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Experiment on The Cooperative Practice of Biomimicry in The Architectural Studio

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Abstract

Life in the architectural design studio is about the acquisition of experience during the cooperative architectural practice Scholars have observed that cooperation between students is the most effective tool in architectural learning. In this scope, the study aims to compare the cooperative spirit of teamwork practice with the solo practice in a biomimetic project-based workshop to measure the influence of cooperation on students` productivity and anxiety state, considering gender, locality, and the state of siblings as influencing factors. The methodology intends to employ a qualitative comparative analysis to indicate the transformation of students` productivity in a biomimetic design workshop after switching from a solo practice to a cooperative peer learning application as well as an embracement for the State-Trait Anxiety Inventory (STAI) test during both practices during two workshops for architectural students from different academic levels emphasizing biomimetic design principles and Nature thinking. The results outlined the positive impact of cooperative biomimetic practice on students` accomplishments and anxiety state.

Keywords: Biomimetic practice, Architectural Students` Anxiety, Peer learning.

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1. Introduction

1.1. Architectural design process

Studies on architectural students and architectural learning experiences are no longer imprecise. Since 1973, Steele has tried identifying the values of creative learning space to describe its primary functions. As mentioned in his attribute, one of the six specified functions is users' social contact inside [1]. Taking into consideration the creative process of architectural thinking, the influence of personal and environmental affairs in generating newborn ideas or solving running issues efficiently [2, 3], the primary stage of preparation, as well as the final stage of verification mainly depends on the cooperative of architectural students and their frequent informal crits in the design studio [4, 5]. Studio space is a physical environment accountable for architecture students' academic, social, and cultural outputs. As a result, students regard their studio life as a myth. Working long hours, making sacrifices for their design, and staying late at the studio are all part of the assumption that this lifestyle is transforming them into architecture students [6]. Their interactions divide the design process into two stages, classroom, and workshop, as shown in Fig. 1. The preliminary stage of architectural learning is a classroom regulation in which students begin their practice by seeking answers or inspiration to start building design concepts and assessing the outcomes to obtain conclusions. This is the welcome stage, with little stress and a higher degree of information acquisition than the workshop stage. Later, the workshop stage is built on the foundations of observation and discussions and ends with the evaluation of design decisions. The experience of feeling free to try new activities inside the design studio allows it to function as a workshop for the time of sketching and modeling [7]. Although the architectural learning process doesn`t include a stage where the design studio is named Home, students spend their sacrifices enjoying the social life of both the classroom and the workshop and turning the design studio into a home. Since it's one of only a few learning locations that is frequently occupied by at least three or four students from early morning until late at night, especially in the days preceding the final presentation. The odd resemblance between a design studio and a house is the tendency to build a community and to have the opportunity for multiple activities, including design practice, such as resting, hanging out, and sometimes sleeping [8].

1.2. Peer learning

The design studio is meant to provide a pleasant environment for all architectural students and each personality with the necessities to ensure an effective learning process and productive architectural work within the studio. For example, first-year students enter the design studio with personal experiences, beliefs, aspirations, and expectations. Yet, their conceptions about architecture, learning ideals, social backgrounds, hopes, and expectations are changed. However, once they can voice their thoughts and perspectives, they adapt to studio life and a sense of belonging [9]. This change is supported in the first place by peer learning, where individuals in similar situations form a collaborative group and build an interdependent way of cooperative work inside a successful social communication. Students employ two forms of peer learning in the process of implementing peer learning in architectural education. Essential peer review learning occurs between students enrolled in

the same course and assigned to the same class curricular responsibilities. Peer tutoring within a formal or informal curriculum between students and other students from a higher-level course is the second type of peer learning [10]. As a result, learning to collaborate with peers in the design studio is essential to the student experience. Institutions have enabled peer learning to be explicitly used as a learning technique for practical considerations. For example, using peer learning or peer review learning as part of the studio curriculum to reduce staff load and financial pressure on educational organizations enriched the learning process without requiring the presence of a teacher [11].

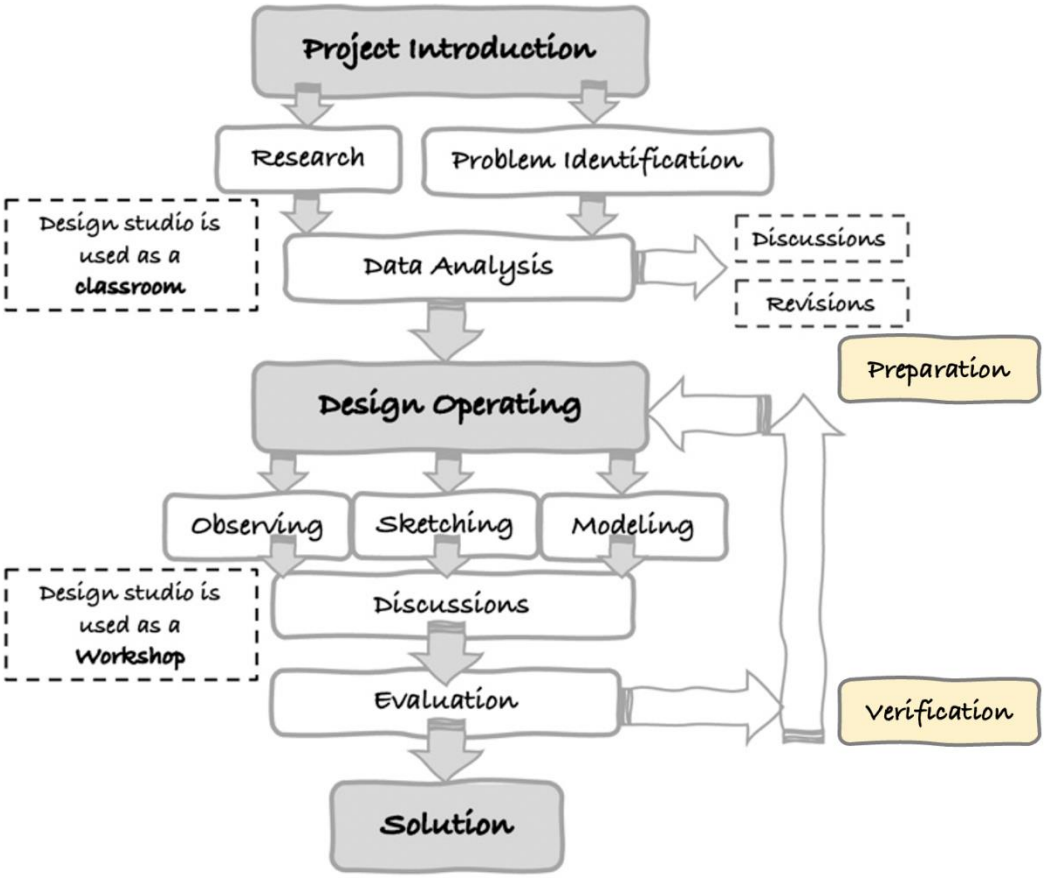


Fig. 1. The architectural design process between the classroom and the workshop stages [Authors]

