims to bridge the gap between biologists who want to share information on nature

and designers, architects, engineers, etc. who wants to make use of such information emerged from nature to develop solutions (Benyus n.d.). It is a systematic approach to classify natural systems and organisms through strategies inspired by nature. In order to achieve that, the website offers a Biomimicry Taxonomy, through which the strategies that are of interest can be found, and the examples of natural systems and organism can be reached." (Bakırlıoglu 2012, p.25)

"The field of biomimicry encompasses a broad range of strategies and approaches, and several research groups and institutes are specialized in this area, each with a different approach and using different terms such as biomimetics, bionics and bio-inspired design (Vincent 2009, Bhushan 2009)." (de Pauw, Kandachar, Karana, Peck and Wever 2010, p.7)

At it's most basic, biomimicry is based on the three core values which is called The Essential Elements. These can also so-called seeds of biomimicry: ethos, (re)connect, and emulate. Also the practice of biomimicry is embodied by these three complementary foundations (Baumeister, Tocke, Dwyer, Ritter, and Benyus 2012, p.4). By combining the Essential Elements together, bioinspired design becomes biomimicry.

Ethos: The ethos element constitutes the essence of underlying philosophy for why biomimicry is practiced. Ethos, the point where biomimicry intersects with sustainable design, arises from the emulation of nature while creating conditions for life (Baumeister 2012, as cited in Rovalo 2017). Biomimicry, an approach to sustainability ethics, uses its own Life's Principles to evaluate the "rightness" of innovations, since nature has already learned what works, what fits and what lasts after 3.8 billion years of evolution (Benyus 1997, Baumeister 2012, as cited in Petrig 2013). In short, the ethos element is about searching for sustainable designs which is to support a sustainable world.

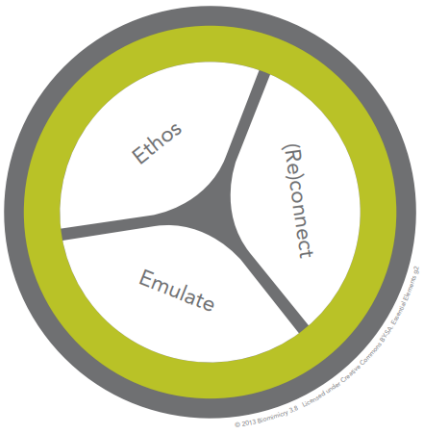

Figure 2.4. The Essential Elements (Source: Biomimicry.net, Biomimicry 3.8 2013)

(Re)connect: The (re)connect element represents the understanding that we humans are part of nature, and not separate from it. It tries to reinforce the understanding that nature and people are actually intertwined. At the same time, this element is a practice and a mindset that explores connection with the rest of nature as a source of creativity and wisdom (Baumeister 2012, as cited in Rovalo 2017). (Re)connect deals with having a different mentality about how nature is perceived. The targeted is to learn from nature instead of extract from it, thus an era that values nature can be created (Benyus 1997, Baumeister 2012, as cited in Petrig 2013). This element is the place where biomimicry and biofilm are strongly connected (Baumeister 2012, as cited in Rovalo 2017).

Emulate: The emulate element is learning from the principles, patterns, strategies, and functions that found in nature, then applying learned lessons to the design to solve human problems. This element represents innovation and design aspect of biomimicry (Baumeister 2012, as cited in Rovalo 2017).

From these it can ben understood that biomimicry stretches widely into a number of spheres and there are many different ways of approaching biomimicry. In order to narrow the scope of the research, some points should be discussed and explained.

2.4. Biomimicry in Terms of Sustainability and Innovation

Today's industrial and economic practices cause the myriad of problems and many individuals, companies, and organizations are searching for sustainable solutions. Considering environmental and social degradation caused by the poorly designed industrial systems, products, and buildings, for the field of design and all of its sub-diary professions: architecture, industrial design, interaction design, engineering, etc. has become a major focal point for sustainability (Stegall 2006).

In almost every design discipline, the terms of "sustainable", "green" and "environmentally friendly" have become catchphrases (Stegall 2006). To prevent pollution and overconsumption from ruining the planet and the natural resources, also governments, communities and industries are working by practicing on design. There is an urgent and important need to make all industrial products and processes "sustainable" to address pressing issues such as climate change, resource scarcity, environmental degradation, growing social

challenges, perceived deterioration of community; with the general discourse, good for people and planet (Young 2010).

The concept of sustainability is becoming increasingly important all over the world. Sustainability has too many synonymous and buzzwords such as green (not that green is any clearer) or eco, meaning the environment. Also, it has other buzzwords from a business point of view. These are environmental management, corporate social responsibility, greening, industrial ecology, stakeholder management, life-cycle management, pollution prevention, sustainable development, design for environment (DfE), green design, urban reinvestment, brownfield redevelopment, ISO 14001, waste reduction, closed loops, resource productivity, sustainable technology, radical transactiveness, systems thinking, corporate governance, and clean technology (London, Hart and Kacou 2011).

Definition of sustainability can change according to different groups, individuals, so this makes it sometimes difficult to discuss it. It can be interpreted as a threat to a way of life, meaning less of everything or a rational blend of constraints both large and small and a way to serve human needs on all levels (Shedroff 2009).

The Brundtland Commission's definition (1987) on sustainability is the most agreed one: "(Use and) development that meets the needs of the present without compromising the ability of future generations to meet their own needs." and Shedroff (2009) sums up this definition simply as "Don't do things today that make tomorrow worse."

Sustainability is more than all of this. It refers to environmental, human and financial issues.

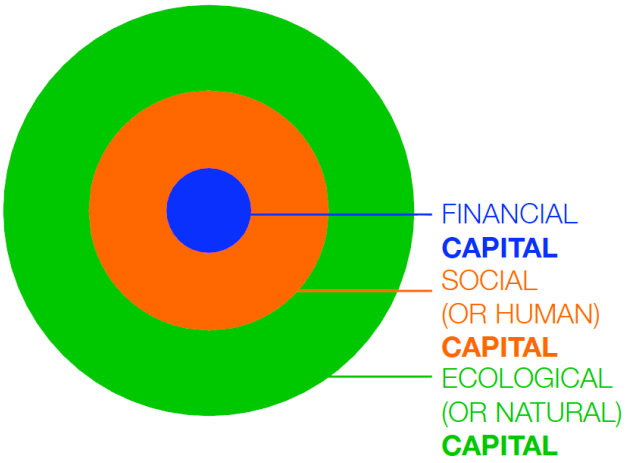

Figure 2.5. A diagram of relationship between the "three pillars of sustainability" (Source: Shedroff 2009)

Walker and Giard (2013, p.4) explain the pillars of sustainability:

> "...the most prominent features of postmodernity (or the late modernity as it is sometimes referred to) are its recognition of social considerations in the form of human rights and concerns about social equity (Smith 2001, p.12; Wilkinson and Pickett 2009) and an increasing recognition of the environmental consequences of human actions. These social and environmental concerns are two of the main pillars of sustainability and major factors in any comprehensive understanding of design for sustainability. Economic issues are usually identified as the third pillar,..."

If this is described in more detail, as can be seen from Figure 2.5, sustainability, then, needs to cover: people (known collectively as "human capital"), cultures, needs and desires; the environment that sustains us (known as "natural capital") and the financial mechanisms (known as "financial capital") that make most forms of design thrive (Shedroff 2009).

Designers have a crucial role in making the world more sustainable. They need to find ways to achieve a more sustainable financial (economic) and social order, and ensure that by providing solutions to one set of environmental problems they are not increasing others (Stegall 2006).

Until the mid-1970's, eco-design was not a discrete discipline. It first emerged to try to integrate environmental concerns into the design of artefacts and the built the world. On the other hand, earlier concerns expressed by ecologists such as Leopold and Naess; and socio-economic and political critiques and visions for a more sustainable worldview, offered by people such as Mumford; Bookchin, Packard, Nader and Schumacher are the roots of eco-design. The citations are made from the publication of Rachel Carson's Silent Spring in 1962 as a catalyst for environmental concern and Victor Papanek's Design for the Real World in 1971 as sparking the emergence of the eco-design movement.

The second wave of environmental concern arose with The Bruntland Report (1987). This was about the green consumer revolution. Design was regarded as important in the development of more mainstream eco-products and in enhancing consumer acceptance of these.

In the early 1990s, designers were beginning to take these messages on board and 'design for the environment' was being placed on the corporate agenda (Mackenzie 1997; Burrall 1991). There was a growing movement aiming to broaden the remit of designers. This attempt was being made by creating a vision for sustainable everyday life that re-defines the need for different types of goods and services. Ezio Manzini (2003) was a part of this

movement. The agenda were changing through new approaches based on biological and ecological systems (inspired by the earlier work of D'Arcy Thompson (1921) as well as natural patterns and morphological processes (such as Alexander's Pattern Language 1977). Also, the work of Walter Stahel at The Product Life Institute and others could be given as spear-headings of the trend named the new dematerialisation via reconfiguring "product service systems" (Richardson, Irwin and Sherwin 2005).

According to history of sustainable design, it can be said that it has started to develop with the appearance of eco-design concept. To understand sustainable design better, the discussion belongs to Chris Sherwin can be examined.

Sherwin (2004) discusses that much have been written the theoretical fields of eco-design and sustainable design and myriad methods, tools and approaches. He considers that many designers have been faced complexity and missing about these concepts depending on his personal experience and observations.

According to Sherwin (2004, p.22), after the concepts and terms "sustainability" or "sustainable development", the concepts of eco-design, sustainable design or design for sustainability were created by the design community in response to the emergent environmental and social pressures and broader sustainability trends. He explains them in more detailed picture describing two broad approaching fitting into a kind of either/or polarity:

> "…between eco-design on the one hand; and sustainable design, on the other. This has been variously presented as: eco-design or sustainable design (Dewberry and Gogging 1996); Ecodesign vs. Sustainable Innovation (Van den Hoed 1997); evolutionary vs. revolutionary eco-design (van Hemel 1998); Eco-design vs. Eco-innovation (Charter, 1998); and Eco-efficient or Eco-effective design (McDonough and Braungart 1998)."

In this sense, eco-design is described simply 'aims to make efficient use of natural resources over the entire life…the product' (Philips Electronics 1997, p.9). Basically, environmental issues are integrated into the development process and/or the results with intent to reducing the total environmental impacts of the design. Sustainable design is something bigger rather than eco-design. It goes "beyond eco-design" (Sherwin 2004).

To understand the sustainable design and to distinguish it from other concepts, the polarities in terms of theory, practise and mental models as the following can be helpful:

- "incorporate more innovative practices and greater levels of innovation – such as system innovation or new concept, product or business development (Brezet 1997);
- incorporate ethics and the socio-economic dimensions of sustainability – in the sense that sustainability has a broader consideration than only 'being green' (Charter and Tischner 2001); or
- it employs ecological principles (nature and natural processes) as the very 'materials of designing' (Beard and Hartmann 1997)" (Sherwin 2004, p.22).

There are several tools, methods, strategies and approaches (frameworks) for sustainable design. These can be adopted by designers to use. It should add that the frame of current definitions and discourses of sustainable design are still predominantly formed by the sustainable production and consumption theme within a market-based economy (Chick and Micklethwaite 2011).

The tools and methods are presented below in rough order (Richardson, Irwin and Sherwin 2005):

- Hierarchy of waste management
- Factor X eco-efficiency concept
- Life cycle assessment (LCA)
- Cradle to cradle
- Product service systems (PSS)
- Bespoke products-services
- Four step model of ecodesign innovation
- Biothinking/Biomimicry
- User-centred design
- Pattern language
- Manzini's principles

Stegall (2006) emphasizes the crisis of sustainability by quoting from David W. Orr (1992, p.1):

> "The crisis of sustainability, the fit between humanity and its habitat, is manifest in varying ways and degrees everywhere on earth. It is not only a permanent feature on the political agenda; for all practical purposes, it is the agenda. No other issue of politics, economics, and public policy will remain unaffected by the crisis of resources, population, climate change, species

extinction, acid rain, deforestation, ozone depletion, and soil loss. Sustainability is about the terms and conditions of human survival....”

The current views of ‘design for the environment’ show that it cannot fully solve the crisis of sustainability, because focusing only on a product's physical attributes: material construction, energy use, manufacture, transportation, and disposal remains incapable to solve the problem of being sustainable. Designers in the modern world mostly focus on the physical issues of products and technology. This creates the current sustainability crisis. A product could be designed and manufactured that used only solar energy, gave off no toxins, and could be one-hundred percent recycled at the end of its useful life, but it would still not be truly sustainable unless every person who used it did so in a responsible manner and returned it for recycling at the end of its life. The lifestyle that people have adopted is quickly destroying their ability to survive (Stegall 2006). Lockton, Harrison and Stanton hold (2013, p.432) the view of Chapman (2009) as puts it “the sustainability crisis is a behavioural issue, and not one simply of technology, production, and volume.”

It is obvious; then, the role of designer should extend beyond sustainable products, to changing consumption, lifestyle aspirations and choices for creating a sustainable future. This requires fundamental changes in behaviours. Influencing people’s behaviour is important for more sustainable lifestyles, in other words, a sustainable future.

As Klein (2009, p.1) stated, reducing human impact on the environment becomes more crucial with each passing day. Reducing human impact on the environment becomes more crucial with each passing day. Our buildings have an enormous impact on the natural and built environment and now this is being realised by the public, designers and clients. As long as sustainable design develops and becomes widely accepted, biomimicry as one of the new approaches is advanced to achieve a sustainable future (Klein 2009, p.1).

To sum up, one of the most important aspects of biomimicry is its relation to the concepts of sustainability and innovation. In biomimicry, nature is used as a model. Owing to the fact that elements in the natural world have evolved over time to sustain their place on the planet, it is seen that the solutions in nature are often more sustainable (Cattano, Nikou, & Klotz 2011, p.177). Benyus (2009) has expressed her opinion in this way: “When we look at what is truly sustainable, the only real model that has worked over long periods of time is the natural world.” For example, in Harare, Zimbabwe, there is a building, named The Eastgate Centre, which was constructed based on biomimicry principle (Fehrenbacher, 2012). It has a passive

cooling system instead of more conventional air-conditioning methods that humans typically use and require energy. This design was inspired by shape of the termit mounds and it is more sustainable due to using less than 10% of the energy (environmental pillar). By means of this, it provides saving the owners 3.5 million dolars (economic pillar) (Cattano, et al. 2011). Also, the core idea of biomimicry is that nature has already solved many of the problems we are grappling with. Animals, plants, and microbes are the consummate engineers. After billions of years of research and development, failures are fossils, and what surrounds us is the secret to survival (Biomimicry Institute 2019). There are many different solutions and ideas hidden in nature. These diverse solutions in nature play a very active role in developing creativity, which in turn foster and leads sustainable innovative solutions and ideas.

CHAPTER 3

THE STATE OF BIOMIMICRY IN THE WORLD AND IN TURKEY

Biomimicry not only examines the biomorphism, the organic shapes of nature, or its mechanisms but also understands nature as a whole system (Benyus 1997). By this means, biomimicry is currently used in a broad range of disciplines and fields such as material research, inventions, engineering, agriculture, architecture, interior design, systems design, communication, business and industrial design discipline (Volstad and Boks 2012; Beattie, et al. 2011; Martín-Palma and Lakhtakia 2013; Armstrong 2013; Hoyos 2010). There are some studies, examples and approaches on the incorporation of biomimicry, biomimetic and bio-design into design education as a discipline and business as a practice.

According a report by The Fermanian Business&Economic Institute which follow biomimicry activity, biomimicry patents, scholarly articles and research grants have increased by more than five times since 2000. It is estimated that the field of biomimicry will represent about $1.6 trillion of the world total output by 2030 (Bagley 2014).

3.1. Biomimicry as a Discipline and as an Area of Academic Research

Biomimicry can be the root of change through academic studies in industrial design education. It accelerated recently its growth in academy as a discipline or a research topic, but it is still in developmental phase. To see the state of biomimicry in the academy, some academic studies related to biomimicry within the field of industrial design should be mentioned.

A study tries to integrate bio-design principles into the context of interior design. The definition of bio-design evolved and was refined through the 1980s and was defined as “The interdisciplinary field of bio-design encompasses systematic studies of functions, relations, structures and processes in biological systems and transforms these data into solutions of primarily technical and technological problems…” (Brebbia and Carpi 2010, p.550). In this study, sustainable design pedagogy is proposed to incorporate bio-design as one of its

fundamental building block. They apply bio-design methodologies which are direct, indirect and hybrid (combination of direct and indirect) approach during the course of three different bio-design studios. The result is that the hybrid type approach had the greatest potential. Study caused results more detail as follows:

> In this approach, the design problem formulation is shifted from the initial stages to the end of the analysis, thus allowing designers to exercise their creative ability and to synchronize it with that of Nature. Rather than a tightly structured methodological approach, a combination of formal approaches allowed designers the freedom to resume the role of a designer with a renewed sense of appreciation of the scientist's contribution. The hybrid approach also allowed the designers to use biological form as a source of inspiration at any stage, as long as it is supported by function and structure studies […] The emerging hybrid method does not privilege either the designer or the biologist as the driving force behind the design process, but instead is built around an equal collaboration. This method has more possibilities for interior designers, even though the biomimicry is performed at the organism level... (Brebbia and Carpi 2010, p.556, 557)

There is another study that compares the Design Process that nature uses to that which interior designers use to solve problems. It employs the method of Challenge to Biology Design Spiral, or direct method to guide the designer through the nature's design process. This method was designed by Carl Hastrich for the Biomimicry Institute. This study discusses that designers now should include a biomimetic approach to explore nature's database for sustainable solutions and innovations, although they utilize time-tested tools and methodologies i.e. programming, schematic and design development. Key points, case studies of applications of biomimicry in product design and manufacturing and an architectural project are reviewed to see the difference of asking nature versus designers.

Hoyos (2009) presents a doctoral thesis that deals with integrating biomimicry into Design for Sustainability (DfS or also called sustainable design) course in industrial design (ID). The research aims "to develop, test, evaluate and refine an integrative and cross-disciplinary teaching method for DfS applicable to undergraduate ID Education" (Hoyos 2009, p.1). The use of biomimicry, combined with eco-design tools and theories of human needs analysis are focused. It discusses that the need of exploring and developing cross-disciplinary methods that improve sustainability in design although there are useful eco-design tools and teaching methods used by diverse programs in ID, Product Design, Product Design Engineering

and other related disciplines. After an extensive research about education for sustainability, bio-inspired design and ecodesign, case studies and examples of student works through experimental workshops, the author proposes a theoretical model through diagrams (Figure 3.1).

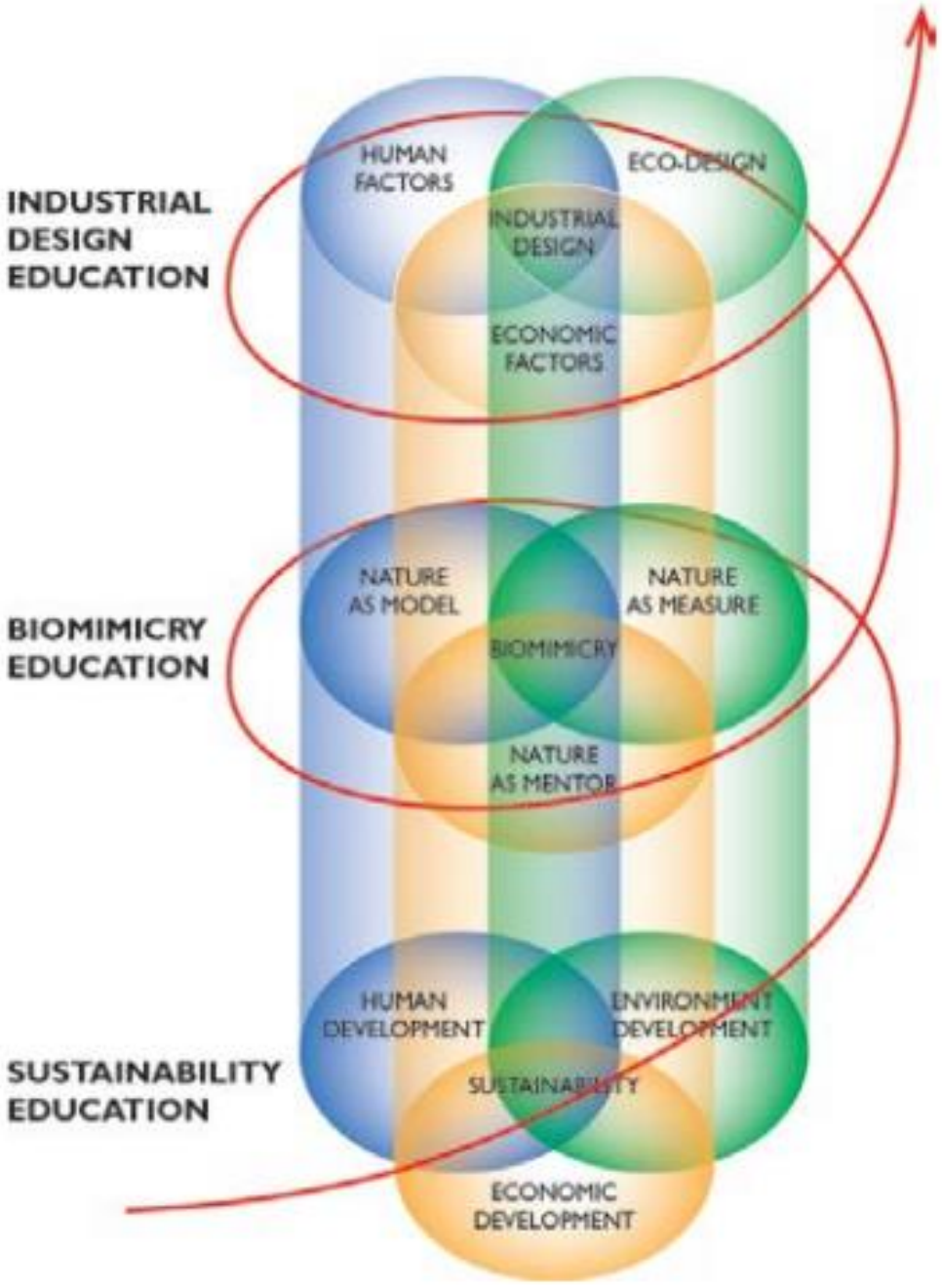

Figure 3.1. Learning spiral of the proposed sustainable design bio-inspired methodology (teaching and learning method for DfS in ID), integrating 3 diagrams (Source: Bakırlıoglu, 2012)

Biomimicry is chosen for this teaching and learning method because of its relationship to sustainability. Biomimicry offers the study of nature from a systems point of view. In this system, all elements are interdependent. The main difference of biomimicry with other bio-inspired disciplines is that biomimicry understands nature as a measure. It respects the limits of nature, so respects the principles of sustaining life in our planet. In this research, two approaches of biomimicry thinking tools (Biology to Design or Biology to Human Needs and Challenge to Biology – Human Needs to Biology) are applied and tested individually in different experimental workshops. As a result:

- A new pedagogic model for teaching-and-learning method is designed and visualized as a growing spiral.
- […] although time-consuming and initially difficult to assimilate by undergraduate students, the teaching and learning method proposed through this research can be a useful tool to enhance cross-disciplinary undergraduate research and motivate creative and critical thinking abilities in the students, while providing basic understanding of the implications of sustainability within the profession of ID.
- Positive feedback from students suggests that the method enhanced their awareness of DfS by linking sustainability and design through biomimicry. In the future, such methods can radically change the way ID`s think and work, proposing new viable designs inspired in nature, for the benefit of all forms of life. (Hoyos 2000, p.1,2)

Bakırlıoğlu (2012) conducted a master thesis titled: "Biomimicry for sustainability: An educational project in sustainable product design." It was related to biomimicry for sustainability and its integration into sustainable product design. According to this study, there are some difficulties of biomimicry. Incorporating the biomimicry approach into design education is one of them, because this has the interdisciplinary nature of it, which counter-balances its considerable potential. Reap (2010) suggests a more holistic approach in re-imagining whole systems via the biomimicry approach. The reason for this, the current applications of biomimicry generally remain limited in conceptual and design detailing phases. Inside the context of an educational project, a generative tool has been designed to make the biomimicry approach more practical and understandable and this tool has been questioned how one is designed, applied and how effective it is. The educational project, BSA (Biomimicry Sketch Analysis) was presented to 3rd grade students at Middle East Technical University as an educational tool. The notions of biomimicry and sustainability are integrated into the early stages of idea generation phase of the design process.

> InnovationSpace, ASU is a trans-disciplinary education and research lab, between The Institute of Design and the Arts and the School of Engineering and the School of Business at the Arizona State University. It aims to provide education on the development of products that create market value, serve societal needs and minimize impacts on the environment. In order to achieve that, InnovationSpace assumes two strategies: integrated innovation model and biomimicry approach. Biomimicry Workshops at the Idea-Generation Phase is a recent educational approach conducted at the University of Houston. It implements the biomimicry approach at the idea-generation phase for sustainability purposes, through a week of workshop -consisting of introduction to biomimicry, guided observation of nature, searching databases and creating ideas on the natural inspirations -and later a one-day workshop on another guided observation of nature. (Bakırlıoglu 2012, p.23)

The scope of this project encompasses developing a family of products through rethinking and reintegrating ceramic bathroom accessories with bathroom tiles and exploring the implications of biomimicry strategies for the sustainable design considerations (i.e. product maintenance, repair, upgrading and personalization) to bring together bathroom accessories and tiles. For BSA, three different natural systems or organisms (e.g. animals, insects, plants, trees, seeds, etc.) are observed, explored and documented by students. For each natural system or organism, a detailed hand sketch analysis is prepared which described and visualized. The positive and negative aspects of the tool, which was stated to be effective in the development of ideas, were identified and concluded. Since it is not known how to use sustainability in students and design education or how to use and evaluate biomimicry tables and since the product design process cannot benefit from biology or nature sufficiently, such an issue has been studied. Such a method has been proposed because there is no biology course in the curriculum of industrial design education and the biology resources used in universities are not written for design. The main feature of the method called Biomimicry Sketch Analysis (BSA) consists of the steps of perceiving nature as a visual perception, using the simple tools such as photographing etc. used in product design while analyzing the functional dimension, revealing the results of the analysis with sketches and transferring them to the application by continuing to analyze. In this example in here, a study made through BSA method is seen (Figure 3.2).

On the other hand, a research titled “On the use of Biomimicry as a Useful Tool for the Industrial Designer” conducted by Volstad and Boks (2012) propose idea generation methods based on applying biomimicry, as “Biomimicry Card Deck”.

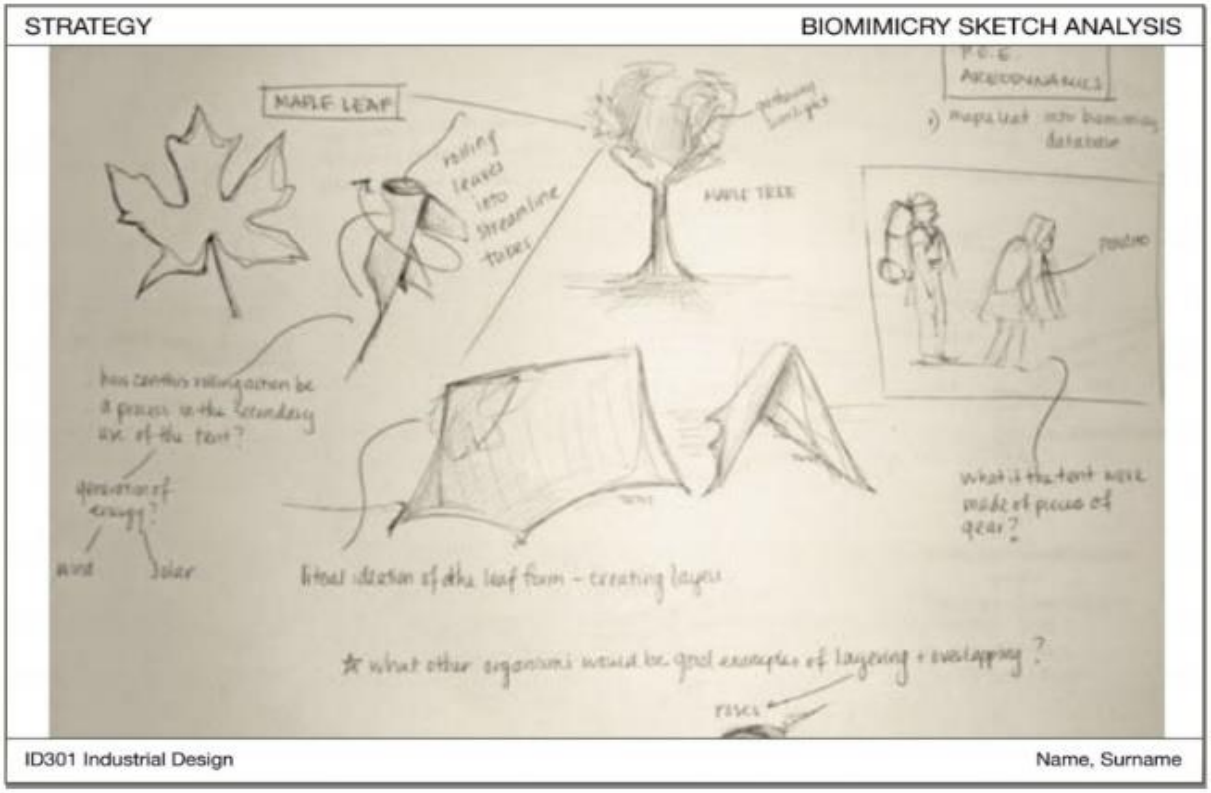

Figure 3.2. A study designed with BSA method (Source: Bakırlıoglu, 2012)

They intended to guide designers generate ideas for novel design concepts drawing on biological principles. The aim of their research is to analyze the applications of biomimicry in industrial design. At the same time, this research try to find an answer the question of whether biomimicry is a tool for sustainable for product design or as a general tool for design inspiration. In line with this objective, this study includes the statement advocated by some biomimicry researchers. This statement supports the idea that the proposals for sustainable design will be incomplete and therefore will be unsuccessful if they do not involve a deeper and more sensitive relationship between the people-nature-built environment (Klein 2009, p.189,190). Their research argues that when biomimicry is used reductively, it does not create an ecologically sound product or give guarantee that it will yield an environmentally sustainable solution. Instead of applying biomimicry reductively, biomimicry should be applied in a deep or holistic way. This corresponds to mimic of a natural ecosystems. “This view involves considering the whole way in which nature manages to produce without damaging the environment, through considering everything as part of a whole system” (Volstad and Boks 2012, p.192). However, Volstad and Boks (2012) considers biomimicry in its traditional way, i.e. the reductive form, because their main aim is to evaluate the usefulness of biomimicry as a source of inspiration

and as a toolkit for solving practical design problems by industrial designers. There are various methodologies have been developed to help transform biomimicry from theory to practice. In this research, the authors (2012, p.194,195) discuss existing tools which incorporates biomimicry into the designer's toolkit:

- Biologists at the Design Table

  Biologists at the Design Table (BaDT) is an effort started by The Biomimicry Guild to help introduce biologists to the design process (www.biomimicryguild.com). The BaDTs are biologists, who have training in a biomimicry design methodology developed by Benyus and the biomimicry.net, and who excel in searching through biological research. They can find the natural strategies that meet specific design challenges, and assess which of those designs or system strategies are most promising. The biologists are experts at translating nature's strategies into strategies that meet design problems. They can also deliver feasibility analyses and plans of action for implementation of selected bio-inspired strategy. There also exists a service called 'Dial-a-Biologist', which is an on-call biology service that is part of the Biomimicry Guild. Here, experts answer technical questions and partake in brainstorming to detect ways in which nature's ideas can help to improve a product or process. The 'Dial-a- Biologist'service also provides lectures, workshops and networking between researchers/scientists and design companies.
- Databases

  -The Biomimicry Database

  This is currently under construction by the Biomimicry Institute and '...intended as a tool to cross-pollinate biological knowledge across discipline boundaries'. It will be a place where designers, architects, and engineers can use advanced tools to search biological information, find experts, and collaborate to find ideas that potentially solve their challenges. The Biomimicry Database will include six different types of information to search/enter; challenges, strategies, organisms, people, citations and products.

  -The Chakrabarti System

  This is a method for generating novel solutions for product design problems developed by Chakrabarti, et al. (2005). The method seeks to provide analogical ideas for design, which can be biologically or artificially inspired. It is basedon two parallel databases–one describing natural systems capable of certain motions (e.g. insects–flying, fish–swimming, grasshoppers–jumping) and another containing artificial mechanical systems capable of various behaviors (gear–transmission, vacuum cleaner–suction, hole puncher–punching holes)– to facilitate interactive, analogical generation of alternative ideas relevant to solving a design problem. To

do this, a common language for describing the motion behaviors in the two databases was developed. Testing of the system has shown that the subjects are able to produce a significant number of additional solutions using the software, but the results do not show how many of these solutions originate from the biological database.

-TRIZ

TRIZ is a well-known tool for creative innovations, based on a database of solutions from different domains, a list of 40 inventive principles distilled from an extensive analysis of successful patents, a procedure for abstracting problem definitions to a general state where they can be compared to any similar principal solution, and a contradiction matrix used to map relationships between the principal problems and the inventive principles. Currently, not much biological data is included in TRIZ. However, a program of work to integrate knowledge from the biological and biomimetic sciences into the TRIZ framework has been conducted at the University of Bath (Vincent, et al. 2006).

Furthermore, combining biomimetics with Triz to produce Biotriz others a structured way of generating possible biologically inspired solutions for problems (Vincent and Mann 2002; Craig, et al. 2008).

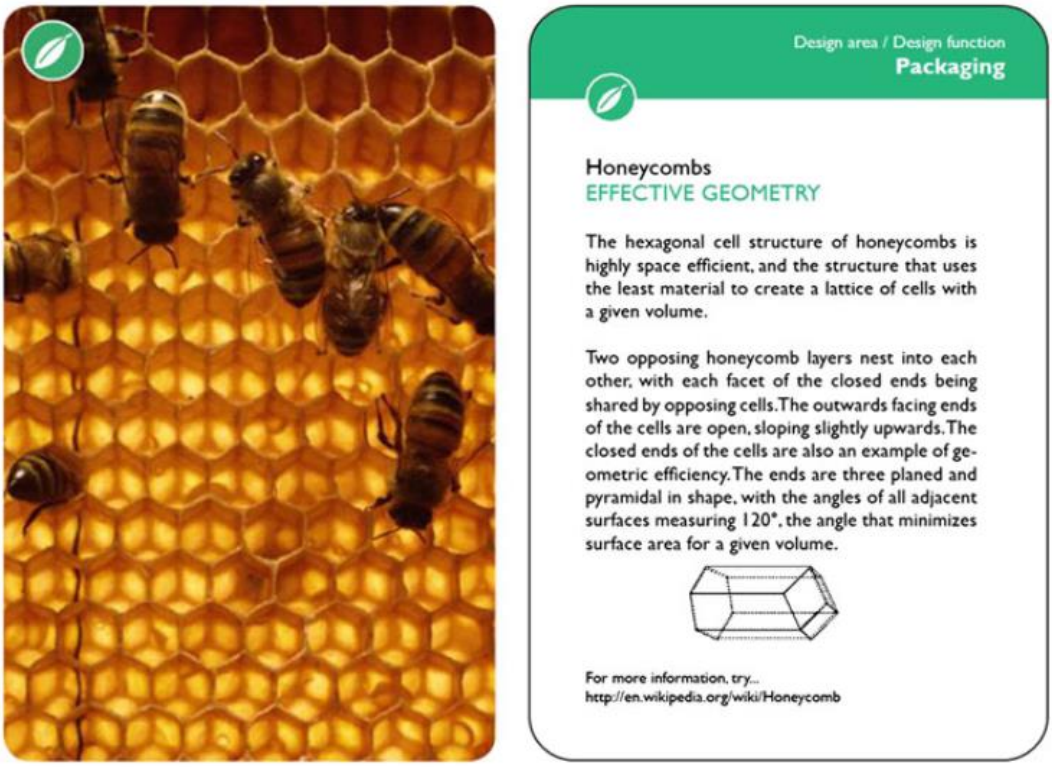

Figure 3.3. Front & back side of the 'Effective Geometry' card from the 'Packaging' deck (Source: Volstad and Boks 2012)

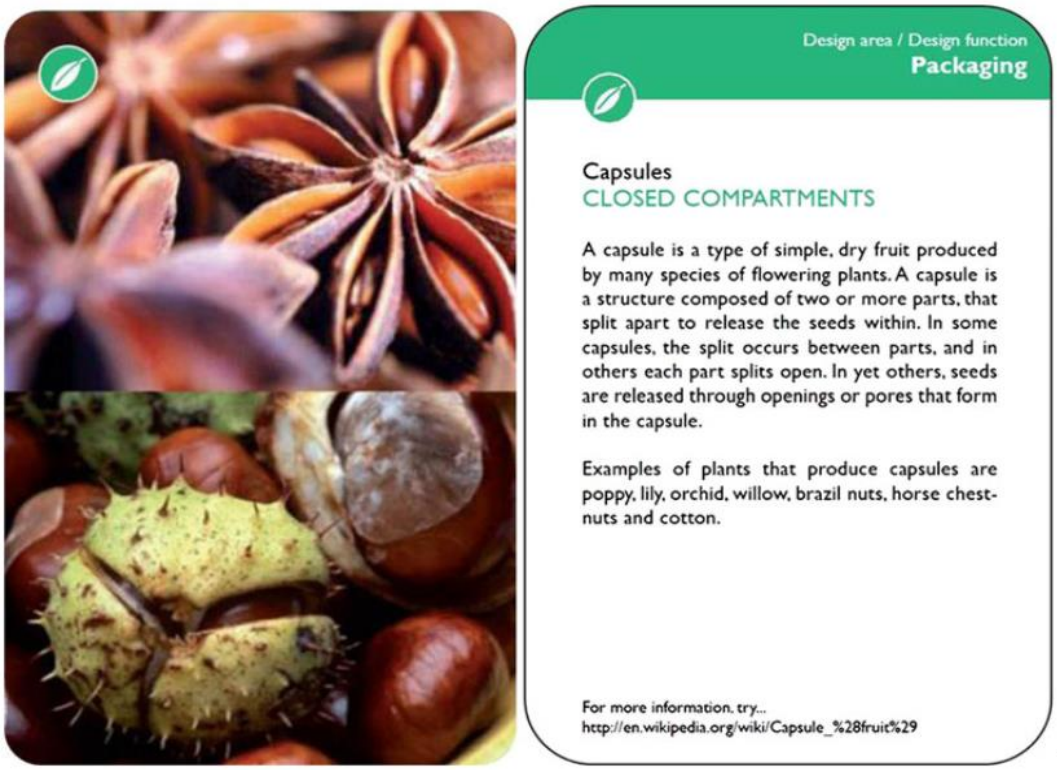

Figure 3.4. Front & back side of the 'Closed Compartments' card from the 'Packaging' deck (Source: Volstad and Boks 2012)

As a result, they proposed an idea generation tool based on applying biomimicry, as "Biomimicry Card Deck", intended to guide and help designers generate and increase creativity for novel concepts drawing on biological principles in idea generation phase. In this new tool, there are many biomimicry cards (Figure 3.3, Figure 3.4), each of which belongs to a particular design area such as function, packaging or architecture. Each card has to side. There in picture related to solution on one side and the other side gives detailed information about function or form. Designers first look at the image to make brainstorming and imagine the possible solution. By reading the other side, they reveal more information about the image. Analysis of test result, idea generation was increased ranged from 57% to 109% (Volstad and Boks 2012).

