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The effects of Teaching Practices Based on Biomimicry Approach on Learning-Teaching Processes

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The aim of this research is to evaluate the effect of biomimicry approach on the learning-teaching process, based on the results of the studies on teaching practices on the biomimicry approach. The research was carried out by systematic review method. Depending on this method, the review protocol of scientific studies, which consists of four stages: planning, research, selection and synthesis, was employed. Within the scope of the research, the studies indexed in the Web of Science (WOS) database were searched with the keywords "biomimicry", "biomimicry in education", and then the relevant studies were selected by scanning TRDizin, Wiley, Scopus databases. Additionally, the relevant postgraduate studies were scanned through the National Dissertation Center and ProQuest databases and were included in the review. Within the scope of research themes, all the related studies in the fields of Educational Sciences, Social Sciences, Education, Psychology and Sociology were included in the review. During the selection phase, the contents were evaluated and the studies suitable for the research purpose were determined in line with the elimination criteria. In the synthesis phase, the selected studies were evaluated in terms of their theoretical basis, aims, methods, findings, and limitations. The total number of studies included in the systematic review was determined as 16. The results of the study provide a perspective on the current status of the biomimicry approach in the field of social sciences, how it is conceptually defined, and the effects of this approach on responding to needs in the field of education and learning characteristics.

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Introduction

In today's rapidly evolving landscape, education is undergoing a profound transformation, driven by a complex interplay of social, cultural, economic, political, historical, psychological, and philosophical factors. The widespread integration of Internet-based technological tools within educational settings, particularly in response to the challenges posed by the pandemic, has accelerated social and cultural changes, thereby affecting not only the value systems but also the cognitive and affective needs of learners. This dynamic shift calls for a holistic understanding of the multifaceted forces shaping modern education and underscores the importance of adapting pedagogical approaches to meet the evolving demands of learners in an increasingly interconnected world. Traditional approaches centered around the classroom and teacher-centric design are giving way to hybrid educational practices. In these new paradigms, learners play a more active role, share responsibility for their learning, and benefit from feedback provided by both teachers and peers. However, the pervasive use of devices such as phones and tablets among students, especially since the onset of the pandemic, has also resulted in the emergence of addictive behaviors among students (Baltacı, Akbulut & Yılmaz, 2021; Berber & Çelik, 2022; Gümüşgül & Aydoğan, 2020; Öztürk, 2021; Yıldız & Bektaş, 2021).

Furthermore, the fact that 68% of the Turkish population resides in cities and that urbanization is prevalent (TUİK, 2022) also hinders children from spending time in nature. This contributes to a significant contemporary issue where students' understanding of natural life is confined to information gathered in virtual environments. Bolat (2018) argues that children are becoming increasingly disconnected from nature and are hesitant to engage with living species outdoors. While some initiatives, such as ecological schools, have emerged to address these concerns, they have not gained widespread traction in society beyond a select group of privileged students. Nonetheless, considerable efforts are being made in this regard, with new approaches being explored for implementation. One such approach is biomimicry.

Biomimicry has gained recognition and acceptance as an approach that offers a fresh perspective on observation and design, making its way into university curricula and educational programs worldwide (Urmann, 2016). In recent times, biomimetic methodologies have attracted attention as alternatives to conventional educational practices, particularly in addressing environmental challenges arising from the industrial age (Blok & Gremmen, 2016). This approach provides students with an innovative way to draw inspiration from nature, fostering respect for the natural world and reestablishing a connection with it. The term 'biomimicry' derives from 'bio,' referring to living organisms, and 'mimesis,' meaning imitation (Stevens et al., 2021). Benyus (1997), a pioneer in integrating and defining biomimicry within educational contexts, conceptualized it as the emulation or adaptation of nature's forms, processes, and ecosystems to fulfill human needs or address challenges (Stevens et al., 2022).

The biomimicry approach significantly contributes to the development of metacognitive and affective characteristics, which are often underrepresented in curriculum objectives. Hu (2023) highlights that biomimicry aims to foster students' creative skills, cultivate their curiosity and motivation, boost their achievement and self-confidence through hands-on learning experiences, promote peer interaction through collaborative teamwork, and encourage the exploration of their own interests and expertise through various applied tasks. It is believed that further development and integration of this approach into education across different disciplines will greatly enhance students' acquisition of metacognitive skills and affective characteristics (Alawad & Yassir, 2014; Avcı, 2019; Roobeek, 2019; Sumrall, Sumrall, & Robinson, 2018; Yakışan & Velioğlu, 2019; Urmann, 2016).

In Türkiye, formal education programs focus primarily on cognitive skills. However, it is impossible to ensure the cognitive development of an individual who has no desire to learn, is anxious about learning, lacks self-confidence and has developed negative attitudes towards learning. This is why, affective characteristics such as self-esteem (Dineen, 1999; Furedi, 2004; Jendouri, 2002; Kramer, 1991), attitude, self-confidence, learning autonomy (Belanger and Farmer, 2012; Hameline, 1999; Hoffmans-Gosset, 1987; Lahire, 2001; Lebrun, Lenoir and Thomas, 2011; Marples, 2002), responsibility for learning (Paturet, 2007), and global values should be integrated into curriculum design to foster holistic development and ensure educational success.