The main motive is to encourage students' social communication to support academic goals of skill development and student pleasure with the studio experience. Researchers at Oxford Brookes University concluded in 1995 that peer arguments and regular evaluations that allowed students to discuss their ideas about learning and coursework improved their self-confidence, self-concept, teamwork spirit, critical thinking, presentation, and oral skills [12]. During this experience, students start to develop engagement connections with their peers. The most recognizable relationship built in the

design studio is (1) the behavioral association described as the initiatives. Sharing the same project or the same attribute, focusing on disputes, and analyzing others' work are patterns of students` behavioral engagement in the studio. Generating the spirit of cooperation, students (2) connect emotionally with their partners to enrich the experience of enjoyment and belonging. Nevertheless, the dimensions of the students` relationships are not all psychological. They use their (3) cognitive relations to adapt to the extensive workload and spend time handling their design projects. Cognitive participation is more than being present or physically sharing; it is also about comprehending the objectives, monitoring, and preparing knowledge evaluation. The three previously discussed links regarding acquiring knowledge and engagement during learning activities. They are followed by (4) the representational connections, which focus on expressing self-work, responding to concerns, clarifying and suggesting, articulating wishes, and finding solutions [13].

1.3. Biomimetic approaches in the architectural practice

Because biomimicry concepts are inextricably linked to architecture, each is a component of the regeneration process. Each emerges in architectural applications when two distinct conceptions regulate their sequential connection. (1) designing with biology in mind, often known as the problem-based method or top-down strategy, is a biology contribution to overcoming difficulties architects face. Following the technique of this approach, architects would first identify the design problem thoroughly, examine Nature's resemblances to the same problem, select an appropriate analogy between limitless design solutions, imitate and abstract the analogy into an architectural design, and finally test the solution for evaluation feedback. The synthesis of this approach with the conventional architectural design process is the necessity of design problem exposure to reach the design solution. The solution-based method or bottom-up strategy is (2) biology-inspiring design begins with biological exposure to Nature's solutions, identifies the appealing solution, understands the essential abstracting principles, sets the technical implementation, and identifies the design challenge [14, 15]. This approach followed the process clarified by Carl Hastrich in 2005 and was named Design Spiral. As shown in Fig. 2, the Design Spiral has six steps to transform the inspiration into an architectural design. (1) Identifying the observations of Nature leads to preparing the functional role of each system that can be embedded in the architectural project. Initially, this step counts on observing the existence of Nature`s genius in each biomimicry level, organism, behavior, or ecosystem. (2) Translating the functions to architectural terms is an attribute of relating the values of biomimicry to the architectural practice through the architectural articulation of Nature`s solutions. Meanwhile, this stage is accompanied by (3) a spontaneous discovery journey exclusive to biomimicry thinking. Having the translated functions is insufficient to start the (4) innovative abstraction of Nature`s strategies back to the architectural engineering profession to conclude a design brief. Starting (5) emulation means returning to a specific architectural project and applying one or more abstracted strategies using comparative analysis methods to decide on a design solution. Therefore, (6) evaluating the design solution is to compare it with the original design brief and reflect on the numerous inspirations generated from each lap around the spiral.

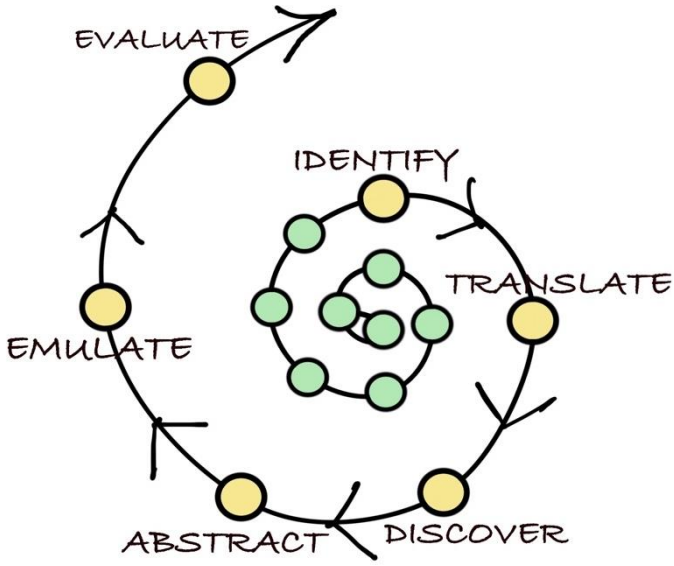


Fig. 2. The solution-based method of Design Spiral [40]

2. Related work

Other fields' findings have always inspired architectural practice. Biology is one of the fascinating sciences to emerge in the twenty-first century. The terms "Nature" and "Bio-inspiration" no longer refer to the aesthetic imitation of Nature's aspects. The foundation of Biomimicry, raised in 1962 and modified to "Biomimetics" by Otto Schmitt in 1982, relates to transdisciplinary approaches to scientific design thinking and technical applications. The word "Biomimicry" has surfaced frequently in research over the last 20 years and has branched to be applied in other sectors. Janine Benyus, a co-founder of the Biomimicry Institute, described it explicitly in 1997 as the conscious emulation of Nature's genius [16, 17]. There has been a common misunderstanding of bio-inspired design in general, which is all about integrating the natural environment and applying green architecture principles in their projects. However, having the opportunity to abstract from Nature can`t be just imitating its shapes and forms, as Nature elements must have more than the aesthetic values of their appearance. In creating regenerative spaces, biomimicry, as a part of bio-inspired design, and the term biophilia are alike. The intersections between both are about enhancing and understanding relationships between Nature and humankind, relying on physical reality in design rather than theories, adding different disciplines, emulating through translation and abstraction, and preserving ecosystems [18, 19].