Boga-Akyol from Istanbul Technical University industrial product design department conducted a thesis titled "Natural Analogy in Design: A Study on the Approaches of Industrial Design Students" in 2013. Then, in 2015, Boga-Akyol and Timur-Ogut conducted a study titled "Exploring Biomimicry in the Students' Design Process" which was published in some international journals. In their studies, they attempted to explore the approach of students in industrial design education about biomimicry which is the type of natural analogy which is one

of the methods of using nature in design and and to explore the place of biomimicry in students' design projects. Boga-Akyol and Timur-Ogut (2016, p.21) argued in their study that especially in industrial design education it is encouraging to mimic the nature while designing new products, but different dynamics affect this use. They observed that industrial design students have learned biomimicry which is a type of natural analogy in different courses as a creativity method, but still not willing to use it in their projects. Therefore, they have tried to find and understand, first the reasons behind this reluctance of industrial designers to not use biomimicry / nature, and secondly, if a methodology was presented, the ways in which this reluctance would be overcome and in what ways the students would go beyond taking the nature as a formal source of inspiration. Two issues related to the study have tried to be find.

There are many ways to use nature in design. Boga-Akyol and Timur-Ogut (2016, p.21) discussed the analogy, which is one of the ways of using nature in design. They investigate the use of biomimicry in industrial design education by using natural analogy method. Natural analogy, which is frequently used to combine nature and design, also has many different forms of application (p.21). In addition to design and engineering, natural analogy is also used in social sciences such as economics, psychology, and culture and so on. In these sciences, nature is used as a guide to explain a process (Boga-Akyol and Timur-Ogut 2016, p.21). This is why Boga-Akyol and Timur-Ogut established the scope of their study on natural analogy, which is a more comprehensive title, and on biomimicry specific to design (p.21). All of these fields share the concept of sustainability as a common denominator (Boga-Akyol and Timur-Ogut 2016, p.21).

Boga-Akyol and Timur-Ogut (2016, p.21) stated that the use of natural analogy has increased dramatically in various fields, but this demand is not so much in industrial design. Moreover, they observe that industrial design students are not willing to use natural analogy in studio projects due to the fact that the modernist understanding of education was far from figurative practices. Most of the time, the use of nature is conveyed to an imaginary project as a one-to-one tracing of the formal qualities of the natural model. When using nature in projects, students who are often looking for abstraction, try to avoid the label of ‘kitsch’, hence all these keeps them away from this method.

In “Why Design Education Must Change”, Donald Norman (2010) expresses that many design students prefer design because of not liking science and mathematics. He argues for that design education can not be considered without science. What Norman tries to say when he says “science” is that although statistics, mathematics and social sciences; according to Boga-

Akyol and Timur-Ogut (2016, p.21,22) argue that biology can also be considered together with these sciences, and that science-based education would help to improve the biomimicry method in a systematic way. According to them, the reason behind the failure of biomimicry in design is the the lack of science knowledge of students.

Biomimicry can be used by businesses, communities, and organizations as well, because it is a form of economic development. Biomimicry innovations can provide businesses in communities to create products and processes that are sustainable perform well, save energy, cut material cost, redefine and eliminate "waste", drive revenue and build your brand. Flint (2013) argues this based on the opinion of Benyus (1997, p.112):

> Businesses, communities, and organizations that are at the cutting edge of the new economy are finding new ways to make old products more efficiently, with less energy and fewer nonrenewable resource inputs. They are also using lessons from nature to develop new products that are more resilient and successful than those that corrupt and exploit the natural world. These new products and services are more competitive because they are using increasingly costly resources more efficiently. That saves money, which can in turn go to higher salaries, enhanced community services, better working conditions, and all the things that make companies and organizations places where people like to work.

Apart from natural capitalism, cradle to cradle, the natural steps for business, life cycle analysis tool as nature inspired design strategies; biomimicry is utilized as a framework, a strategy and a toolkit for businesses. Petrig (2013) develops the Design Manager's Biomimicry Toolkit for design managers to apply biomimicry in product innovation by integrating it into product development. Biomimicry is tried to be integrated by means of design thinking with a user-centered focus in company's processes. Thus, it is tried to support companies to achieve breakthrough innovations in product development and helps a design manager to steer the activities in an ecologically, socially and economically sound way.

There are many example of utilization of biomimicry in design process. Biomimicry can be used for bio-inspired solutions to sustainability challenges in brainstorming activities (Benyus 2004) and for developing a computational tool for supporting designers to generate novel solutions for product design problems by providing natural or artificially inspired analogical idea. Moreover, biomimicry can be used as source of inspiration for solving product design problems, especially in idea generation step of design process (Chakrabarti, et al. 2006).

In the literature, there are methods, tools, strategies (the Biomimicry Institute's Design spiral, including tools for scoping & creating, guidelines and evaluating) which are related to biomimicry to offer for sustainable product development (Biomimicry Institute 2014; Hoyos 2010; Vincent and Mann 2002; Craig, et al. 2008). Biomimicry can be applied in several steps of a design process. The Biomimicry Institute gives the following options for integrating biology into design:

- In scoping: (re)defining the design problem.
- In idea-generation: retrieving inspiration and engineering solutions from nature.
- In engineering and evaluation: guidelines and (sustainability) criteria for product engineering.

As a short summary of the general usage of biomimicry in industrial design discipline, the usage of "biomimicry" which refers a source of inspiration, of problem solving, of design thinking, tools and/or methods for product development in the design process. Also, usage of "biomimicry as a strategy" can be applied for sustainable product development, which excludes strategies only used in other design fields such as architecture, graphic, engineering or fashion design (Pauw, et al. 2010).

- Biomimicry is used by businesses, engineering, agriculture, architecture, interior design, systems design, communication and industrial design discipline.
- Biomimicry is increasingly becoming part of the regular lexicon of industrial design and sustainability.
- Biomimicry is complex, multi-dimensional, inter-disciplinary and collaborative. It has a strong and powerful approach, yet it is not easy to manage.
- In industrial discipline, biomimicry is used as a tool or technique giving inspiration, innovation and enhancing creativity. Also, it is used an approach, a strategy, a framework and a method.
- From the point of education, biomimicry is mostly integrated into idea-generation phase of design process (sketching, brainstorming, problem solving) for product development or sustainable product design.
- Especially, it is utilized through designing in the form of toolkit by both industrial design and the business.

3.2. Biomimicry as a Practice

The discipline is no longer just an academic exercise. It has become an innovation tool for companies in the business field that allows developing a new class of products and services. Many companies conduct research to apply the principles of nature to the design of products. There are many various industrial biomimetic applications and examples.

Figure 3.5. Design of Mercedes-Benz Bionic Car (Source: Geary 2018)

Mercedes benz's boxfish aerodynamic car, a concept vehicle can be given as one example. The Mercedes-Benz's Bionic car was designed mimicking an ostracion cubicus fish called the Boxfish that lives in a tropical coral reed. This fish has a rather large body, but is able to swim very fast because of its low co-efficient of drag and rigid exoskeleton. Noting the aerodynamic shape, low co-efficient of drag and rigid exoskeleton of the boxfish, they identified the similarities between cars and the boxfish, the designers began modelling a new vehicle after the Boxfish. Their final design had an unusual form that looked like a boxfish and after testing proved to have one of the lowest co-efficient of drag ever tested. The result is a very streamlined vehicle with a 65% lower drag coefficient than other compact cars out at the time. It also has 80% lower nitrogen oxide emissions. Reduction of the air friction by up to 0.19. Also this allows the car to travel approximately 70 miles per gallon to increase traveling distance ("Design of New Mercedes-Benz Bionic Car" 2005, as cited in Young and Dhanda 2012, p.155).

Another company Sto Corp has developed exterior paint called Lotusan. Lotus plants used in this product have self-cleaning and hydrophobic properties. If the water molecules come into contact with a surface of this paint, they are immediately bonded together and rolled off the surface, because there is a repulsion between water and nonpolar substance. Paint's self-cleaning feature occurs by allowing the dirt particles of the lotus plant to adhere to the water droplets. The claims of lotus paint are to extend the surface life of the outer surfaces and to reduce the cleaning costs of the building owners. It has also been proven to be high resistant to many factors such as water damage, dirt, mold and even UV rays (Sto Corp. Lotusan Videos n.d., as cited in Young and Dhanda 2012, p.156). The GE Company are trying the potential applications of this technology on metal surfaces, because if it can be synthesized in the form of a spray coating, this feature could be used to quickly defrost the airplanes (Young and Dhanda 2012, p.156). Some of the other examples of biomimicry are as follows:

Whalepower Company applied tubercles to reduce drag problem in wind turbines (Young and Dhanda 2012, p.156).

When it is discovered that chimpanzees go to Veronia-genus trees as they become ill, the chemical compounds of these trees are being begin to be tested in the hope of improving the parasites found in humans (Young and Dhanda 2012, p.156).

EvoLogics developed a high-performance underwater modem to get early warnings of tsunamis' danger. This modem emulates the distinctive frequency-modulated acoustics of the dolphins (“What Could Nature Teach Us?” n.d., as cited in Young and Dhanda 2012, p.156).

The front end of the Shinkansen bullet train was redesigned taking the features of the kingfisher bird. The aim of the design was to increase speed and efficiency and also to reduce the noises produced by these trains (Brennan 2015, p.440).

In order to remove the use of formaldehyde in plywood, an adhesive was made by inspiring from the mussel (Brennan 2015, p.440).

Sweat of hippopotamus with antiseptic, insect-repelling, and antifungal properties was the source of inspiration to a waterproof sun lotion (Brennan 2015, p.440).

Goldstein and Johnson indicate (2014, p.1) that “biology has become big business”. The global circulation of biological materials and bio-based services have entered life's most basic elements and processes in parallel to the rise of Post-Fordism and the ‘information economy’ in the latter half of the twentieth century. Regimes of innovation and industrialization are within this scope (Goldstein and Johnson 2014, p.1), because new connections between the life sciences, technological innovation, and the generation of profits have established, and these

have made the materials of "life itself" an even more integral part of production practices (Rajan 2006; Cooper 2008; Braun 2008); (Goldstein and Johnson 2014, p.1,3).

According to Goldstein and Johnson (2014), biomimicry is a novel field of technoscience that makes biological research a resource for innovation in industrial engineering (p.2). Although biomimicry is nothing new, it has gained importance as a discipline and organizational framework that connects engineering, design and biological research only over the past two decades.

The corporate side of biomimicry/biomimetic design is also growing. The study conducted by Goldstein and Johson (2014) shows that there are now many consultancy firms that help to organize possible collaborations between biological knowledge and the needs of commercial engineers with a global network that they have. In 2009, The US Patent and Trademark Office got 900 patents from inverntors comprising the term 'biomimicry' (Global Biomimicry Efforts 2010). Corporations involving in biomimetic developments extend to economic sectors with various levels of engagement. The global leader in pioneering biomimicry/biomimicry design, Biomimicry 3.8 is the consulting firm. It has worked with over 150 corporations which are the biggest firms in the industry like Boeing, Proctor and Gamble, Dupont and Nike, also architecture firms, universities and manufacturers of eco-friendly materials. A biomimectic agenda is being supported by cities and local governments as well. For example, San Diego city is putting itself as a center of biomimetic research and development by means of initiatives at the San Diego Zoo. The other example is from New York State. The New York State Energy Research and Development Authority (NYSERDA) started on a biomimetic R&D program in 2011. There is also some emerging small startups in biomimetic technologies. NBDNano, for example, has a work about nanomaterial coating inspired by the Namib Desert beetle that will draw off resh drinking water directly out of the air, so NBDNano recently get venture funding because of this work (p.6).

In 2007, a report the DTI Global Watch Mission coordinated by Thoughtcrew Ltd, an associate member of Faraday Packaging Partnership (FPP), issued. This report represents the findings of a mission that "studied the development and application of biomimetics by industry and commerce in Germany and the Netherlands and explored the development and value of generic design rules and procedures which can be drawn from nature." The purpose of this mission was to examine the technological, design and commercial points of application of biomimetic design principles and concepts. The mission location is Germany as a centre point,

and also includes the Netherlands, but contains datas from the UK (Vincent, Richardson, Poitevin, Knott, Schampel, Kemp, Hollington, Gester and Barnes, p.5) (DTI Report, p.5).

Globally, there are four key research centers based on biomimetics. These are the UK, Germany, the Netherlands and the USA. Germany that adopts an integrated approach that includes commercial applications and sees the most support and investment of a network of competence from the government, is the pioneer in the field of biomimetic research. Also, Germany has developed at both academic and industrial level in biomimetics. Many companies have forming several high-profile operations. It places world-leading position. The situation of biomimetic in the Netherlands is similar to in the UK. While many leading research institutes and commercial organizations in the Netherlands use biomimetic concepts to develop product and design ideas, but this is in an isolated state. The Netherlands also has no network to share ideas, unlike BIONIS in the UK (Vincent, et al., p.4) (DTI Report, p.4).

In Germany there is a BIOKON network. This network has a very important place in terms of marketing efforts organization and information / knowledge transfer. The link between fundemental research and the creation of prototypes is good, but when looking at real products on the shelf, the result is not good (Vincent, et al., p.4) (DTI Report, p.4).

It can be seen the oppurtunities of create a vital mass of thinking, research and commercial intelligence in Europe driven by the UK (Vincent, et al., p.4) (DTI Report, p.4).

While reviewing the book of The Shark's Paintbrush, Brennan stated (2015, p.440, 441) by basing on the book's writer Jay Harman that even though biomimicry has the potential to create innovation, it is not easy to turn these two together into a profitable business. One of the reasons for this is that it seems that companies are not interested in innovation as much as they make to turn their existing business models into a major transformation, while there is a great need for change and transformation for innovation, because it seems a risky step for companies to make something new or invest in an uncertain market. In general, companies prefer technology that lowers costs and increases the profits of the products they produce. The other is the lack of investment support for new companies from government to innovation. A capital is absolutely necessary for a Prototype productions and test steps in the first stages of a newly produced and developed product. It is sad that all of these can only bring short-term gains that are unrealistic, and create situations that are unsustainable and hinder innovation.

A hope and a chance for us and our planet to survive may born by creating true innovation, sustainable designs and business models with biomimicry initiatives based on principles and principles of nature.

CHAPTER 4

INVESTIGATION OF THE AWARENESS AND USAGE OF BIOMIMICRY IN INDUSTRIAL DESIGN EDUCATION IN TURKEY

4.1. Method of the Study

The city of Izmir is taken as a sample for this study in order to understand and evaluate the current state of biomimicry concept in industrial design education and the level of awareness of this subject among students and academicians. It is aimed to measure to what extent the concept of biomimicry in design are known and used by today's students and academicians in industrial design education. To this end, I have conducted two different surveys, one with students and one with academicians, at the three universities with Industrial Design Departments in Izmir. Surveys were conducted to find answers to the questions below:

How recognized is biomimicry in industrial design education (in Izmir)?

To what extent is biomimicry applied in industrial design education?

How students and academicians react to the concept of biomimicry?

What is the level of awareness of students and academicians regarding the concepts?

Is there any knowledge transfer from academicians to students in industrial design education at universities?

How do academicians address the concept?

4.2. Scope of the Study

There are nine state and eighteen foundation universities with industrial (product) design undergraduate and/or graduate programs in Turkey. As a result of the analysis, nine state and fourteen foundation universities were included in the table below (Table 4.1) for the

purposes of this study, since universities without courses containing biomimicry or similar subjects were not included in the study.

Table 4.1. An analysis of educational curriculum of universities in Turkey

University Name	Degree	Courses	Total
Izmir Institute of Technology	MSc	ID552 - Design Management	7
		ID584 - Sustainable Design	
		ID621 - Product Innovation	
		ID512 - Advanced Product Development	
		ID531 - Industrial Design Studio	
		ID521 - Research Methods in Design	
		ID592 - Seminar	
Izmir University of Economics	Bachelor	ID380 - Biomaterials: Designing with Living Systems	13
		PD316 - Design for Sustainability	
		PD312 - Industrial Design Engineering	
		ID300 - Innovative Design Strategies	
		ID202 - Product Design Studio	
		PD314 - Industrial Design Studio	
		ID302 - Contemporary Issues in Industrial Design	
		PD498 - Graduation Project(Production Design)	
		DM498 - Graduation Project(Design Management)	
	MSc Design Management (Without Thesis)	FFD572 - Creativity and Design Management	
	MSc Design Studies (With Thesis)	FFD555 - Imaginary & Futuristic Design Studies	
		FFD557 - Ecological and Bio-Climatical Design	
	PhD Design Studies	FFD662 - Innovative Design Research	
Yasar University	Bachelor	INDD3370 - Industrial Design and Innovation	6
		ID3350 - Sustainability in Design	
		INDD1109-INDD1112 - Basic Design	
		INDD1105-INDD1106 - Introduction to Industrial Design	
		INDD2201-INDD2202 - Industrial Design Studio	
		INDD330-INDD3302 - Industrial Design Studio	
Eskisehir Technical University	Bachelor	ENT457 - Sustainable Design Studio	4
		ENT333 - Design Management	
	MSc	ENT528 - Sustainable Design Practice	
Karabük University	Bachelor (Industrial Product Design)	EUT392 - Design Management	2
Gazi University	MSc & PhD	5051331 - Biomimetics	1

(cont. on next page)

Table 4.1. (Cont.)

Marmara University	Bachelor	EUT3022 - Sustainable Design	3
		EUT4022 - Biomimetic Design	
	MSc	EUT723 - Design Management	
Istanbul Technical University (ITU)	MSc	EUT505E - Design Management	3
		EUT551E - Design for Social Innovation and Sustainability	
	PhD	EUT612E - Advanced Topics in Design Management	
Bilecik Şeyh Edebali University	Bachelor	GST116 - Biomimicry	3
		TAS322 - Sustainable Design	
		TAS405 - Project & Design Management	
Selcuk University	Bachelor	2410603 - Design Management	1
Middle East Techhnical University (METU)	Bachelor	ID480 - Design Management	4
	MSc & PhD	ID542 - Design Management	
		ID561 - Product Design for Sustainability	
		ID728 - Generate Design Research for Sustainability	
Yeditepe University	Bachelor	INDD 441 - Design Management	1
Bahcesehir University	Bachelor	DES3032 - Design Management	8
		INT3904 - Sustainable Design	
	MSc (Turkish & with Thesis)	ETI5512 - Yenilik ve Yeni Ürün Yönetimi	
		ENI5513 - Ürün Geliştirmede Yenilikçi Tasarım	
		GEP0314 - Yenilikçi Ürünler ve Hizmetler	
		DES3032 - Atılımcı Düşünce, Yaratıcılık ve İnovasyon	
Istanbul Arel University	Bachelor	6EUTMAS001 - Product Development Philosophy	2
		6UETMAS005 - Sustainable Design	
TOBB Economy and Technology University	Bachelor	EÜT 316 - Sustainable Design	5
		EÜT 400 - Design Management	
	MSc	TSR507 - Advanced Product Studies	
		TSR514 - Sustainability in Design	
Istanbul Bilgi University	Bachelor	ID462 - Design Management	1
Ozyegin University	Bachelor	IDE303 - Design Strategy & Management	8
		IDE457 - Design Management Studio	
		IDE458 - Design Management Graduation Project	
		IDE314 - Sustainable Materials & Processes	
		IDE411 - Co-creation and Social Innovation by Design	
	MSc & PhD	DIS513 - Innovation through Design	
		DIS519 - Design Management & Strategy	
		DIS524 - Social Entrepreneurship, Social Innovation and Innovation for Social Change	
Işık University	Bachelor	ENT311 - Design Management	1
Haliç University	Bachelor	EÜT361 - Design Management	3
		EÜT457- Industrial Product Design & Sustainability	
	MSc	EÜT513 - User and Product Development Relations of Design	
Okan University	Bachelor	EÜT300 - Sustainability in Design	3
		EÜT420 - New Product Development	
		EÜT448 - Biomimicry in Design	
Kadir Has University	Bachelor	ID328 - Design Innovation and Product Strategies	3
		FAD363 - Design Management	
		FAD464 - Sustainability in Industrial Design	
Istanbul Aydın University	Bachelor	EUT429 - New Product Development	1
Atılım University	Bachelor	EUT371 - Sustainability in Product Design	2
		EUT331 - Design Management and Marketing	

4.3. Findings and Evaluation

This chapter presents the results and findings of the two surveys of the research section. The first section presents the students' views and the second section presents the views of the academicians. After this chapter, the overall results of the whole thesis are put forward.

Content analysis was used to analyze the surveys' questions with long or short descriptions and comments with mostly open-ended and semi-closed questions, and results were categorised by thematic coding.

The analysis of the student survey was tried to be done both qualitatively and quantitatively. However, the data was digitized as much as possible and the analysis was supported quantitatively.

However, since the sample population was very small in the survey of academician and in order to interpret and analyze the data in a more accurate, realistic and holistic manner, the analysis of survey of academician was attempted to be based on the qualitative analysis. In this sense, this analysis focuses on what each academician writes and says. However, the limitations of the analysis should be taken into consideration, such as the prejudices of the participating academicians or the difficulty of expressing their experiences as they are. In some questions, the complex and intertwined variables in the answers made the analysis difficult. It has become difficult to measure the relationships between the answers of some questions and the perspectives of the participating academicians.

4.3.1. Findings and Analysis of the Student Survey

This survey, which includes thirteen questions, was conducted with the 2nd, 3rd, 4th year of bachelor students and master students studying in the industrial design departments of Izmir Institute of Technology, Izmir University of Economics and Yasar University in the spring of 2018-2019. A total of fifty students with thirty bachelor and twenty master students participated in the survey.

There are three open-ended questions (Questions 1., 5., 6.), two closed-ended questions (Questiones 3., 9.), eight semi-closed-ended questions (Questions 2., 4., 7., 8., 10., 11., 12., 13.) in the student survey.

In this section, a brief of the findings of the survey conducted with the students from three universities are presented, highlighting important issues. Detailed graphs and tables can be found in Appendix C.

Question 4: : Have you heard of the concepts of biomimicry / biomimetic / learning from nature - inspired by nature in design? If yes, where and in what context have you heard?

88% (44/50) of the students answered "yes" to this question, while 12% (6/50) answered "no".

Table 4.2 shows that where these concepts were heard and encountered according to universities and the education status of the 44 students within these universities.

In Figures 4.1., 4.2. and 4.3., the distribution of responses in Table 4.2 is shown separately according to each university as percentage.

Table 4.2. Q4 graph

WHERE	Izmir Institute of Technology	Izmir University of Economics				Yasar University			TOTAL
	Master	Bachelor			Master	Bachelor			
		2.	3.	4.	M	2.	3.	4.	
Design Studios in Bachelor	1	0	0	0	0	3	3	3	10
Design Projects in Bachelor	1	0	0	1	1	3	2	0	8
Content of Courses in Bachelor	2	2	2	0	1	0	0	0	7
Selective Courses in Architecture in Bachelor	0	0	0	1	1	0	0	0	2
Design Studios in Master	2	0	0	0	0	0	0	0	2
Content of Courses in Master	2	0	0	0	1	0	0	0	3
Individual Research for Courses or Design Projects (article, magazine, design-related texts/websites, etc.)	4	0	1	1	1	0	0	0	7
Conferences, Workshops, Design Events etc. (Which is not related to attended university)	0	1	0	0	0	0	0	0	1
Personal Interest	0	0	0	1	0	0	0	0	1
Professional Life	1	0	0	0	0	0	0	0	1
Other factors (instruction, informing - lecturer or advise of friends, etc.)	1	0	0	1	0	0	0	0	2
TOTAL	14	3	3	5	5	6	5	3	44

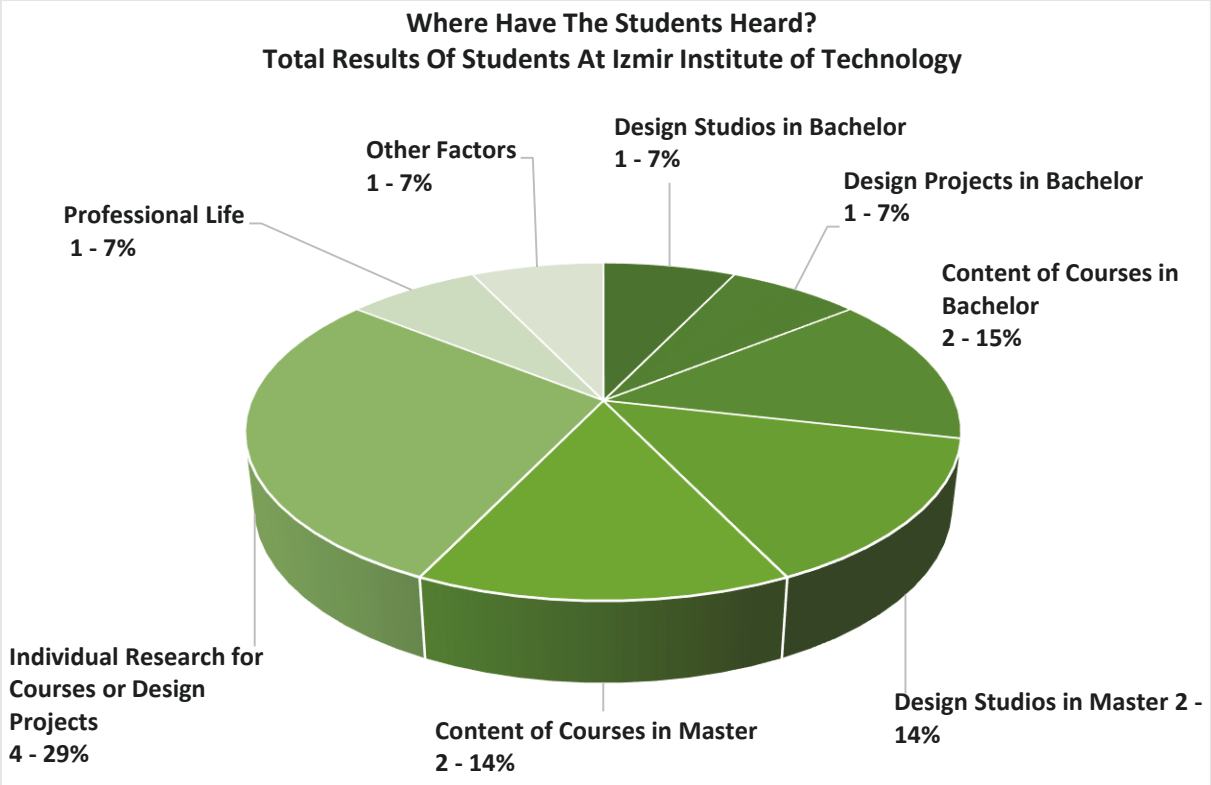

Figure 4.1. Q4 graph

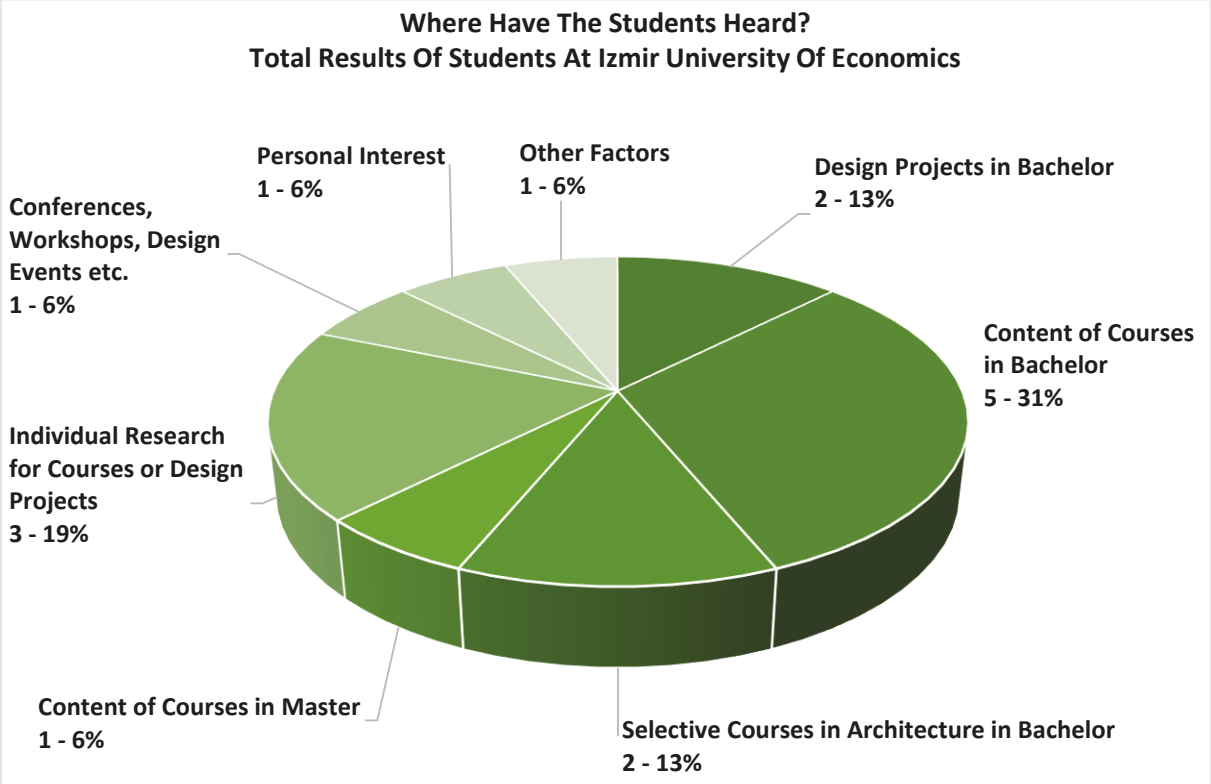

Figure 4.2. Q4 graph

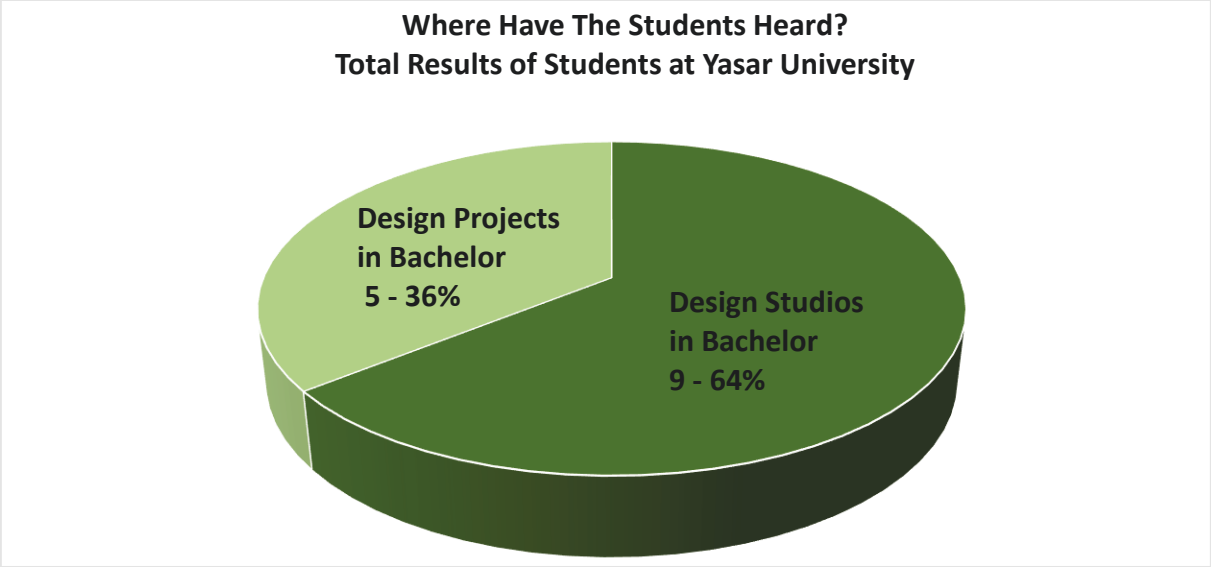

Figure 4.3. Q4 graph

When the bachelor student groups of Izmir University of Economics and Yasar University are compared, the first prominent group in the table is 2nd year students in Izmir University of Economics. It can be seen that students in this group have not yet fully met these concepts with their bachelor education. Students have come across by non-university factors such as conferences, seminars and workshops. At Yasar University, students get acquainted with these concepts from the 2nd year onwards in the design studio courses, design projects and other course contents, while students at Izmir University of Economics can only meet them in the 3rd year. Early education on this subject this starts in Yasar University. However, the department of architecture and its elective courses of architecture at the Izmir University of Economics offer students a great advantage and opportunity to access to information biomimicry and its related concepts. In Izmir University of Economics, it is seems that these concepts are not limited to the industrial design department, and students can learn from in other disciplines. While this situation shows the multidisciplinary approach of biomimicry, it offers to students to encounter biomimicry in another discipline and to understand and learn how the concept interacts with that discipline. Thus, it can upskill the student a broad perspective in terms of these concepts, and bring forth more awareness to students.

When the master students of Izmir Institute of Technology and Izmir University of Economics are compared, master students gave answers in common saying that they met these concepts in design projects and contents of courses during their bachelor education, and the contents of the courses during their master education, and also in doing personal research for

courses or design projects. Distinctive differences in the Izmir Institute of Technology are learning from the design studios in master, the design studios in bachelor and professional life. The design education structure of Izmir University of Economics allows students to benefit from courses in other departments. Hearing or learning the concept of biomimicry under another discipline, together with the multidisciplinary and interdisciplinary nature of biomimicry, may provide industrial students with a different awareness and knowledge. There is an answer, which is not included in the table but is also again related to architecture. This is the the computer-aided design programs used for parametric design. For example, one master student in Izmir University of Economics stated that he had encountered and used this concept while benefiting from the Rhinoceros & Grasshopper program to construct a parametric design while constructing architectural structural elements. When looking at organisms and systems in nature, it is seen that they are efficient in many ways, such as rigidity, lightness, stability, and materials. However, forms, structures, processes, and materials in nature are complex and difficult to analyze and fully describe. These computational models and new computer-aided techniques make complex dynamic and static behaviors and structures easier to simulate and analyse. They provide architectural modeling.

The distribution of total responses according to each university as percentage are analysed separately.

At Izmir Institute of Technology, it is seen that there is the most accumulation in the response of the master students heard these concepts in while they were doing individual research for their courses and design projects. The scattered distribution of responses of four students shows that they have heard these concepts during their previous bachelor education.

Since only master students at the Izmir Institute of Technology participate in the survey, it cannot be determined whether different education levels tend to give the same answer or not. However, when Izmir University of Economics and Yasar University are examined, it is seen that there are almost accumulations in certain answers. At Yasar University, where only bachelor students participated in the survey, the accumulation of different educational levels reveals that the educational level at bachelor level is not determinative for this question.