Modeling and social interaction are of great importance in the development of affective characteristics. Bandura (1989), one of the pioneers of social learning theory, emphasizes the mutual interaction between behaviour and environment, and states that behaviour can be learned through observation and modelling. Given the omnipresence of both real-world and virtual environments in children's lives today, the concept of learning from nature by comprehending, observing, and adapting observations to social dynamics assumes heightened significance. This situation underlines the fact that curricula should be developed not only from cognitive paradigms, but also from a holistic perspective, taking into account socio-emotional domains. Encouraging students to develop their self-image in a positive way from an early age, encouraging them to grow up as responsible and autonomous learners, and ensuring that they have the skills to better define their future educational needs and to access and evaluate the required information are of great importance in achieving the program's objectives.

Despite its extensive history, the biomimicry approach has only recently gained widespread attention (Kennedy, 2017). While biomimicry offers a framework for imitating or drawing inspiration from nature to address learning needs, there remains a scarcity of research on its practical implementation and the acquisition of problem-solving and critical thinking skills during the process (Stevens et al., 2022). In existing literature, the biomimicry approach is predominantly viewed as design-oriented, rooted in principles of science and engineering. The translation of biological knowledge into design applications has sparked interdisciplinary research across fields such as materials science, architecture, urban planning, computer science, and robotics (MacKinnon et al., 2020). Although limited in number, studies focusing on the application of the biomimicry approach in formal education highlight its theoretical foundations, which revolve around concepts of design-based learning, analogical reasoning, and ethics (Stevens et al., 2021).

On the other hand, the widespread adoption of STEM and STEAM methodologies in Türkiye and globally has reinforced the association between the biomimicry approach and these methodologies, albeit leading to some misconceptions. The biomimicry approach has been somewhat conflated with STEM and STEAM applications. Initially labeled as STEM (Science, Technology, Engineering, Mathematics) in educational discourse, these methodologies later expanded to include the arts, evolving into STEAM. The design-centric nature of these practices has facilitated their alignment with the biomimicry approach, which draws inspiration from nature, thereby rendering them complementary methodologies. Conversely, while STEM education at the primary level predominantly centers around mandatory mathematics and science curricula for all students, research in this domain has typically focused on student engagement and performance in these subjects (Xie, Fang, and Shauman, 2015). In actuality, biomimicry transcends mere emulation of nature to design products catering to human needs. Biomimicry necessitates a thorough examination of natural processes, the interplay between organisms and their surroundings, and an innate understanding of nature's cycles. It provides a

framework for reevaluating the relationship between humans and nature, rediscovering humanity's role in the natural world, and striving for balance, harmony, and renewal. In this regard, biomimicry can be viewed as a form of 'natural pedagogy' rather than merely a design tool or approach (Dawson & Winks, 2021).

The fact that pedagogical designs based on the biomimicry approach do not have enough concrete projects in the field of educational sciences, that they are combined with STEAM activities and that existing applications stand out as lesson plans highlight the need for systematic evaluation in this field. The objective of this research is to conduct a systematic review to analyze teaching practices grounded in the biomimicry approach and evaluate their impact on the learning and teaching process.

Within the scope of this study, the research aimed to address the following research questions:

(1) How is the distribution of research conducted within the biomimicry approach in terms of years, target group and research methods?
(2) What are the effects of biomimicry educational research on the learning and teaching process?

Methodology

The research, which aims to evaluate the impact of teaching practices based on the biomimicry approach on the learning-teaching process, was conducted using the systematic review method. Systematic literature review, as defined by Kitchenham (2004), involves evaluating all research related to the relevant subject area by analyzing it with a review protocol. Kitchenham (2004) defines systematic literature review as a protocol-based method for analyzing and evaluating all research relevant to research questions or a subject at issue. The most crucial component of systematic review studies, the review procedure, consists primarily of the following steps: identifying databases, selecting appropriate databases, defining selection and elimination criteria, and interpreting research. The review protocol for this study is divided into four stages: planning, research, selection, and synthesis. Research topics, keywords, databases, and research criteria were all defined during the planning phase. In the research phase, a detailed search was carried out in the databases according to pre-determined criteria (Figure 1).