Both biomimicry and biophilia advocate connecting with Nature and anticipating its values, but biomimicry is more concerned with Nature's mind and the utility of its elements. In contrast, biophilia is more concerned with surrounding ourselves with Nature or aspects that remind us of Nature [20]. Therefore, incorporating biomimicry ideas into architectural

studio practice is conducted in the case study to grasp Nature's sense of function and the usage of Nature's solution methodologies. Based on that, many architectural schools attempt to implement biomimicry in architectural design courses to enhance the performance of architectural students by reflecting on their observations in Nature and having the chance to create theories about the technicality of Nature. In parallel, the study aims to use biomimicry practice in the architectural studio to support cooperation and peer learning work experience.

2.1. Biomimicry attempts in the design studio

They are using the architectural design studio to create an informal space for students who trigger the architectural studio with a social experience related to the learning process. As a result, architectural activities in a workshop-style studio improve their collaboration skills and teamwork contribution. Furthermore, working in groups influences their critical thinking because of the constant informal discussions within one group. The architectural workshop can promise a compelling performance of a collaborative practice that heavily relies on collegiality and teamwork spirit through peer review learning between students of the same academic year under the same practice rules and peer tutoring within open discussions between students and other students from a higher-level course [21, 22]. On a multidisciplinary project-based workshop, the biomimicry implementation attempts to reconnect architecture students with Nature's wisdom. Observing animals, arthropods, and plants for architectural solutions is an effective technique for teaching biomimicry architecture at the bottom-up level of biomimicry design thinking. It not only helps students grasp knowledge, but it also broadens their imagining abilities. This reinterpretation of bio-inspired design as a biomimicry workshop results in converting the design studio into a dynamic environment that influences the learning process and meets the majority of architectural students' psychological needs [23]. Most biomimetic architecture integration attempts in the last decade have avoided old traditional design methods. While the recommendations extend beyond 2D environments to 3D modeling due to the tested hypnosis that suggests increasing the design dimensions helps students find new concepts, push design boundaries using pen and paper, and bring their creative visions to life by making models or utilizing 3D software [24].

2.2. The influence of biomimicry on students` cooperation

The practice of biomimicry thinking in the design studio enhances more than one cooperative connection between students. The fact that more than one successful attribute of implementing biomimicry in the architectural learning process revealed the same pattern of teamwork practice assures the strong connection between both biomimicry approaches and the practical cooperation practice in the design studio. The study conducted in the College of Environmental Design at the University of California in 2019 offered a clear perspective of applying bio-inspired concepts in design fabrication. Studio One integrated teamwork practice using the second biomimicry approach, biology-inspiring design, within two years to present four design projects. Each handled the design spiral process in groups to fulfill the structure of the biomimetic projects [25]. Others have included teamwork in bio-inspired workshops as a complete pedagogy with project introductions, seminars, and presentations.

These attempts have been held in design studios targeting students` understanding of the physical characteristics of some species, primarily insects, to enlighten students` experience with the ultimate adaption techniques of different creatures [26, 27]. The mutualism of these pedagogies is avoiding individualism and separating students` work. Moreover, grouping students in the design studio and encouraging teamwork and peer crits have been positioned to meet students` needs.

Meanwhile, several scholars have been digging into the influence of pedagogy on design students and how their engagement in the exchange of knowledge process, the interactions between peers, and the development of self and others` identities are shaping the efficiency of their reflections on learning outputs. The results of such studies detected the importance of educational pedagogy and its control of whether or not students can improve themselves and have the courage to create original designs, think out of the box, and get used to the community of their profession. In this regard, educational pedagogy is also responsible for identity development, which includes the cognitive self-concept, self-confidence, aspirations, and the feeling of belonging to a group [28]. For humans, self-concept is referred to as the nature of existence. Although each student's identity values are expected and impacted by the social life inside the design studio, they are linked to the individual's life experience outside the studio, society, culture, and traditions. In general, the shifting characteristics of the studio setting foster the development of architectural students' identities with new values associated with the architectural learning process [29]. Both dimensions created the urgent need to investigate the collaborative practice of architectural students during biomimicry applications in the design studio and the influence of biomimetic architecture pedagogy in refreshing the creative performance of architectural teamwork.

3. Problem statement

The research work mentioned above has covered earlier attempts at incorporating biomimicry thinking in architectural education and raises the following questions:

- What effects can a cooperative biomimicry-based workshop have on novices` architectural performance?
- What are the influences of gender, locality, and the state of siblings on the attendance and the results of the STAI post-test?
- What values are embedded in the design studio with a peer learning experience?

4. Research objective

The study aims to assess the impact of the cooperative practice of biomimicry on the productivity of architectural students and their state of anxiety during a project-based workshop in the architectural design studio.

5. Ethical considerations

The assessment of students` productivity was conducted after obtaining students' permission to engage in scientific study and informing them of the information gathered during the procedure of two design workshops. Moreover, the published outputs of participants` architectural work were honestly integrated into the research, after getting permission from the participants, without adding, deleting, or changing their content.

6. Methodology

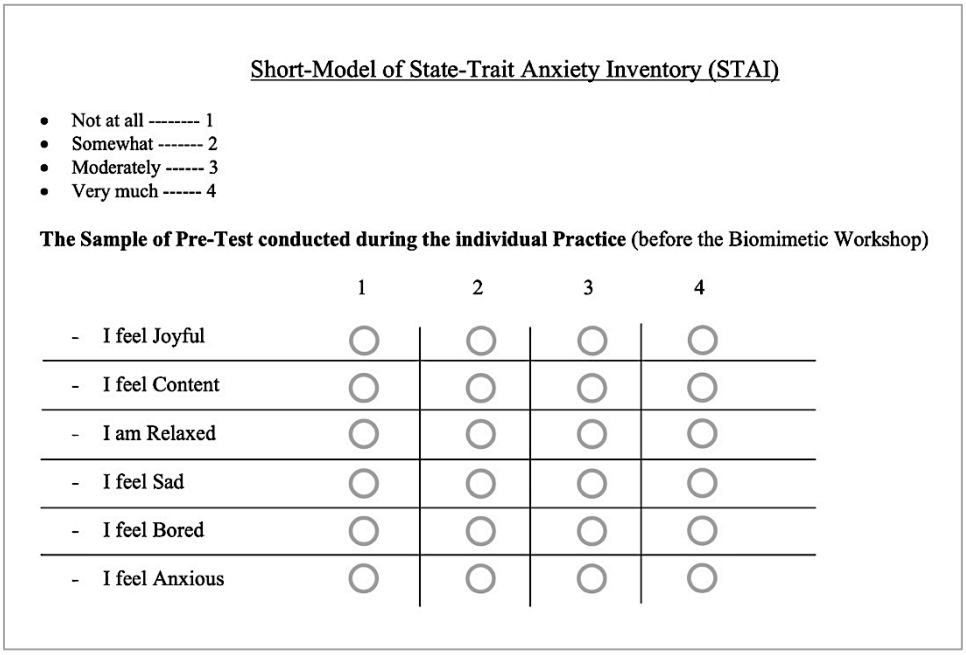
The research uses a qualitative study to assess students` design work before and after the collaborative implementation of biomimetic design in the architectural design studio during two biomimetic design workshops conducted during the summer architecture design course at Fayoum University. The principles of evaluating students` design work in both workshops include (1) assessing the design preparation process by following the sequence of the Design Spiral, identification, translation, discovering, abstraction, and emulation. The second principle of the comparative study is (2) the assessment of the design verification process by noting students` crits and discussions to rethink design concepts and modeling. More prominently, the authors have related (1) students` attendance in the design studio without feeling bored or experiencing anxiety to the study factors inside the quantitative study.