When the total distribution of responses is examined concerning Izmir University of Economics, it can be said that in industrial design education at this university, these concepts are more often mentioned in contents of theoretical courses in bachelor degree than in design studios and design projects. Furthermore, what makes this university different is the interaction

of the industrial design department with the architecture department and the opportunity for students to hear these concepts from a different discipline.

At Yasar University, it is seen that there is significant accumulation is observed on specific answers. At Yasar University, where only bachelor students participated in the survey, all students (14) have heard of these concepts in design studio courses (64%) in and design projects (36%)

It can be interpreted that students at Yasar University can hear the concept(s) mostly during practical studies and courses or apply them in their design projects, meaning there may be a deliberate knowledge transfer from academicians to students.

Table 4.3 below shows how 44 students who have heard of these concepts answer the 'context' part of the question. According to the responses, common points were set and the following table was formed.

In Figures 4.4., 4.5. and 4.6., the distribution of responses in Table 4.2 is shown separately according to each university as percentage.

Table 4.3. Q4 graph

IN THE CONTEXT OF	Izmir Institute of Technology	Izmir University of Economics				Yasar University			TOTAL
	Master	Bachelor			Master	Bachelor			
		2.	3.	4.	M	2.	3.	4.	
Design	4	3	1	1	2	0	0	0	11
Industrial Design	1	0	1	0	1	0	0	3	6
Product Design	2	0	0	1	0	0	5	0	8
Architecture	0	0	0	1	1	0	0	0	2
Biology	1	0	0	0	0	0	0	0	1
Sustainability (sustainable design, design for sustainability)	0	0	1	0	1	0	0	0	2
Designing Products Inspired by Nature / Transferring to Product (form based, function based)	0	0	0	0	0	6	0	0	6
Creating / Finding Solutions (sustainable solutions)	2	0	0	0	0	0	0	0	2
Being a Discipline	2	0	0	0	0	0	0	0	2
Being a Method	2	0	0	1	0	0	0	0	3
Being a Trend	0	0	0	1	0	0	0	0	1
TOTAL	14	3	3	5	5	6	5	3	44

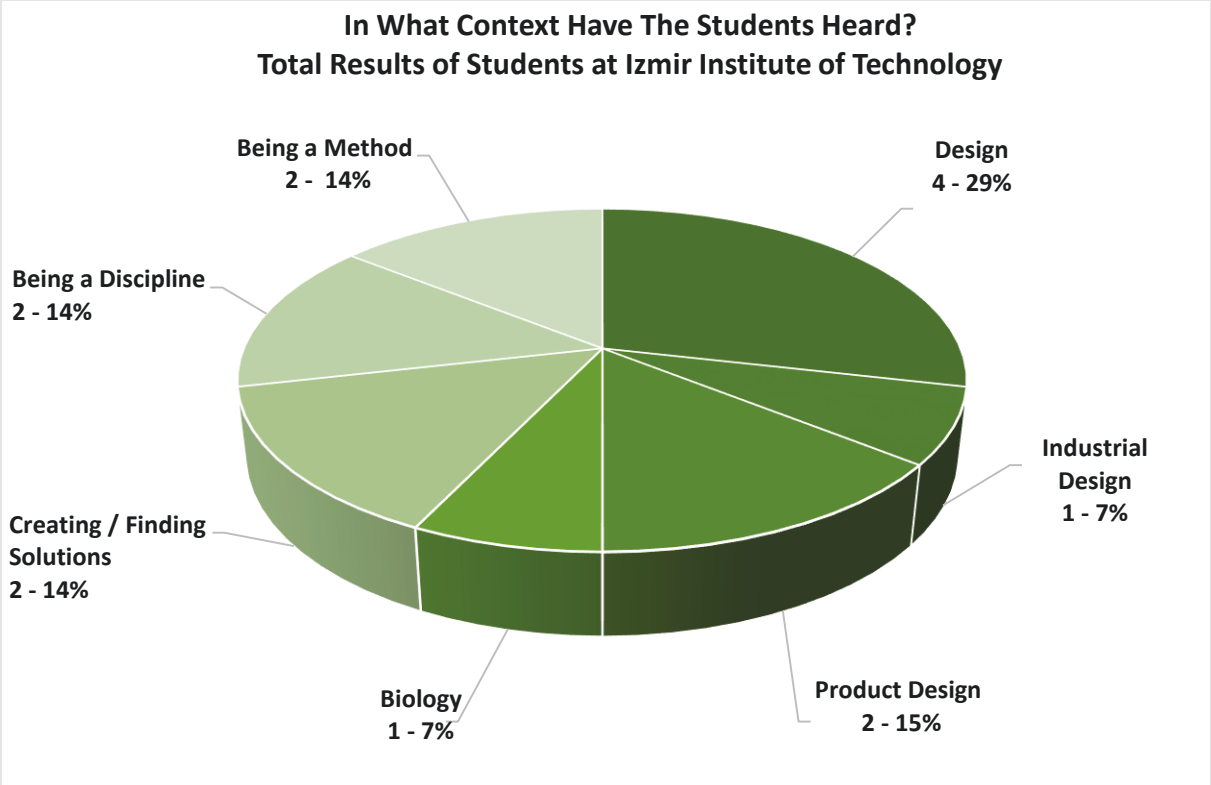

Figure 4.4. Q4 graph

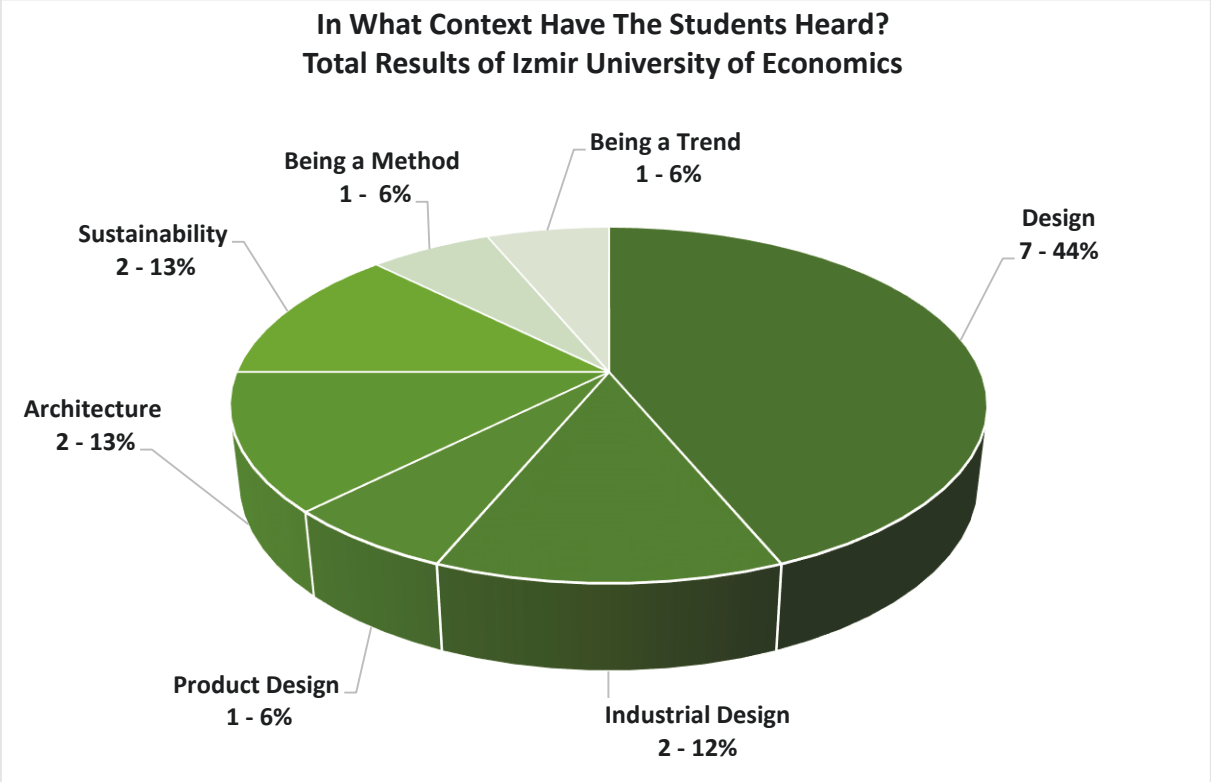

Figure 4.5. Q4 graph

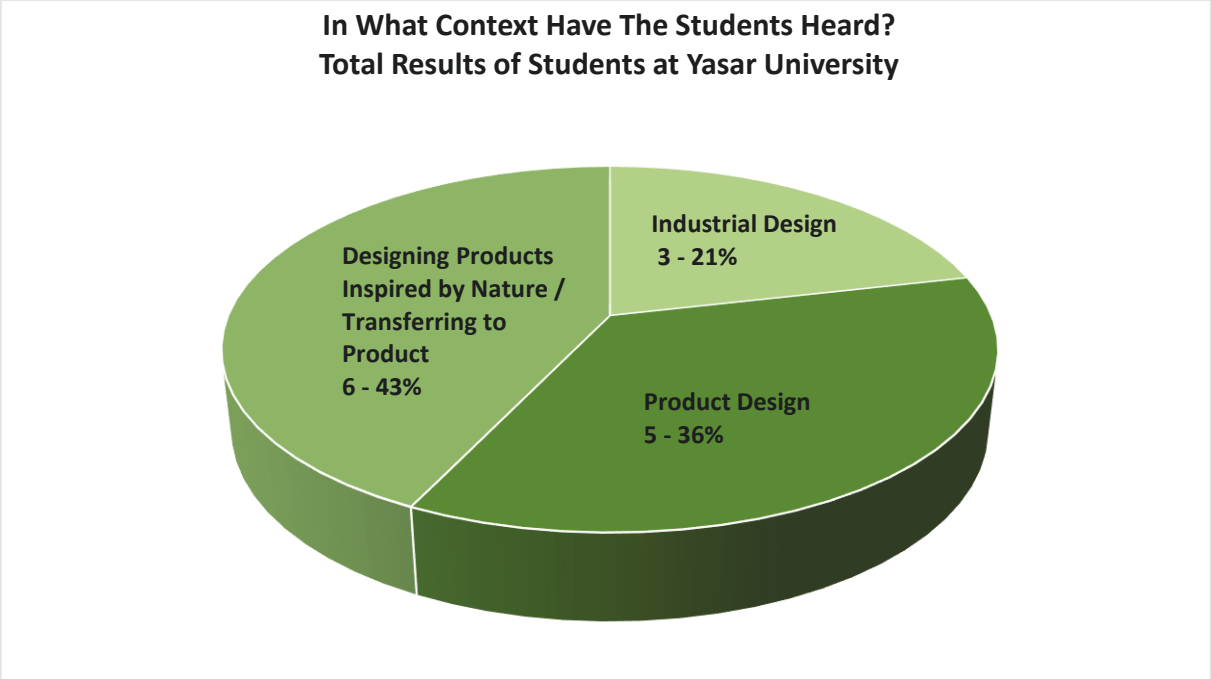

Figure 4.6. Q4 graph

According to how 44 students who have heard of these concepts answer the 'context' part of the question, common points were set and was formed.

Answers which have noticeable accumulation are often given in the context of design, of product design, of industrial design and of designinig products based on form or function inspired by nature. The reasons for is that the educational field of the students and they have considered biomimicry mostly in the context of design. 31 of the 44 students heard biomimicry in the most general contexts within the framework of design and industrial design.

In addition, the fact that some master and bachelor students in Izmir Institute of Technology and Izmir University of Economics consider biomimicry as a discipline, method and trend may show that these students have a different and more awareness on this concept. The fact that 3rd year and master students from Izmir University of Economics hear about biomimicry in the context of sustainability may indicate a tendency for the concept of sustainability in this university.

The other thing that stands out is that although biomimicry has a very close connection with biology, only one master student has responded in this direction. It can be said that although students know the concept of biomimicry, they cannot go very deep.

The distribution of total responses according to each university as percentage are analysed separately.

In Izmir Institute of Technology University and Izmir University of Economics (two universities having master students as survey participants), the number of students (bachelor and master) who have heard about biomimicry in the context of "design" is higher than the number of students who have given other answers as context. Besides, the answers given by the participants from these two universities shows a balanced distribution. However, there is a concentration in certain answers in Yasar University, where only bachelor students as survey participants are present.

When evaluated in terms of independent variables such as age and education levels, it was found out that master students had a broader vision in terms of contextual evaluation of biomimicry, but considering the education level of bachelor students, it turned out be inevitable that specific answers would be given by many participants due to their limited knowledge. In Yasar University, the three answers that arise when students evaluate biomimicry contextually are designing products inspired by nature / transferring to product, product design and industrial design (Figure 4.6). The reason why designing products inspired by nature / transferring to product, product design and industrial design answers are so high is that 2nd and 3rd year students have made projects in design studios about biomimicry. Especially 3rd year students certainly carried out a project on biomimicry with the guidance and trafferring informations from academicians.

Question 5: If you have learned or applied these concepts in the universities, in which course did you learn?

From this question onward, the participant students who answered “no” to the previous question were left out of assestment. In this context, the number of participants is now 44. There are 25 (%57) bachelor students and 19 (%43) master students in total. In the new situation, there are again only master students at Izmir Institute of Technology, only bachelor students at Yasar University, and %68,75 bachelor and %31,25 master students and Izmir University of Economics.

Table 4.4 below is made according to on which courses the students have learned or applied the concepts of biomimicry in their universities.

Table 4.4 lists the courses in which the concept of biomimicry is mentioned and the number of students taking these courses. Figure 4.7, Figure 4.8, and Figure 4.9 demonstrates the distribution of these numbers as a percentage.

Table 4.4. Q5 graph

COURSES	Izmir Institute of Technology	Izmir University of Economics				Yasar University			TOTAL
	Master	Bachelor			Master	Bachelor			
		2.	3.	4.	M	2.	3.	4.	
2nd, 3rd and 4th Class Studios in Bachelor	5	0	0	0	1	0	0	0	6
Contents of Theoretical Courses in Bachelor	2	2	0	0	0	0	0	0	4
ID 531- Industrial Design Studio	3	0	0	0	0	0	0	0	3
ID 592- Seminar	1	0	0	0	0	0	0	0	1
ID 521- Research Methods in Design	1	0	0	0	0	0	0	0	1
ID 202- Product Design Studio	0	1	0	1	0	0	0	0	2
PD 314- Industrial Design Studio	0	0	0	2	0	0	0	0	2
PD 498- Graduation Project	0	0	0	1	0	0	0	0	1
ID 302- Contemporary Issues in Industrial Design	0	0	1	0	0	0	0	0	1
PD 316- Design for Sustainability	0	0	1	0	0	0	0	0	1
Furniture Design Course (in Bachelor)	0	0	0	0	1	0	0	0	1
FFD 557- Bio-Climatical Design Course	0	0	0	0	2	0	0	0	2
ARCH 328- Designing with Nature: Biomimicry in Architectural Design (elective course of Architecture Department)	0	0	0	1	0	0	0	0	1
ARCH 202- Architectural Design II (course of Architecture Department)	0	0	1	0	0	0	0	0	1
Courses of Architecture Department	0	0	0	0	1	0	0	0	1
INDD 1109-INDD 1112- Basic Design	0	0	0	0	0	3	0	0	3
INDD 1105-INDD 1106- Introduction to Industrial Design	0	0	0	0	0	2	0	0	2
INDD 2201-INDD 2202- Industrial Design Studio	0	0	0	0	0	1	0	0	1
INDD 3301-INDD 3302- Industrial Design Studio	0	0	0	0	0	0	5	3	8
Others Unrelated To Universities (research from magazines, articles and websites)	2	0	0	0	0	0	0	0	2
TOTAL	14	3	3	5	5	6	5	3	44

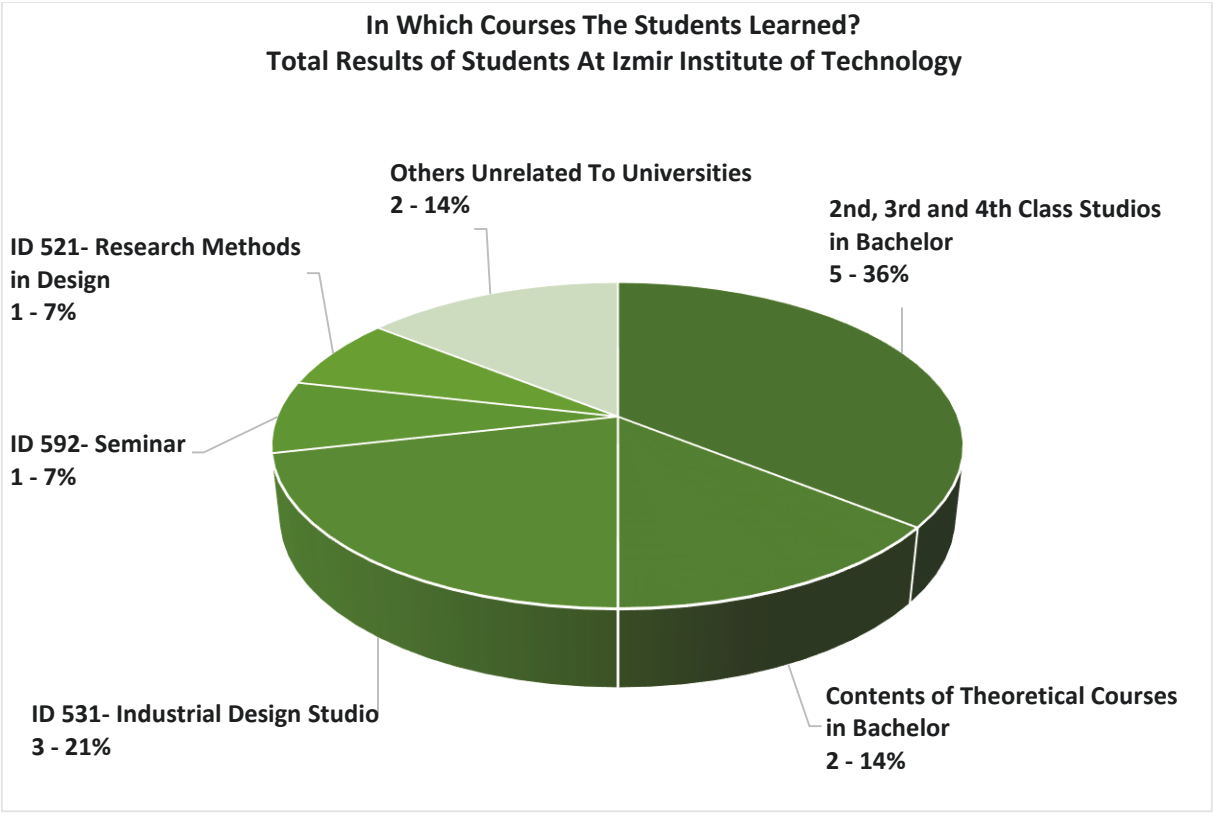

Figure 4.7. Q5 graph

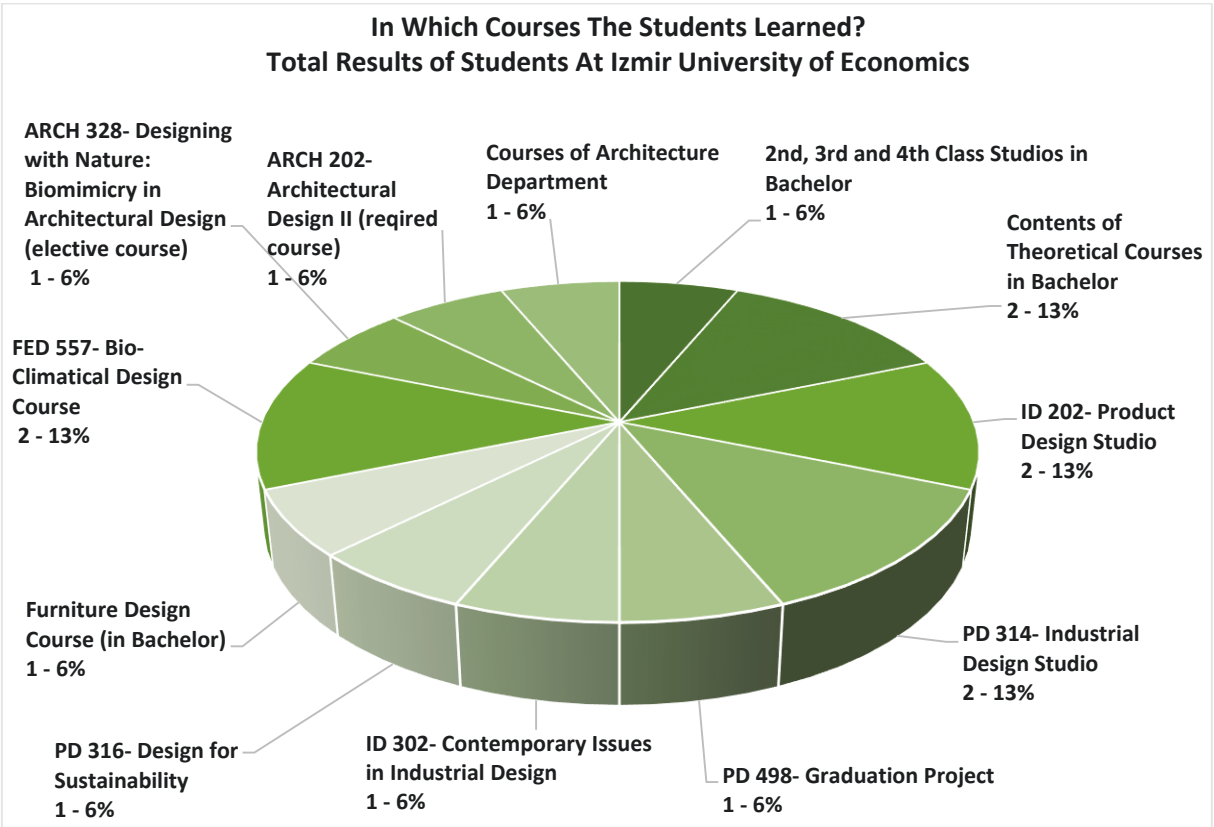

Figure 4.8. Q5 graph

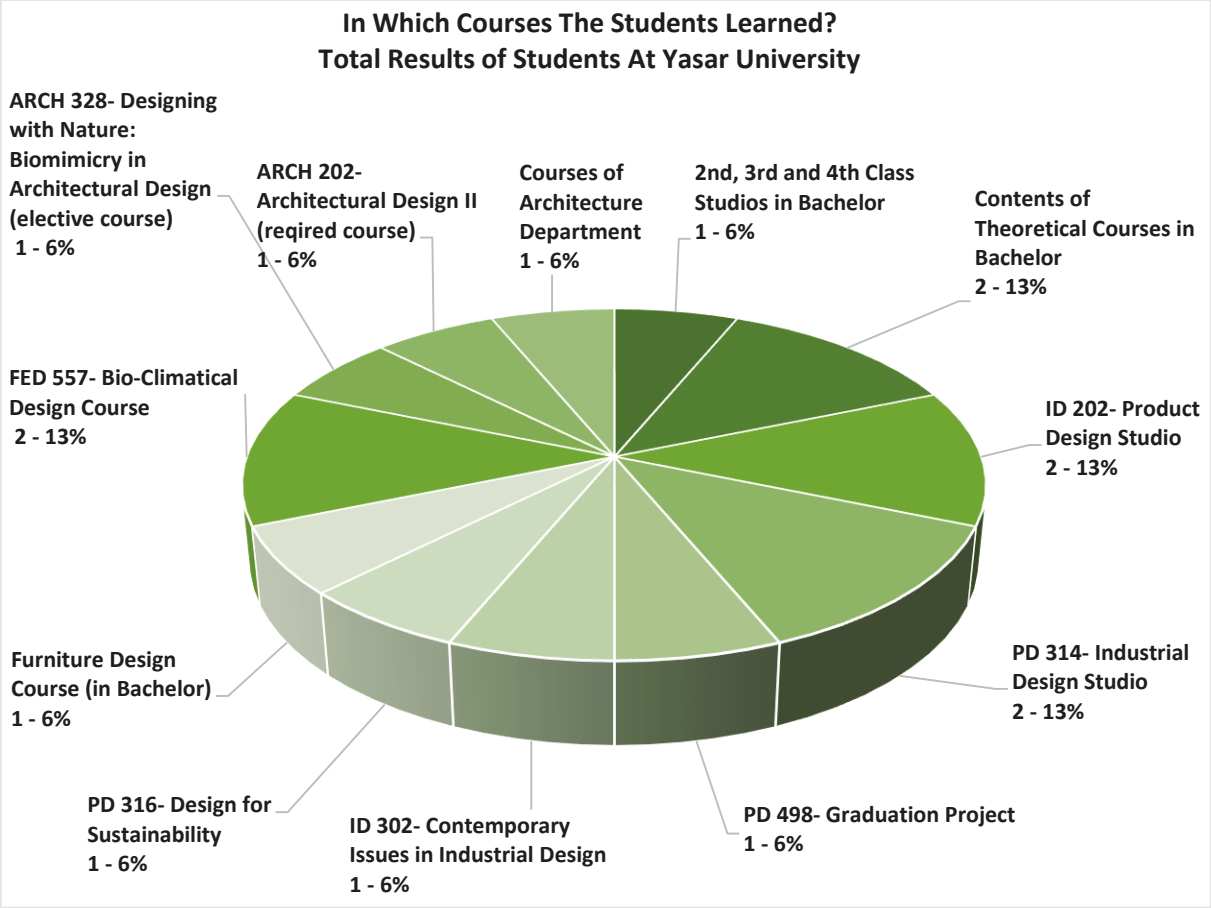

Figure 4.9. Q5 graph

In the comparison between bachelor educations of universities, Yasar University is more inclined towards this concept and the level of awareness seems to be higher. At Yasar University, there is a conscious approach to the concept of biomimicry and an conscious transfer from academicians to students. The courses at Izmir University of Economics are varied and more in number. In some courses, biomimicry may be mentioned and covered, but this is superficial and may not be very thorough.

The fact that there is no direct biomimicry courses in industrial design departments at all three universities can be interpreted that universities which surveyed consider biomimicry as a complementary, supportive and subsidiary concept to industrial design.

Question 6: How do you explain / describe the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design?

This question was about understanding of the students' perception of the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design, and the responses were divided into seven groups through the analysis.

This question was about understanding of the students' perception of the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design, and the responses were divided into seven groups through the analysis (Table 4.5).

The definitions of the biomimicry as given by the students are listed in the table below (Table 4.5). In Figures 4.4., 4.5. and 4.6., the distribution of these definitions as percentage is shown separately according to each universities as percentage.

Table 4.5. Q6 graph

DEFINITIONS	Izmir Institute of Technology	Izmir University of Economics				Yasar University			TOTAL
	Master	Bachelor			Master	Bachelor			
		2.	3.	4.	M	2.	3.	4.	
Inspiring from nature in design – form based	4	2	0	1	1	1	1	0	10
Inspiring from nature in design – function/process and mechanism based	4	0	0	0	0	0	0	0	4
Inspiring from nature in design to perform sustainable design	0	0	2	0	0	0	0	0	2
Inspiring from nature in solving design problems -as a solution to problems	2	0	1	1	0	3	0	0	7
Imitating/Inspiring nature's models, forms, systems, and behaviours to solve design problems -design adaptation -by observing, exploring	3	0	0	1	0	0	4	0	8
Imitating/Inspiring nature's forms, processes, systems and elements to find sustainable and innovative solutions for design or human problems	1	0	0	2	0	0	0	3	6
To get inspired to solve design or human problems by interpreting survival adaptations, skills, solutions and forms developed by living things in nature within the framework of design discipline	0	0	0	0	4	0	0	0	4
TOTAL	14	2	3	5	5	4	5	3	41

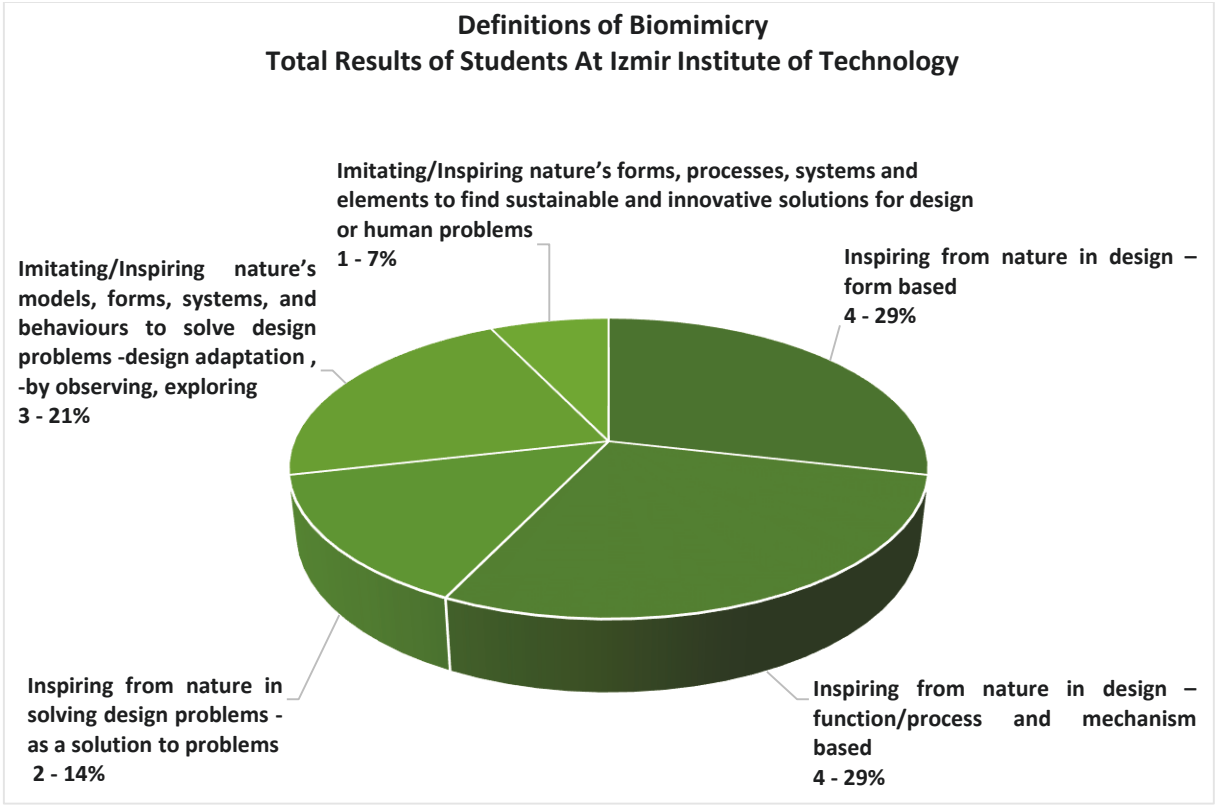

Figure 4.10. Q6 graph

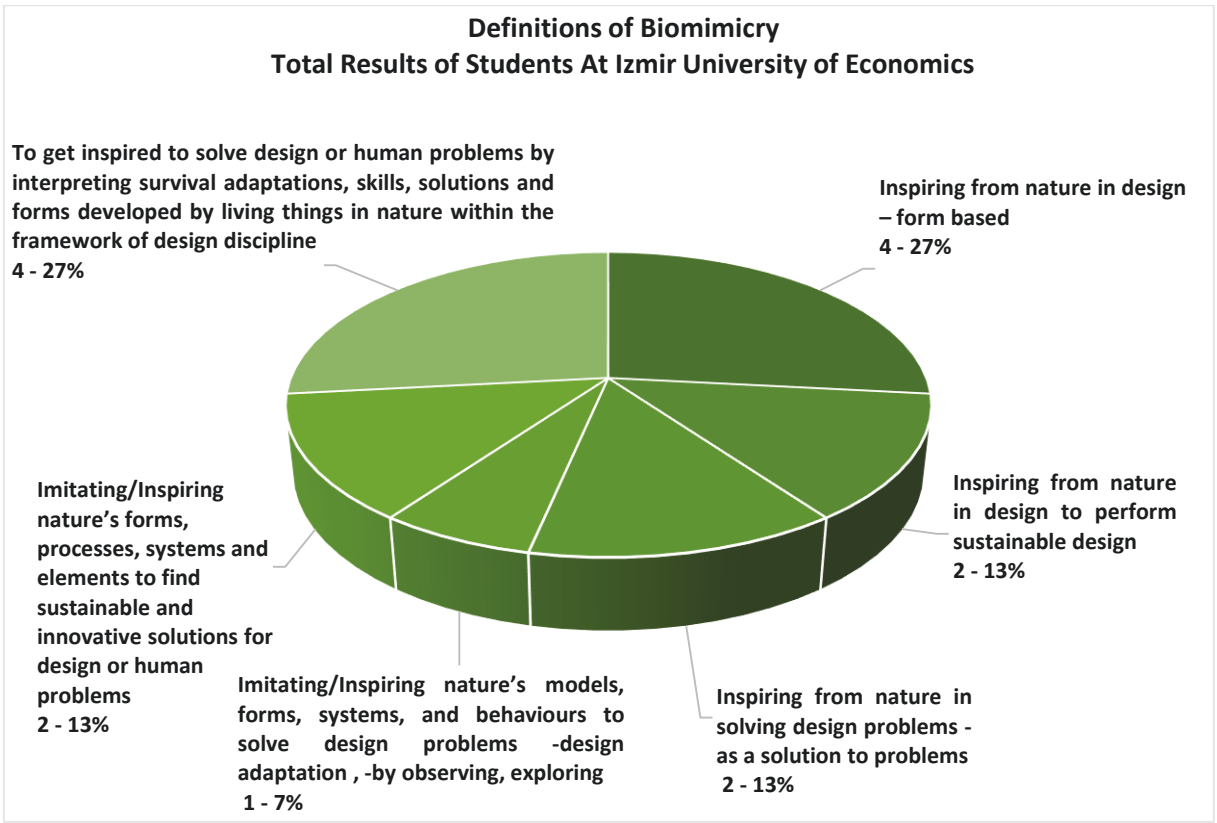

Figure 4.11. Q6 graph

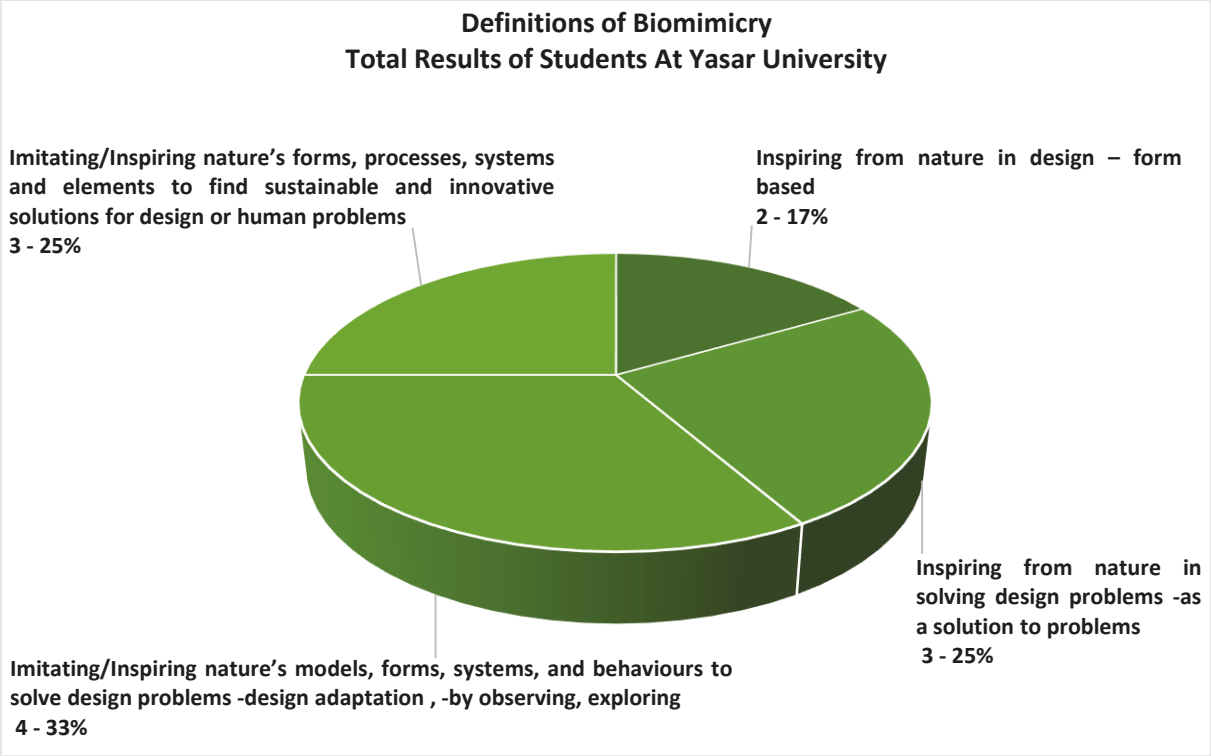

Figure 4.12. Q6 graph

In general, the definitions from top to bottom (Table 4.5) have become more complex and more comprehensive. In particular, the last five definitions are highly intertwined or complementary.