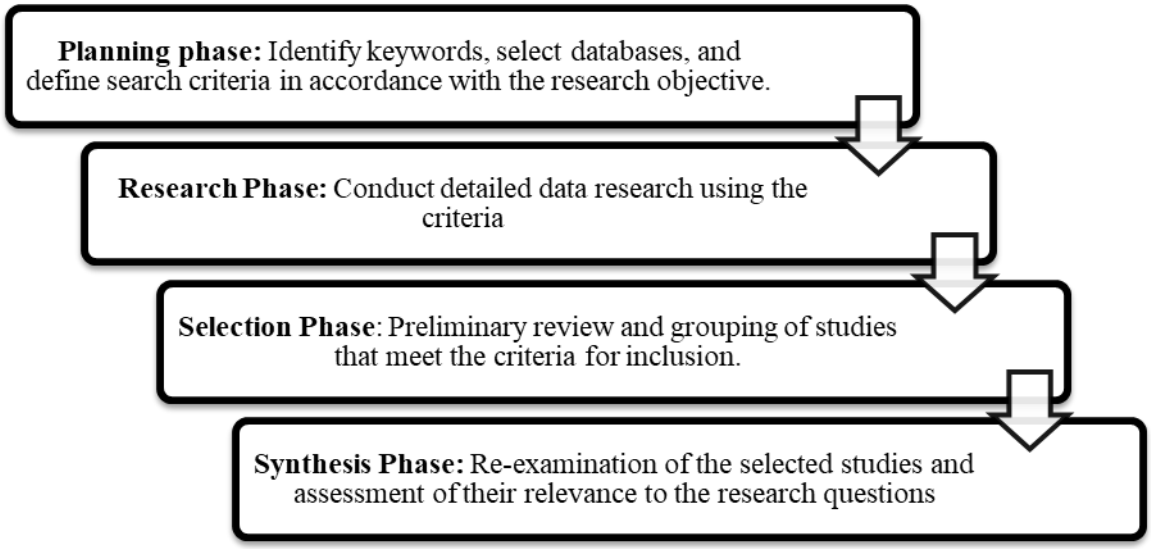

Figure 1. Systematic review procedure

During the planning and research phases, a descriptive analysis form was developed to capture information regarding the purpose, target audience, geographical region, methodology, and results of biomimicry research within the scope of the two research questions. The research initially involved studies indexed in the Web of Science (WOS) database using keywords such as "biomimicry" and "biomimicry in education." Additionally, searches were conducted within the TRDizin, Wiley, and Scopus databases, and relevant studies were selected. Furthermore, postgraduate studies were identified through the National Dissertation Center and ProQuest databases and included in the review process. After the screening process, 3,686 studies were identified in the first stage.

During the selection phase, the identified studies underwent further screening based on criteria including language (English), article type (research articles), field (educational sciences), and publication year. Following this screening, 16 studies relevant to the field of educational sciences and learning were identified. These studies were subsequently reclassified based on their content and subjected to in-depth analysis.

*During the Synthesis stage***,** the 16 selected studies were thoroughly examined and evaluated within the framework of the research questions. Content analysis was employed to analyze the studies. Accordingly, all studies were classified based on their methods, purposes, target audiences, types, years, and main findings. This classification was conducted using Excel format, where all studies were examined, and the information under relevant categories was summarized and coded. The research aims and prominent findings were then themed, and research trends were analyzed based on the synthesized data. The inclusion and exclusion criteria are depicted in Figure 2.

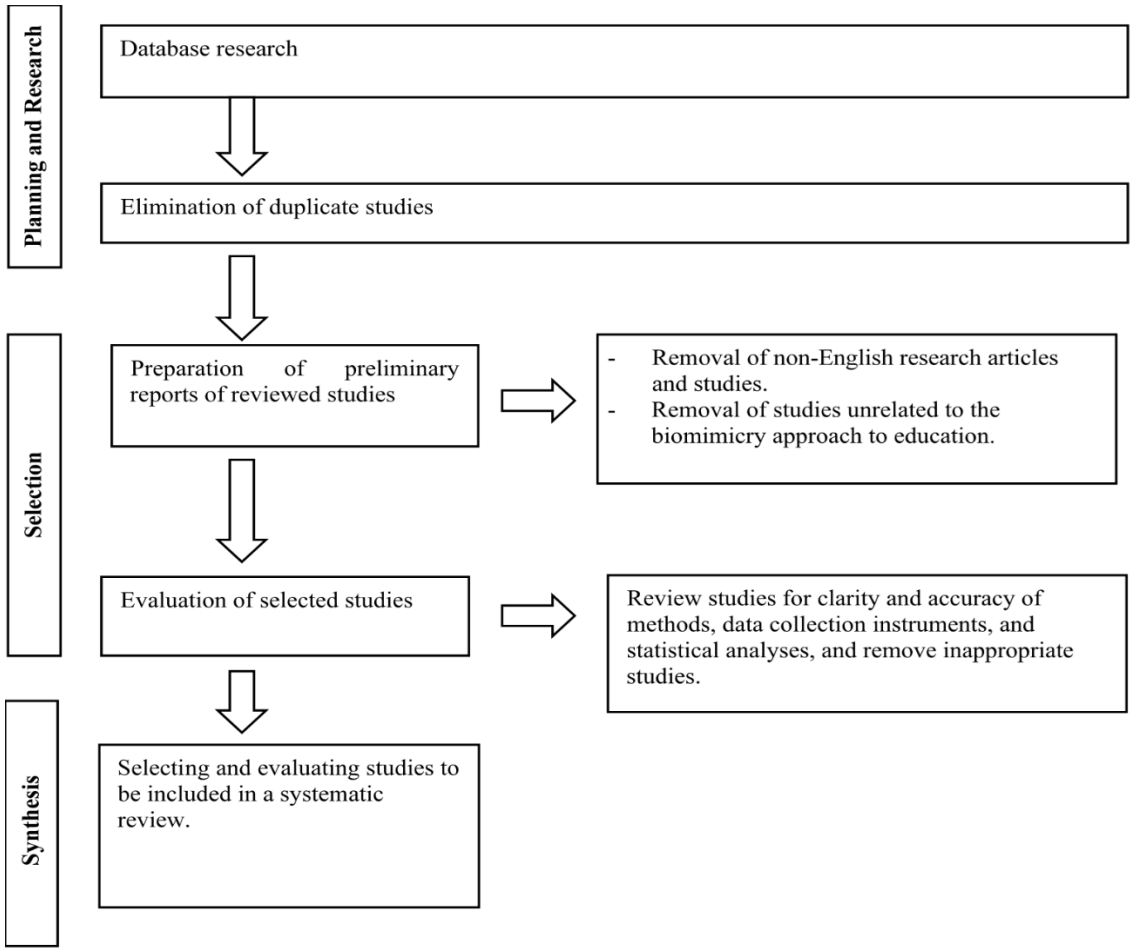

Figure 2. Systematic review inclusion and exclusion criteria

Table 1 presents the criteria employed for the systematic review in this research:

Table 1. Number of Research According to Selection Criteria

Database	Number of publications reached as a result of the first search	Number of publications reached as a result of selection criteria	Number of publications remaining after removing duplicate studies
Web of Science	2,167	44	5
Proquest	23	21	1
Postgraduate thesis	79	21	7
Scopus	1,391	75	1
Wiley	10	0	0
TR Index	16	12	2
Total			16

Results

The first research question addressed by this study revolves around the distribution of research conducted within the framework of biomimicry, considering various factors such as years, target groups, and research methodologies. Table 2 presents a breakdown of research categorized by method, target group, type, and year.

Table 2. Distribution of Studies by Methods, Target Audience, Type and Years

Tag	Method	Participants	Type
Akkaya & Yazıcı, 2020	Descriptive Analysis	-	Article
Alperen, 2020	Experimental research method	Secondary school 5th grade student (n=68)	Master's Thesis
Canbazoğlu Bilici, Küpeli & Guzey, 2021		Secondary school 8th grade student (n=24)	Research Paper
Cakir, 2019	Descriptive Research Method	Undergraduate (78) students	Master's Thesis
Shepherd, 2019	Action Research	Secondary school 5th grade student (n=19)	Master's Thesis
Çoban & Coştu, 2023	Action Research	Secondary school 5th grade student (n=19)	Research Paper
Fried, Martin, Esler, Tran & Corwin, 2020	Case Study	Undergraduate students (n=103)	Research Paper
Gencer, Doğan & Bilen, 2020	Case Study	Secondary school 5th grade (n=21)	Research Paper
Demircioğlu, 2022	Case Study	Undergraduate level students (n=34)	Master's Thesis
Kaya, 2022	Experimental Design	Undergraduate level students (n=53)	Master's Thesis
Mejía-Villa, Torres-Guevara, Prieto-Sandoval, Cabra, & Jaca, 2023	Mixed Research	Undergraduate level students (n=336)	Research Paper
Qureshi, 2022	Mixed Research	Undergraduate level students (n=70)	Research Paper
Ture, 2023	Action Research	10th grade high school students (n=80)	PhD Thesis
Yakışan & Velioğlu, 2019	Case Study	Primary school 4th grade (n=58) students	Research Paper
Yildirim, 2019	Case Study	Bachelor's level (n=17) teacher candidate	Research Paper
Star, 2023	Action Research	Secondary school 5th grade (n=189) students	Master's Thesis

Upon examining studies pertaining to biomimicry in the realm of education, it was found that four studies were conducted in 2019, five in 2020, one in 2021, two in 2022, and four in 2023. Among these 16 studies, the dissemination formats varied, with one study being disseminated as a doctoral thesis, six as master's theses, and nine as research articles.

Further scrutiny of these studies with regards to the educational levels at which they were applied revealed a varied distribution: one study was implemented at both elementary and secondary school levels, six at the secondary school level, and seven at the undergraduate level. Interestingly, one study was noted to lack a specified participant group, thereby presenting a unique aspect warranting additional investigation.

In addition to years and educational levels, the analysis also delved into the methodological approaches employed across these studies. Results indicate that two studies adopted an experimental model, two followed a descriptive approach, four engaged in action research, five were based on a case study methodology, and two embraced a mixed methods research design. It is worth noting that in one study, the methodology employed was not explicitly specified,

highlighting a potential area for further clarification and investigation.

The second research question addresses the impact of biomimicry research within the field of educational science on the learning-teaching process. After a comprehensive analysis of the objectives, content, and main findings of the biomimicry studies, it was determined that the objectives of these studies were the development of cognitive, metacognitive, affective, and social characteristics of learners. The learning characteristics targeted by these studies are visualized in Figure 3 using Gephi 0.10 software.