Although several research on architecture students have found no significant variations in effective productivity or creative thinking abilities depending on gender, several researchers connected to gender and social interactions in the design studio. The research incorporates (1) gender as one of the primary study factors in this framework to identify a clear outcome of the variations between male and female students in engagement with the peer learning experience [30]. In addition, (2) locality, distinguished by whether students live in rural, suburban, or urban areas, shows the effect of students' environmental backgrounds on the quality of their social interactions. Furthermore, the experiment considered a final factor for both the qualitative and the quantitative study, studying (3) the state of siblings, balanced, only brothers, only sisters, or no siblings, and their influence on their willingness to participate in peer learning cooperation.

6.1. Instrument

In addition to the assessment criteria of the qualitative study that evaluate students` contribution to studio activities, the quantitative study tends to use a short version of the State-Trait Anxiety Inventory (STAI), including only four questions out of 20 questions for testing anxiety state, randomly selected from the full version and implemented in both workshops for the pre-post cooperative biomimetic workshop. The design of the short version, as shown in Fig. 3, integrated three negative questions (e.g., “I feel joyful”; “I feel content”; “I am relaxed”; etc.) with three positive questions (e.g., “I feel sad”; “I feel bored”; “I feel anxious; etc.). According to a four-level scale, the selected questions managed to ask participants what they feel at the moment of individual and teamwork practice. A low score indicates a lower level of anxiety and vice versa, a high score indicates a greater level of anxiety. Furthermore, the repetition of the test in the cooperative workshop

didn`t copy the six questions from the pre-test model. Instead, the second model of the post-test embraced the same context of the six questions with different synonyms to avoid activating a boring stimulus during the experiment [31]



Short-Model of State-Trait Anxiety Inventory (STAI)

- Not at all -------- 1
- Somewhat ------- 2
- Moderately ------ 3
- Very much ------ 4

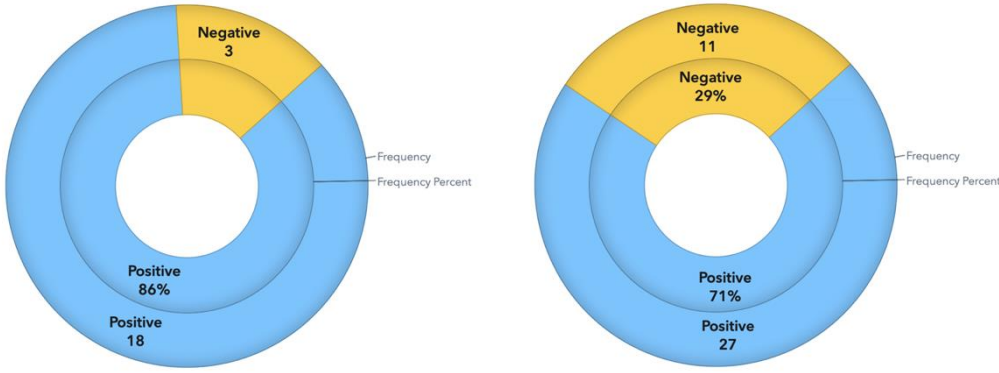
The Sample of Pre-Test conducted during the individual Practice (before the Biomimetic Workshop)

	1	2	3	4
- I feel Joyful	○	○	○	○
- I feel Content	○	○	○	○
- I am Relaxed	○	○	○	○
- I feel Sad	○	○	○	○
- I feel Bored	○	○	○	○
- I feel Anxious	○	○	○	○

Fig. 3. The Pre-Test of State-Trait Anxiety Inventory integrated during the individual practice [Authors]

6.2. Sample design

Participants are mainly novices, first-year graduates, and juniors, from Fayoum University's Architectural Engineering Department with higher-level students from second, third, and fourth academic courses included as facilitators for peer review learning practice. Juniors are preparatory-year graduates who are about to enter their first year in the architecture department. The main participants in both workshops' total population, as shown in Fig. 4, are 59 architectural students, 19 first-year graduates, and 38 juniors. Actively participated in both workshops, a sample of 78 percent participated in the study, 27 first-years, and 18 second-years. While facilitators' participation from higher courses resembled 40 percent of the total population of facilitators, 34 students out of 84. The motivation for choosing novices as the main participants is that because of their adaptability skills and refreshing enthusiasm to learn more, with one year or no architectural experience, they are expected to show an active mood of grasping knowledge and initiative behavior in volunteering in each of the two workshops. Furthermore, their primary skills of architectural modeling fit the type of manual practice the workshops support. To stimulate their interest, the study adopted specific pedagogy based on how collaborating to find out Nature functions and solves problems are capable of creating deployable forms with less material in biomimetic structure systems.



(a) (b)

Fig. 4. The population of novices and the participating sample of the experiment (main participants), (a) the sample of the first workshop, and (b) the sample of the second workshop [Authors via SAS]

6.3. Data analysis

The study tends to use Statistical Analysis Software (SAS) to illustrate the results of the experiment. The qualitative and quantitative studies correlate the experiment results to the influence of factors, gender, locality, and state of siblings. In addition to the automated explanation utilized to illustrate this correlation, the bubble plot, and the bar chart, the study has employed a dual-axis line chart to clarify the transformation of the score of the State-Trait Anxiety Inventory test before and after teamwork practice.