Regarding to actual definitions of biomimicry in the literature, 27 out of 41 students were able to respond this. 14 out of 44 students did not actually misidentify, but according to the biomimicry approach, their responses were shallow and were not descriptive. These 14 students defined biomimicry as inspiring from nature in terms of form and function of designing only product without considering any other ultimate goals.

Generally, it can be concluded that 27 of 41 students have knowledge of biomimicry. They know what biomimicry is and they are aware of biomimicry. The remaining 14 students have a general and superficial idea of biomimicry and relevant concepts, but their knowledge is not comprehensive and refined. It appears that even though they do not have deep knowledge of the given concepts, most of the students are at least familiar with these concepts.

When the definitions of the students from all three universities are evaluated, it is seen that the master students at Izmir Institute of Technology generally make various definitions, and there are not many common answers. On the other hand, the responses of Izmir University of Economics master students (4/5) are almost all gathered under single definition. Similarly,

the responses of the 4th year of Izmir University of Economics and Yasar University (5/8) seem to be gathered under a single definition. Thanks to courses about in Izmir University of Economics, many of the students defined biomimicry as a design solutions aiming for sustainability. It can concluded that universities and their content of courses in education may have an impact on definitions.

When the definitions of inter-universities master students are compared, 5 different definitions emerge at Izmir Institute of Technology, while 2 different definitions emerge at Izmir University of Economics. Even, 4 out of 5 master students of Izmir University of Economics gave only one definition. The course called "FFD 557- Bio-Climatical Design" which is given in Izmir University of Economics in master's education, may have caused students to learn biomimicry from a certain point of view and give the definition with the same or close focus.

When the definitions of inter-universities bachelor students are compared, it is seen that the diversity of definitions in Izmir University of Economics and Yasar University are very close to each other and more or less the same answers were given. The only thing that stands out at Izmir University of Economics and is different from Yasar University that it is the definition made with a focus on sustainable design that may have been due to the course called "PD 316- Design for Sustainability". In Yasar University, especially the 2nd and 3rd year students who indicated in the survey that they had done projects on this subject in design studios focused on two different definitions. When these two definitions are examined, it is seen that in the first one, biomimicry is defined based on the relationship of the design problem - solution in nature (made by the 2nd year). In the second, it is defined in a more detailed manner and again in relationship of the design problem - solution in nature, this time is defined over the state and process of adapting nature to design. (made by the 3rd year). It can be understood that the theoretical and practical knowledge and experience they gained during the projects in their universities was effective in the definitions of 2nd and 3rd years.

The limited the diversity of definitions at the master or bachelor level and common definitions even from different universities, can be interpreted as the content of courses in education in universities has an impact on the comprehensibility and definability of the concept of biomimicry.

The increase in the variety of definitions at the bachelor or master level is due to the fact that the participant students make definitions not only in line with what they have learned from the courses but also according to their own comments, experiences and knowledge.

Question 7: Do you think there is a relationship between sustainability and the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design? If yes, how do you explain / describe this relationship?

80% of the total 44 students think that there is a relationship between sustainability and the concept(s) of biomimicry. 20% of these students do not think that there is a relationship.

While the ways of relationship between sustainability and the concept(s) of biomimicry is presented in the Table 4.6, the distribution of the answers given according to universities is presented in figures 4.13, 4.14 and 4.15.

Table 4.6. Q7 graph

RELATIONSHIP	Izmir Institute of Technology	Izmir University of Economics				Yasar University			TOTAL
	Master	Bachelor			Master	Bachelor			
		2.	3.	4.	M	2.	3.	4.	
For ages, livings in nature have always found a solution to survive under earth operating conditions and thus maintained their lives.	2	0	2	1	1	1	1	1	9
Recyclable and energy-efficient design inspired from nature can become self-sufficient and sustainable.	2	0	0	3	1	2	0	0	8
Nature always works on the balance that will ensure its continuity. Biomimicry can extract methods from nature to achieve sustainability.	0	0	1	0	2	0	1	0	4
The cycle in nature continues all the time. Therefore, recyclable design can provide continuous cycle and sustainability.	3	0	0	0	0	1	0	0	4
Self-renewal and everlasting properties of nature underlie the idea of sustainability.	1	0	0	1	0	2	0	1	5
A solution intertwined with nature creates environmental friendly and sustainable processes. However, the combination of biomimicry with unsustainable production techniques and materials disrupts the relationship of sustainability.	1	0	0	0	1	0	0	0	2
The waste of a living thing is used as the source of other living things. Nature tries to use its resources in the best and most efficient way. Designs are intended to have a life cycle and biomimicry can present sustainable designs	2	0	0	0	0	0	0	1	3
TOTAL	11	0	3	5	5	6	2	3	35

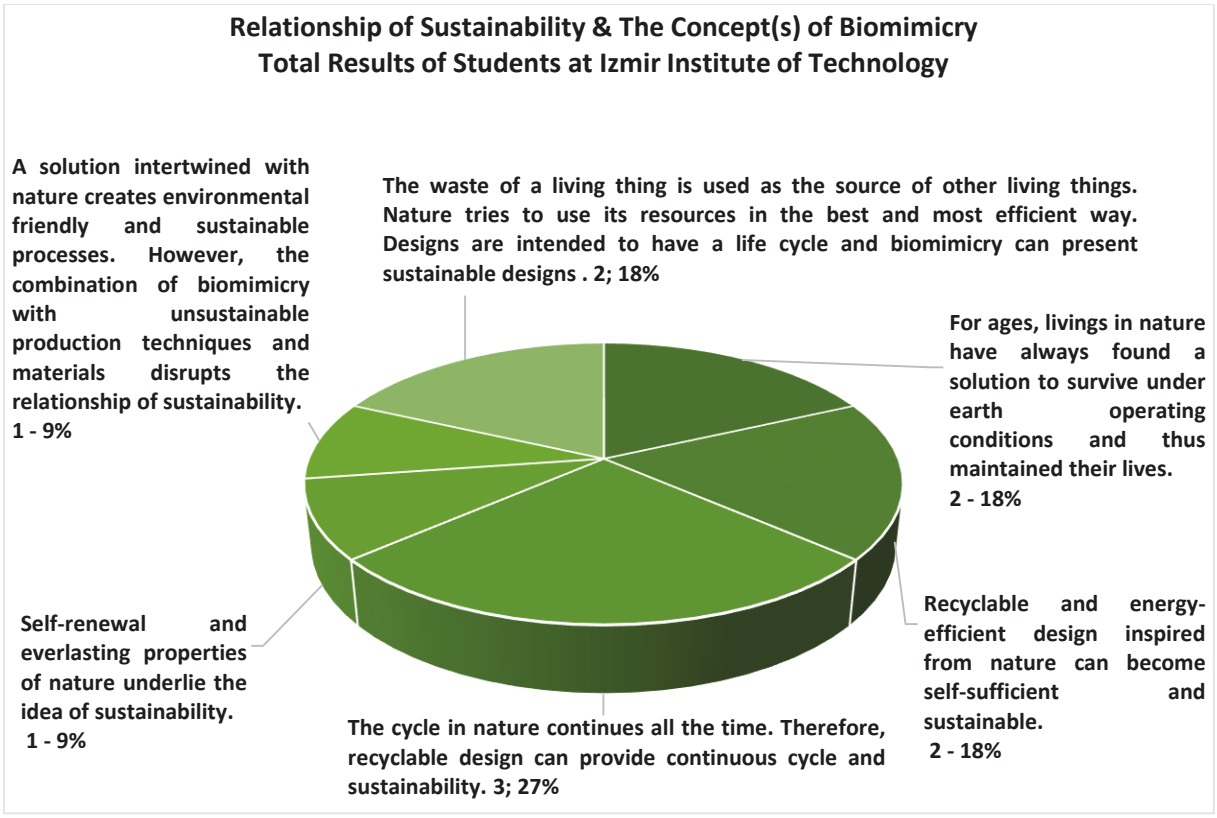

Figure 4.13. Q7 graph

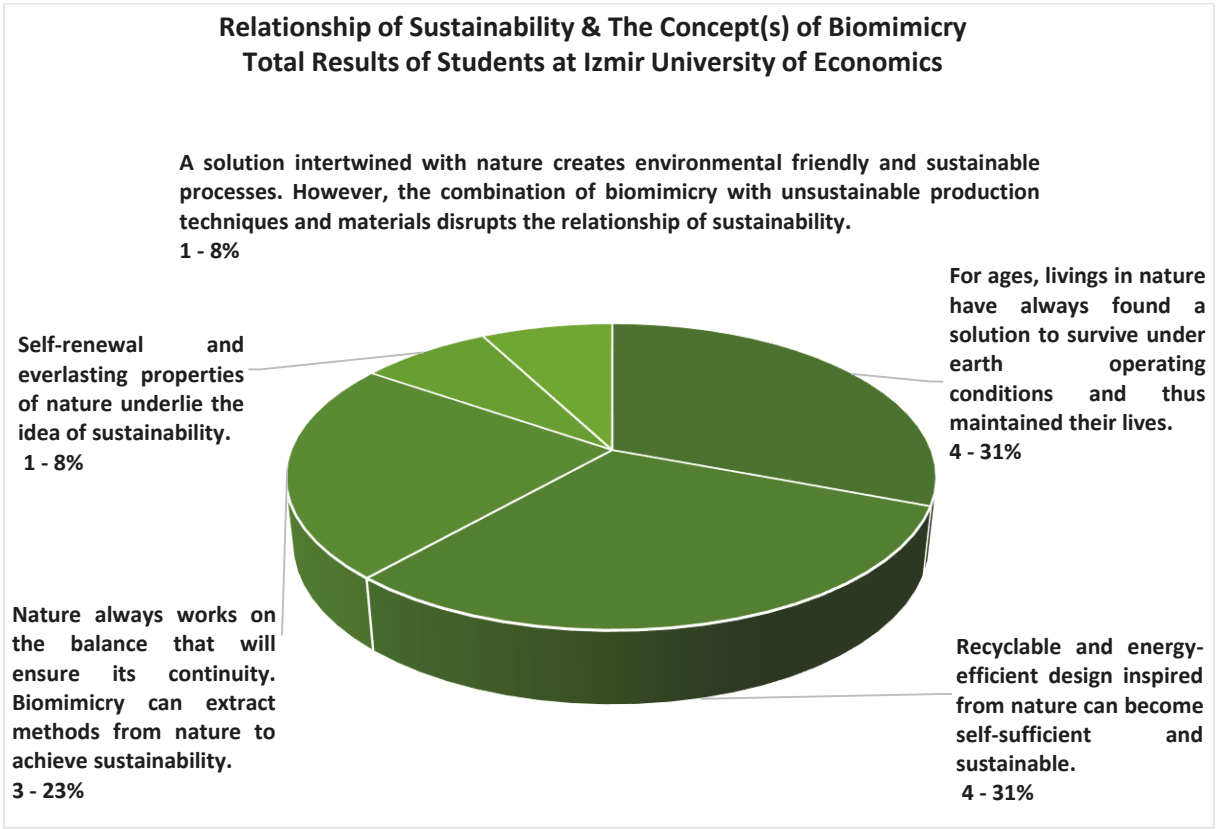

Figure 4.14. Q7 graph

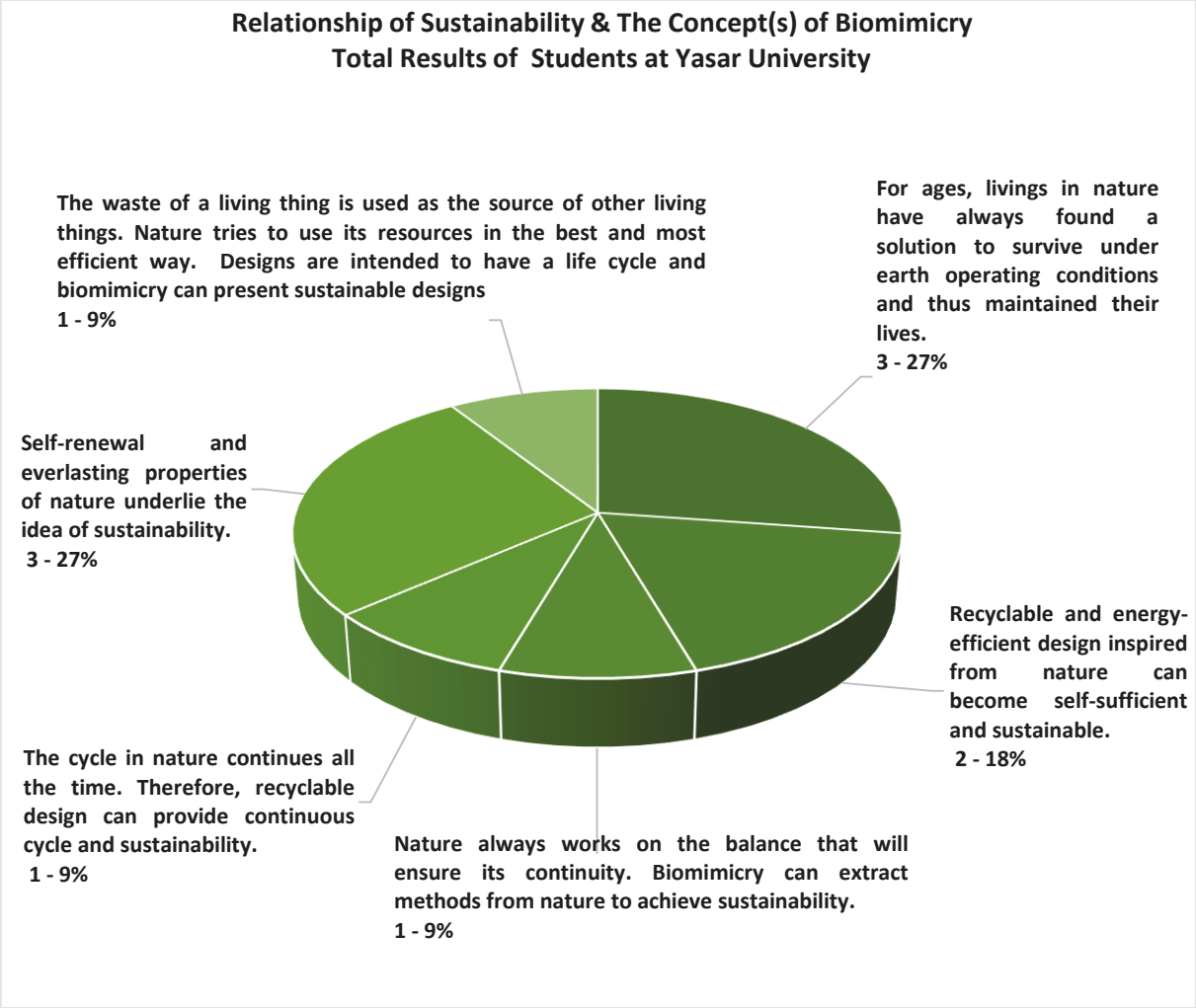

Figure 4.15. Q7 graph

When the overall definitons are examined, it is understood that the definitions of the relationship established between the two concepts are highly intertwined. There are no sharp differences between the definitions and the definitions have become difficult to analyze due to this fuzziness. Definitions of relationship especially in the last lines are quite fuzyy; however, the summary of the relations in the table can be explained as follows:

- Being efficient in resources such as materials and energy.
- Consuming less resources.
- Recycling of resources.
- Reducing energy use, energy saving by using as little energy as possible.
- Obtaining maximum efficiency with minimum energy consumption.
- Recycling, reversing, re-using and renewaling of materials
- Being more environmentally and beneficial to nature.

- Considering life-cycle of products, services and systems that manufactured / designed.

Looking at the analysis of the answers given according to universities, all of the undergraduate 2nd year students of Izmir University of Economics who participated in the survey have suggested that there was no relationship between sustainability and biomimicry. On the other hand, all bachelor 2nd year students of Yasar University who participated in the survey have stated that there was a relationship between sustainability and biomimicry. The case that the two groups with the same level of education give completely opposite responses can be interpreted as the level of education has no effect on the correlation of sustainability and the concept(s) of biomimicry. On the other hand, it can be said that universities and their content and courses of education have an impact on definitions of relationships.

Question 8: Do you think there is a relationship between innovation and the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design? If yes, how do you explain / describe this relationship?

With a small margin, students were more able to relate biomimicry to innovation than sustainability. Comparing the results of Q7 and Q8, there has been an increase in the relationship with innovation in most universities compared to the question of the relationship with sustainability.

89% of the total 44 students who participated in the survey think that there is a relationship between innovation and the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design. 11% of these students do not think that there is a relationship. However, the definitions of the relationship are highly intertwined and fuzzy as in the previous question related to sustainability.

The ways of relationship are described in Table 4.7. In the graphs (Figure 4.16, Figure 4.17, and Figure 4.18), the distribution of answers in Table 4.7 is shown separately according to each universities.

When the previous graphs and tables of Q7 comparing to Q8 are examined, it is observed that the variety of responses in this question given by the students of all three universities, slightly increased. The reason for this may be that the concept of innovation can be handled more concretely than the concept of sustainability. In parallel, there is no significant difference between the distribution of answers given by bachelor and master students. This means that the level of education may not be decisive in the answers to this question.

Table 4.7. Q8 graph

RELATIONSHIP	Izmir Institute of Technology	Izmir University of Economics				Yasar University			TOTAL
	Master	Bachelor			Master	Bachelor			
		2.	3.	4.	M	2.	3.	4.	
New way of sustainable thinking.	2	0	0	0	0	1	1	0	4
Exploring of nature can open new doors in design thinking.	1	2	1	0	0	2	3	2	11
It can be inspired by nature when developing technological innovations.	4	0	0	0	0	2	0	0	6
Nature as a resource of innovative solutions for problems we are struggling to solve.	1	0	1	0	0	0	0	0	2
A product development process with proven solutions of nature has innovative results.	0	0	0	0	1	0	0	0	1
Although mimicking from nature can not be defined as innovation, variation of application method can be innovative.	1	0	0	1	2	1	0	0	5
Evaluation of nature against struggles causes continuous improvements, which enable innovative designs.	2	0	0	0	1	0	1	0	4
Innovation can be defined as bringing new solution instead of reinventing. That is why biomimicry can offer a solution in an innovative way.	0	0	0	0	1	0	0	0	1
High performance and resource-efficient survival strategies as a result of natural selection can be used to overcome the technical challenges not only in aspect of product but also in technology, idea or system.	0	0	0	4	0	0	0	1	5
TOTAL	11	2	2	5	5	6	5	3	39

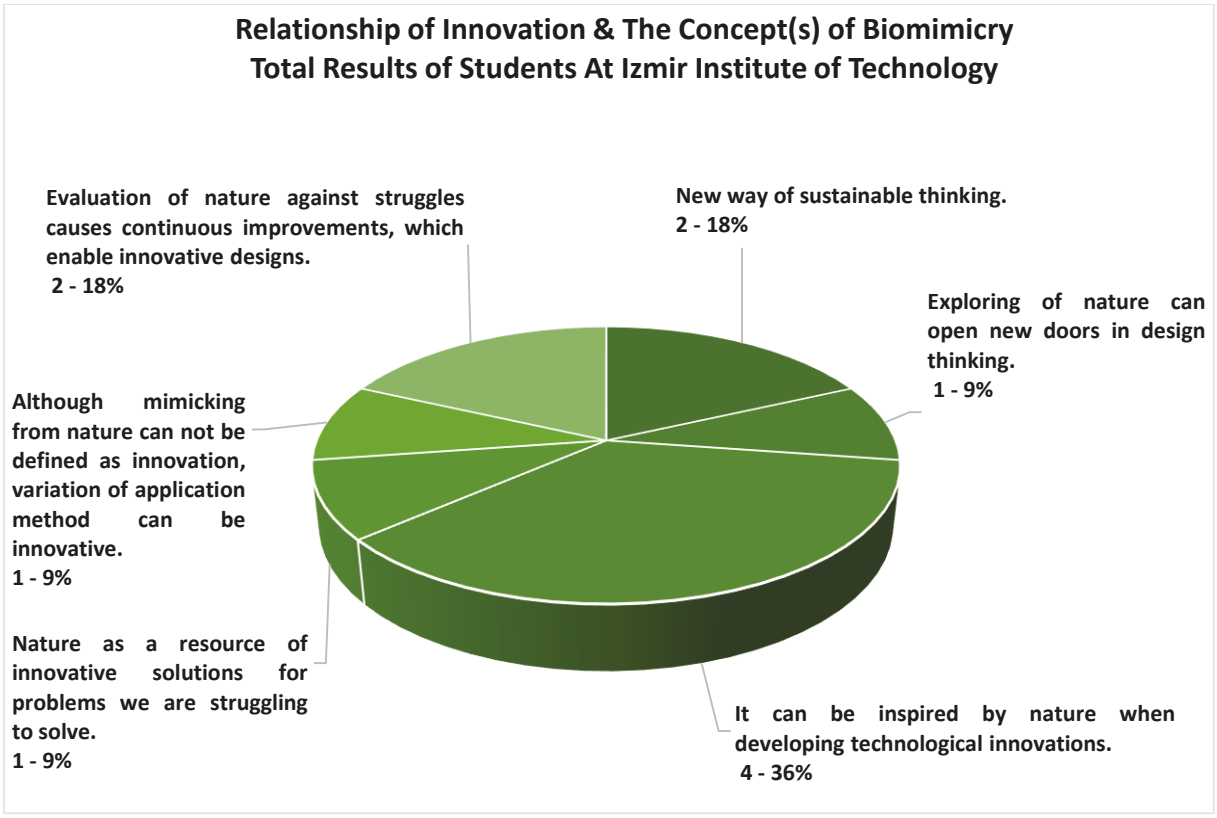

Figure 4.16. Q8 graph

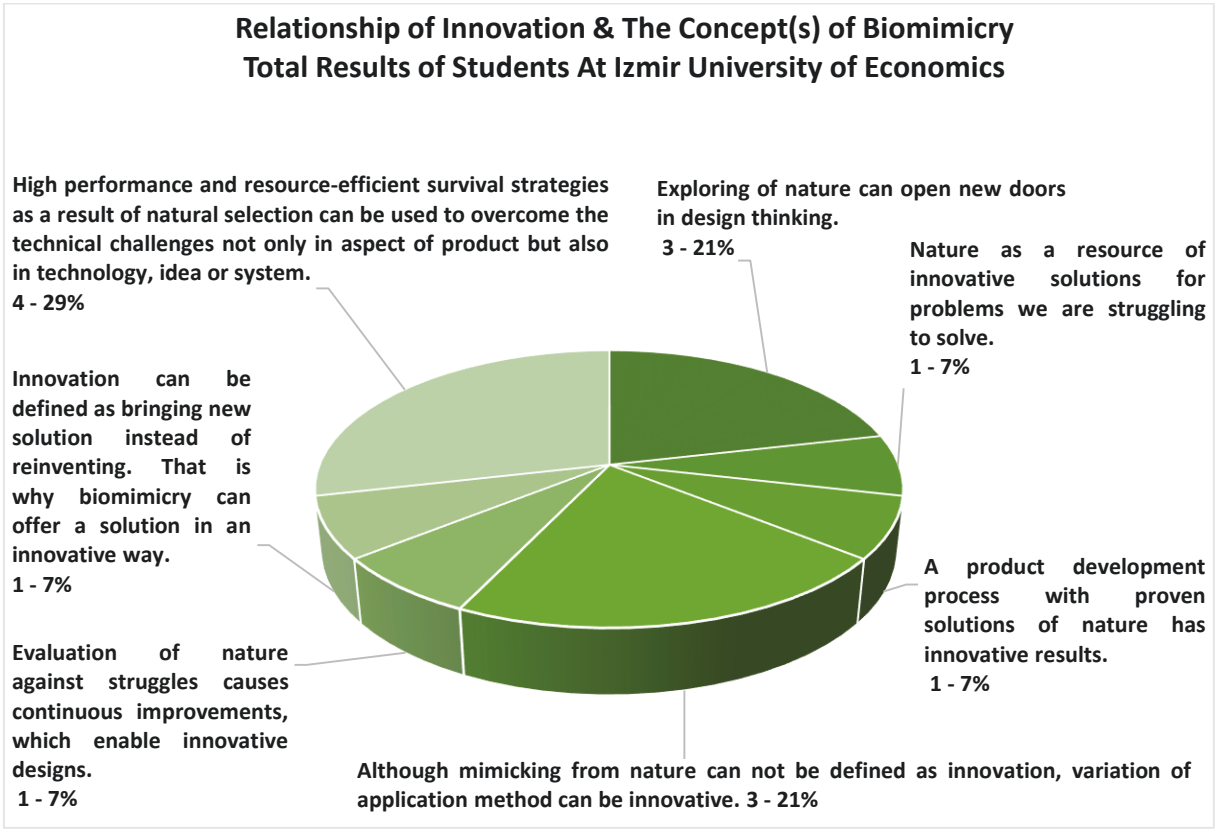

Figure 4.17. Q8 graph

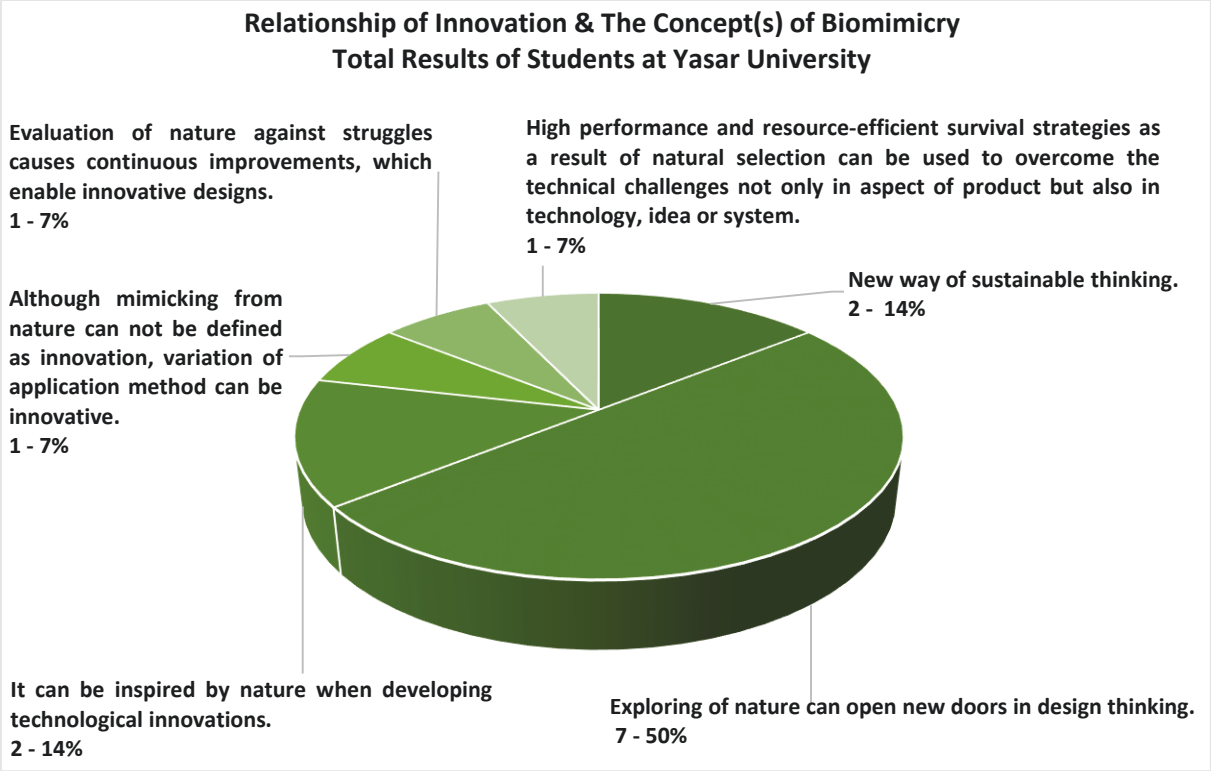

Figure 4.18. Q8 graph

Question 9: Do you think there is a relationship between industrial design and the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design?

All participating students answered "yes" to the question of whether there is a relationship between biomimicry and industrial design.

While students may not be able to relate biomimicry to more specific concepts such as sustainability and innovation, the state of associating biomimicry with industrial design by all of these students may have stemmed from that the students may regard biomimicry as a complementary and supportive method, tool or approach to industrial design discipline. This also supports the view mentioned in analysis of the previous questions.

Question 10: Do you think that the concept(s) and processes of biomimicry / biomimetic / learning from nature - inspired by nature in design are necessary in industrial design education? If your answer is necessary / not necessary, why?

93.18% of the students think that the concepts of biomimicry should be included in industrial design education. The fact that such a large proportion gives the same answer when considering the bachelor, master and different age groups means that the answer to the question is independent of age and levels of education.

Table 4.8. Q10 graph

NECESSARY	Izmir Institute of Technology	Izmir University of Economics				Yasar University			TOTAL
	Master	Bachelor			Master	Bachelor			
		2.	3.	4.	M	2.	3.	4.	
- Develops & Gives a Point of View - Gains a Different Point of View - Brings a New Perspective	3	0	1	0	1	2	1	0	8
- Provides a Broad Source of Inspiration	1	2	0	0	0	2	1	0	6
- Offers a Source of Solutions - Offers a Wide Range of and Best Solutions for Design Problems & Unforseen Needs - Offers a New Approach / Method for Problem Solving - Provides Ease in Solving Design Problems	5	0	2	1	1	1	3	0	13
- Supporting and Enhancing Creativity	0	1	0	1	1	0	0	2	5
- Enabling Sustainability (sustainable designs, sustainable solutions, a sustainable-oriented point of views)	2	0	0	1	1	1	0	0	5
- Adding Aesthetic (form, shape) and Functional Properties in Design	0	0	0	1	0	0	0	0	1
-Making Designs Which are Less Harmful to Environment -Designer's Role, Sense of Responsibility -Changing and Increasing Awareness of the Environment - Nature -Changing of Product - Nature Relationship	2	0	0	1	0	0	0	0	3
TOTAL	13	3	3	5	4	6	5	2	41

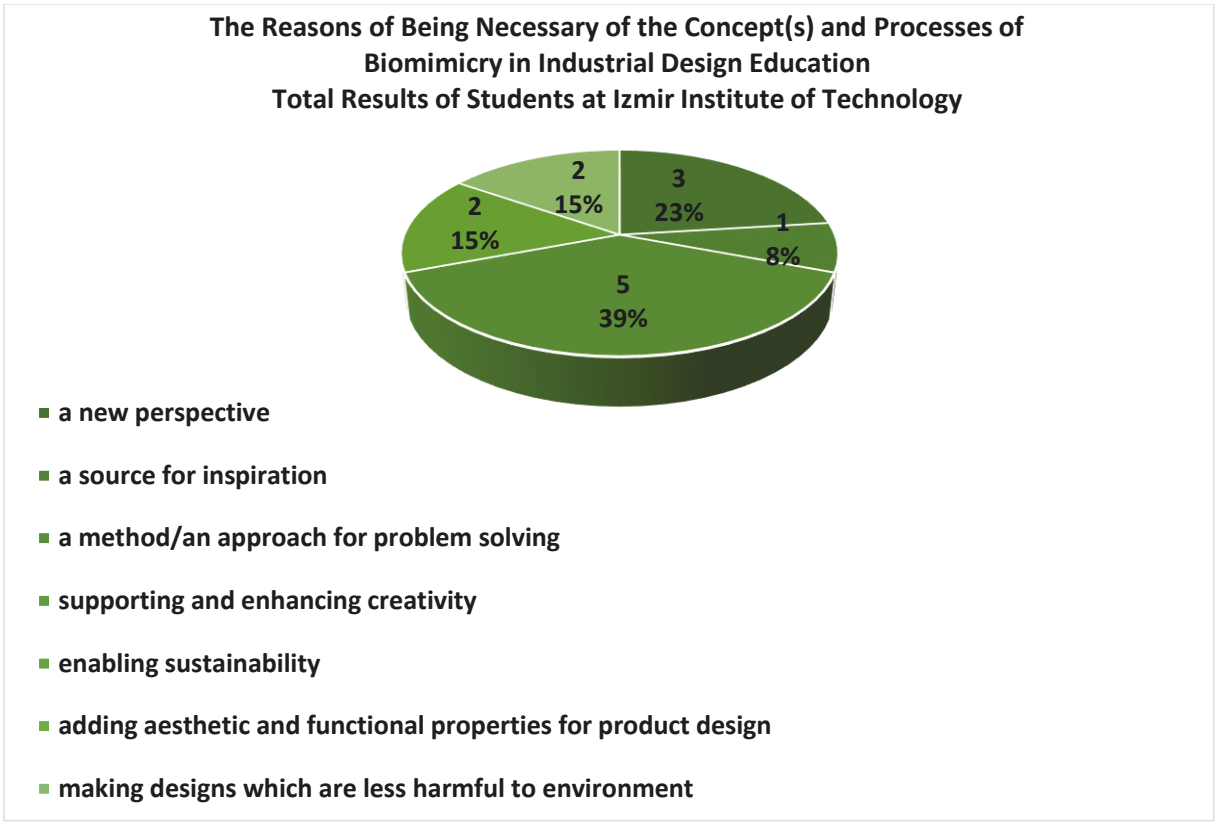

Figure 4.19. Q10 graph

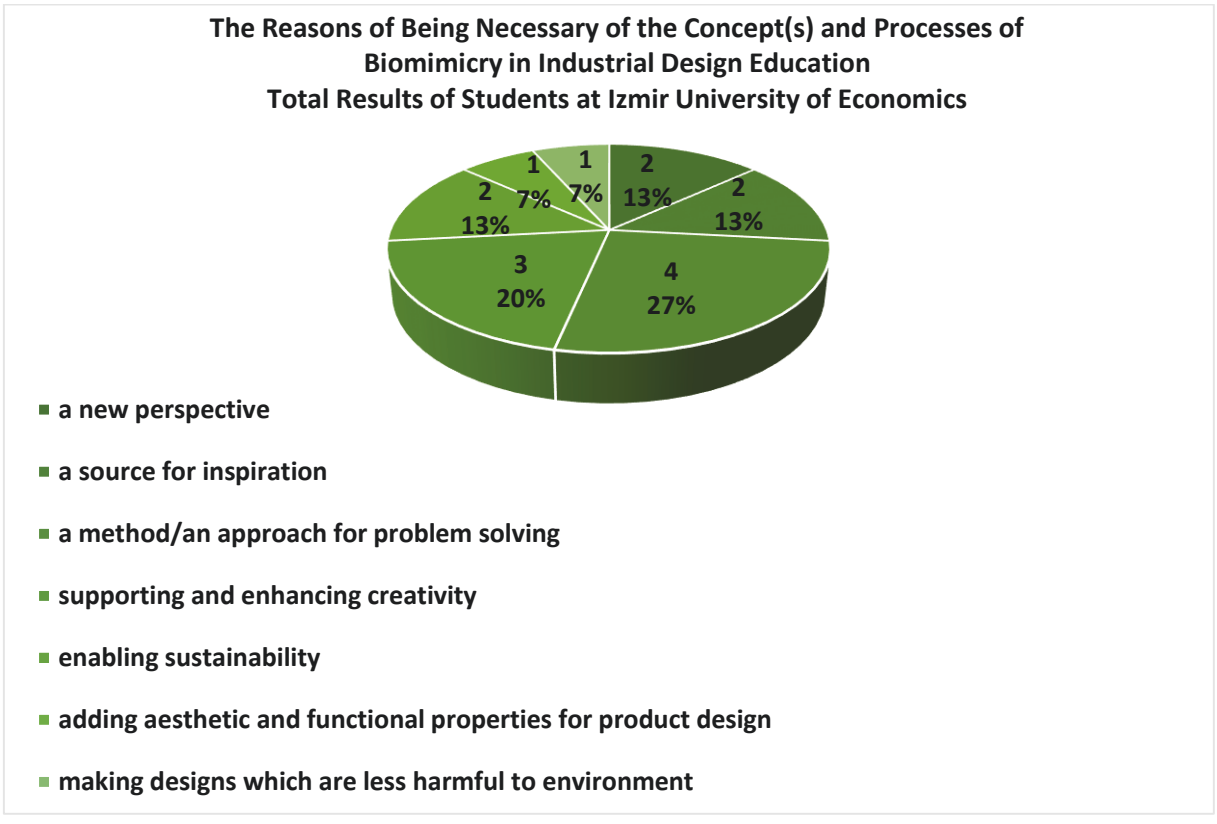

Figure 4.20. Q10 graph

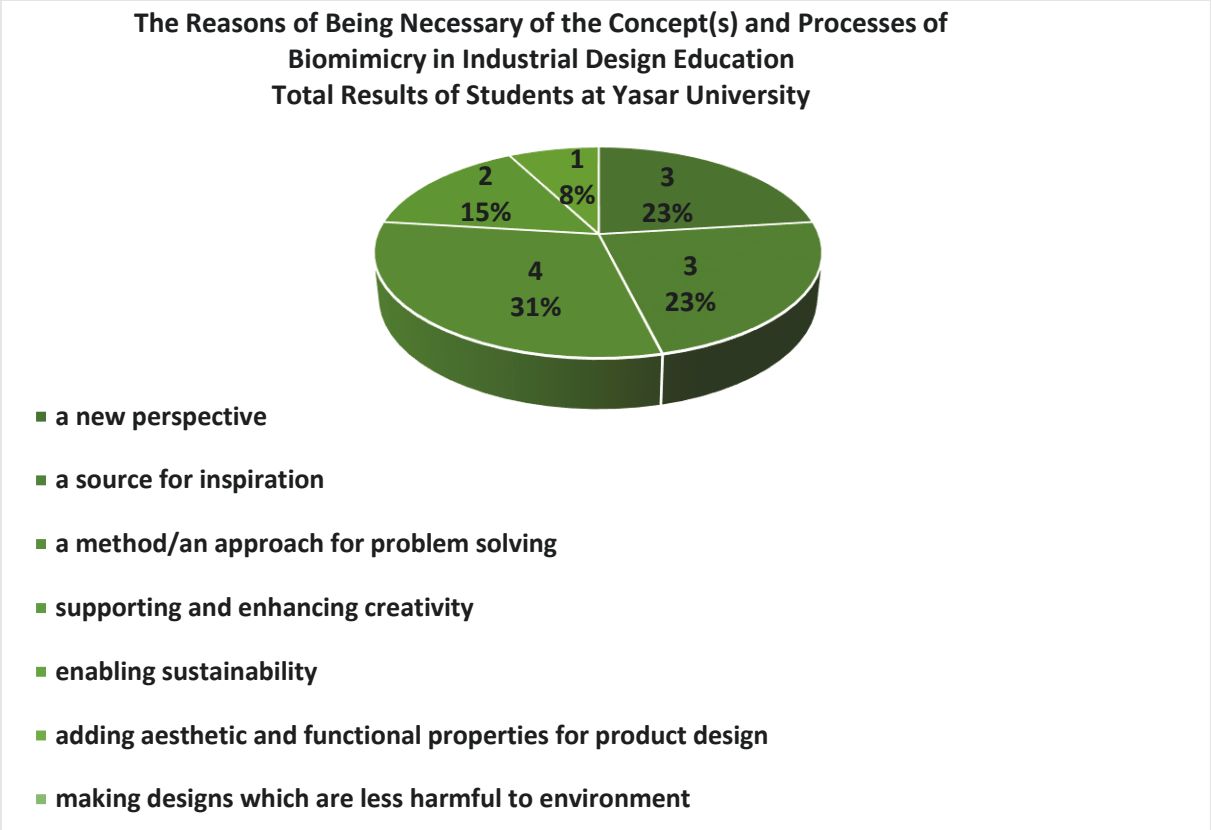

Figure 4.21. Q10 graph

The only participant who thinks that the concept(s) of biomimicry should not be used in industrial design education is bachelor 4th year student of Yasar University. This participant did not make any comments why these concepts should not be involved in industrial design education.