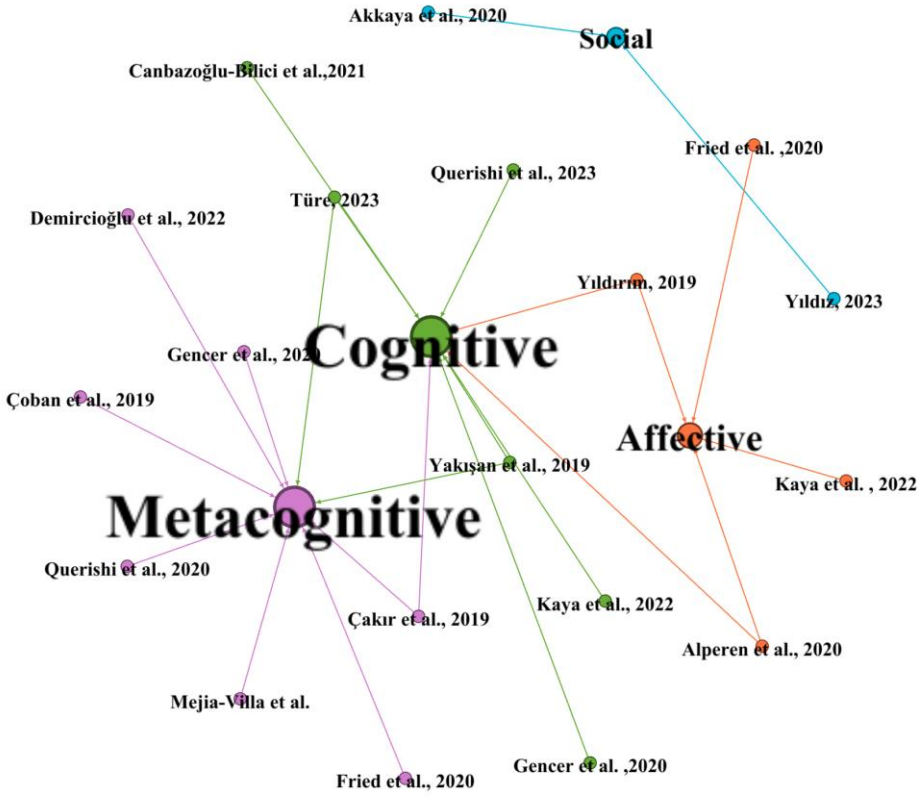

Figure 3. Distribution of studies based the learning characteristics

As shown in Figure 3, the Gephi program used to visualize the data displays the font size, line thickness, and frequencies by centering the number of studies and connecting the studies that have in common with each other as in a social network analysis. This analysis shows that the studies are primarily aimed at the development of cognitive and meta-cognitive skills. Upon deeper examination, it becomes evident that cognitive and metacognitive skills are usually analyzed together in the same studies. For example, the study by Çakır et al, 2019 aimed at developing both cognitive and metacognitive skills. Similarly, the study by Yakışan et al, 2019 aimed to develop both skills. After cognitive and metacognitive skills, a smaller number of studies focused on the development of affective skills. While four studies were dedicated to enhancing affective characteristics, two of these also explored the interplay between cognitive and affective skills. It is noteworthy that there are no studies addressing the simultaneous development of cognitive, metacognitive, and affective characteristics. In addition to the aforementioned learning characteristics, a notable gap exists in the literature regarding the impact of the biomimicry approach on learners' social skills. Among the studies reviewed, a scant two studies specifically addressed the enhancement of learners' social skills. All these studies show that the biomimicry approach is mainly focused on the development of cognitive

and metacognitive skills, or on observing their effects. On the other hand, the conclusion is that there has been insufficient analysis of its impact on the development of affective characteristics and social skills.

Figure 4 illustrates the distribution of subdomains associated with these learning characteristics, with data visualized using Gephi 0.10.