6.4. Biomimicry-based workshop content

The cooperation of architectural students has been directed to optimize structural systems' design to create bio-inspired deployable buildings. The theory of using the stimulation of interacting with Nature intelligence to enhance the cooperation of students is built over the approaches of biomimicry thinking that mainly start by deep observation of Nature elements or design problems [32]. The notion of designing a lightweight structure was first employed in architecture by the German architect Frei Otto who employed Nature principles, 1) diversity, 2) asymmetry, 3) hierarchy, 4) flexibility, and 5) resilience, in mimicking natural lightweight systems in the form of optimized deployable lightweight structures. Thereinto, the biological structures used, according to students' research and suggestions, are the following types:

6.4.1. Tension structure

Structural notion based on the most appealing bio-inspired example of spiders that weds the phenomenon of a 400-million-year-old eco-evolution. For thousands of years, the reflection of viewing stress in Nature has existed. Meanwhile, architecture identified the system only this century, when architects were captivated by the strength of spider silk, which can retain over 70 or 72 percent of its strength under 26 percent elongation stretch

from its actual size, and the way it uses small trees, stems, and tunnel walls to balance their houses [33, 34].

6.4.2. Woven (Reciprocal) structure

Woven and Interwoven terms describe weaving methods primarily inspired by the nests of various bird species. The curiosity about their labor influenced early structure design, particularly the reciprocal system of the nest's basal support, which prompted architect Villard de Honnecourt to develop similar reciprocal designs in France at the beginning of the thirteenth century [35].

6.4.3. Tree structure

Tree structure, a cantilevering system, employs its shape's three-dimensional qualities to change orientation and avoid stress. The diameter of the basal region and the density of the stems are the two key measuring parameters. Unlike concrete-manufactured buildings, solid material is created to bear and distribute the load, but its shape and size are not designed to match the final conditions of stress. The tree structure is found in many buildings in the form of tree-like columns using single support, three-shaped support, or multi-branching support to avoid overturning in the context of determining the shape and diameter of the basal area, connection with the soil, and so on [36].

6.4.4. Skeleton structure

Skeletons are well known for their work that has proposed diversity and stability. They are distinguished by their capacity to sustain loads and absorb energy via multidirectional fibers. By lowering the number of bones, birds have evolved a novel composition that allows them to withstand the increasing strain on their heads and wings with lightness and efficiency. Many architects have been influenced by these skeletons in the past, such as the abstracting of the vulture metacarpal in the Warren truss. Furthermore, the structural behavior of the organisms` skeletons is observed in the form of reciprocal structure. Boxfish with hexagonal and pentagonal plates, Sea Urchins with interconnecting plates, and Glass Sponges with fiber-smooth axial surfaces are examples of these organisms [37].

6.4.5. Bamboo structure (hollow tubes)

In addition to the exceptional potential of bamboo as a viable structural material. The study intends to concentrate on the hollow nature of the segmented culms of the plant. The notion of distinguishing the bamboo plant in the study of bio-inspired buildings is the extraordinary composite hollow vessel that may exceed 40 meters in height in some bamboo species without filling support as in tree constructions. The culm nodes, which link the culm pieces into a stiff stem with strong bending and shearing resistance, are a critical structural feature for avoiding system failure and ensuring excellent mechanical performance. Additionally, the incredibly lightweight construction of bamboo is based on the culm's exterior layer, the stiff section with somewhat flexible internodes, and the inner side layer,

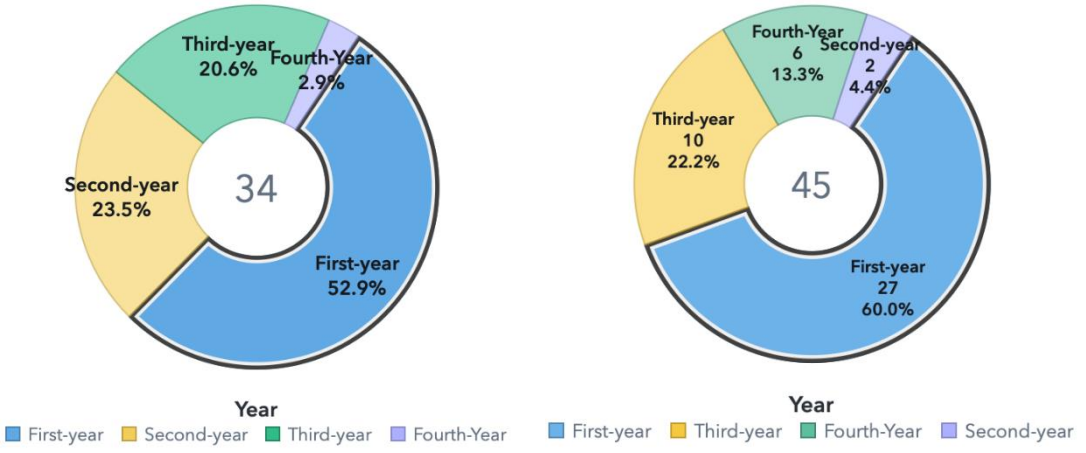
which behaves like foam and absorbs energy and distributes it along the pattern of the culm wall [38].

6.4.6. Deployable structure

The research aims to adopt this system in particular and include the concept of kinematic structure into each project to produce a lightweight and dynamic building. Students can choose whether they want to produce deformation throw lines, surfaces, or colors using soft, elastic, or hard material in this context. deployable systems are smart assembly constructions that use foldable surfaces, rigid bars, strut-cable compositions, or deformable plates to achieve a high level of sustainability by creating deployable and mobile structures that can be located at different places or perform a motion [39].

7. Experimental case studies

The experiment includes two biomimicry-based workshops conducted during the summer of 2022 in the department of Architectural Engineering at Fayoum University. Novices and facilitators have volunteered in both workshops by submitting an online application form asking them to identify their names, academic year, locality, and state of siblings to classify them according to the selected factors, gender (Male or Female), locality (Rural, Suburban, or Urban), and state of siblings (Balanced, Only same-sex, Only opposite-sex, or No siblings). The main participants of the first workshop, as shown in Fig. 5, resample 52.9 percent, while the second workshop includes 60 percent of the total participation.