In general, the students mostly think that biomimicry and its processes are necesseary in industrial design education. New point of view, source of inspiration, method-approach-source of solutions, which are the dominating answers among the all students for Q10 can be gathered under the title "the contributions to biomimicry in the processes of designing".

The most common answer given by students at all universities is that biomimicry is necessary in industrial design education because it functions as a source of solution to design problems.

Question 11: Do you think that the concept(s) and processes of biomimicry / biomimetic / learning from nature - inspired by nature in design are necessary for professional practice of industrial design (in the sector)? If your answer is necessary / not necessary, why?

31 of the 44 students (70%) who participated in the survey think that the concept(s) and processes of biomimicry/biomimetic/learning from nature-inspired by nature in design are necessary for professional practice of industrial design (in the sector).

The reasons of why biomimicry is necessary are listed in the Table 4.9. The distribution of responses listed in the table are analyzed based on universities as percentage in figures 4.22, 4.23 and 4.24.

Table 4.9. Q11 graph

NECESSARY, BECAUSE	Izmir Institute of Technology	Izmir University of Economics				Yasar University			TOTAL
	Master	Bachelor			Master	Bachelor			
		2.	3.	4.	M	2.	3.	4.	
- Provides a Broad Source of Inspiration	1	3	0	0	0	0	0	0	4
- Develops & Gives a Point of View - Gains a Different Point of View - Brings a New Perspective	0	0	0	1	1	1	1	0	4
- Create Awareness by Taking into Consideration of Relation Between Nature and Design	1	0	0	1	0	1	0	0	3
- Offers a Source of Solutions - Offers a Wide Range of and Best Solutions for Design Problems & Unforseen Needs - Offers a New Approach / Method for Problem Solving - Provides Ease in Solving Design Problems	0	0	0	0	0	1	2	1	4
- Being Useful in Research & Development - More Practicable and Applicable Design Approaches	1	0	0	0	0	0	0	0	1
- Enabling Innovative and Sustainable Design - Supporting Recyclable Design Approach	3	0	1	1	2	1	0	0	8
- Making Designs Which are Less Harmful to Environment - More Environmentally- Friendly Designs - More Compatible Environmental Approach	2	0	0	2	0	1	0	1	6
- Useful Tool for Developing Concept in Parametric Design	0	0	0	0	1	0	0	0	1
TOTAL	8	3	1	5	4	5	3	2	31

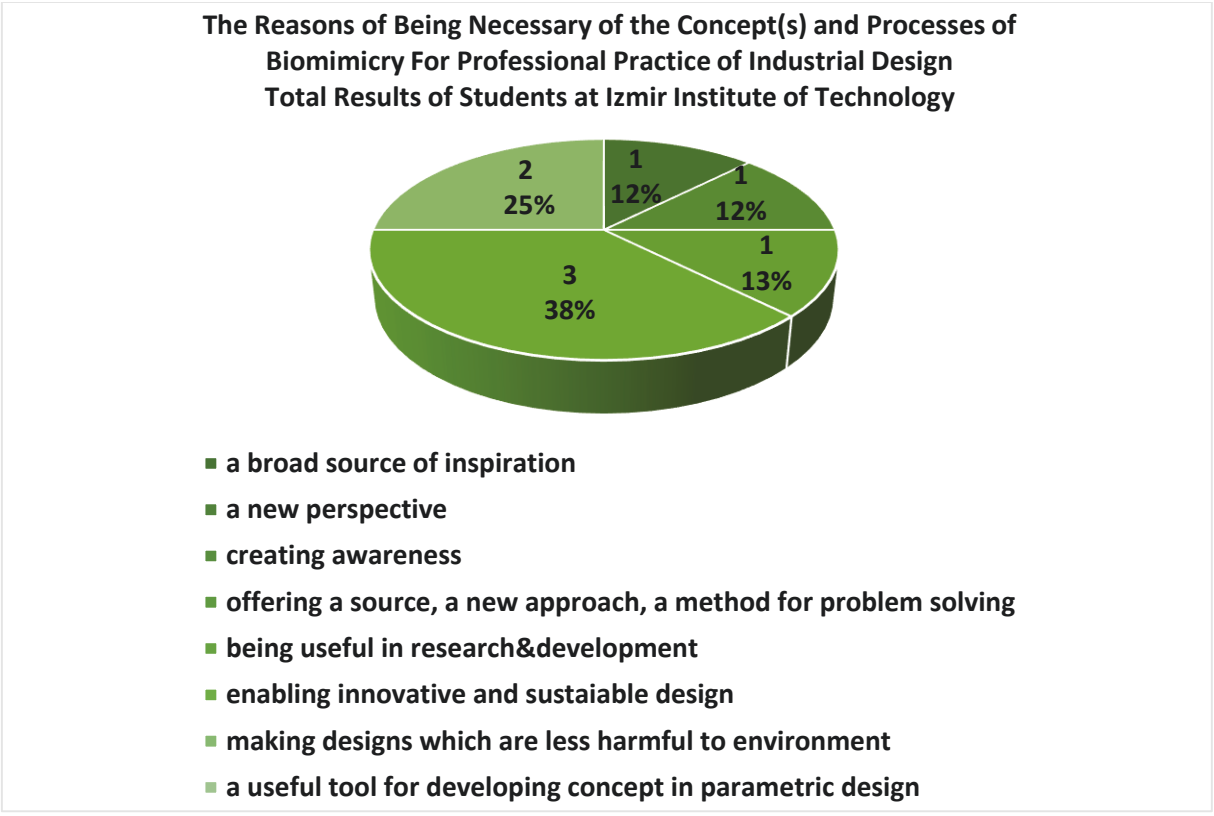

Figure 4.22. Q11 graph

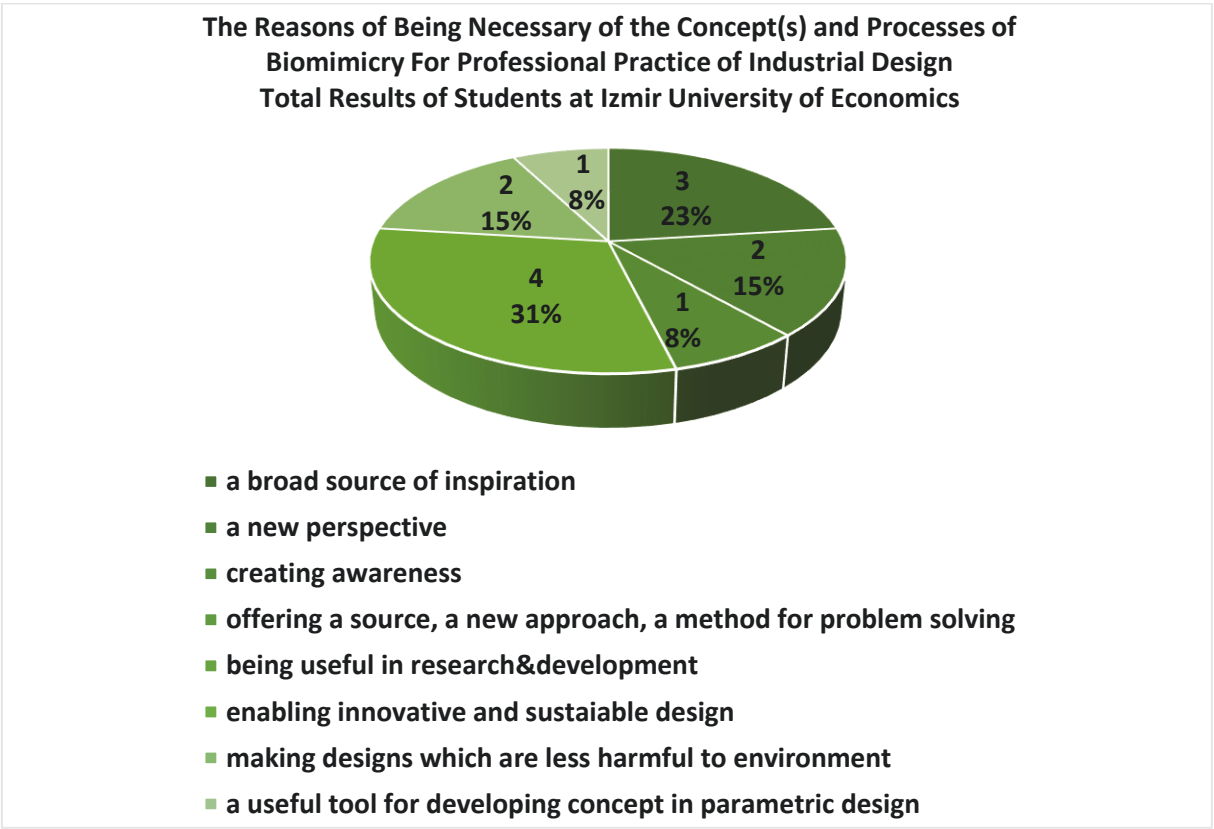

Figure 4.23. Q11 graph

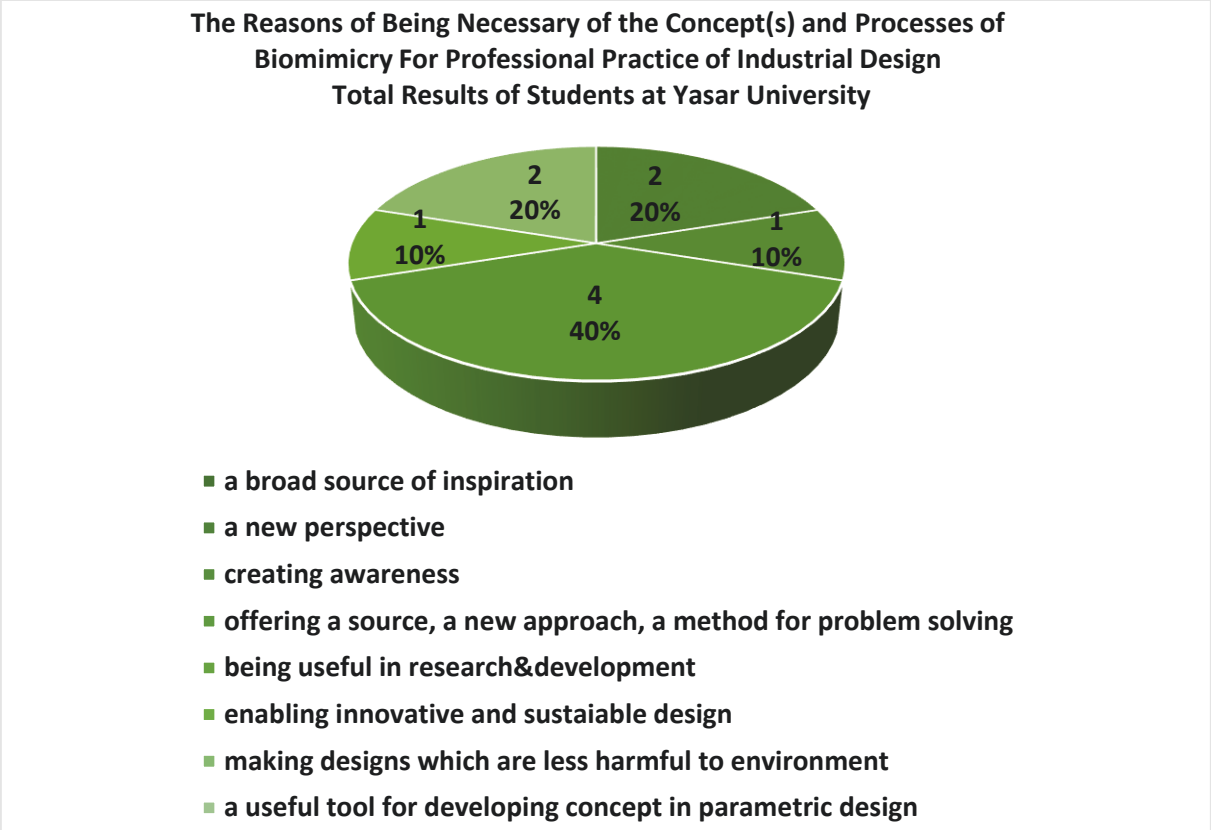

Figure 4.24. Q11 graph

Compared to Q10, the increase of the students who indicated as "no idea" may arise from the lack of sufficient work experience. The students who think that biomimicry is necessary in industrial design education are more than those who think that it is necessary in the sector. Yasar University students' answers to the Q10 are consistent with the answers they gave to this question. Students of Yasar University, who think that the concept(s) and processes of biomimicry are necesseary in industrial design education because of providing a solution source for design problems, students deemed it necessary for the same reason in the professional practice of industrial design. Consistency is not seen in other universities according to the Q10. Theoretical courses on sustainability at Izmir University of Economics may have been effective in providing students answer this question with a sustainability approach.

Question 12: As an industrial design student, did you apply / have you applied the concept(s) and processes of biomimicry / biomimetic / learning from nature - inspired by nature in design in your lessons? If yes, which methods did you use / have you used?

26 of the 44 students who participated in the survey stated that they have applied the concept(s) and its processes in their lessons. The university where the concept(s) and its

processes of biomimicry is applied most in lessons is Yasar University, where its 13 bachelor students answered "yes". 18 of the 44 students who participated in the survey stated that they have not applied them. The highest "no" answer with 10 master students belongs to the Izmir Institute of Technology.

Table 4.10. Q12 graph

METHODS	Izmir Institute of Technology	Izmir University of Economics				Yasar University			TOTAL
	Master	Bachelor			Master	Bachelor			
		2.	3.	4.	M	2.	3.	4.	
Abstraction or Morphological at the level of morphological / at the level of form	1	1	0	0	0	3	0	0	5
Analogy – at the level of form	1	0	1	0	0	1	0	2	5
Analogy – at the level of form and function	1	0	1	1	1	1	0	0	5
Biology to Design (Biomimicry Thinking) - mimicking at the form level	0	0	0	0	0	0	3	0	3
Biology to Design (Biomimicry Thinking) - mimicking at the form and functional level	1	0	0	0	0	0	2	0	3
Challenge to Biology (Biomimicry Thinking) - mimicking at the process level --- transfer to functional level of design	0	0	0	1	0	0	0	0	1
As a method, as an approach	0	0	0	1	1	0	0	0	2
As a research tool for idea-generation and brainstorming	0	0	0	1	0	0	0	1	2
TOTAL	4	1	2	4	2	6	5	3	26

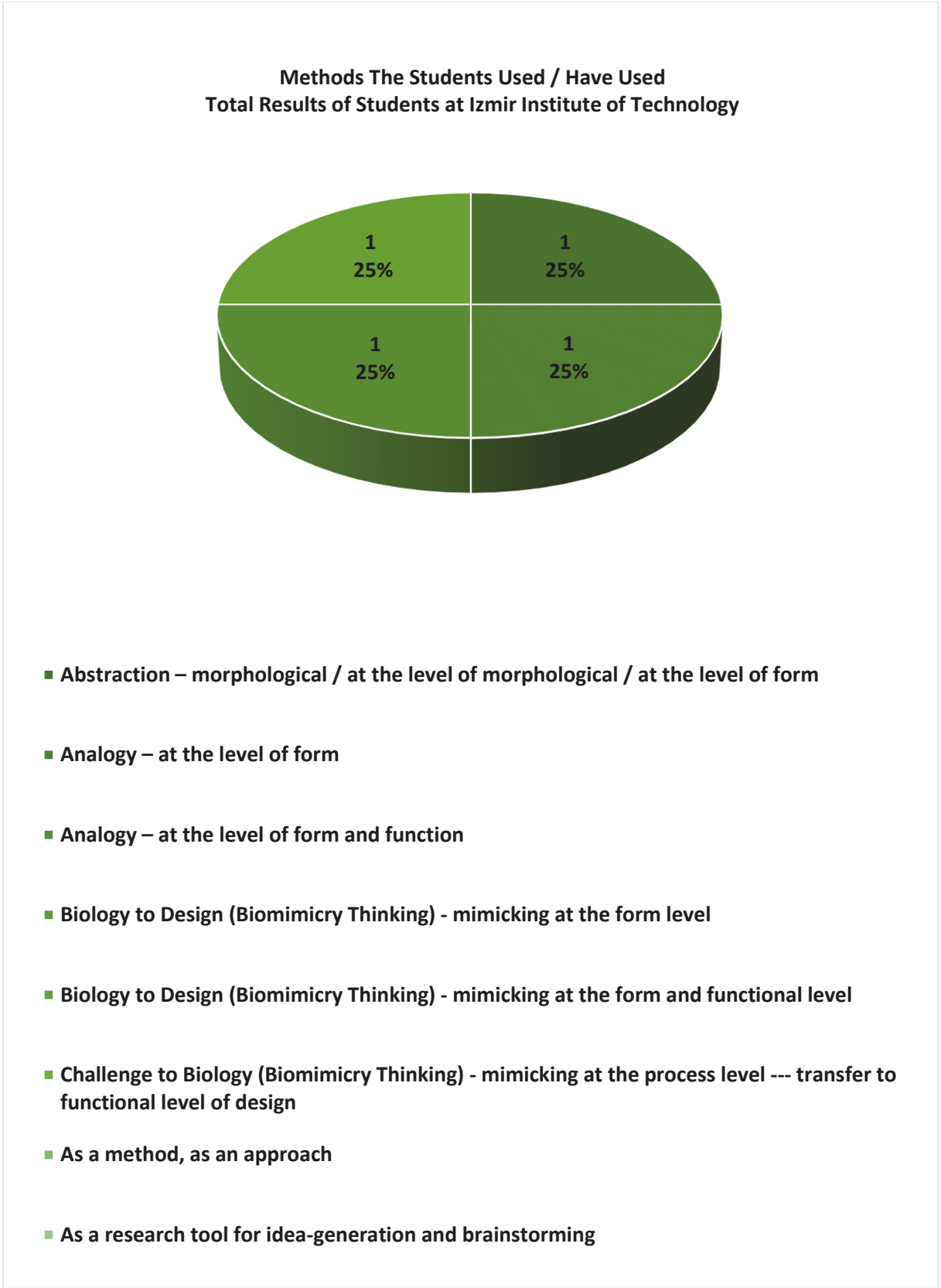

Figure 4.25. Q12 graph

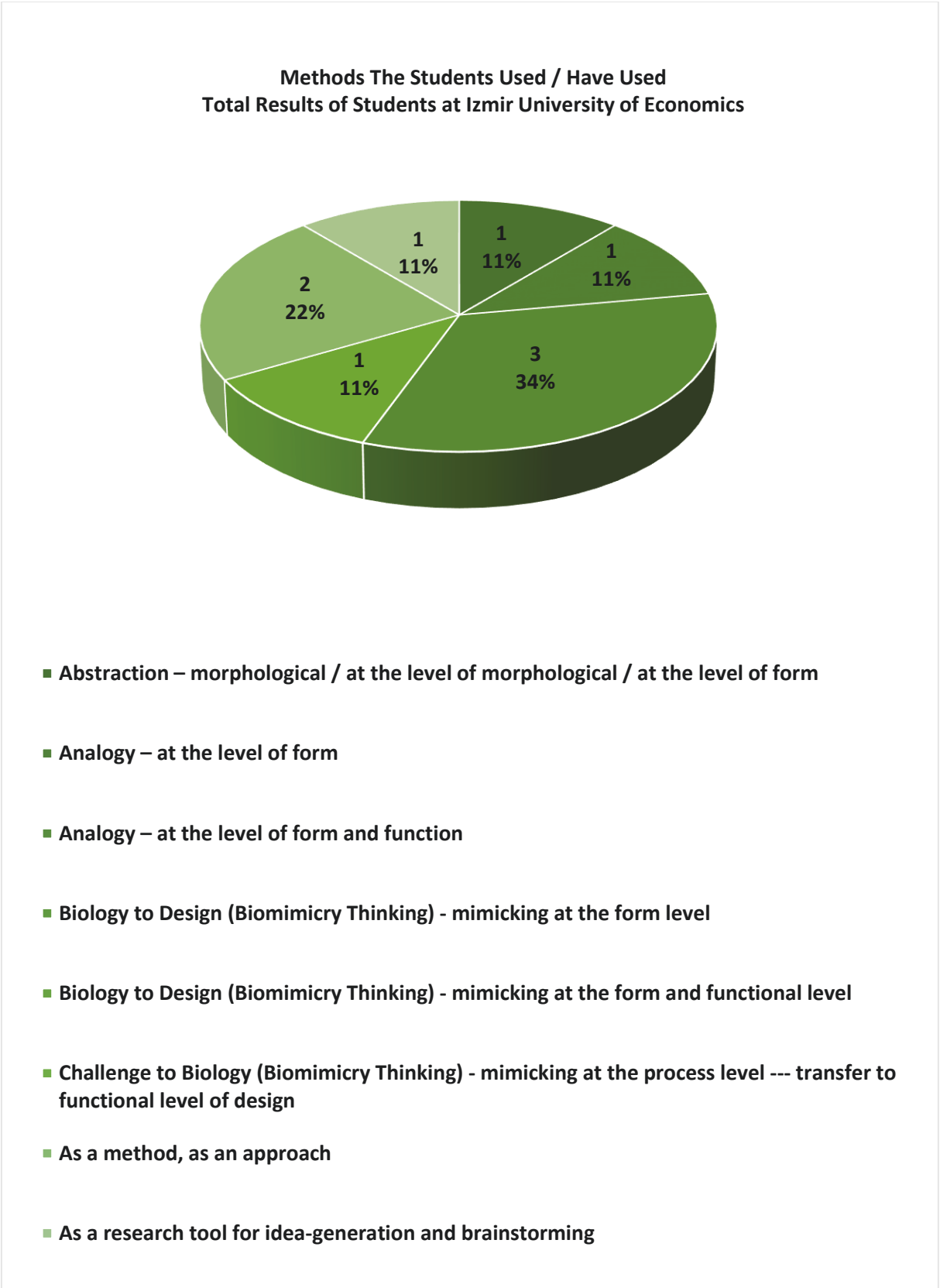

Figure 4.26. Q12 graph

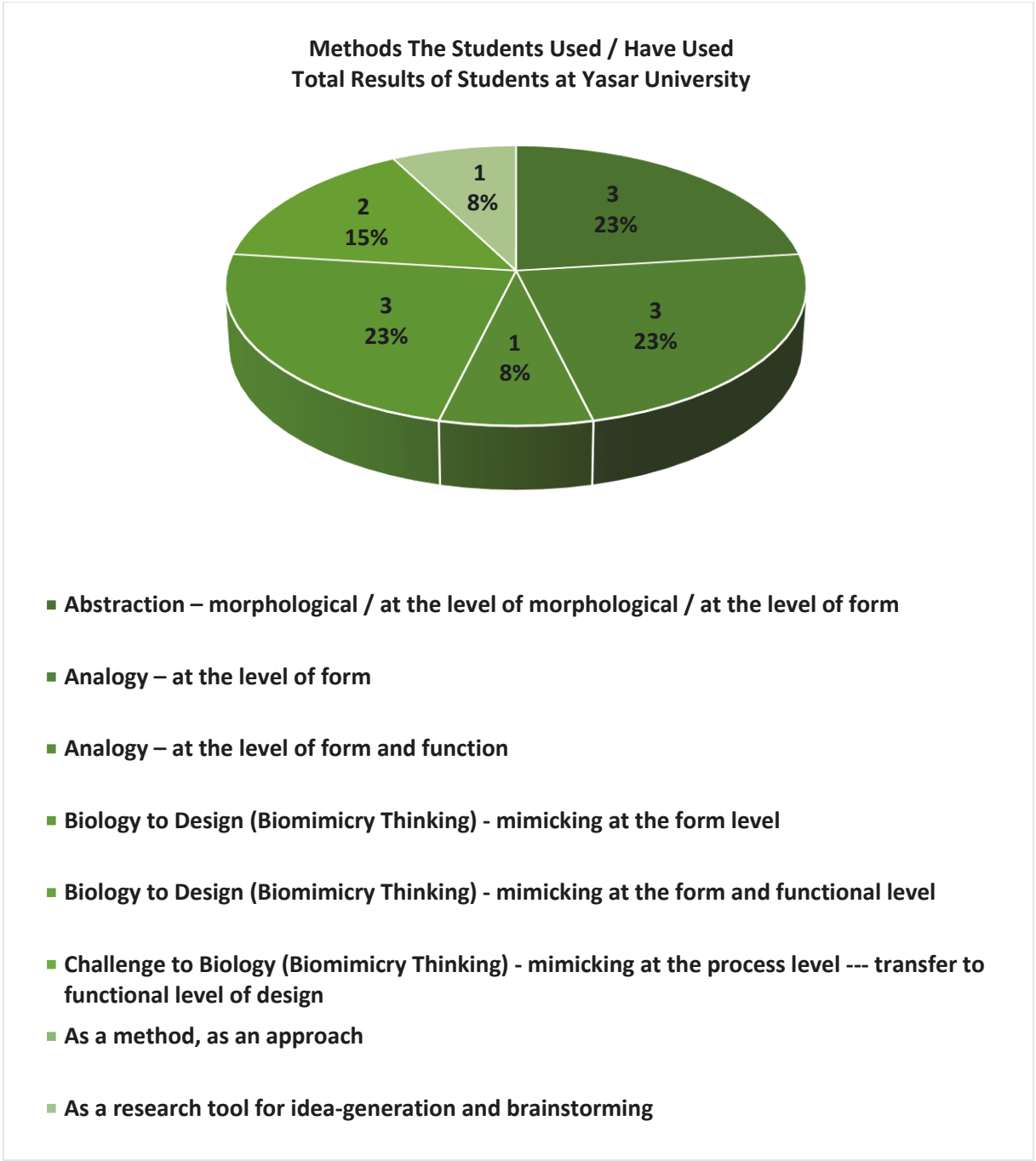

Figure 4.27. Q12 graph

Most of the students could not give clear and decisive answers to explain the method. It is seen that while they have knowledge about concepts and able to define concepts at one level, they are not fully aware of the methods or they do not know exactly what the methods of these concepts are. Therefore, an analysis has been tried to be made according to the limited responses of the students.

According to the answers to the method-related part of the question, students applied concepts of nature-inspired inspiration and learning from nature to their projects in their design studios during their education. The methods the students mostly used are abstraction or morphological and analogy, but these inspirations are based on mostly form and then function.

Inspiration at the level of form with the intent of creating and developing the aesthetic aspects, style, shape and form of design is mostly seen in the 2nd years; while inspiration at the level of function with the intent of developing the technique and the mechanism of design is mostly seen in the 3rd and 4th years.

Looking at bachelor students, those who are 2nd and 4th year, are students of Izmir University of Economics and Yasar University and those who are 3rd year are students only of Izmir University of Economics. Besides, such methods are also seen in among master students. Mostly, it is seen in Izmir Institute of Technology (three students), but less in Izmir University of Economics (one student).

In the design process, it was understood that most of the students first observed the characteristics of the livings in nature, examined them and then analyzed them. It is determined that later, some have transferred to design through abstraction, some through analogy, applying them to design. This is the first level of mimicking in biomimicry. It is understood that students in the universities mostly mimick the nature at the level of the natural form. Although this way of inspiration methods method coincides with the concept of biomimicry, it may not be sufficient and comprehensive for the aim and methodology of biomimicry. The aim of biomimicry is not only the formal analogy. The scope of and intended final outcome of biomimicry is broader.

In the first place, the methods that students use the most are abstraction or morphological and analogy as mentioned above. In the second place, the following methods are applied the most by the students are Biology to Design which is one of the specific paths-methods placed under the Biomimicry Thinking. Biomimicry Thinking offers a framework to help people from any kind of discipline or area practice biomimicry while designing. This method was used by only the 3th class bachelor students of Yasar University. As mentioned in the previous questions of the survey, this group of students made a design projects by focusing on biomimicry approach in their design studios with informing and guiding from academicians. These students applied it moslty at the level of form, the at the level of function. In Biology to Design method, students firstly starts to seek and discover biological strategies in nature. It begins with the biological inspiration by observing, exploring and interacting with the natural

world, then continues to identify an application in design for these features, funtions and strategies of living things.

In addition to Biology to Design method, one of the 4th class bachelor students in Izmir University of Economics applied Challenge to Biology which is an another path-method placed under Biomimicry Thinking. This method begins with a design challenge; i.e. specific design problems or opportunities, and then continues to seek inspiration and models in nature to find solutions to these design problems. However, this student may have applied this method on his own without realizing it or knowing exactly how the method is progressing, since it can be said in Izmir University of Economics based on the other questions of the survey that there was no specific information transfer on the concept from academicians.

Apart from using biomimicry as a form or function source in the framework of method, some students have used it as a design method or approach and research tool. Those who have used biomimicry as a research tool of inspiration used it find and generate ideas for their design projects

Question 13: Do you think it is useful / beneficial that being given place the concept(s) and processes of biomimicry / biomimetic / learning from nature - inspired by nature in design in the education that you take in? If yes, what benefits does it provide?

Overall, 89% of the participant students in all three universities think that the concept(s) and processes of biomimicry provides benefits in industrial design education.

When the answers given to this question were compared with the question that measures whether biomimicry was applied in the lessons (see Q12), Yasar University was the only university where the answers given show parallelism with. In Yasar University, 92% of the students stated that they applied concept(s) and processes of biomimicry in their lessons, and 92% of them stated that biomimicry are useful for industrial design education. The parallelism of the answers given to the two questions at Yasar University shows that the concept(s) and processes of biomimicry are actively used in some grades in industrial design education of Yasar University. In the manner of supporting this result, as the percentage of practice increases in the courses, the rate of opinion that it is beneficial has also increased.

28% (4/14) of the students who participated in the survey at Izmir Institute of Technology and had knowledge about the concept(s) of biomimicry stated that they applied the concept(s) and processes of biomimicry in their lessons. However, 85% (12/14) of the same group stated that biomimicry provides benefits in the education that they take. The discrepancy of the answers given to the two questions at Izmir Instittute of Technology shows that the

concept(s) and processes of biomimicry are not actively applied in the courses and not enough used in the industrial design education at this university.

According to the Q12, the answers of the bachelor students at Izmir University of Economics did not show much discrepancy, but there seems to be a slight discrepancy among the master students. Even if it is theoretically used in master's education, there is not enough practice in Izmir University of Economics, as in Izmir Institute of Technology.

The answers relating to the benefits of being given place to the concept(s) and processes of biomimicry in education are listed in the table below.