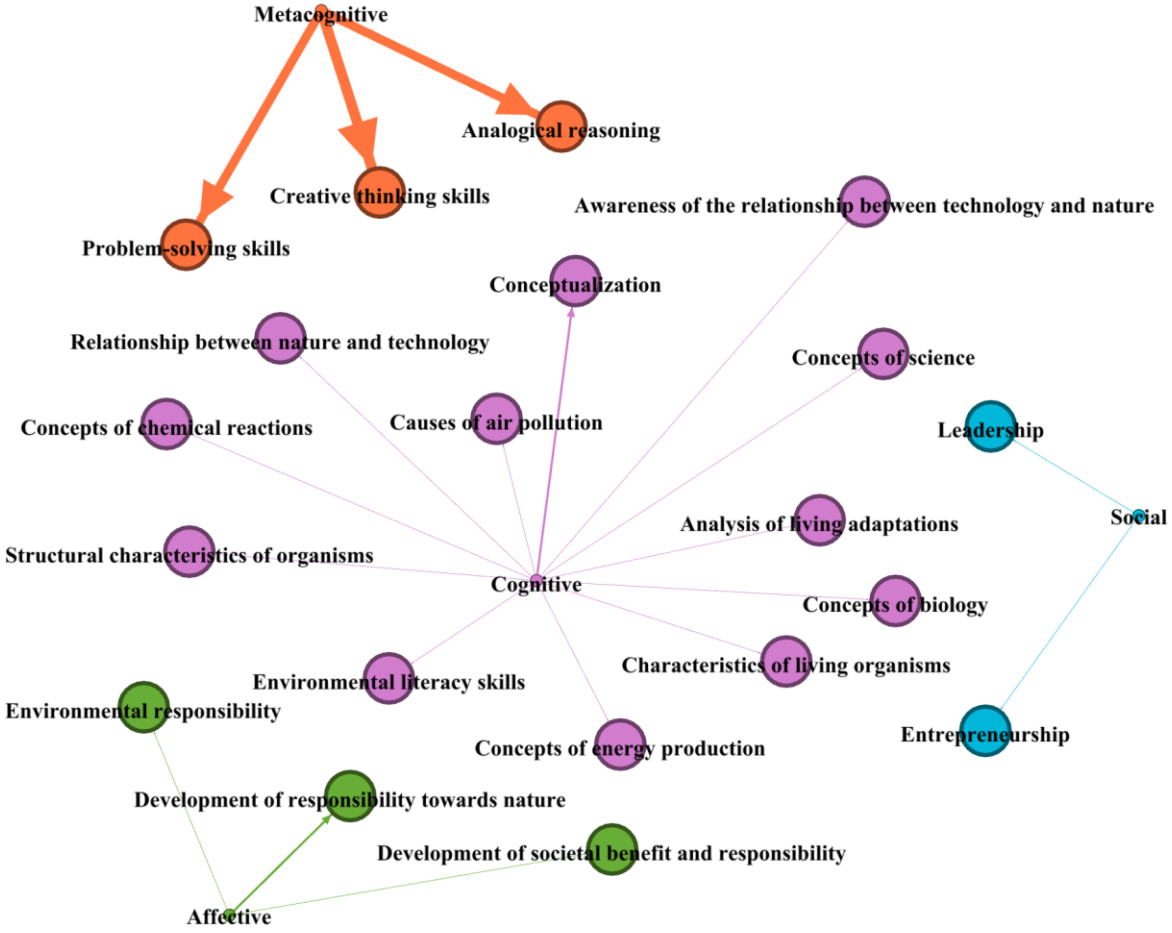

Figure 4. Distribution of subdomains associated with learning characteristics

In the development of cognitive skills, as shown in Figure 4, learning outcomes in science and technology were emphasized. Among these acquisitions, the studies on the conceptualization of the structures for the science subjects were more important, while the other studies were in general evenly distributed. It is worth noting that the results of cognitive learning in the social sciences were limited among the studies. In the analysis of metacognitive characteristics, analogical reasoning, creative thinking, and problem-solving skills are prominent. There were no relevant statistical differences between these studies. Social usefulness, responsibility, and environmental awareness stand out in the analysis of affective characteristics. In the context of social skills, a limited number of studies examined leadership and entrepreneurship characteristics.

The results of the second research question are examined below, with a focus on two main dimensions: the impact on the learner's cognitive and metacognitive skills, and the impact on affective characteristics and social skills.

The effect of the biomimicry approach on learner cognitive and metacognitive skills: When reviewing studies on biomimicry, it was observed that all the research pertained to the fields of science and engineering. These studies, which aim to enhance cognitive and metacognitive skills, primarily concentrate on nature-inspired concepts. The findings of this study demonstrate the effectiveness of the biomimicry approach in improving students' cognitive and metacognitive abilities. Specifically, research on biomimicry has shown that designs inspired by nature positively contribute to students' critical and creative thinking skills in achieving science-related objectives. For instance, Canbazoğlu Bilici et al. (2021) concluded that activities based on biomimicry assist students in exploring scientific concepts such as air pollution and the structural characteristics of various living organisms. The study observed that following biomimicry activities, students developed diverse ideas concerning ecological tools inspired by nature. Moreover, it was determined that examining the systems and structural properties of organisms in the nature-inspired process facilitated learners in acquiring scientific knowledge more effectively (Canbazoğlu-Bilici et al., 2021). Similarly, Çoban and Coştu (2023) concluded that students, when attempting to create various designs by considering the functional and physical properties of living organisms in nature, demonstrated the ability to generate creative and practical design concepts.

In addition to studies documenting the beneficial impacts of the biomimicry approach on students' cognitive and metacognitive skills, the literature also highlights certain limitations. For instance, in a study conducted by Qureshi (2022), it was noted that while students were adept at drawing inspiration from nature for their projects, they struggled to generate creative ideas by amalgamating the behaviours of multiple organisms. This underscores the significance of implementing novel teaching strategies or providing concrete examples to support students in their application of biomimicry.

In experiments based on the biomimicry approach, positive effects were observed on students' cognitive characteristics as well as their scientific research skills. The fact that students turn to formal and informal sources in the product design process, including examining different learning resources such as TV programs, films, documentaries, books, animations and accessing Internet content, contributes to the examination, analysis and interpretation of data from these different sources.

Researchers have revealed that the biomimicry approach can be used in STEM activities, can be effective in the design and analysis processes of interdisciplinary projects and will improve scientific research skills (Canbazoğlu-Bilici et al. 2021). Similarly, Gencer et al. (2020) pointed out that for biomimicry and STEM activities, students' examination of books, viewing documentaries, collecting data, interpreting, developing models, explaining scientific concepts, sharing their ideas, and enriching these ideas by discussing with their peers improve their scientific research skills and enable them to be part of the active learning process.

In studies, biomimicry and STEM methods are commonly integrated conceptually. For instance, in a study conducted by Yakışan and Velioğlu (2019), biomimicry and STEM applications were combined, tasking students with creating product designs through drawing. Initially, students developed products imitating living organisms in their local environment, and then proceeded to craft imaginative product drafts inspired by animals such as turtles, frogs, chameleons, and cheetahs. The influence of students' local environment and region on their design process underscored the application of biomimicry principles, adhering to the concept of 'near to far' design. Introducing children to various local living systems in biomimicry practices is believed to enhance creativity by providing elements that fuel their imagination.

Similarly, in a study by Alperen (2020), it was determined that the pedagogical design effectively integrated biomimicry into STEM instruction, enhancing students' understanding of biomimicry and their awareness of the interplay between technology and nature. In another study, it was reported that activities prepared for STEM teaching using biomimicry implementations significantly increased students' academic performance (Kaya, 2022).