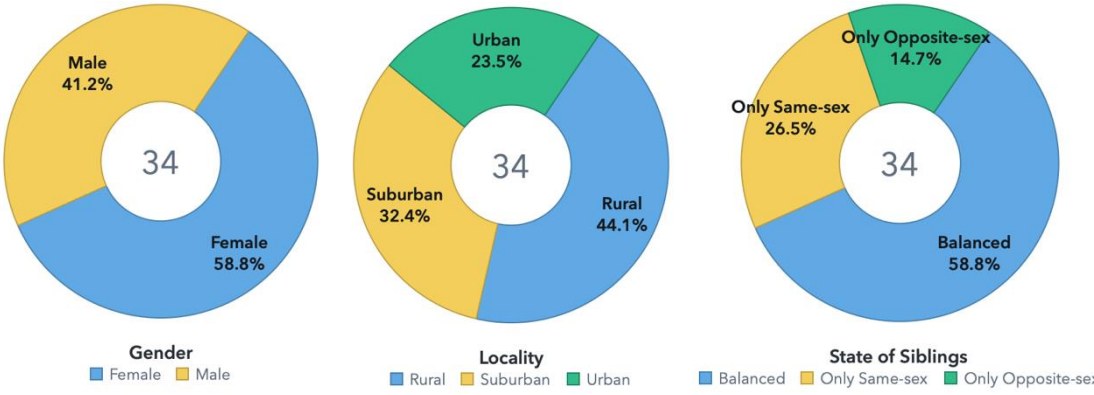


(a) (b)

Fig. 5. The participants of the experiment, (a) the distribution percentage of the first workshop, and (b) the distribution percentage of the second workshop [Authors via SAS]

7.1. Workshop A: "Biomimetic Deployable Structure"

From July 23 to 27, the first experiment of incorporating biomimicry in architectural articulation was carried out in five design studios with a total of 18 freshmen and 16 facilitators. As shown in Fig. 6, females are 58.8 percent, and males are 41.2 percent of participants. Whereas the initiative volunteering role of females highlights their active mood and willingness to cooperate little more than males. Likewise, the participants` locality statuses verified the variety of their culture as 44.1 percent belong to a rural environment, 32.4 percent come from suburban areas, and only 23.5 percent are living in urban environments. However, the higher percentage of rural locality participants doesn`t imply a higher level of collaboration as the reality is that most students in the Architectural Engineering Department of Fayoum University carry the rural culture of living in the countryside. Additionally, the results of the application form have also declared a high percentage of the balanced state of siblings, 58.8 percent, and a low percentage of the only opposite-sex state, 14.7 percent, while students with the only same-sex state resemble 26.5 percent of the participants.



(a) (b) (c)

Fig. 6. Factors distribution in the first workshop, (a) the distribution percentage of students' gender, (b) the distribution percentage of students' locality, and (c) the distribution percentage of students' state of siblings [Authors via SAS]

7.1.1. The procedure of the solo practice

The first day of the workshop started with a two-hour open discussion on biomimicry and mimicking the functionality of Nature. Following that, all students were instructed to begin drawing a conceptual design, assuming any function for the space without being required to give a specific design viewpoint, plans, sections, elevations, or three-dimensional views. After spending an hour in the solo practice, as shown in Fig. 7, the STAI pre-test was executed by all main participants and facilitators. Two hours later, participants handed in their sketches and the authors played a conventional role as instructors in the individual practice of the first day in addition to their main mission of observation.

(a) (b)

Fig. 7. The solo practice on the first day of workshop A, (a) part of the individuality of the design studio, and (b) an introverted novice minding his design practice (ID: A01) [Authors]

7.1.2. The procedure of the teamwork practice

Starting from the second day of the workshop participants performed biomimetic architecture in teamwork. Before asking them to start the first step of biomimetic practice of searching and observing Nature, they were asked to freely group in teams as they wish to collaborate. Before taking the STAI post-test on the third day, the authors noticed that students have a great inclination of working with peers, in the same group, of the same gender. Meanwhile, their random distribution of groups created variability that lately affected the results of the workshop observation as well as the qualitative assessment. The variation in the number of workshop groups is significant between Group 3 and Group 1, as the former doubles the latter in members` number. Group 3 contained ten participants while Group 1 got only five, Group 2 was formed by seven participants, and Groups 4 and 5 each contained six participants.

Allowing them to experience the genius of natural organisms and creatures they used to see without noticing their incredible characteristics of adaption, the research conducted on the second day has yielded great capabilities of novices to absorb an untraditional way of collaborative practice. In addition to their willingness to participate, they have shown inspiring enthusiasm to share their design work with higher-level facilitators. Furthermore, gender had an impact on their choices of emulation as females were noticed by their affinity for implementing gentle and feminine organisms such as Flowers, Sea shells, Bees, Peacocks birds, Worms, and Butterflies, while males were noticed by mimicking more muscular and not domesticated animals such as Scorpions, Eagles, Armadillos, and Ostriches. Hereafter, the five groups have arranged many mutual evaluation crits in the form of presenting pencil sketches of their source of inspiration or estimating others' sketches.

The cooperative practice of biomimicry has been employed in the design studio in two different ways. As shown in Fig. 8, the first and main way unintentionally added by students to the teamwork practice is peer review learning among each group and between

separate groups. All groups have adopted evaluation as an attitude as each group has got at least two members responsible for assessing each step of the biomimetic design. Moreover, workshop facilitators have carried out the tutoring job by giving their reviews on novices' design work and guiding them to analyze the integrated study of natural organisms. The experience of facilitators sharing their ideas with novices has surprisingly been observed as the core of the design studio practice and the most influencing factor in the experiment. Group "1" has been noticed with a ratio of two novices to three facilitators, group "2" has been established by three novices with four facilitators, groups "3" and "4" have been observed with equality of novices and facilitators numbers, and group "5" has incorporated only one facilitator as a mentor for five novices.

(a) (b) (c)

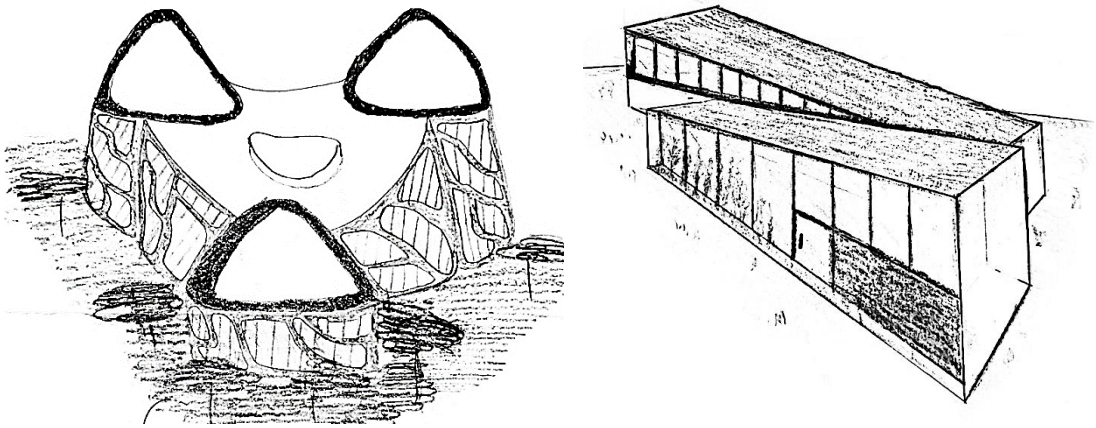
Fig. 8. Types of cooperation in workshop A, (a) peer learning of G4, (b) peer learning of G5, and (c) peer tutoring of G1 [Authors]