Table 4.11. Q13 graph

BENEFITS	Izmir Institute of Technology	Izmir University of Economics				Yasar University			TOTAL
	Master	Bachelor			Master	Bachelor			
		2.	3.	4.	M	2.	3.	4.	
Supporting and Boosting Creativity	2	0	0	0	2	1	0	1	6
Improving and Gaining New Perspective and Vision	2	1	0	2	1	2	2	1	11
More Innovative Designs and Innovative Design Thinking	1	0	0	0	0	0	0	0	1
Enabling Sustainability (a tool for sustainable design)	0	0	1	0	0	0	0	0	1
Facilitating Problem Solving	3	0	0	0	0	1	1	0	5
Giving Inspiration (a source of inspiration and information to find better and meaningful ideas)	1	1	1	0	1	0	0	1	5
Making Designs Which are Less Harmful to Environment	0	0	0	1	0	0	0	0	1
In Bringing Up More Concious Designers In Making / Educating Designers More Aware / Concious In Determining and Changing the Role of the Designer In Developing a Sense of Responsibility of Designer	1	0	0	0	1	0	0	0	2
Improving Research Skills During Concept Design Facilitating the Design Process Facilitating the Process of Design from Development to Implementation	0	0	0	1	0	2	1	0	4
Creating and Expanding Awareness	1	0	0	0	0	0	0	0	1
Guiding, Instructive and Mentor in Design	1	0	0	1	0	0	0	0	2
TOTAL	12	2	2	5	5	6	4	3	39

Figure 4.28. Q13 graph

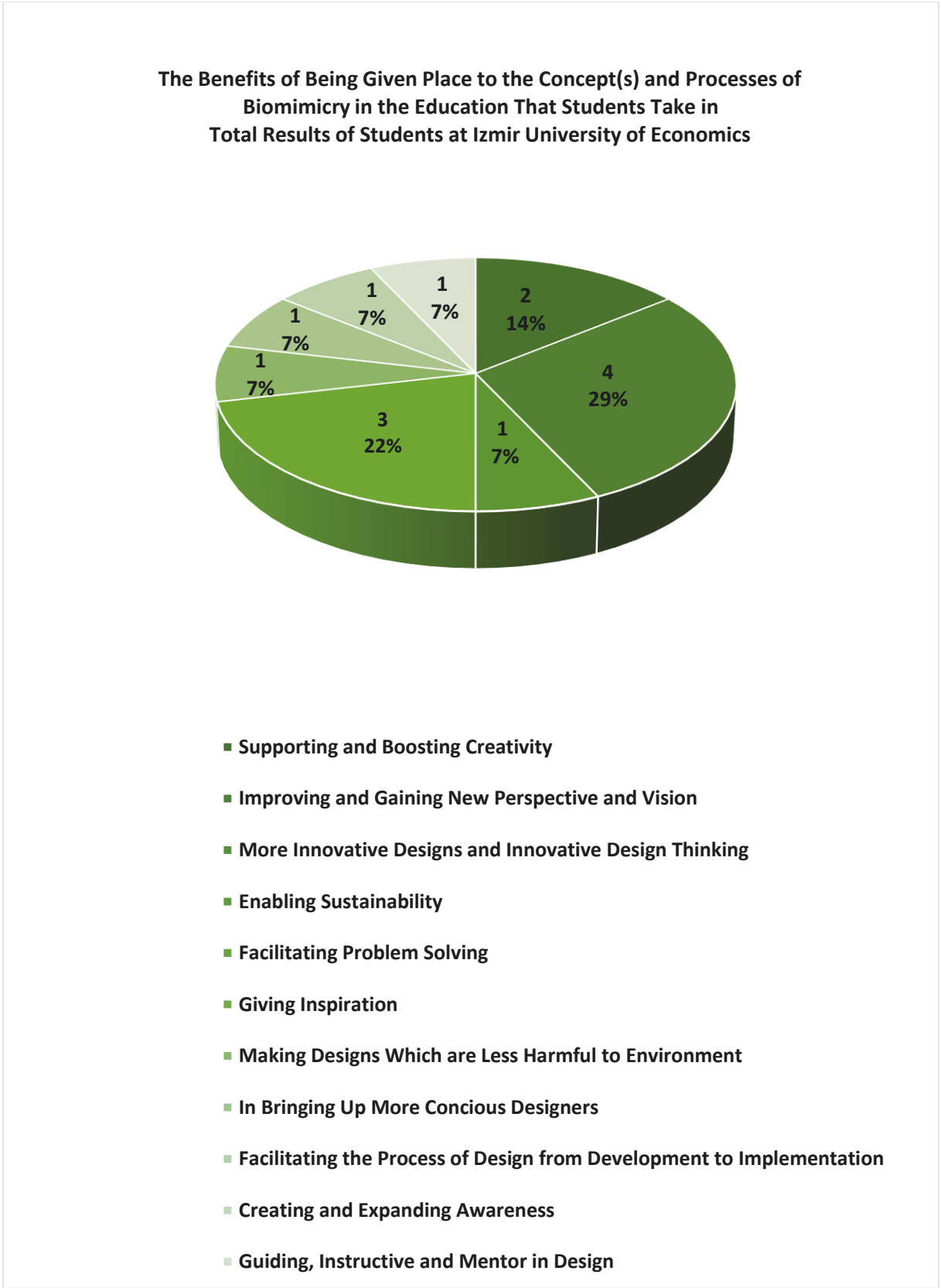

Figure 4.29. Q13 graph

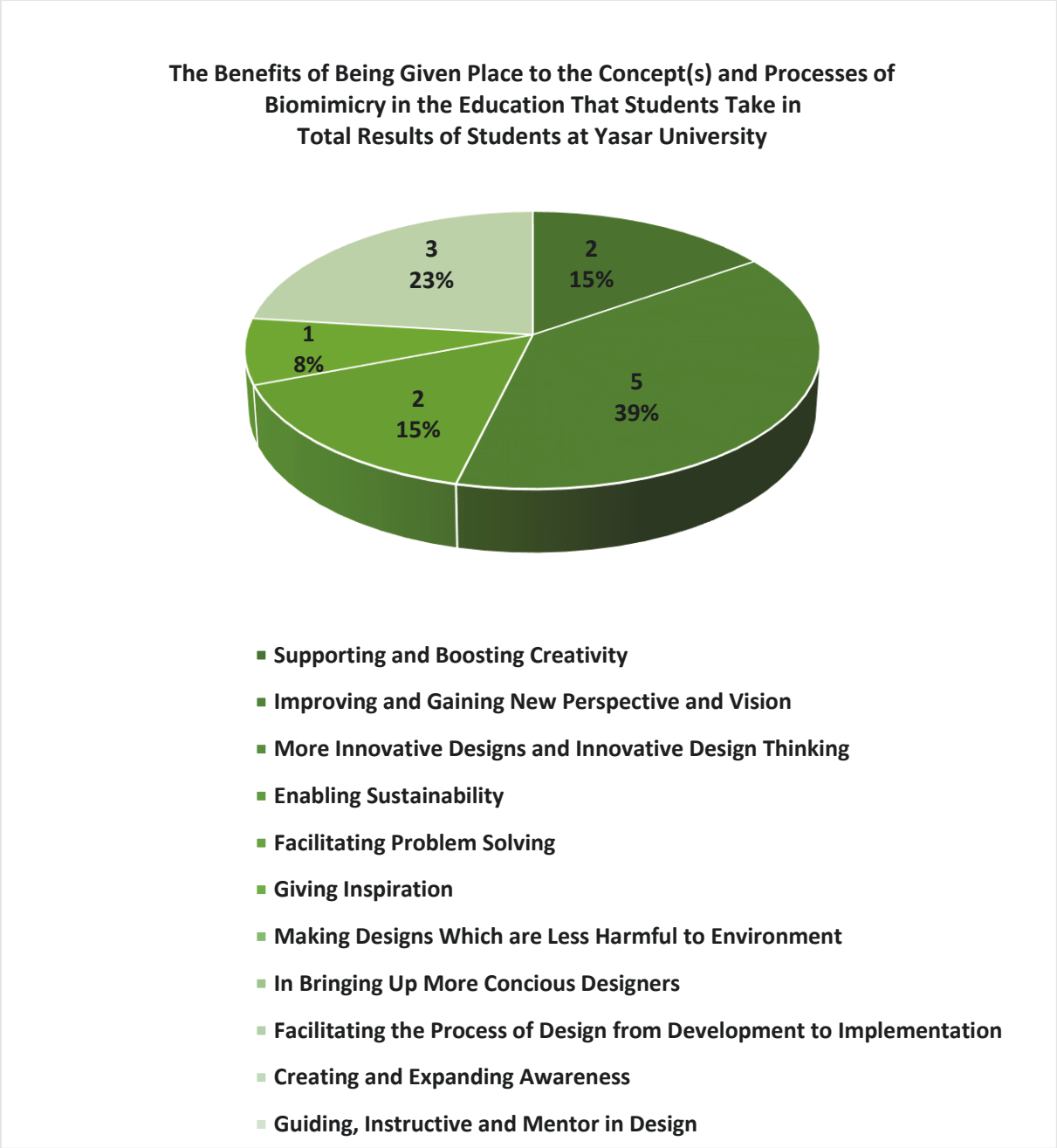

Figure 4.30. Q13 graph

The students mostly stated that the biomimicry is highly beneficial to provide and gain a new perspective in terms of design, design process, in the relations with nature. Secondly, they also mentioned that they are useful in terms of supporting and boosting creativity. As third, benefits in facilatating problem solving and giving inspration and information to find better and meaningful ideas were given.

When the answers are considered, the most benefit of biomimicry to industrial design education is that it improves students' perspectives and vision, supports the students' creativity,

being an inspiration and facilitates problem solving. These responses can be interpreted as that students consider and understand biomimicry as a supportive and helpful approach, tool, method, source and mentor that gives a different thinking and dimension to industrial design, rather than directly utilizing biomimicry's own methodology or practicing biomimicry with known design methods.

4.3.2. Findings and Analysis of the Academician Survey

This survey, which includes twelve questions, was conducted with academicians lecturing in the industrial design departments of Izmir Institute of Technology, Izmir University of Economics and Yasar University. Total of ten academicians participated in the survey: two from Izmir Institute of Technology, three from Yasar University and five from Izmir University of Economics.

There are two open-ended questions (Questions 1., 4.), one closed-ended questions (Questions 7) nine semi-closed-ended questions (Questions 2., 3., 5., 6., 8., 9., 10., 11., 12.) in the academician survey.

In this section, a brief of the findings of the survey conducted with the academicians from three universities are presented, highlighting important issues. Detailed graphs and tables can be found in Appendix D.

Question 3: : Have you heard of the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design? If yes, where and in what context have you heard?

All of the academicians in three universities answered “yes” to this question. All of them stated that they have heard the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design. The answers to this question in such a way that supporting the inference of the Q2 is independent of the level of education. The fact that all academicians had previously heard about biomimicry could be interpreted as the answers given to the other questions of the survey would be more reliable than the student survey.

The second part of the question was aimed to find out where and what context the academicians have heard these concepts. In addition, it can be seen how academicians associate these concepts with other concepts and subjects. Thus, the state of awareness levels of academicians and tendency towards biomimicry in industrial design education in these three universities are tried to be put forth.

Table 4.12 shows where the academicians, who responded “yes” to this question, have heard and encountered these concepts.

Some academicians had heard this concept in some courses in their previous educational lives. One from Izmir University of Economics and one from Yasar University, the two academicians who gave these answers, also stated that they had heard that while they were preparing course content and material or syllabus for their own courses as an instructor in their current universities. These two can be related to each other. The knowledge, experiences and perspectives gained by academicians in their previous educational lives can show that they are progressing in this direction in their current professions. It can demonstrate that they can implement this knowledge, experiences and perspectives by transferring them to the students as academicians. These two academicians (A4, A9) in different universities may have shown a more tendency to the concept of biomimicry or similar concepts, and may be transferring them to students in their own courses.

Table 4.12. Q3 graph

WHERE	Izmir Institute of Technology		Izmir University of Economics					Yasar University			TOTAL
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	
Students Thesis of students	0	1	0	0	0	0	1	0	0	0	2
Academic publications Literature reviews Texts related to design	1	1	0	0	1	1	1	1	0	1	7
From content of courses in-during previous education	0	0	0	1	0	0	0	0	0	0	1
Sustainability-oriented course at PhD	0	0	0	0	0	0	0	0	1	0	1
In preparing a course content and material, and a syllabus for their own courses	0	0	1	1	1	0	0	0	1	0	4
Conversations and chats in the university	0	1	0	0	0	0	0	0	0	0	1
TOTAL	1	3	1	2	2	1	2	1	2	1	16

Table 4.13. Q3 graph

IN THE CONTEXT OF	Izmir Institute of Technology		Izmir University of Economics					Yasar University			TOTAL
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	
Design	1	1	0	0	1	1	1	0	0	1	6
Product Design	0	0	0	0	0	2	0	1	0	0	3
Conceptual Design	0	0	0	0	0	0	0	1	0	0	1
Architecture	1	1	0	0	0	0	0	0	0	0	2
Art	1	0	0	0	0	0	0	0	0	0	1
Engineering	1	0	0	0	1	0	0	0	0	1	3
Technology	0	0	0	0	0	0	1	0	0	0	1
Computer-Aided Design	0	0	0	0	0	0	1	0	0	0	1
Sustainability (sustainable design, design for sustainability)	0	0	1	0	0	0	0	1	0	0	2
Being a Sustainable-Oriented Design Approach Being an Approach for Sustainable Design	0	0	0	1	0	0	0	0	1	0	2
Being a Method in Design Process	0	0	0	1	0	0	0	0	0	0	1
TOTAL	4	2	1	2	2	3	3	3	1	2	23

Table 4.13 shows in which contexts 10 academicians have heard the concept(s) of biomimicry.

According to the contexts in which 10 academicians have heard the concept(s) of biomimicry, all of these contexts can show the academic profiles of academicians in universities, the impact of their fields of expertise, the foundations of their academic background, and their personal interests and tendencies as instructors. Moreover, they can show whether the areas in which academicians tend, their backgrounds, their perspectives and visions are broad, diverse and different from each other. These may allow comparisons within and between universities.

The general interpretation that can be drawn according to the table is that academicians at Izmir University of Economics and Yasar University may have more different and various backgrounds and they may have academic profiles in wider areas than academicians at Izmir Institute of Technology. Some academicians in these two universities may be more aware of biomimicry than those of the Izmir Institute of Technology and may have in different tendency to such subjects. In addition, it seems to be given a more emphasis and be shown tendency to the concept of sustainability in these two universities. That can be interpreted as that all these can be reflected on in the industrial design education content of the two universities and can be shaped the educational content. The implications above seem to coincide with the overall results of the student survey.

Question 4: How do you explain / describe the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design?

Each academician made own definition of the concept of biomimicry. This may be due to the fact that each academician conducts academic studies in different fields, as well as being able to make definitions reflecting their own perspectives with the accumulation of being an academician. However, in general, most of these 10 definitions are not very different from each other and are not separated in very sharply. Some definitions are intertwined, close to each other or the same meaning. The definitions given by each academicians at three universities are listed in Table 4.14.

If a generalization and comparison is made between universities, according to the content and scope of the definitions, Izmir Institute of Technology has put the most different definitions compared to other universities. Definitions that explain biomimicry clearly and systematically well have come from Izmir University of Economics with 4 academicians and Yasar University with 1 academician. When looking at the definitions of an academician at

Izmir University of Economics (A4) and an academician at Yasar University (A9), they are very close to each other according to both the form of expression of the definitions and the framework of the main idea on which they are based. As can be seen from the previous question (Q3), the perspectives and vision of biomimicry, biomimicry knowledge and awareness of these two academicians, who have common points on sustainability, are close to each other and may even be more than other academicians may.

Table 4.14. Q4 graph

DEFINITIONS	Izmir Institute of Technology		Izmir University of Economics					Yasar University			TOTAL
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	
As Analogy: Establishing similarities between the working systems of living things in nature and man-made systems.	1	0	0	0	0	0	0	0	0	0	1
Abstraction of geometries of natural objects, analyzing the composition principles of natural objects and the mechanisms of movement of natural objects from parts to whole, and re-interpreting these informations to produce new things. These things can be abstract and concrete.	0	1	0	0	0	0	0	0	0	0	1
With the shortest definition, designs realized by inspiring from nature and by reinterpreting similar principles in nature.	0	0	1	0	0	0	0	0	0	0	1
Using methods, systems and models found in nature as a resource for solving design problems.	0	0	0	1	0	0	0	0	0	0	1
Examining the processes and phenomenons in nature scientifically in detail and applying these in design to products, systems, processes.	0	0	0	0	1	0	0	0	0	0	1
Analyzing the biological properties and structures of living organisms in nature and using them in the design process and final products.	0	0	0	0	0	1	0	0	0	0	1
Simulation of the structural fiction of nature.	0	0	0	0	0	0	1	0	0	0	1
Imitating nature and using the mind of nature artificially.	0	0	0	0	0	0	0	1	0	0	1
Adaptation of solutions of the forms and functions that exist in nature to human-centered/oriented problems.	0	0	0	0	0	0	0	0	1	0	1
Transferring the living or nonliving physical results or economic solutions in nature to design or engineering.	0	0	0	0	0	0	0	0	0	1	1
TOTAL	1	1	1	1	1	1	1	1	1	1	10

Question 5: Do you think there is a relationship between sustainability and the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design? If yes, how do you explain / describe this relationship?

Only 2 of them stated that there is no a relationship between them. participant academicans associated sustainability and the concept(s) of biomimicry.

The ways in which 7 participant academicans associate sustainability and the concept(s) of biomimicry are described in the table below

Table 4.15. Q5 graph

RELATIONSHIP	Izmir Institute of Technology		Izmir University of Economics					Yasar University			TOTAL
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	
Best examples of survival and sustainability are presented in nature.	1	0	0	0	0	0	0	0	0	0	1
There is no direct relation between them. It depends on interpretation of designer.	0	1	0	0	0	0	0	0	0	0	1
Processes and cycles in nature are related to concept of sustainability .	0	0	0	1	0	0	0	0	0	0	2
Without human intervention, nature is a sustainable system. Natural organisms have optimized to benefit from inorganic objects or substances in the environment and other living things and make them part of the life cycle.	0	0	0	0	1	0	0	0	0	0	1
The efficiency of systems in nature is directly related to sustainability.	0	0	0	0	0	1	0	0	0	0	1
There is sustainability in nature, and when we imitate nature, there is sustainability in biomimicry.	0	0	0	0	0	0	0	1	0	0	1
In the cyclical system existing in nature, the waste of one system is used as the nutrition of another system and there is a balance and continuity. With the biomimicry approach, it is possible to contribute to sustainability when this balanced cycle is adapted to production and consumption processes. However, when biomimicry is not addressed at the system level but remains at the level of mimicking only natural forms or functions, the result may not always meet the sustainability criteria.	0	0	0	0	0	0	0	0	1	0	1
TOTAL	1	1	0	1	1	1	0	1	1	0	7

It can be said that industrial design education in Izmir University of Economics has more tendency to the concept of sustainability than other universities. This shows that some academicians may also transfer their information to students in the courses. Given the answers of the student survey, it can be seen that this interpretation is partially correlated, because it was observed that the awareness of some of the students of Izmir University of Economics on sustainability in general is high. Although Izmir University of Economics is placed the first place on this awareness, it is seen that some academicians (A9) at Yasar University also have a greater understanding and knowledge of both sustainability and biomimicry. She/he stated that the biomimicry approach could have more sustainable results not only taken at the level of form and function, but when taken at the system level. It can be inferred that this academician's awareness and tendency towards concepts of biomimicry and sustainability are higher than many academicans in the survey. This proves that, given the answers of the students of Yasar University, there is a transfer of information to the students at this university. Izmir Institute of Technology takes the lowest place in this regard. Apart from these, A10 at Yasar University, one of the academicians who said “no” stated a different view for sustainability: “It is necessary to accept the fact that sustainability is an illusion and cannot go beyond romanticism”. She emphasized that the concept of sustainability should be questioned.

Question 6: Do you think there is a relationship between innovation and the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design? If yes, how do you explain / describe this relationship?

All academicians in three universities answered "yes" to the question of whether there is a relationship between the concept(s) of biomimicry and innovation.

To sum up, academicians associate biomimicry more with innovation rather than sustainability. This situation coincides with the results of the student survey. It has been observed that biomimicry has been established relationship with mostly innovation also among students. This may indicate that academicians may have thought that the sustainability dimension and goal of biomimicry cannot be realized sufficiently in the field of industrial design (education) within the knowledge and research of academicians. Since the projects made by the students in education cannot reach this dimension, they may be able to comment according to the table resulting from these projects. Another implication is that the sustainability goal of biomimicry may be neglected by most academicians, and this may indicate that biomimicry is remained limited to the dimension of innovation when transferring information to students.

Table 4.16. Q6 graph

RELATIONSHIP	Izmir Institute of Technology		Izmir University of Economics					Yasar University			TOTAL
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	
Examples of engineering and system design in nature renew themselves in field of structure, function, material and form.	1	0	0	0	0	0	0	0	0	0	1
Nature is a resource with unlimited riches. Since the diversity of resources is a factor that increases creativity, the possibilities that increase creativity also increase the probability of innovation.	0	1	0	0	0	0	0	0	0	0	1
There is a direct relationship between biomimicry and innovation. Innovation is a method that can be used to develop innovative ideas and systems, and biomimicry can be used in the formation and development of these innovative ideas.	0	0	0	1	0	0	0	0	0	0	1
As biomimetic is a fairly new field, there is great potential to bring innovation in design by inspiring from nature and studying natural sciences. Scientists, engineers, companies have started to use these opportunities in innovation and many new products and concepts have emerged.	0	0	0	0	1	0	0	0	0	0	1
The analysis of living systems and organisms in nature allows for new material and product ideas.	0	0	0	0	0	1	0	0	0	0	1
it's a superficial relationship.	0	0	0	0	0	0	1	0	0	0	1
In product design, the concept of innovation, qualities that have never been looked at before are hidden in nature. When found, it is new.	0	0	0	0	0	0	0	1	0	0	1
There are many innovative solutions developed using the biomimicry approach. (Asknature.org) One of the most famous innovative examples is Velcro. Innovation is possible by defining a problem and looking at how this problem is solved in nature or by using a solution in nature to solve a problem. The important thing is to have the knowledge of nature to establish the relationship between them.	0	0	0	0	0	0	0	0	1	0	1
Is it an innovative direction to try to achieve its success by imitating an existing system?	0	0	0	0	0	0	0	0	0	1	1
TOTAL	1	1	0	1	1	1	1	1	1	1	9

Question 7: Do you think there is a relationship between industrial design and the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design?

All academicians in three universities answered "yes" to the question of whether there is a relationship between biomimicry and industrial design.

Question 8: Do you think that the concept(s) and processes of biomimicry / biomimetic / learning from nature - inspired by nature in design are necessary in industrial design education? If your answer is necessary / not necessary, why?

70% of the survey participants think that the concept(s) of biomimicry are necesseary in industrial design education. 30% of academicians think that concept(s) of biomimicry are not necesseary in industrial design education.

Table 4.17. Q8 graph

NECESSARY	Izmir Institute of Technology		Izmir University of Economics					Yasar University			TOTAL
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	
The subject needs to be researched and developed, and requires an interdisciplinary study.	1	0	0	0	0	0	0	0	0	0	1
I think it should be taught as a method that can be used in processes such as creativity, innovative thinking and developing alternative to existing problems that are the basis of design.	0	0	0	1	0	0	0	0	0	0	1
- It is necessary to tell the design students that such a concept exists. - Since sustainability is becoming increasingly important, biomimetic approaches can create sustainable solutions - It is necessary because it can help to come up with creative and innovative ideas.	0	0	0	0	1	0	0	0	0	0	1
It will contribute to the development of ideas in the context of form and structure.	0	0	0	0	0	1	0	0	0	0	1
It needs to be recognized as much as any other concept about design and methodology.	0	0	0	0	0	0	1	0	0	0	1
When biomimicry is used as the primary and only approach to solving a problem, it is not always possible to obtain results. However, it may be one of the methods that designers can use when researching the solution area. Knowing the tools and methods that will enable industrial design students to use biomimicry in design process can enrich problem solving processes.	0	0	0	0	0	0	0	0	1	0	1
TOTAL	1	0	0	1	1	1	1	0	1	0	6

Table 4.18. Q8 graph

NOT NECESSARY	Izmir Institute of Technology		Izmir University of Economics					Yasar University			TOTAL
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	
It can be useful as an elective course. I think that nature should remain a natural source of inspiration without being mechanizing it. I don't find it right to define it by rules and methods. I do not think it needs to be dictated as a mechanical method in creativity and production processes.	0	1	0	0	0	0	0	0	0	0	1
Deeper studies should be done on this subject. Relationship with nature and deep understanding of nature enriches the designer.	0	0	0	0	0	0	0	1	0	0	1
I think that biomimicry during design education will be attractive for the student but he/she will remain limited in terms of design It is the easiest way especially in shell/exterior design. Designing of car headlight like a snake for wild appearance is not a biomimicry.	0	0	0	0	0	0	0	0	0	1	1
TOTAL	0	1	0	0	0	0	0	1	0	1	3

Inferences that were made according to the results show paralellism to the answers and the situation of the students of Izmir Institute of Technology in the student survey (see Q5 in student survey). However, these inferences do not coincide with the answers of the students at Izmir University of Economics and Yasar University. When looked at the Q5 of the student survey, it is seen that all bachelor students of Yasar University come at first among the groups of students who have heard or learned these concepts at their university. According to the student survey, while it seems that there is knowledge transfer at many practical courses at Yasar University, there are two different types of courses as theory and practice at Izmir University of Economics and Izmir Institute of Technology. However, in these two universities, students seem to have access to knowledge and awareness in a more meaningful way through theoritical courses rather than practical. Especially at Izmir University of Economics, these concepts are handled more consciously in theoretical courses and transferred to the students. In the practical courses, students at Izmir University of Economics and Izmir University of Technology seem to try to apply these concepts by themselves without any guidance or knowledge transfer from the academicians. For this reason, most of the students of Yasar University show to have more knowledge and awareness of the concept. Even though these

concepts were mostly included in the design studios and the information is transferred to students at Yasar University, this transfer may have been realized with the effect of some academicians (A9) at Yasar University who tend to biomimicry and similar concepts. For Izmir University of Economics, even if all the academicians tend to indicate the necessity of these concepts in industrial design, however, they may not reflect this enough in their educational content or the transfer to students may be simple and superficial. It can be interpreted that the remaining of transference at the theoretical level rather than practical compared to Yasar University has affected the results of the student survey.

Question 9: Do you think that the concept(s) and processes of biomimicry / biomimetic / learning from nature - inspired by nature in design are necessary for professional practice of industrial design (in the sector)? If your answer is necessary / not necessary, why?

7 of the 10 academicians who participated in the survey think that the concept(s) and processes of biomimicry/biomimetic/learning from nature-inspired by nature in design are necessary for professional practice of industrial design (in the sector). Only 3 academicans; one (A2) from Izmir Institute of Technology, two (A8, A10) from Yasar University think that the concepts and its processes are not necesseary in industrial design education.

The result of this question is the same as the Q8. In Q8, which academicians answered that concepts and processes of biomimicry are not necessary in industrial design education, the same academicians answered for this question that these concepts and processes are not necessary for the professional practice of industrial design. This result may show that some of the academicians (A2, A8, A10) have the same or close view, perspective and approach to the concept of biomimicry. Actually the results of Q8 and Q9 should be expected to be similar because academicians take significant role in education life of each student and they act in proffesional life according to their knowledge which is taught by their academicians.

When compared with the students' answers to this question (see Q11 in student survey), the necessary and not necessary responses of students and academiccians were generally parallel. The fact that only 20% of students (9/44) that do not have the idea differs from academicians. Having ability of commenting more easily thanks to their knowledge as an instructor, being more familiar with the developments in both academic and business fields than the students thanks to their research and studies and having more experience have made academicians to give a clearer and more precise answer to this question.

The reasons of only those who think that these concept(s) and processes are necessary are listed in the table below.

Table 4.19. Q9 graph

NECESSARY	Izmir Institute of Technology		Izmir University of Economics					Yasar University			TOTAL
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	
İt is important for the subject which is researched and developed in terms of becoming a product and realization.	1	0	0	0	0	0	0	0	0	0	1
Although not always used, I think it is a useful way to find solutions to the design problem. I think it can be useful in bringing creative solutions to sectoral problems.	0	0	0	1	0	0	0	0	0	0	1
Users / customers are increasingly paying attention to sustainability. Therefore, if such designs are well explained, they will find more buyers or the design will gain more value.	0	0	0	0	1	0	0	0	0	0	1
Particularly necessary for inter-disciplinary design teams to develop innovative product ideas.	0	0	0	0	0	1	0	0	0	0	1
I think it is a title that has a useful and rich potential when applied appropriately.	0	0	0	0	0	0	1	0	0	0	1
I gave answer to this question as necessary but rather than being necessary, it would be good for a designer to be aware of biomimicry and to have methodological information that he can use whenever he wants. Or I don't think it's absolutely necessary.	0	0	0	0	0	0	0	0	1	0	1
TOTAL	1	0	0	1	1	1	1	0	1	0	6

The academicians answered the second part of the question about the necessity of these concept(s) and processes for proffesional practice of industrial design from different aspects and approaches.This indicates that biomimicry may be necessary or useful in many different aspects, not only in education but also in business. It also shows that most academicians do not think biomimicry is necessary only on an educational basis. It shows that biomimicry may have the potential to be beneficial for many fields, processes and different people in the sector. In addition, the answers given to Q8 and Q9 are expected to overlap in thought, because academicians who think that the concepts of biomimicry are necessary in education need to directly associate that the students who are educated by them will able to do their professions as a designer in the future thanks to educational content given by their universities. If the academicians think the necessity of these concepts in the sector, then they need to think in parallel that it is also necessary in education.

Question 10: Do you think the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design are used in industrial design education in Turkey? If your answer is no, should it be used?

50% of the academicians think that the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design are used in industrial design education in Turkey. The other 50% do not think.

The fact that the result contains contradictory answers and that they are numerically equal to each other may indicate that there is not a complete consensus on this subject at the academy. It may show that there are completely opposing views on the question. The ideas of all academicians seem not to fit each other under the direction of whether being used the concept(s) of biomimicry in industrial design education in Turkey, it is seen that the two opposing thoughts.

The point that stands out here is this, according to the inference from Q3, some academicians at Izmir University of Economics (A3, A4,A5) and Yasar University (A9) were or have been partially, superficially or comprehensively discussed these concepts in their own courses. Two of these (A3,A9) four academicians responded "yes" and the other two (A4, A5) responded "no" to this question. Another inference can be made according to this. Although some of those academicians in Izmir have been using these concepts in their courses of their universities, they may think that these concepts are not used much or enough in industrial design education considering across Turkey, or they may think otherwise.

The following table lists the answers of the second part of the question given by the academicians who responded "no" to this question.

Table 4.20. Q10 graph

SHOULD IT BE USED?	Izmir Institute of Technology		Izmir University of Economics					Yasar University			TOTAL
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	
It should definitely be used. Separate courses on the subject should be opened.	1	0	0	0	0	0	0	0	0	0	1
It should be used.	0	0	0	1	0	0	0	0	0	0	1
Partially used. More should be used.	0	0	0	0	1	0	0	0	0	0	1
Very rare. There is very rare expert academician on top of this subject.	0	0	0	0	0	0	0	1	0	0	1
It should not be used. Portfolio of each student has one biomimicry trial. No more second or third.	0	0	0	0	0	0	0	0	0	1	1
TOTAL	1	0	0	1	1	0	0	1	0	1	5

Question 11: As an industrial design academician, do you integrate the concept(s) and processes of biomimicry / biomimetic / learning from nature - inspired by nature in design into your courses? If yes, which methods do you use / did you use?

Accordingly, although the academicians of Izmir Institute of Technology stated that they integrate concept(s) and processes of biomimicry into their courses, it can be interpreted that there may have been some problems during the knowledge transfer to the students in the courses, the transfer may have not been made completely or the concept(s) of biomimicry may have not fully adressed. It may also be infer that academicians to adress this concept in a superficial and simple way both in practice and in theory during the transfer of information to the students. Yasar University can be interpreted as the university which has the least transfer to students and has the least tendency to biomimicry concept, but according to the student survey' results, the situation revealed by this university is the exact opposite of the table here. In the academician survey, except for one academician at Yasar University (A9), the other two academician generally do not lean towards the concept of biomimicry. Biomimicry awareness and tendency in this university by each academicians is not very high, and these concepts may not be mentioned in the courses and may not be put into practice by all. However, a design project commissioned by one or more academicians on the basis of practice has been very decisive Yasar University students to increase their knowledge, awareness and tendency in terms of detailed informations about the concept and its application in design provided directly by academicians. The university which most does not contradict the results of the student survey is Izmir University of Economics. According to the student survey, it is seen that even if the transfer of information is done in practice and theory at Izmir University of Economics, it cannot be realized very successfully in practice as in Yasar University. Since the transfer of knowledge at Izmir University of Economics is successful in theory, this has positively affected the students' responses in certain aspects, but there is not much positive reflection about the practice compared to Yasar University.

The methods used by academicians who stated that they integrate the concept(s) and processes of biomimicry into their courses are listed are listed in the Table 4.21.

If the general summary of the table is given, 3 (A4, A5, A9) out of 6 academicians (2 of Izmir University of Economics, 1 of Yasar University) show the having the knowledge of biomimicry concept the most according to other academicians that responded this question. Their explanations of methods serve as sign to their awareness of and tendency biomimicry concept. Theirs are higher than the other three academicians are. The other three academicians

(A1, A2, A7) have knowledge and also may show tendency, but their perspectives' and views' do not always coincide the biomimicry approach and the scope of it. Furthermore, when it is associated with Q5 in the student survey, the results of this question coincide with the results in Q5. This consistence is that about make knowledge transfer to the students in application-oriented courses at Yasar University and in both application and theoretical courses at Izmir University of Economics. Although there is overlap in the Izmir Institute of Technology, both theoretical and practical courses appear in Q5 of the student survey, in this question it is seen from the explanations of academicians that they integrate these concepts mostly into practical courses. This situation stems from the fact that both the number of samples in Izmir Institute of Technology is low and the samples are randomly selected.

When the answers of the academician to this question are associated with the answers of the students who say that they have learned or applied this concept in the courses at the university to the Q5, it is seen that there is consistency in partially or in majority. In all three universities, there are courses in which these concepts are taught superficially or deeply; and if not all, most of the students (30/44) have found the opportunity to learn or apply these concepts through the education at their universities. When compared with academicians' explanations about the method, the situation presented by the students in the three universities shows parallelism to this question in terms of some course titles, and being these courses as practical and theoretical.

According to Q12 of the student survey, the approaches and scopes in the answers given by the academicians to this question show parallel with the approaches and the scopes of the method answers of some student groups in universities. The explanations of 3 of the 4 master students at the Izmir Institute of Technology who answered to the open-ended part of Q12 are consistent with those of their academicians. The methods given by 3 students were abstraction and analogy methods. While there is no overlap or similarity (mostly analogy and abstraction methods) in the 2nd and 3rd year students at Izmir University of Economics, the only group that stands out is three 4th year bachelor students and one master student. Some of the 4th years and a master student stated that in parallel with their answers to this question, biomimicry was used as a method, an approach, a research tool to produce ideas and brainstorm. Some of the 4th year students and one master student stated that they used biomimicry as a method, an approach, as a research tool to generate an idea and brainstorming in parallel with the answers given by academics to this question. These explanations coincide with the fact that A4 and A5 transfer biomimicry to courses as a method for developing a creative and innovative ideas, solutions

and products. Also, as stated in the explanations of A4 and A5, the fact that they are transferring knowledge to 4th year or graduate students may have contributed to the formation of this overlap. In Yasar University, the methods applied by 3rd year students are compatible with method given by A9. The 2nd and the 4th year students remained in simple methods during practice.

Table 4.21. Q11 graph

METHODS	Izmir Institute of Technology		Izmir University of Economics					Yasar University			TOTAL
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	
As an analogy method in jewelry design.	1	0	0	0	0	0	0	0	0	0	1
There is a three weeks of homework in basic design. We make vegetable and fruit abstractions. We do geometric analysis of these natural objects. We analyze the design principles they contain. We make abstract compositions based on the latest analyzes.	0	1	0	0	0	0	0	0	0	0	1
Although the design proposals inspired by nature are not a method that should be used in every project, I describe the concept of biomimicry as the Biomimicry Design Method every year. PD 498 Graduation Project (product design) - DM 498 Graduation Project (design management).	0	0	0	1	0	0	0	0	0	0	1
I mention these subjects mostly in master and PhD courses. I usually show good applications in design. Sometimes I want them to develop new projects / products as ideas. I show it as a creative method in an elective course in the bachelor program.	0	0	0	0	1	0	0	0	0	0	1
Explaining of contributions of forms which survive or fail as a result of evolutionary process.	0	0	0	0	0	0	1	0	0	0	1
In the third grade studio, we focused entirely on the biomimicry approach in a project. First, we explained to students how to integrate biomimicry into the design process ("challenge to biology" and "biology to design"). On the Asknature site, students searched for strategies and solutions that could be related to the project (we used Biomimicry Taxonomy). We asked them to take a stroll in the nature and photograph the examples they could be inspired by. We also used the biomimicry sketch analysis method developed within the scope of a master's thesis in the Department of Industrial Design at METU.	0	0	0	0	0	0	0	0	1	0	1
TOTAL	1	1	0	1	1	0	1	0	1	0	6

Question 12: Do you think it is useful / beneficial that being given place to the concept(s) and processes of biomimicry / biomimetic / learning from nature - inspired by nature in design in the design education that you give?

9 of the 10 academicians who participated in the survey think that the concept(s) and processes of biomimicry/biomimetic/learning from nature-inspired by nature in design are beneficial that are being given place in the design education that they give. It can be said that academicians in these three universities tend to biomimicry in some way and are more likely to integrate biomimicry into their education that they give. Only one academican (A10) from Yasar University thinks that these are not beneficial.

Table 4.22. Q12 graph

BENEFITS	Izmir Institute of Technology		Izmir University of Economics					Yasar University			TOTAL
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	
Solution possibilities related to the mechanism of products.	1	0	0	0	0	0	0	0	0	0	1
The student can more easily internalize the information she/he has acquired by examining a familiar natural object in everyday life. She/he can learn from straight line to curved line, from slippery texture to rough texture, each tone of colors, solid void relationship, radiality, linearity, axiality by examining tomato or pepper.	0	1	0	0	0	0	0	0	0	0	1
Provides benefits such as creative thinking, developing of creative problem-system solutions.	0	0	0	1	0	0	0	0	0	0	1
I think the awareness of the students will increase, but I did not make a measurement about it. Nevertheless, some students (influenced by what they saw in another elective course) did their graduation projects in this area.	0	0	0	0	1	0	0	0	0	0	1
It consolidates knowledge of form, structure and material.	0	0	0	0	0	1	0	0	0	0	1
Structures that exist in nature have been tried and proven. In perspective with right analogy it can provide know-how of nature to humanity.	0	0	0	0	0	0	1	0	0	0	1
Brings a new dimension to education.	0	0	0	0	0	0	0	1	0	0	1
- Students learned a new way of developing ideas. - Students learned how and in which situations they can integrate this method into the design process.	0	0	0	0	0	0	0	0	1	0	1
TOTAL	1	1	0	1	1	1	1	1	1	0	8

The answers relating to the benefits of being given place to the concept(s) and processes of biomimicry in education are listed in the Table 4.22.

As it can be seen, all academicians in general stated that the concept of biomimicry in education would provide benefits from different and various angles in design to students.

When considering the question of whether biomimicry concept is necessary in industrial design education, which is the Q8 of the academician survey, the reasons given by the three academicians (A4, A6, A9) for Q8 and the benefits given to this question seem parallel.

CHAPTER 5

CONCLUSION

Within the scope of this thesis revolutions such as Agricultural Revolution, Scientific Revolution, Industrial Revolution, Petrochemical Revolution and Genetic Engineering Revolution and their socio-cultural, environmental, technological, political and economic impacts have been examined to better understand why people want to re-connect with nature again, why biomimicry and other related concepts have become the most sought-after concepts, and the importance of biomimicry have been rapidly rising. As a result of these revolutions that have created a long-lasting impact and serious changes in every day life, an inevitable orientation in many fields such as medicine, architecture, engineering, design, and art has occured towards the concept of biomimicry.

The concept and origins of biomimicry as well as other related and interchangeably used concepts have been examined to understand and to reveal the difference of the term biomimicry. The methodology of biomimicry, which is indicative of the practicablity of biomimicry, has been examined. Biomimicry has been applied to design generally in two ways: Biology to Design and Challange to Biology. The first one is searching for answers by the inclusion of design in biology, and the other is the inclusion of biology in the design. Sustainability and innovation search, which is one of the most urgent needs and important focuses of today in the design and business world, have been dealt within the scope of design.

Biomimicry design examples, works and developments of biomimicry as a discipline in the field of education and as an application in the business world has been examined to understand the state of biomimicry within the scope of industrial design in Turkey and in the world. The designers in the field of industrial design use the solutions developed by livings in nature against the problems they faced, as a search for solutions in today's sustainability and innovation issues and design problems.