Studies indicate that educators, including current and prospective teachers equipped with knowledge of the biomimicry approach, are better poised to inspire curriculum outcomes from nature, effectively design and monitor curriculum enhancements. For instance, Çakır's (2019) examination of biology teachers revealed that while teachers frequently drew inspiration from natural phenomena to illustrate curriculum outcomes, their understanding of the concept of biomimicry was relatively weak. However, as teachers became more familiar with the concept of biomimicry, they increasingly drew inspiration from nature and exhibited heightened interest in natural creations. Similarly, findings from Yıldırım's (2019) study concluded that biomimicry practices positively affected various cognitive and psychomotor characteristics of pre-service teachers, leading to shifts in their perspectives regarding nature and technology. Moreover, it was observed that pre-service teachers predominantly utilized scientific process skills such as observation, inference, and decision-making, as well as engineering design processes including searching for possible solutions, creating models, and identifying problems, within the context of biomimicry studies (Yıldırım, 2019).

The effect of the biomimetic approach on the learner's affective characteristics and social skills: Although biomimicry studies are not directly aimed at developing affective characteristics, it has been established that learning motivation, leadership, collaborative work, environmentally friendly behaviours, as well as cognitive processes, contribute positively to students' affective characteristics and social skills. Research findings indicate that design practices based on the biomimicry approach positively improve students' communication, cooperation with peers, cognitive field skills and value perceptions towards technology (Hu, 2023). For example, in the study conducted by Yıldız (2023), when students' awareness of the biomimicry approach was established, it was observed that students' awareness of their environment and examples from nature increased and they began to give more examples, particularly of living behaviours. Similarly, in the study conducted by Çoban and Coşkun (2023), an increase in students' learning performance and motivation to participate in the course was observed after the biomimicry approach, and it was observed that they developed nature-inspired creative suggestions for product design. In another study by Gencer et al (2020), it was observed that students who had to work together on product design gained knowledge about group work, collaborative work and group dynamics through the conflicts they experienced. In this study, which aims primarily to develop cognitive and metacognitive skills, the formation of affective products can be considered a secondary learning product. Considering only cognitive products in biomimicry studies limits the use of this approach.

Familiarizing students with the biomimicry approach, and increasing learners' environmental awareness and motivation, offers an important opportunity to develop the fundamental values and affective characteristics that are desired in educational programs. It is also possible that the use of applications based on the biomimicry approach in the social sciences will enable important acquisitions of socio-affective characteristics such as respect for the environment and living beings, cooperation, collaboration, the importance of family, leadership, being a member of a group, and alike. For example, in the experimental research conducted by Kaya (2022), it was reported that biomimicry-STEM activities brought about a significant shift between learners' affective dispositions and environmentally responsible behaviours.

Discussion and Suggestions

The present study explores the impact of teaching practices based on the biomimicry approach on learning and teaching processes. It highlights the increasing proliferation of biomimicry research since 2019, primarily characterized by qualitative research methods and focusing on secondary school and university students. Research findings highlight significant improvements in students' cognitive, metacognitive, affective, and social skills through incorporating biomimicry practices. Specifically, significant gains in basic science, particularly in the science and chemistry curriculum, were observed in the area of cognitive skills. Special emphasis was placed on concepts that highlight the intricate interplay between nature and technology. Regarding metacognitive skills, the results show that the biomimicry approach promotes critical thinking, creative thinking, and analogical reasoning among students. In addition, it strengthens scientific research skills, increases awareness of the relationship between technology and nature, and enhances problem-solving skills. For in-service and pre-service teachers, the key findings highlight the importance of using nature to effectively illustrate program outcomes, design more effective applications, increase awareness of nature-based outcomes, and foster scientific process skills in learners.

Beyond cognition and metacognition, the study illuminates profound affective outcomes stemming from biomimicry practices. Learners exhibit heightened motivation to engage with the material, driven by a newfound appreciation for the natural world and its innovative solutions. Moreover, the cultivation of leadership skills emerges as students take on roles of inquiry, experimentation, and collaboration within biomimicry-inspired projects. In terms of socio-emotional development, the study underscores the cultivation of responsible and environmentally sensitive behaviour among learners. Through biomimicry exploration, students deepen their understanding of ecological principles and the interconnectedness of human activities with natural systems, leading to a heightened sense of environmental stewardship and a commitment to sustainable practices.

The research findings indicate that design practices rooted in the biomimicry approach yield positive outcomes across various aspects of student development. According to Hu (2023), these practices enhance students' communication abilities, foster collaborative interactions with peers, bolster domain-specific cognitive skills, shape a positive perception of technology's value, boost self-confidence, and elevate motivation and attentiveness levels. Furthermore, biomimetic projects serve as potent vehicles for knowledge and skill acquisition while instilling a mindset of sustainability and cyclical thinking (Gardner, 2012). By engaging with real-world challenges through biomimicry, students not only gain a deeper understanding of subject matter but also cultivate essential 21st-century skills and a heightened awareness of global citizenship (Biomimicry Institute, 2017). Aligned with educational objectives, the biomimicry approach facilitates learning across a wide range of topics and learning domains. Through real-world exploration and inquiry, students learn to tackle complex issues and hone their critical thinking, problem solving, and creativity skills.