7.1.3. Results

The qualitative study aimed to highlight the assessment of students' solo practice as well as teamwork practice according to their performance in the preparation and verification design processes. Moreover, understanding the relationship between each practice type and the time spent in the design work according to the three factors, gender, locality, and the state of siblings. Therefore, the study tended to confirm the previous inquiries by testing students' performance through a design sketch on the first day of the workshop. Thus, each participant in the workshop has been coded with an ID declaring his/her academic year with an upper-case alphabet, A for the first-year students and D for seniors, in addition to the numerical arrangement of each academic year starting from 01. The results of their sketches have been observed with the following:

- The preparation process was conducted separately depending on their architectural backgrounds without heading to any kind of research or inner brainstorming in the design studio.
- Students spared no effort in the verification process and each one of them, without any exceptions, handed in their drafts as soon as he/she has decided that the work is done.

- Most of them, novices and facilitators, used single cubes to illustrate their design concept about a biomimetic deployable building, except for only four participants who integrated green roofs and curved lines instead, as shown in Fig. 9.



(a) (b)

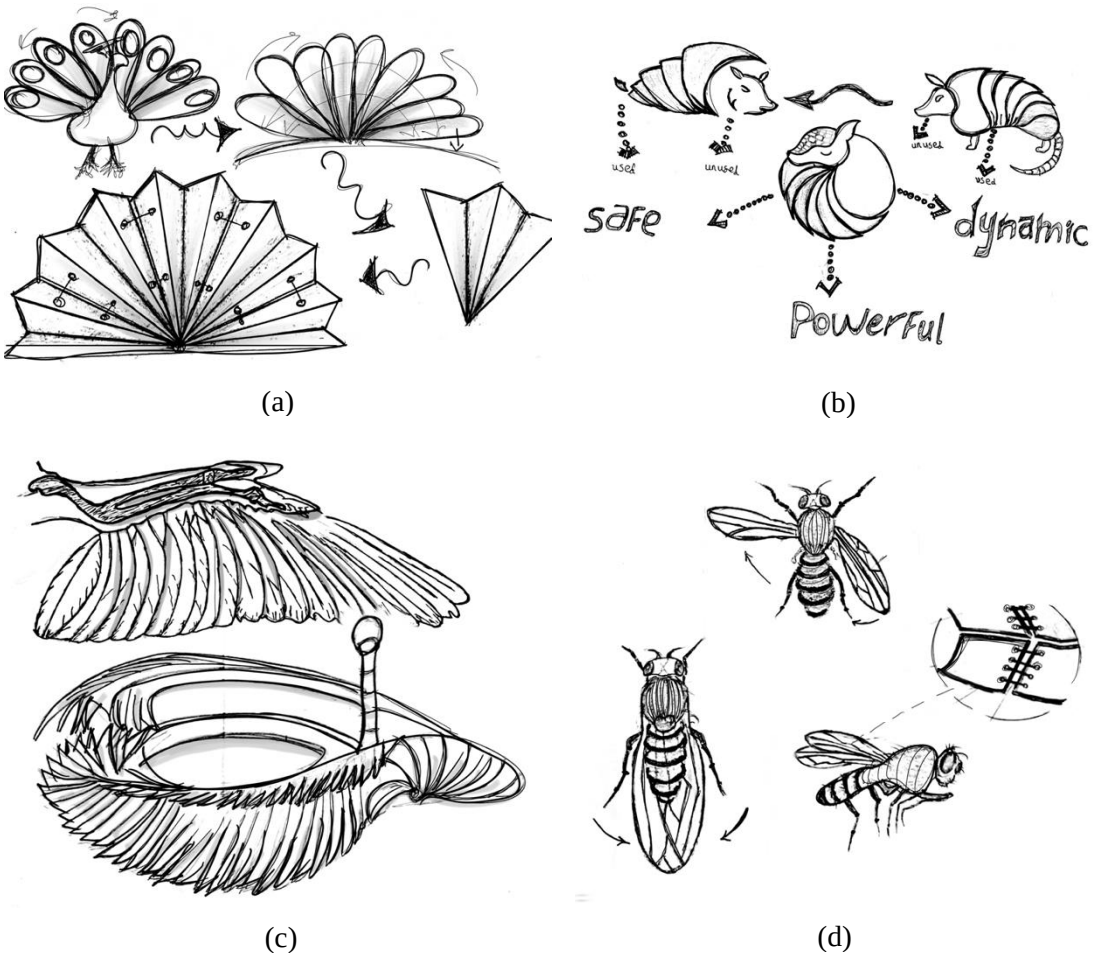
Fig. 9. Samples of the individual practice workshop A, (a) the output of a female novice (ID: A06), and (b) the output of a male novice (ID: A02) [Novices of Workshop A]

Meanwhile, the process of sketching during the third day of teamwork practice embraced a more analytical view of translating Nature's language of deployment and abstracting the notions of applying these examples in architectural design work. As shown in Fig. 10, each group adopted specific examples for the mechanism of deployment. It should be noted that more than two creatures have presented by each group at the end of the second-day research presentation with a full analytical study of the emulation method for each creature. The results of the qualitative study of this practice revealed the following observations:

- The preparation process in each group independently followed the sequence of design spiral starting from problem identification, creating a deployable building structure, to the emulation process of applying their engagement level to biomimicry through research work.
- Activating the verification of their establishment was frequently conducted during formal and informal gatherings by criticizing and discussing improvements with others.
- Facilitators remarkably are credited for the frequent assessment crits that mostly included more than one group.

The results of the study of participants' attendance on the five days of workshop A, an average of six hours a day, declared that attendance ranges between 12 to 29 hours, in most cases, 27 of 34, attended between 20 and 29 hours. The most related factors of this study are in sequence the state of siblings and gender differences, while locality had the lowest influence on attendance as the difference of attendance value between locality cases

doesn`t exceed one hour between urban and rural and half an hour between urban and suburban and so on. On contrary, as shown in Fig. 11, the classification of the state of siblings reported that students with a balanced state, having siblings from both sexes, spent more hours in the design studio than others. Moreover, the categorization of students according to gender assure that females spend more hours in the studio than males. Eventually, this study's importance is measuring the influence of cooperative biomimetic practice on optimizing students` dutifulness and commitment toward architectural design practice.