In brief, this study has explored the concept of biomimicry and its usage as well as the awareness level in industrial design education at universities in Izmir. This research has shown that:

- Contrary to explanations of academicians, the results of the student survey have shown that it isseen not incorporated into industrial design education as much as it should.

- The students mostly prefer to use biomimicry as a source of inspiration, creativity and problem solving method, if they use, it does generally not go further than imitation based on form and function.
- It was seen that biomimicry helps to make difference in the students' perspective.
- Due to lack of proper knowledge transfer by academicians, biomimicry could not be used every time in an efficient and accurate way.
- There is no course dedicated to biomimicry, but biomimicry is employed as a supporting or complementary tool method approach for creativity, idea generation or developing a design process instead of being implemented as a primary approach.
- The relationship between biomimicry and sustainability should be explained by the academicians in the process of design, so that the students would better realise the goal of biomimicry.
- Biomimicry should be taught not only a theoretically but also practically in design studios or project-based courses.
- Biomimicry should be handled with a holistic view and an interdisciplinary approach in the design curricula.
- When the students are informed properly about the goal of biomimicry, they could be more eager to use it and biomimicry can be achieved accurately.

This thesis appears to be a pioneering study because of the absence of similar research on Izmir scale and it may be a starting point for further studies. In the future, this study could be applied to all universities that give industrial design education across Turkey. If this had been done, the results could be different and the results could be more generalized. Furthermore, the reason why there are so many open-ended questions in the survey was actually to get more in-depth information. However, this has made the analysis more difficult, so it could have been structured in a more convenient way. Hopefully, the results of this study may encourage or lead researchers to develop new design curricula.

REFERENCES

Appelman, Jaco, Anoek Van Den Bosch, Brigit Van Brenk, Denise Groneweg, Quincy Holzapfel and Wobke. 2017. "Introduction Biomimicry Magazine." *Joint Conference on Bio-Inspiration and Biomimicry.* Utrecht, Netherlands. 1-28. Accessed December, 2019. http://www.biomimicrynl.org/uploads/2/5/7/8/25784046/biomimicry_magazine.pdf

Armstrong, Rachel. 2013. "Parametric Snake Oil." *Architectural Review* 234 (1397): 102–103.

Aygün, Banu, and Ahmet Mutlu. 2006. 'Ekolojik Toplumun Organik Toplumla İlişkisi Üzerine', *Ankara Üniversitesi SBF Dergisi* 61 (1): 3-35.

Bagley, Rebecca O. 2014. "Biomimicry: How Nature Can Streamline Your Business For Innovation." Forbes. April 15, 2014. Accessed July 01, 2019. https://www.forbes.com/sites/rebeccabagley/2014/04/15/biomimicry-how-nature-can-streamline-your-business-for-innovation/#6932a8e84380.

Bakırlıoğlu, Yekta. 2012. *Biomimicry for Sustainability: An Educational Project in Sustainable Product Design.* Master's Thesis, Ankara: Middle East Technical University.

Baumeister, Dayna. 2013. *Biomimicry Resource Handbook: A Seed of Bank of Knowledge and Best Practices.* Doctoral Thesis, Missoula, MT: Biomimicry 3.8

Beattie, Andrew. J., Mark Hay, Bill Magnusson, Rocky De Nys, James Smeathers, and Julian F. V. Vincent. (2011). "Ecology and Bioprospecting." *Austral Ecology* 36 (3): 341-356.

Benyus, Janine M. 1997. *Biomimicry: Innovation Inspired by Nature.* New York: William Morrow and Company.

Benyus, Janine M. 2009. "Biomimicry in Action." TED. Accessed June 04, 2019. https://www.ted.com/talks/janine_benyus_biomimicry_in_action.

Benyus, Janine M. 2011. *Biomimicry: Innovation Inspired by Nature.* New York, USA: Harper Collins Publishers Inc.

Benyus, Janine M. 2011. "A Biomimicry Primer." *Biomimicry 3.8*. Accessed January 16, 2017. https://biomimicry.net/b38files/A_Biomimicry_Primer_Janine_Benyus.pdf

—. 2019. "Biomimicry DesignLens." Biomimicry 3.8.Accessed April 3, 2019. https://biomimicry.net/the-buzz/resources/biomimicry-designlens/.

—. 2019. Biomimicry Institute, Creative Commons BY-NC 4.0 | Biomimicry.org (2018-2017). *"AskNature, The Biomimicry Taxonomy: Biology Organized by Function."* Last Modified March 03, 2017. https://toolbox.biomimicry.org/wpcontent/uploads/2017/03/Taxonomy_Explainer_2017diagram.pdf

Boga-Akyol, Miray, and Sebnem Timur-Ogut. 2016. "Exploring Biomimicry in the Students' Design Process." *Design and Technology Education: An International Journal* 21 (1), 21-31.

Brebbia, Carlos A., and Angelo Carpi. 2010. *Design and Nature V: Comparing Design in Nature with Science and Engineering*. Southampton: WIT Press.

Brennan, Patricia L. R. 2015. "The Business and Promise of Biomimicry." *BioScience* 65 (4): 440-441. Accessed doi: https://doi.org/10.1093/biosci/biv023

Brynjolfsson, Erik, and Andrew McAfee. 2014. *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies*. New York: WW Norton & Company.

Cattano, Corey, Tina Nikou, and Leidy Klotz. 2011. "Teaching Systems Thinking and Biomimicry to Civil Engineering Students." *Journal of Professional Issues in Engineering Education and Practice* 137 (4): 176-82.

Cederberg, Jenna."Biomimicry DesignLens." Biomimicry Examples, Tips, & Resources - SYNAPSE by Biomimicry 3.8. October 18, 2017. Accessed April 08, 2019. https://synapse.bio/blog/2017/10/18/free-download-biomimicry-designlens.

Chakrabarti, A., Sarkar, P., Leelavathamma, B., and B. S. Nataraju. 2005. "A Functional Representation for Aiding Biomimetic and Artificial Inspiration of New Ideas." *Artificial Intelligence For Engineering Design, Analysis And Manufacturing*, Ai Edam 19 (2):113-132.

Chandler, Alfred D. 2009. *Shaping the Industrial Century: The Remarkable Story of the Evolution of the Modern Chemical and Pharmaceutical Industries*. Cambridge: Harvard University Press.

Chick, Anne, and Paul Micklethwaite. 2011. *Design for Sustainable Change: How Design and Designers Can Drive the Sustainability Agenda*. Lausanne: Ava Pub Sa.

Craig, Salmaan, David Harrison, Andrew Cripps, and David Knott. 2008. "BioTRIZ Suggests Radiative Cooling of Buildings Can Be Done Passively by Changing the Structure of Roof Insulation to Let Longwave Infrared Pass." *Journal of Bionic Engineering* 5 (1): 55-66.

Edwards, Andrés R. 2005. *The Sustainability Revolution: Portrait of a Paradigm Shift*. Gabriola, BC: New Society Publishers.

Flint, R. Warren. 2013. *Practice of Sustainable Community Development: A Participatory Framework for Change.* New York, NY: Springer.

Fehrenbacher, Jill. 2012. "Biomimetic Architecture: Green Building in Zimbabwe Modeled After Termite Mounds." Inhabitat Green Design Innovation Architecture Green Building. November 29, 2012. Accessed August July 5, 2019. https://inhabitat.com/building-modelled-on-termites-eastgate-centre-in-zimbabwe/.

Geary, Daniel. 2018. "The Yellow Boxfish Bionic Car." Atmosphere Resorts & Spa. January 29, 2018. Accessed July 2, 2019. https://atmosphereresorts.com/yellow-boxfish-bionic-car/.

Güvenç, Bozkurt, and Merih Zillioğlu. 1993. *"Antropoloji (İnsan Bilimi).*" Eskişehir: AUAÖF Yayınları.

Güzel, Bekir. 2014. "Reflections of Social Problems Based on Industrial Revolution in Literature: Germinal by Émile Zola." *The Journal of International Social Research* 33 (7): 157-165.

Harman, Peter. 2013. *The Scientific Revolution.* (Vol. 14). London: Routledge.

Hart, Stuart L., Eric Kacou, and Ted London. 2011. *Business Strategies for the Bottom of the Pyramid (Collection)*. FT Press.

Hoyos, Carlos A. M. 2009. (*Bio-ID4S): Biomimicry in Industrial Deisgn for Sustainability: An Integrated Teaching-and-Learning Method.* Doctoral Thesis, Graduate School of Design Research: Kobe Design University.

Ingrid de Pauw, Prabhu Kandachar, Elvin Karana, David Peck, and Renee Wever. 2010. "Nature Inspired Design: Strategies Towards Sustainability." *Proceedings of ERSCP-EMSU* 2010. Delft, Netherlands. 25-29.

Kennedy, Emily, Daphne Fecheyr-Lippens, Bor-Kai Hsiung, Peter H. Niewiarowski, and Matthew Kolodziej. 2015. "Biomimicry: A Path to Sustainable Innovation." *Design Issues 31*(3): 66-73

Lockton, Daniel. 2013. *Design with Intent: A Design Pattern Toolkit for Environmental and Social Behaviour Change*. Doctoral thesis, Brunel University.

Lockton, Dan, David Harrison, and Neville A. Stanton. 2013. "Exploring Design Patterns for Sustainable Behaviour." *The Design Journal* 16 (4): 431-459.

Macnab, Maggie. 2012. *Design by Nature: Using Universal Forms and Principles in Design*. Berkely: New Riders, Voices That Matter.

Martín-Palma, Raúl J., and Akhlesh Lakhtakia. 2013. "Engineered Biomimicry for Harvesting Solar Energy: A Bird's Eye View." *International Journal of Smart & Nano Materials* 4 (2): 83-90.

Morgan, Sally. 2003. *Genetic Engineering: The Facts*. London, UK: Evans Brothers.

Nair, Güney. 2009. "Sanayi Toplumu'ndan Bilgi Toplumu'na Homo Economicus' tan Homo Technologicus'a." *Toplumsal Dönüşümler ve Sosyolojik Yaklaşımlar, VI. Ulusal Sosyoloji Kongresi*, Aydın, Türkiye: Adnan Menderes Üniversitesi. 309-328.

Osler, M. J. (2000). *Rethinking The Scientific Revolution*. Cambridge University Press

Patra, Satyajit, Araromi A. Andrew. 2015. "Human, Social, and Environmental Impacts of Genetic Engineering." *Journal of Biomedical Sciences* 4 (2): 1-3. Accessed Semptember 11, 2017. http://www.jbiomeds.com/biomedical-sciences/human-social-and-environmental-impacts-of-human-genetic-engineering.pdf,

Pawlyn, Michael. 2011. *Biomimicry in Architecture*. (Vol. 15). London: Riba Publishing.

Petrig, Thomas. 2013. *Product Innovation Inspired by Nature: How Biomimicry Can Help Business to Innovate.* Bachelor Thesis, Lucerne: Lucerne University of Applied Sciences and Arts, School of Art & Design. Accessed May 28, 2016. http://businessinspiredbynature.com/wp-content/uploads/2013/03/BA-Thesis-Thomas-Petrig.pdf

Reed, Emily J., Lisa Klumb, Maxwell Koobatian, and Christopher Viney. 2009. "Biomimicry As a Route to New Materials: What Kinds of Lessons are Useful?." *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 367* (1893): 1571-1585. Accessed June 5, 2016. https://doi.org/10.1098/rsta.2009.0010

Richardson, Julie, Terry Irwin, and Chris Sherwin. 2005. "Design & Sustainability: A Scoping Report for the Sustainable Design Forum." June 27, 2005. London, UK: *Design Council Publications.*

Ritu Vasu, Primlani. 2013. "Biomimicry: On the Frontiers of Design." *Vilakshan: The XIMB Journal Of Management* 10 (2): 139-148.

Rovalo, Erin. "What Are the Essential Elements of Biomimicry?" Biomimicry Examples, Tips, & Resources - SYNAPSE by Biomimicry 3.8, November 17, 2017. https://synapse.bio/blog//essential-elements-of-biomimicry.

Russell, Cynthia L. 2005. "An Overview of the Integrative Research Review." *Progress in Transplantation* 15 (1): 8-13.

Saçlı, Ahsen. 2009. *Uluslar Arası Çevre Politikaları Çerçevesinde Çevre-Teknoloji İlişkisi* Doctoral Dissertation, Ankara: Ankara Üniversitesi. Accessed October 19, 2016. acikarsiv.ankara.edu.tr/browse/5542/6226.pdf

Versos, Carlos A. M., and Denis A. Coelho. 2011. *Biologically Inspired Design: Methods and Validation*. Industrial Design - New Frontiers. 101-120. InTech Open Access Publisher. ISBN: 978-953-307-622-5. Accessed December 13, 2018. http://www.intechopen.com/books/industrial-design-new-frontiers/biologically-inspired-design-methods-and-validation

Vine, Harry Le. 2006. *Genetic Engineering: A Reference Handbook (Second Edition)*. Santa Barbara, Calif: ABC-CLIO.

Shedroff, Nathan. 2009. *Design Is the Problem: The Future of Design Must Be Sustainable*. Brooklyn, NY: Rosenfield Media.

Sherwin, Chris. 2004. "Design and Sustainability." *The Journal of Sustainable Product Design* 4 (1-4): 21-31.

Shukla, Mukta M., and Ashok K. Shukla. 2012. A Look Into the Petrochemicals Industry. *American Laboratory* 44 (1): 16-18.

Stegall, Nathan. 2006. "Designing for Sustainability: A Philosophy for Ecologically Intentional Design." *Design Issues* 22 (2): 56-63.

Tromp, Nynke, Paul Hekkert, and Peter-Paul Verbeek. 2011. "Design for Socially Responsible Behavior: A Classification of Influence Based on Intended User Experience." *Design Issues* 27 (3): 3-19

Uzogara, Stella G. 2000. "The Impact of Genetic Modification of Human Foods in the 21st Century." *Biotechnology Advances* 18 (3): 179-206.

Vassiliou, Marius S. 2009. *Historical Dictionary of the Petroleum Industry*. Lanham, Md: Scarecrow Press.

Volstad, Nina Louise, and Casper Boks. 2012. "On the Use of Biomimicry as a Useful Tool for the Industrial Designer." *Sustainable Development* 20 (3): 189-199

Walker, Stuart, and Jacques Giard (ed.). 2013. *The Handbook of Design for Sustainability*. London: Bloomsbury Pub Plc.

Walker, Stuart, and Ed Dorsa. 2001. "Making design work–Sustainability, Product Design and Social Equity." *The Journal of Sustainable Product Design* 1 (1): 41-48.

—. 2019. "What Is Biomimicry?" Biomimicry Institute. Accessed June 19, 2019. https://biomimicry.org/what-is-biomimicry/

Young, Grant. (2010). "Design thinking and sustainability." *Zumio Meaningful Innovation* 61 (0): 1-27. Accessed March 08, 2017. https://zum.io/wp content/uploads/2010/06/Design-thinking-and-sustainability.pdf

Young, Scott T., and Kanwalroop K. Dhanda. 2012. *Sustainability: Essentials for Business*. Thousand Oaks: SAGE Publications.

APPENDIX A

A STUDENT SURVEY FORM

A Research On Evaluation Of Awareness and Tendency Of Usage Of Industrial Design Students Concerning The Concept(s) Of Biomimicry/Biomimetic/Learning From Nature-Inspired By Nature In Design

This survey was prepared in order to provide data to the master thesis titled as 'Use of Biomimicry in Industrial Design in Turkey: The Case of Izmir Universities' conducted in the industrial design department of Izmir Institute of Technology. It aims to measure to what extent the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature is known and used in industrial design education. Personal information will be collected for academic purposes and will not be shared with any person or institution except the researcher(s). The results of this research can be used in scientific and professional publications or educational purposes, but the personal identity information of the participants will be kept confidential.

Thank you for your contribution.

* 1. Your age:

2. What is your educational status and please indicate the university where you are studying.

Bachelor

Master

PhD

Other

3. If you are a bachelor student, please indicate your class.

- ◯ 1st class
- ◯ 2nd class
- ◯ 3rd class
- ◯ 4th class

Figure A.1.The first page of survey form for students

* 4. Have you heard of the concepts of biomimicry / biomimetic / learning from nature - inspired by nature in design?

- ◯ Yes
- ◯ No

If yes, where and in what context have you heard?

5. If you have learned or applied these concepts in the universities, in which course did you learn?

* 6. How do you explain / describe the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design?

* 7. Do you think there is a relationship between sustainability and the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design?

- ◯ Yes
- ◯ No

If yes, how do you explain / describe this relationship?

* 8. Do you think there is a relationship between innovation and the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design?

- ◯ Yes
- ◯ No

If yes, how do you explain / describe this relationship?

Figure A.2.The second page of survey form for students

* 9. Do you think there is a relationship between industrial design and the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design?

- ◯ Yes
- ◯ No
- ◯ I don't know / No idea

* 10. Do you think that the concept(s) and processes of biomimicry / biomimetic / learning from nature - inspired by nature in design are necessary in industrial design education?

- ◯ Necessary
- ◯ Not necessary
- ◯ I don't know / No idea

If your answer is necessary / not necessary, why?

* 11. Do you think that the concept(s) and processes of biomimicry / biomimetic / learning from nature - inspired by nature in design are necessary for professional practice of industrial design (In the sector) ?

- ◯ Necessary
- ◯ Not necessary
- ◯ I don't know / No idea

If your answer is necessary / not necessary, why?

Figure A.3.The third page of survey form for students

* 12. As an industrial design student, did you apply / have you applied the concept(s) and processes of biomimicry / biomimetic / learning from nature - inspired by nature in design in your lessons?

- ◯ Yes
- ◯ No

If yes, which methods did you use / have you used?

* 13. Do you think it is useful / beneficial that being given place the concept(s) and processes of biomimicry / biomimetic / learning from nature - inspired by nature in design in the education that you take in?

- ◯ Yes
- ◯ No

If yes, what benefits does it provide ?

Figure A.4.The fourth page of survey form for students

APPENDIX B

AN ACADEMICIAN SURVEY FORM

A Research On Evaluation Of Awareness and Tendency Of Usage Of Industrial Design Academicians Concerning The Concept(s) Of Biomimicry/Biomimetic/Learning From Nature-Inspired By Nature In Design

This survey was prepared in order to provide data to the master thesis titled as 'Use of Biomimicry in Industrial Design in Turkey: The Case of Izmir Universities' conducted in the industrial design department of Izmir Institute of Technology. It aims to measure to what extent the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature is known and used in industrial design education. Personal information will be collected for academic purposes and will not be shared with any person or institution except the researcher(s). The results of this research can be used in scientific and professional publications or educational purposes, but the personal identity information of the participants will be kept confidential.

Thank you for your contribution.

* 1. Your age:

2. What is your educational status and at which university do you currently give education?

- ◯ Bachelor
- ◯ Master
- ◯ PhD
- ◯ Other

At which university do you currently give education?

* 3. Have you heard of the concepts of biomimicry / biomimetic / learning from nature - inspired by nature in design?

- ◯ Yes
- ◯ No

If yes, where and in what context have you heard?

Figure B.1. The first page of survey form for academicians

* 4. How do you explain / describe the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design?

* 5. Do you think there is a relationship between sustainability and the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design?

- ◯ Yes
- ◯ No

If yes, how do you explain / describe this relationship?

* 6. Do you think there is a relationship between innovation and the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design?

- ◯ Yes
- ◯ No

If yes, how do you explain / describe this relationship?

* 7. Do you think there is a relationship between industrial design and the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design?

- ◯ Yes
- ◯ No
- ◯ I don't know / No idea

Figure B.2. The second page of survey form for academicians

* 8. Do you think that the concept(s) and processes of biomimicry / biomimetic / learning from nature - inspired by nature in design are necessary in industrial design education?

- ◯ Necessary
- ◯ Not necessary
- ◯ I don't know / No idea

If your answer is necessary / not necessary, why?

* 9. Do you think that the concept(s) and processes of biomimicry / biomimetic / learning from nature - inspired by nature in design are necessary for professional practice of industrial design (In the sector) ?

- ◯ Necessary
- ◯ Not necessary
- ◯ I don't know / No idea

If your answer is necessary / not necessary, why?

* 10. Do you think the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design are used in industrial design education in Turkey?

- ◯ Yes
- ◯ No
- ◯ I don't know / No idea

If your answer is no, should it be used?

Figure B.3. The third page of survey form for academicians

* 11. As an industrial design academician, do you integrate the concept(s) and processes of biomimicry / biomimetic / learning from nature - inspired by nature in design into your courses?

- ◯ Yes
- ◯ No

If yes, which methods do you use / did you use?

* 12. Do you think it is useful / beneficial that being given place the concept(s) and processes of biomimicry / biomimetic / learning from nature - inspired by nature in design in the education that you give?

- ◯ Yes
- ◯ No

If yes, what benefits does it provide ?

Figure B.4. The fourth page of survey form for academicians

APPENDIX C

GRAPHS AND TABLES OF THE STUDENT SURVEY

Question 1: Your age:

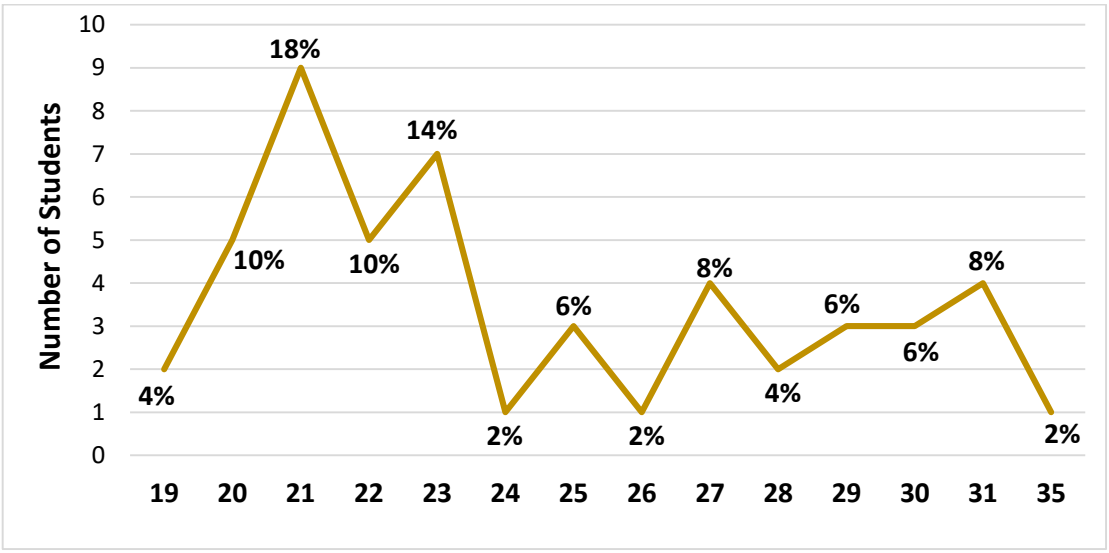

Figure C.1. Q1 graph

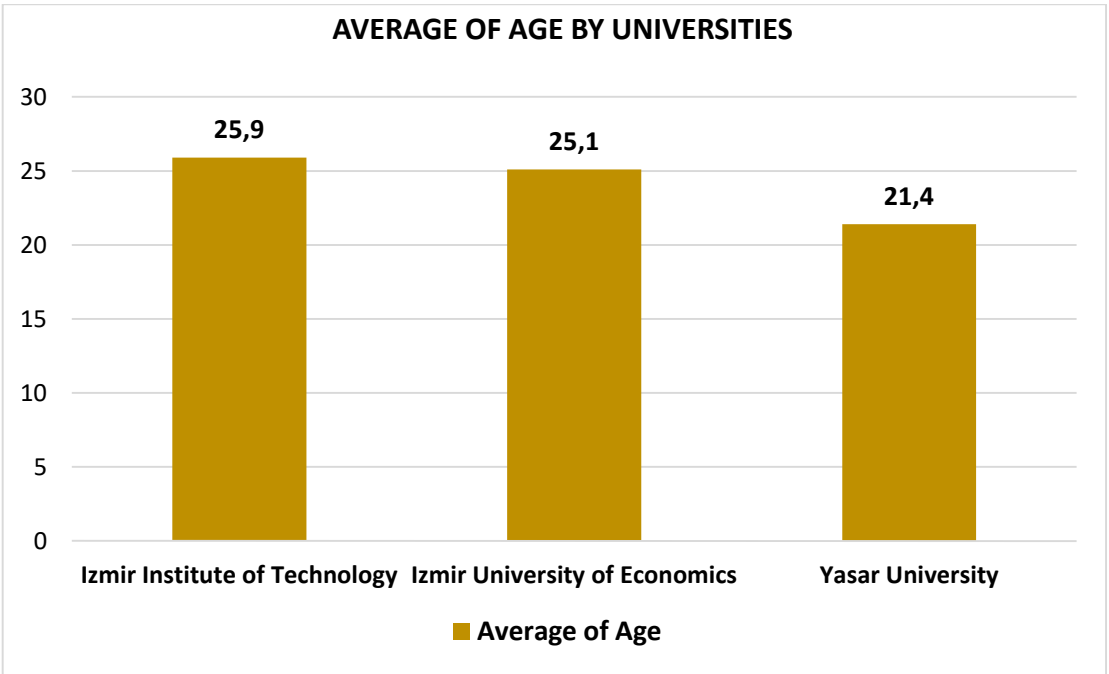

Figure C.2. Q1 graph

Question 2: What is your state of educational status and please indicate the university where you are studying.

Table C.1. Q2 graph

EDUCATIONAL STATUS	Izmir Institute of Technology	Izmir University of Economics	Yasar University	TOTAL
Bachelor	0	14	16	**30**
Master	15	5	0	**20**
TOTAL	**15**	**19**	**16**	**50**

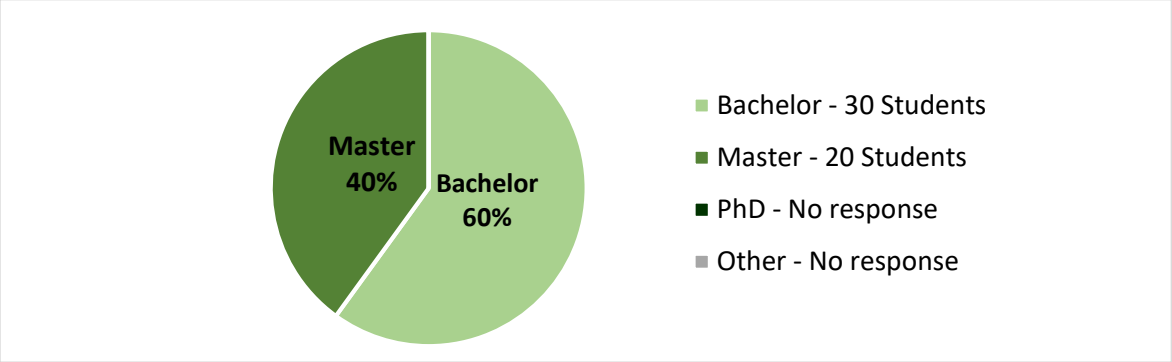

Figure C.3. Q2 graph

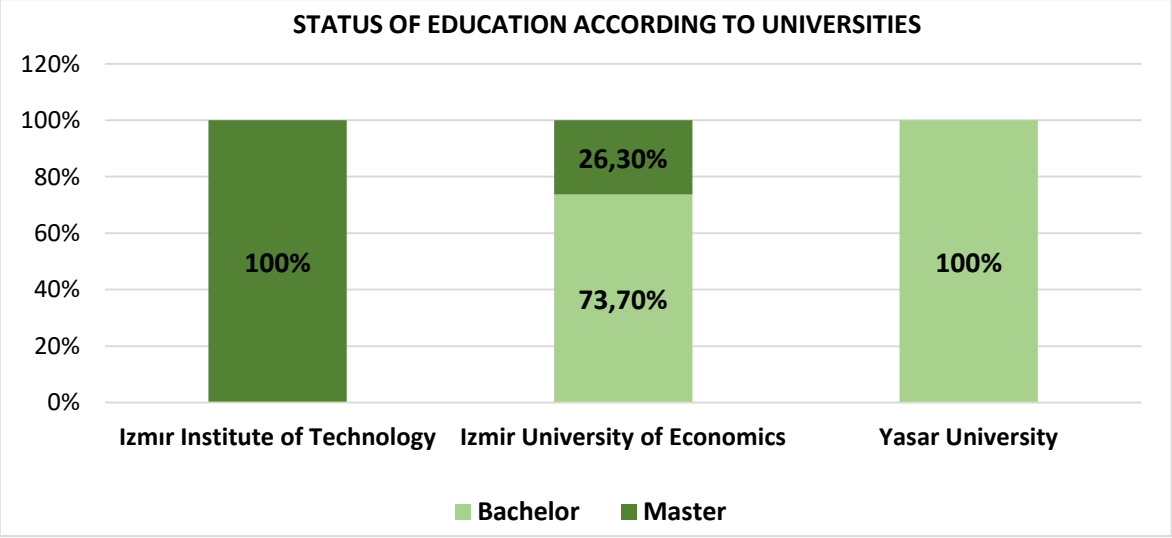

Figure C.4. Q2 graph

Question 3: If you are a bachelor student, please indicate your class**.**

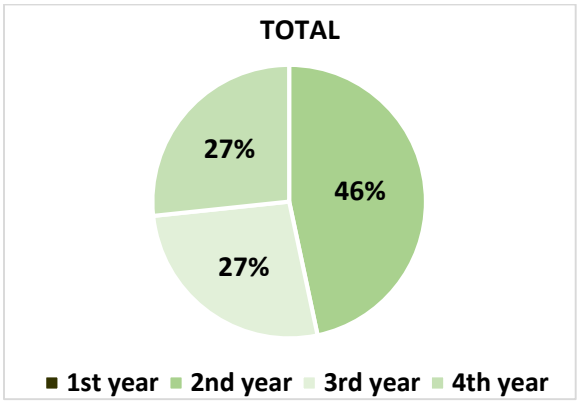

Figure C.5. Q3 graph

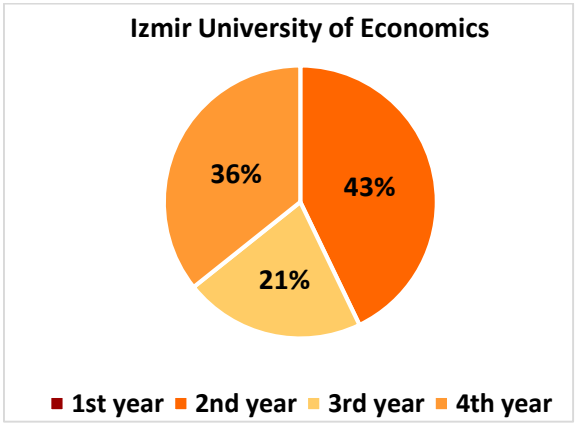

Figure C.6. Q3 graph

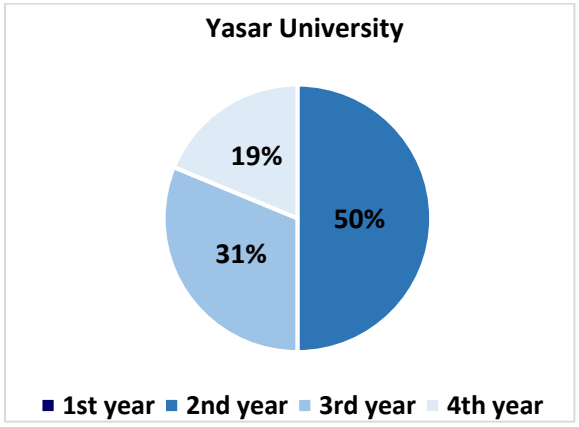

Figure C.7. Q3 graph

Question 4: : Have you heard of the concepts of biomimicry / biomimetic / learning from nature - inspired by nature in design? If yes, where and in what context have you heard?

Table C.2. Q4 graph

ANSWER OPTIONS	Izmir Institute of Technology	Izmir University of Economics				Yasar University			TOTAL
	Master	Bachelor			Master	Bachelor			
		2.	3.	4.	M.	2.	3.	4.	
YES	14	3	3	5	5	6	5	3	44
NO	1	3	0	0	0	2	0	0	6
TOTAL	15	6	3	5	5	8	5	3	50

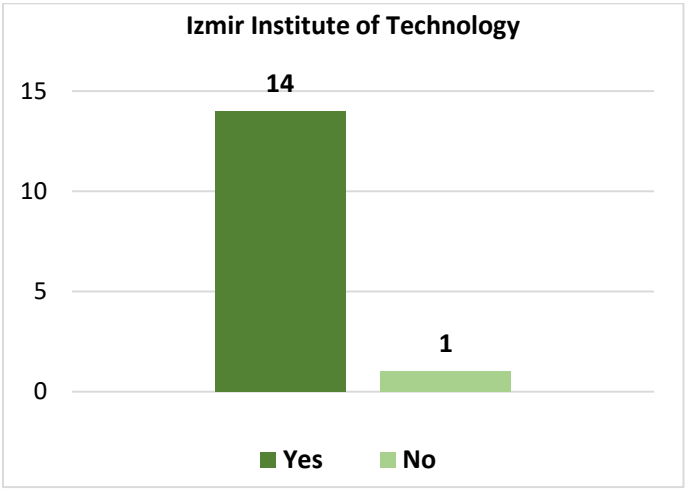

Figure C.8. Q4 graph

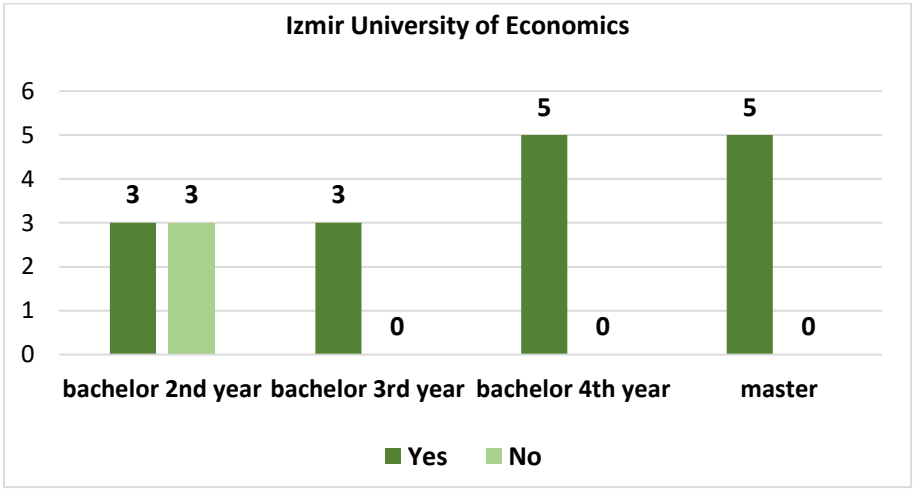

Figure C.9. Q4 graph

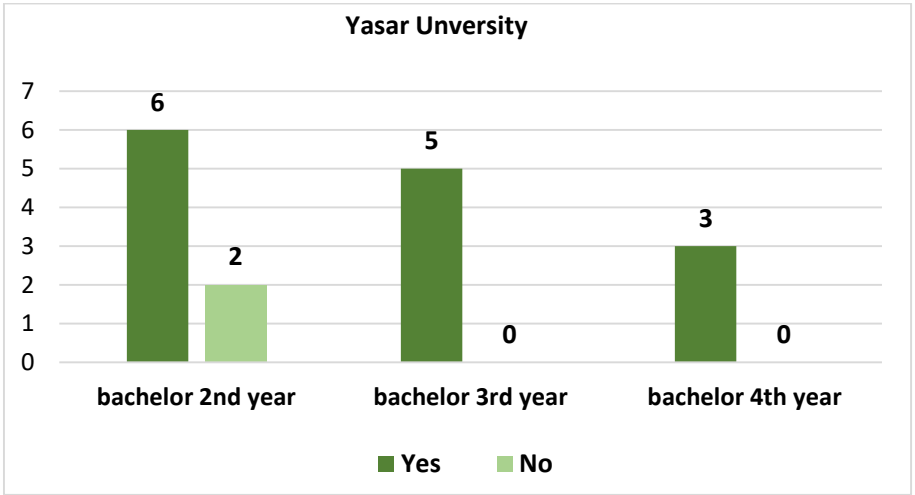

Figure C.10. Q4 graph

Question 5: If you have learned or applied these concepts in the universities, in which course did you learn?