Research findings underscore the potential of integrating biomimicry into education, as highlighted by Roobeek (2019). Biomimicry-related resources facilitate student-centered learning, sparking curiosity, fostering active engagement, and seamlessly integrating 21st-century skills into interdisciplinary project-based learning initiatives. Moreover, studies by Alawad and Yassir (2014) reveal that biomimicry plays a pivotal role in honing essential skills such as self-reflection, critical thinking, and creativity. This approach positively influences students' design decisions and enhances their overall thinking skills, contributing to a more holistic educational experience. The biomimicry approach advocates for a dynamic curriculum

design that transcends centralization, as elucidated by Priesnitz (2022). This curriculum is characterized by flexibility, continuously adapting to new information and evolving conditions, and actively incorporating feedback mechanisms a paradigm supported by the findings of the included studies. Indeed, the collective results from these studies underscore the transformative potential of biomimicry in education, heralding a shift towards dynamic, student-centered learning environments that cultivate essential skills for the ever-changing demands of the 21st century.

The studies analyzed in this research underscore the prevalent utilization of biomimicry as a pedagogical method within the realms of science and technology. This inclination is attributable to the inherent suitability of the biomimetic approach for elucidating scientific concepts, particularly evident in its application to STEM programs, where science and mathematics acquisition are paramount. However, it is imperative to recognize that not all current practices, despite their potential to cultivate metacognitive skills and social-affective traits, can be unequivocally classified as biomimicry. This distinction becomes evident when scientific and technical aspects dominate without the integration of foundational biomimicry principles. Therefore, it is imperative to systematically integrate the biomimicry approach as a pedagogical instrument, not solely to bolster scientific and mathematical acumen, but also to nurture affective and social competencies like values, attitudes, communication, and social skills. Indeed, the methodical inclusion of biomimicry in educational frameworks holds promise for surmounting existing limitations within curricula concerning the cultivation of learners' affective attributes. This approach presents an invaluable opportunity to enrich the educational milieu, fostering a more comprehensive learning environment and fostering holistic development among learners.

According to the findings of the analyzed studies, students exhibit a heightened inclination to draw inspiration from nature and expand the scope of their designs once they become familiar with the principles of biomimicry. Remarkably, this trend is mirrored in the attitudes of teachers. Both students and teachers who possess an understanding of biomimicry demonstrate an increased propensity to seek inspiration from nature and, notably, to observe and appreciate natural patterns and organisms in their immediate surroundings. These findings underscore the importance of intensifying awareness-building efforts and incorporating illustrative examples for both students and teachers. The emphasis on enhancing teacher awareness of biomimicry's concepts, as highlighted in research, suggests that targeted teacher training initiatives can significantly contribute to diversifying curriculum outcomes with nature-inspired examples and facilitating more effective implementation of biomimicry-based practices. Providing teachers with this knowledge and skillset improves communication in the classroom, promotes active learning, and makes the results more actionable by incorporating real-world examples. Consequently, such teacher training initiatives hold immense potential to enrich the educational experience, foster a deeper appreciation for nature's wisdom, and empower students and teachers alike to use biomimicry as a transformative educational tool.

The biomimicry approach emphasizes the integration, inspiration, and learning derived from nature, transcending the confines of the classroom walls. By activating students' creativity, critical thinking, observational prowess, and curiosity, it is anticipated that biomimicry will catalyze a positive shift in children's attitudes towards learning and schooling. By immersing students in the exploration of nature's intricate designs and problem-solving strategies, biomimicry fosters a holistic perspective that extends beyond traditional classroom boundaries. This experiential approach encourages students to engage with real-world challenges, sparking a sense of wonder and appreciation for the natural world. Moreover, the interactive and hands-

on nature of biomimicry cultivates essential skills such as creativity, critical thinking, and observation, empowering students to approach learning with enthusiasm and confidence. As students discover the relevance of biomimicry across various disciplines, from science and engineering to art and design, they develop a deeper appreciation for the interconnectedness of knowledge and the relevance of their education to real-world contexts. Ultimately, the biomimicry approach not only enriches students' learning experiences but also fosters a positive attitude towards education by instilling a sense of purpose, curiosity, and empowerment. As students learn to draw inspiration from nature's genius, they develop a lifelong passion for learning and a profound appreciation for the natural world.

In the biomimicry approach, teachers assume an essential role in the learning and teaching process, influencing students' learning characteristics through their field expertise and pedagogical skills. Therefore, to effectively implement the biomimicry approach in educational settings, it is imperative to enhance teachers' understanding and proficiency through targeted professional development programs, both during their initial training and through ongoing in-service training focused on practical application. By training teachers with a solid foundation in biomimicry principles and methodologies, educational institutions can empower them to effectively incorporate nature-inspired learning experiences into their teaching practices. This enables teachers to guide students in recognizing the brilliance of nature, extracting valuable lessons from natural systems, fostering interdisciplinary connections, and improving critical problem-solving and creativity skills. Moreover, the biomimicry approach encourages a dynamic learning environment that extends beyond the confines of the classroom, fostering a culture of lifelong learning among both teachers and students. By embracing biomimicry in education, teachers and students alike are empowered to explore, innovate, and collaborate in ways that harness the wisdom of nature to address real-world challenges. In essence, investing in teachers' knowledge and skills in the realm of biomimicry not only enhances the quality of education but also cultivates a generation of learners equipped with the tools and mindset necessary to thrive in an ever-evolving world.

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