From this question, the participant students who answered "no" to the previous question were left out of assestment. The new table according to universities and educational status is as follows:

Table C.3. Q5 graph

EDUCATIONAL STATUS	Izmir Institute of Technology	Izmir University of Economics	Yasar University	TOTAL
Bachelor	0	11	14	**25**
Master	14	5	0	**19**
TOTAL	**14**	**16**	**14**	**44**

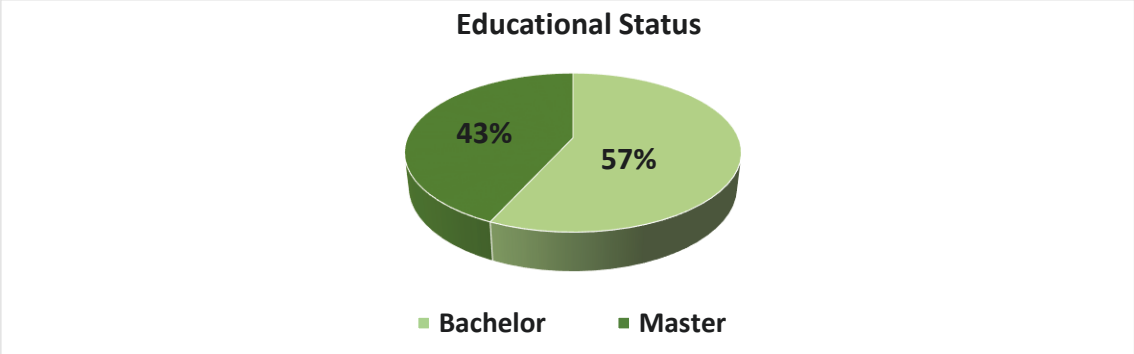

Figure C.11. Q5 graph

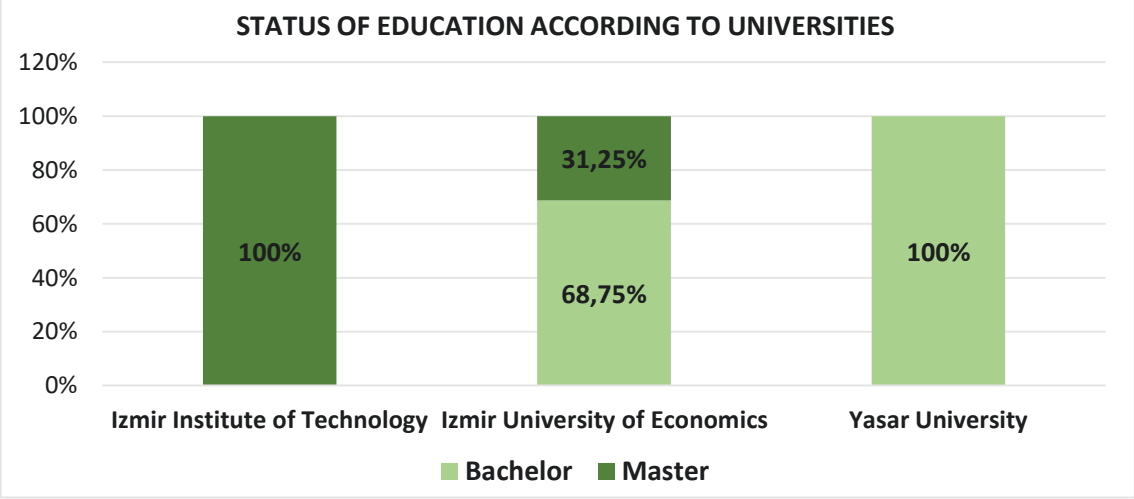

Figure C.12. Q5 graph

Question 7: Do you think there is a relationship between sustainability and the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design? If yes, how do you explain / describe this relationship?

Table C.4. Q7 graph

ANSWER OPTIONS	Izmir Institute of Technology	Izmir University of Economics				Yasar University			TOTAL
	Master	Bachelor			Master	Bachelor			
		2.	3.	4.	M.	2.	3.	4.	
YES	11	0	3	5	5	6	2	3	35
NO	3	3	0	0	0	0	3	0	9
TOTAL	14	3	3	5	5	6	5	3	44

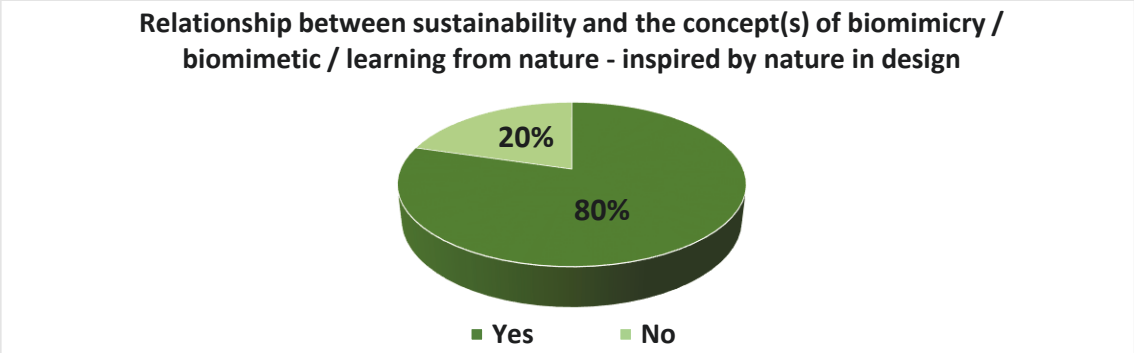

Figure C.13. Q7 graph

Question 8: Do you think there is a relationship between innovation and the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design? If yes, how do you explain / describe this relationship?

Table C.5. Q8 graph

ANSWER OPTIONS	Izmir Institute of Technology	Izmir University of Economics				Yasar University			TOTAL
	Master	Bachelor			Master	Bachelor			
		2.	3.	4.	M.	2.	3.	4.	
YES	11	2	2	5	5	6	5	3	39
NO	3	1	1	0	0	0	0	0	5
TOTAL	14	3	3	5	5	6	5	3	44

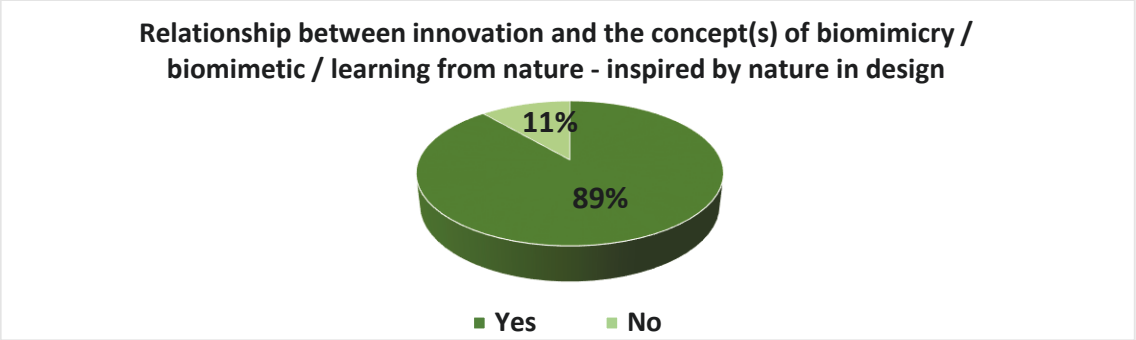

Figure C.14. Q8 graph

Question 10: Do you think that the concept(s) and processes of biomimicry / biomimetic / learning from nature - inspired by nature in design are necessary in industrial design education? If your answer is necessary / not necessary, why?

Table C.6. Q10 graph

ANSWER OPTIONS	Izmir Institute of Technology	Izmir University of Economics				Yasar University			TOTAL
	Master	Bachelor			Master	Bachelor			
		2.	3.	4.	M.	2.	3.	4.	
NECESSARY	13	3	3	5	4	6	5	2	41
NOT NECESSARY	0	0	0	0	0	0	0	1	1
NO IDEA	1	0	0	0	1	0	0	0	2
TOTAL	14	3	3	5	5	6	5	3	44

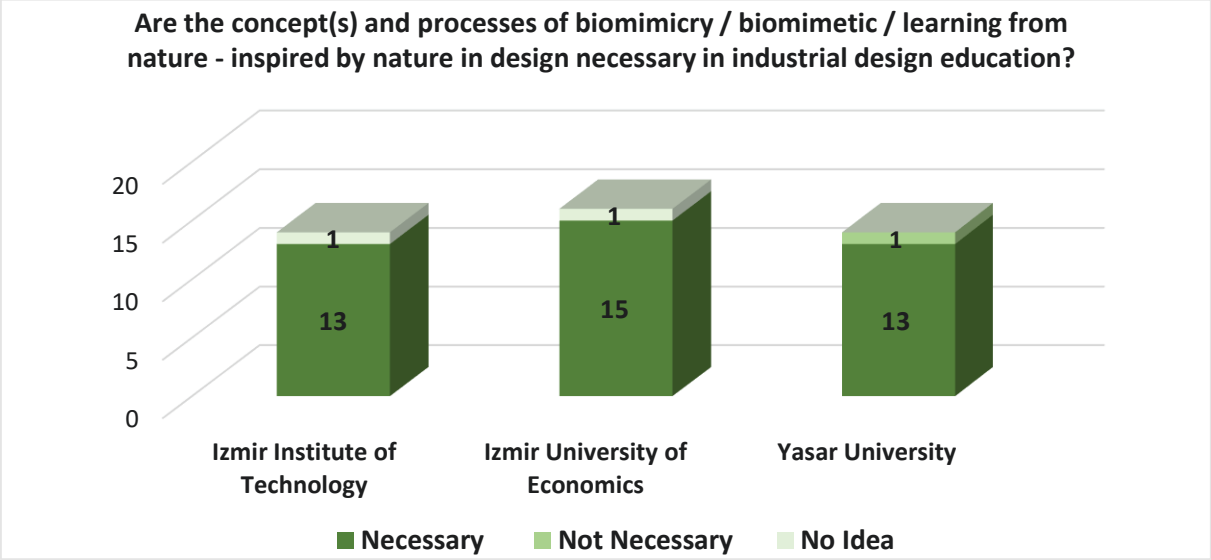

Figure C.15. Q10 graph

Question 11: Do you think that the concept(s) and processes of biomimicry / biomimetic / learning from nature - inspired by nature in design are necessary for professional practice of industrial design (in the sector)? If your answer is necessary / not necessary, why?

Table C.7. Q11 graph

ANSWER OPTIONS	Izmir Institute of Technology	Izmir University of Economics				Yasar University			TOTAL
	Master	Bachelor			Master	Bachelor			
		2.	3.	4.	M.	2.	3.	4.	
NECESSARY	8	3	1	5	4	5	3	2	**31**
NOT NECESSARY	0	0	2	0	0	0	1	1	**4**
NO IDEA	6	0	0	0	1	1	1	0	**9**
TOTAL	**14**	**3**	**3**	**5**	**5**	**6**	**5**	**3**	**44**

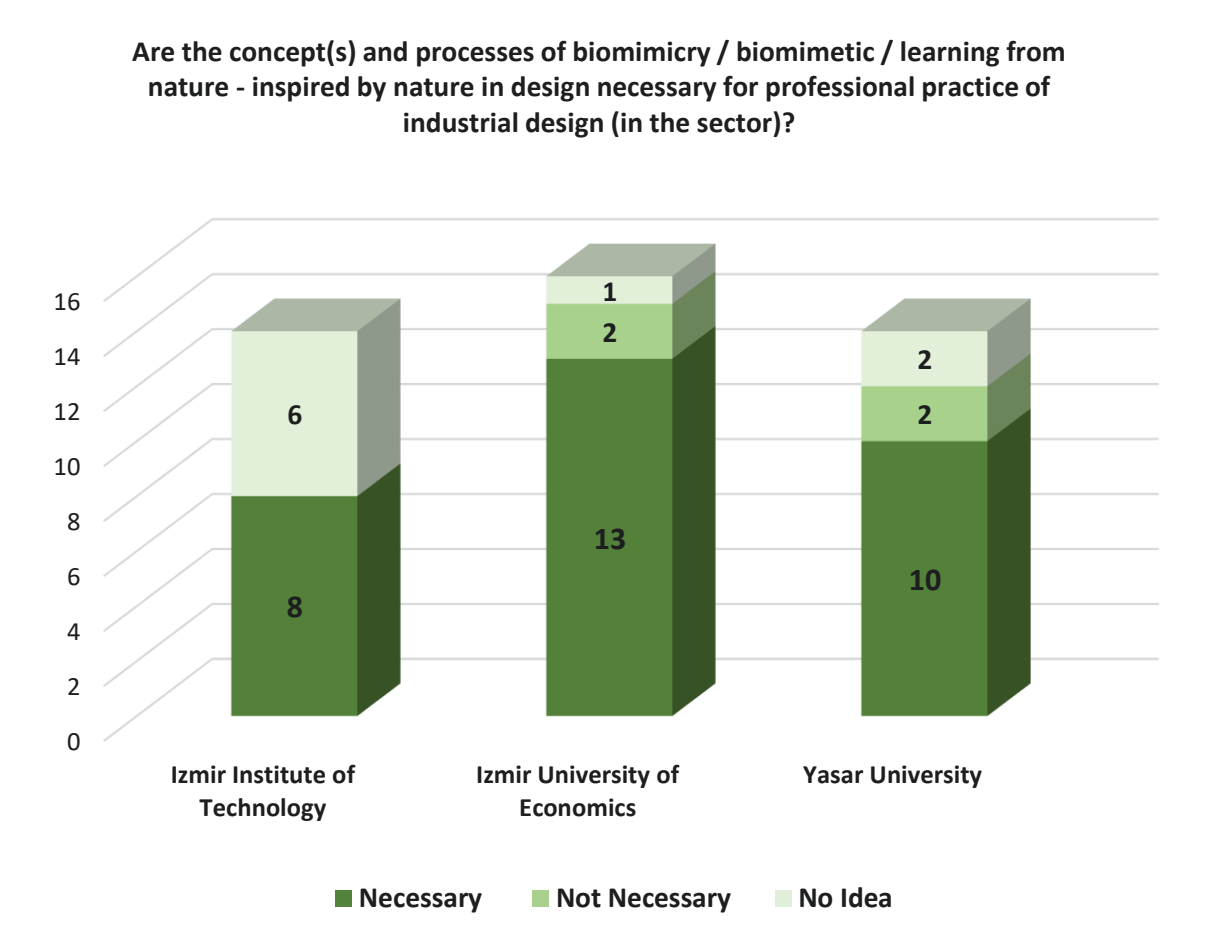

Figure C.16. Q11 graph

Question 12: As an industrial design student, did you apply / have you applied the concept(s) and processes of biomimicry / biomimetic / learning from nature - inspired by nature in design in your lessons? If yes, which methods did you use / have you used?

Table C.8. Q12 graph

ANSWER OPTIONS	Izmir Institute of Technology	Izmir University of Economics				Yasar University			TOTAL
	Master	Bachelor			Master	Bachelor			
		2.	3.	4.	M.	2.	3.	4.	
YES	4	1	2	4	2	5	5	3	**26**
NO	10	2	1	1	3	1	0	0	**18**
TOTAL	**14**	**3**	**3**	**5**	**5**	**6**	**5**	**3**	**44**

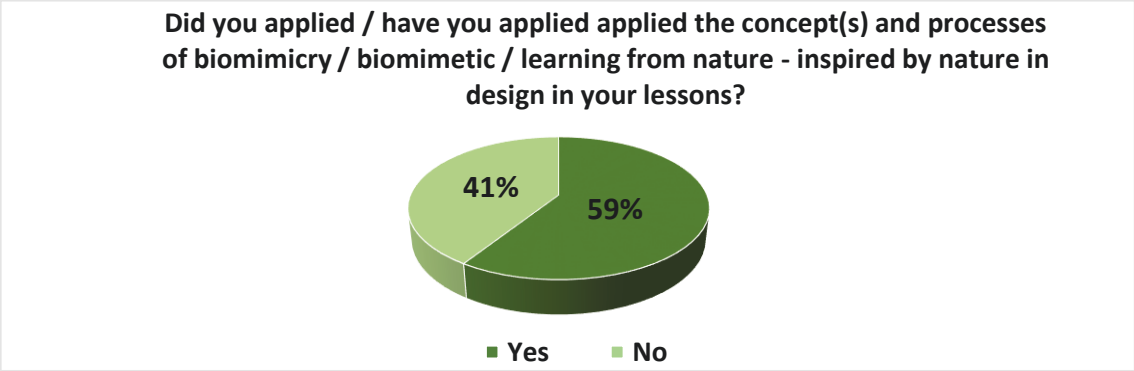

Figure C.17. Q12 graph

Question 13: Do you think it is useful / beneficial that being given place the concept(s) and processes of biomimicry / biomimetic / learning from nature - inspired by nature in design in the education that you take in? If yes, what benefits does it provide?

Table C.9. Q13 graph

ANSWER OPTIONS	Izmir Institute of Technology	Izmir University of Economics				Yasar University			TOTAL
	Master	Bachelor			Master	Bachelor			
		2.	3.	4.	M.	2.	3.	4.	
YES	12	2	2	5	5	6	4	3	**39**
NO	2	1	1	0	0	0	1	0	**5**
TOTAL	**14**	**3**	**3**	**5**	**5**	**6**	**5**	**3**	**44**

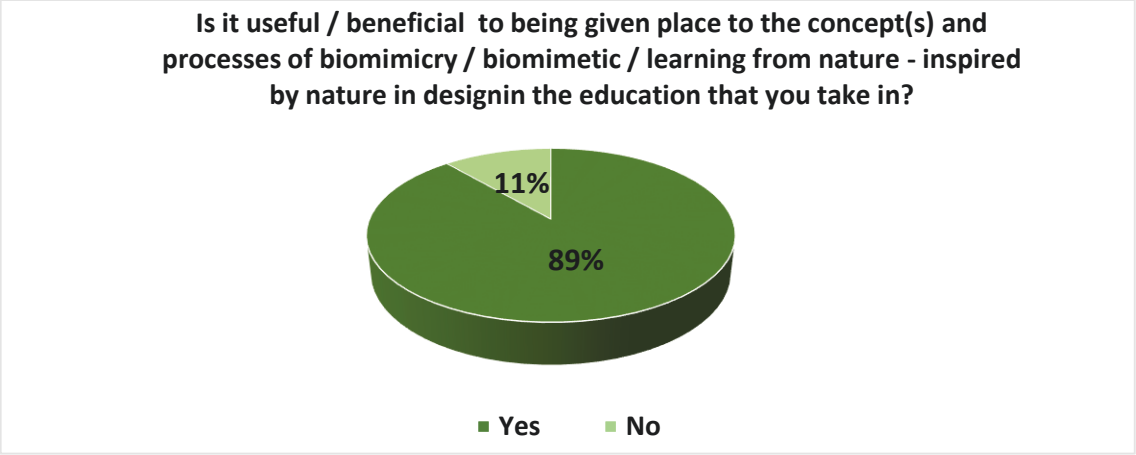

Figure C.18. Q13 graph

APPENDIX D

GRAPHS AND TABLES OF THE ACADEMICIAN SURVEY

Question 1: Your age:

Table D.1. Q1 graph

UNIVERSITIES	AGES OF ACADEMICIANS	TOTAL NUMBER OF ACADEMICIANS
Izmir Institute of Technology	45	2
	49	
Izmir University of Economics	34	5
	38	
	43	
	50	
	55	
Yasar University	32	3
	37	
	8	

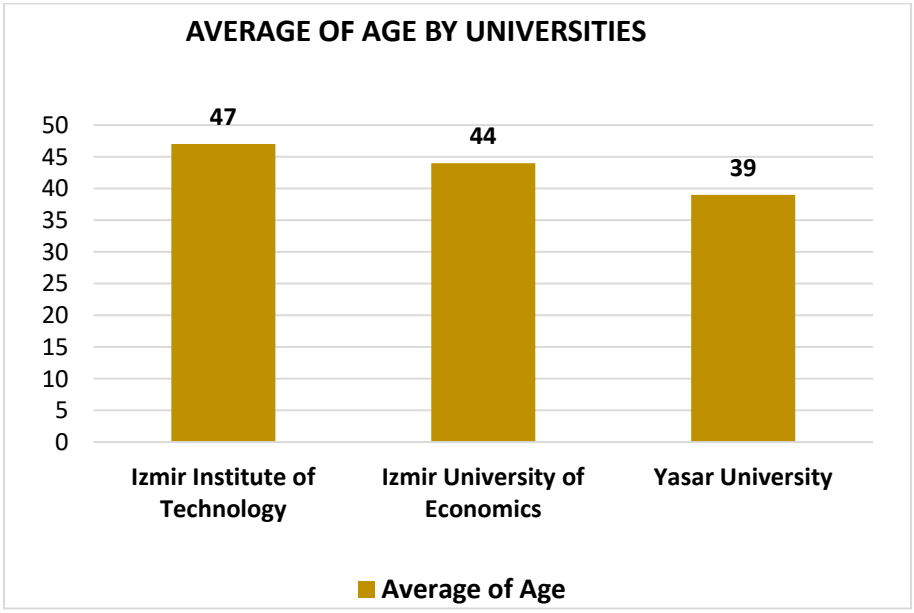

Figure D.1. Q1 graph

Question 2: What is your educational status and at which university do you currently give education?

Table D.2. Q2 graph

ANSWER OPTIONS	Izmir Institute of Technology		Izmir University of Economics					Yasar University			TOTAL
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	
Bachelor	0	0	1	0	0	0	0	0	0	0	1
Master	1	0	0	0	0	0	0	1	0	0	2
PHD	0	1	0	1	1	1	1	0	1	1	7
TOTAL	2		5					3			10

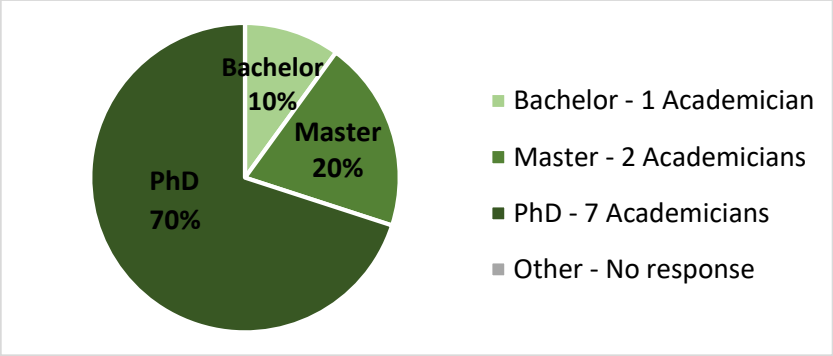

Figure D.2. Q2 graph

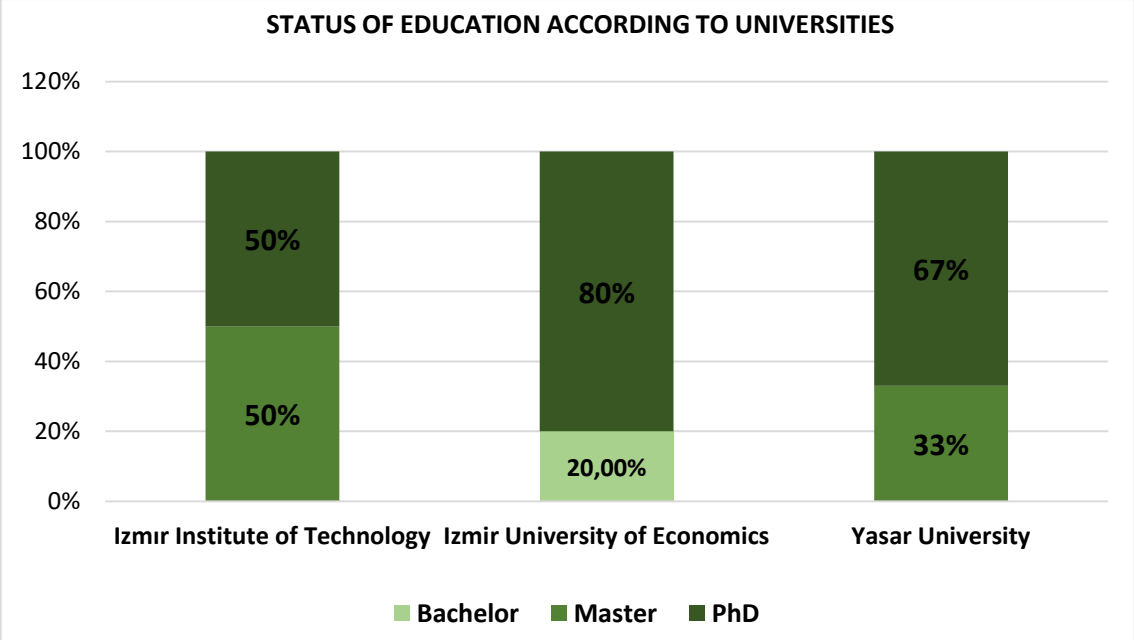

Figure D.3. Q2 graph

Question 3: : Have you heard of the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design? If yes, where and in what context have you heard?

Table D.3. Q3 graph

ANSWER OPTIONS	Izmir Institute of Technology		Izmir University of Economics					Yasar University			Total
	A1	A2	A3	A4	A5	A5	A6	A7	A8	A9	
YES	1	1	1	1	1	1	1	1	1	1	10
NO	0	0	0	0	0	0	0	0	0	0	0
Total	2		5					3			10

Question 5: Do you think there is a relationship between sustainability and the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design? If yes, how do you explain / describe this relationship?

Table D.4. Q5 graph

ANSWER OPTIONS	Izmir Institute of Technology		Izmir University of Economics					Yasar University			Total
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	
YES	1	1	1	1	1	1	0	1	1	0	8
NO	0	0	0	0	0	0	1	0	0	1	2
Total	2		5					3			10

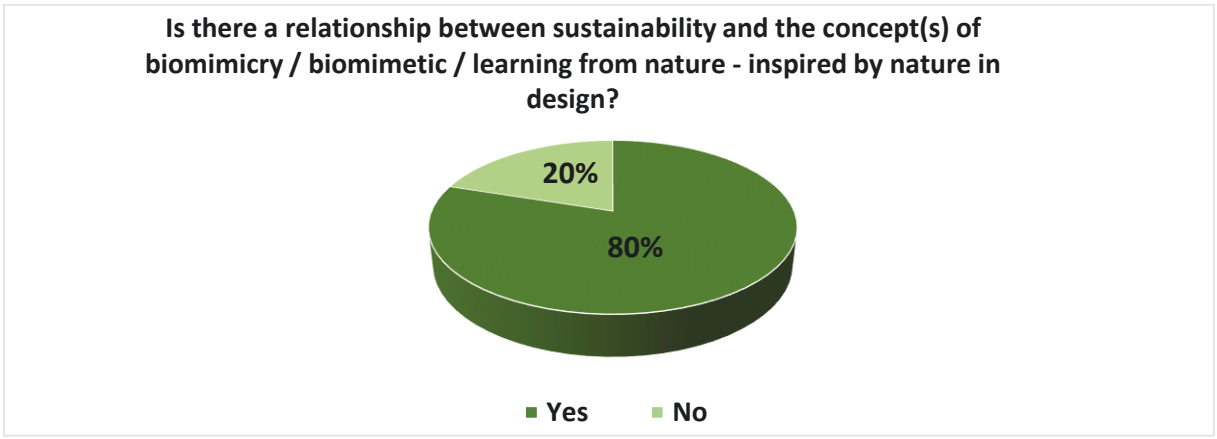

Figure D.4. Q5 graph

Question 8: Do you think that the concept(s) and processes of biomimicry / biomimetic / learning from nature - inspired by nature in design are necessary in industrial design education? If your answer is necessary / not necessary, why?

Table D.5. Q8 graph

ANSWER OPTIONS	Izmir Institute of Technology		Izmir University of Economics					Yasar University			Total
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	
NECESSARY	1	0	1	1	1	1	1	0	1	0	7
NOT NECESSARY	0	1	0	0	0	0	0	1	0	1	3
NO IDEA	0	0	0	0	0	0	0	0	0	0	0
Total	2		5					3			10

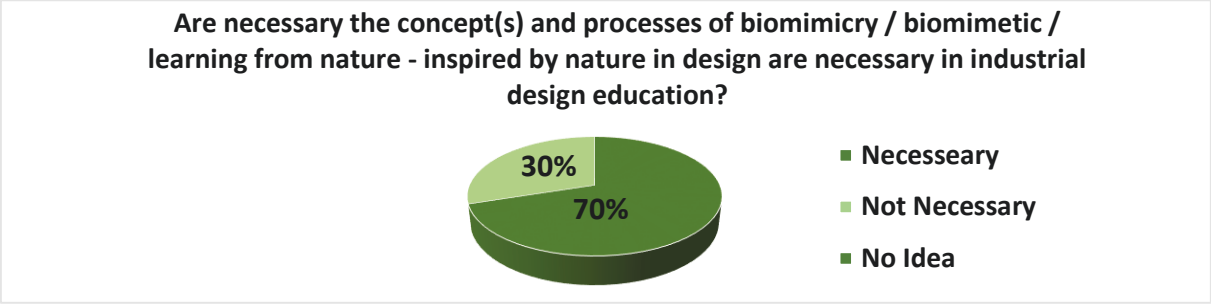

Figure D.5. Q8 graph

Question 9: Do you think that the concept(s) and processes of biomimicry / biomimetic / learning from nature - inspired by nature in design are necessary for professional practice of industrial design (in the sector)? If your answer is necessary / not necessary, why?

Table D.6. Q9 graph

ANSWER OPTIONS	Izmir Institute of Technology		Izmir University of Economics					Yasar University			Total
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	
NECESSARY	1	0	1	1	1	1	1	0	1	0	7
NOT NECESSARY	0	1	0	0	0	0	0	1	0	1	3
NO IDEA	0	0	0	0	0	0	0	0	0	0	0
Total	2		5					3			10

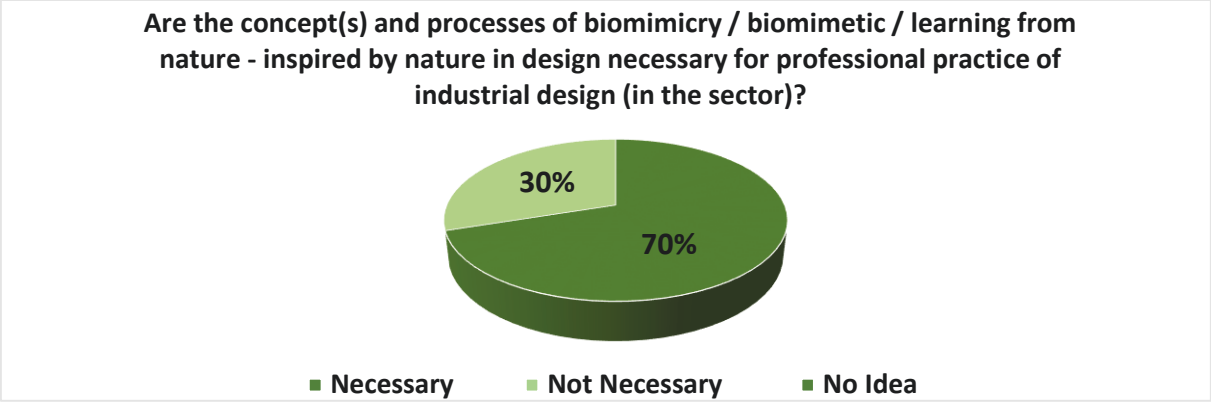

Figure D.6. Q9 graph

Question 10: Do you think the concept(s) of biomimicry / biomimetic / learning from nature - inspired by nature in design are used in industrial design education in Turkey? If your answer is no, should it be used?

Table D.7. Q10 graph

ANSWER OPTIONS	Izmir Institute of Technology		Izmir University of Economics					Yasar University			Total
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	
YES	0	1	1	0	0	1	1	0	1	0	5
NO	1	0	0	1	1	0	0	1	0	1	5
NO IDEA	0	0	0	0	0	0	0	0	0	0	0
Total	2		5					3			10

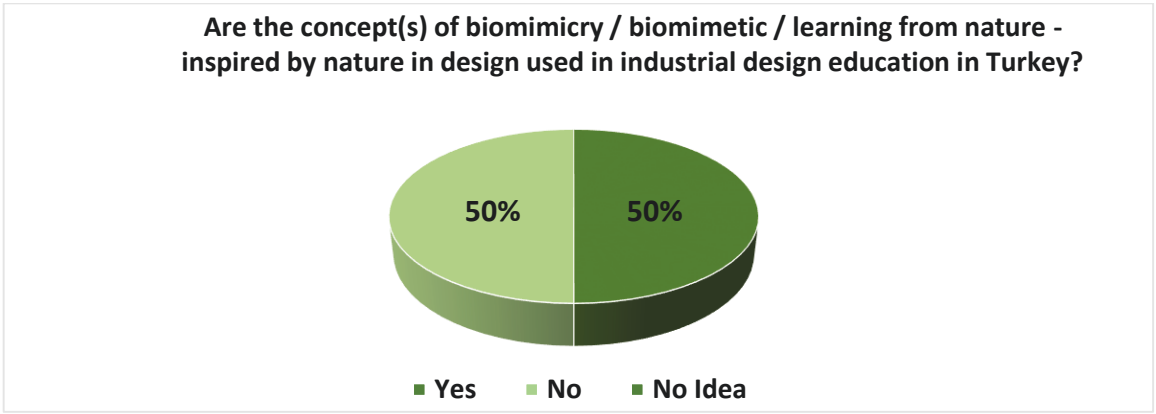

Figure D.7. Q10 graph

Question 11: As an industrial design academician, do you integrate the concept(s) and processes of biomimicry / biomimetic / learning from nature - inspired by nature in design into your courses? If yes, which methods do you use / did you use?

Table D.8. Q11 graph.

ANSWER OPTIONS	Izmir Institute of Technology		Izmir University of Economics					Yasar University			Total
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	
YES	1	1	1	1	1	0	1	0	1	0	7
NO	0	0	0	0	0	1	0	1	0	1	3
Total	2		5					3			10

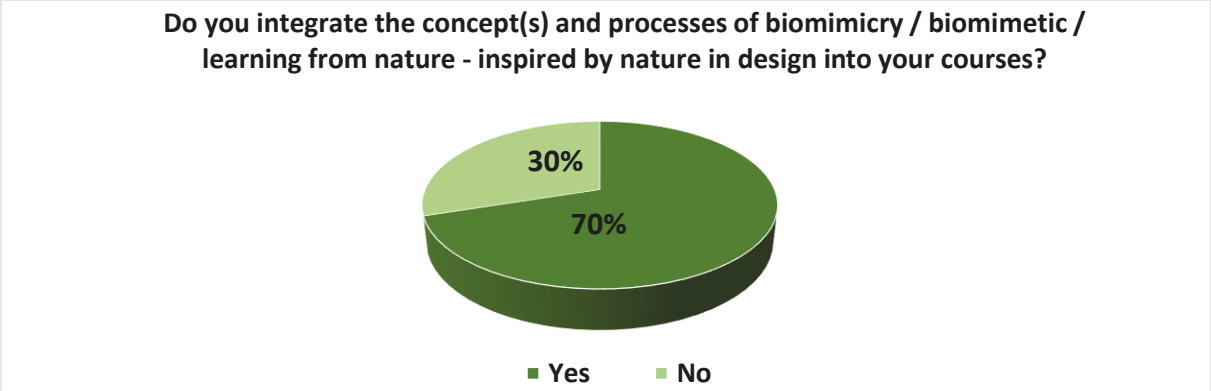

Figure D.8. Q11 graph

Question 12: Do you think it is useful / beneficial that being given place to the concept(s) and processes of biomimicry / biomimetic / learning from nature - inspired by nature in design in the design education that you give?

Table D.9. Q12 graph

ANSWER OPTIONS	Izmir Institute of Technology		Izmir University of Economics					Yasar University			Total
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	
YES	1	1	1	1	1	1	1	1	1	0	9
NO	0	0	0	0	0	0	0	0	0	1	1
Total	2		5					3			10

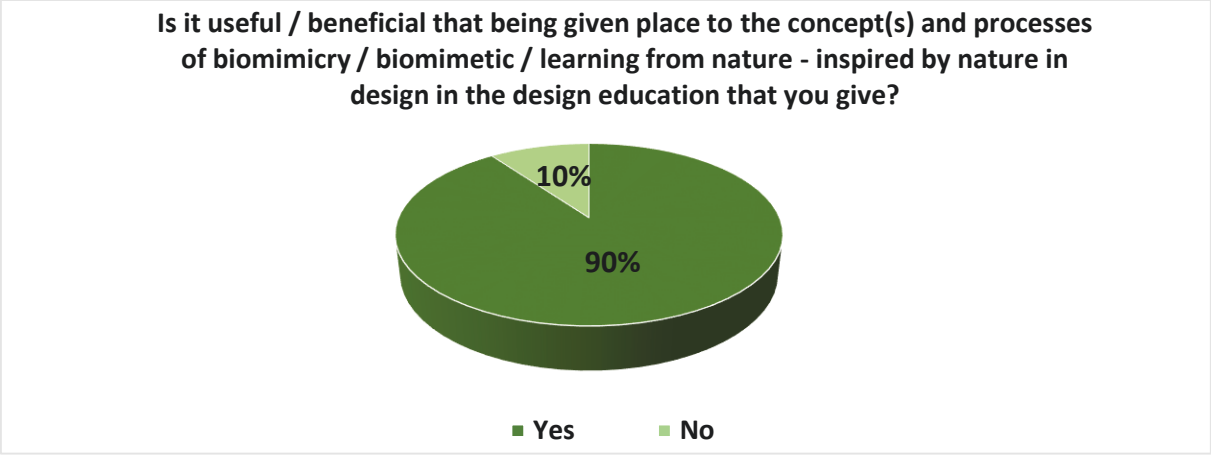

Figure D.9. Q12 graph