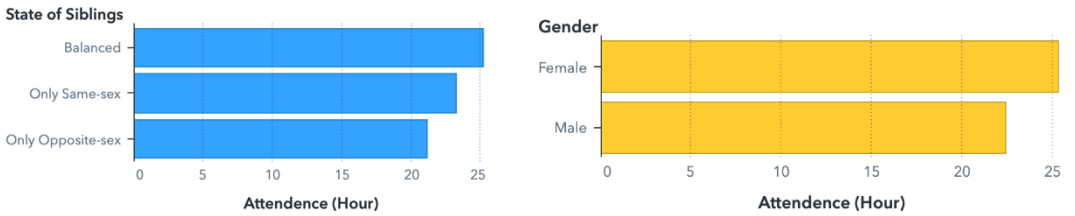
(a) (b)

(c) (d)

Fig. 10. Part of the teamwork practice of biomimetic design during Workshop A, (a) analytical sketching of G1, (b) part of the analytical sketches of G3, (c) the applicable level of mimicking eagle's wings in G2, and (d) the analytical study of bee's wings in G5 [Participants of Workshop A]

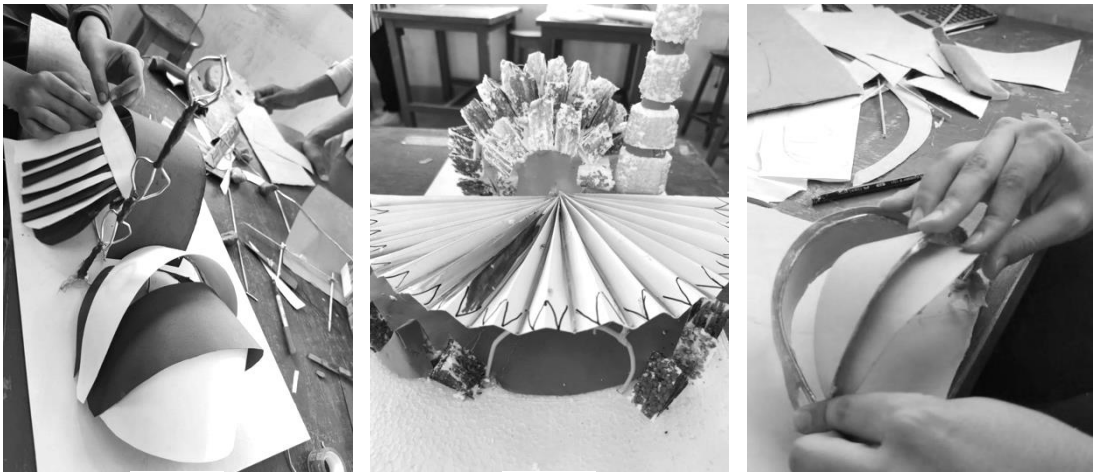
The concluding output of the cooperative practice led to the creation of hand-made 3D models on the last day of the workshop differentiated students` practice of biomimetic architecture into three levels, (1) understanding, (2) applying, and (3) creating as creating is the optimum practice of biomimicry. Three groups out of five, G1, G3, and G5, reached the

highest level of biomimicry practice, creating. However, G1 members couldn't move through the engagement level toward the applying level. Their research work provided them with a wide perspective of biomimicry thinking although these outputs only made their way to theories without analysis or practical attempts. Moreover, G4 members' practice was limited to analysis and applying their biomimicry engagement level. Though, their design sketches and model were never completed. As shown in Fig. 12, creating a biomimetic deployable structure system is a result of passing the initiative levels of understanding and application. The main factor that made the three creative groups reach the level of creating original ideas is the cooperative self-evaluation among group members.



(a) (b)

Fig. 11. The relationship between attendance in workshop A and participants' classifications, (a) the state of siblings as the most influencing factor on attendance, and (b) students' gender as the second most influencing factor on their attendance [Authors via SAS]



(a) (b) (c)

Fig. 12. The output of the cooperative practice of biomimicry in workshop A, (a) the applying level of G2, (b) the creating level of G5, and (c) part of the creating level of G3 [Authors]

The missing part of the practice of G2 is evaluation as they intended to emulate biomimicry thinking in architecture with one idea without producing any design alternatives (weak emulating level). Their strategy failed to emulate the eagle`s wings in architectural

walls and couldn't appropriately apply their biomimicry abstract or translation phase, as illustrated in Fig. 10, The participation of G4 members incorporated theoretical brainstorming and oral discussions into the workshop without accomplishing any practical activities as their difficulties in following the design spiral started at the fourth stage of innovative abstraction. Consequently, they ended up with primitive sketches and an incomplete design model of not-biomimetic design.

The results of the quantitative study that mainly depended on the scores of STAI pre and post-test illustrated the transformation of students' experiences with anxiety from the solo to the teamwork practice. Most participants showed great improvements in the STAI post-test in comparison with their scores on the STAI pre-test, as clarified in Fig. 13, The majority transformed from a positive value of experiencing anxiety, 1,2, or 3, to a negative value, -1, -2, or -3, while only two participants, ID: B01, and B02, showed the opposite transformation. In addition to one participant, ID: A04, remained in the same state of anxiety (value = -2) before and after the cooperative biomimicry practice.

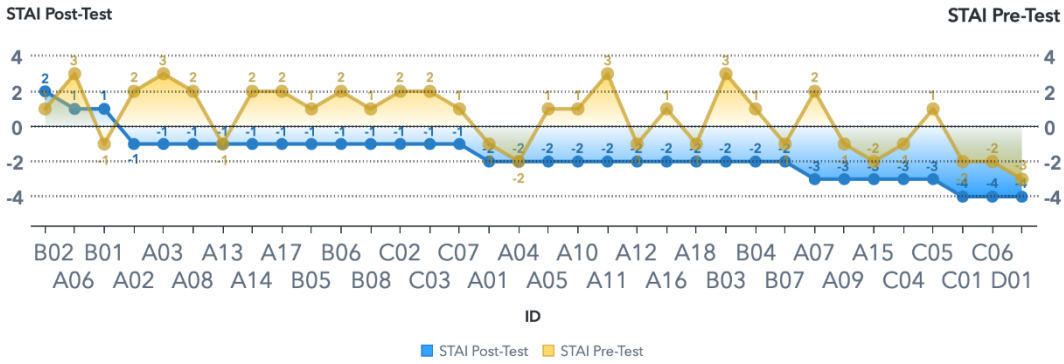


Fig. 13. The transformation of participants' state of anxiety in workshop A [Authors via SAS]

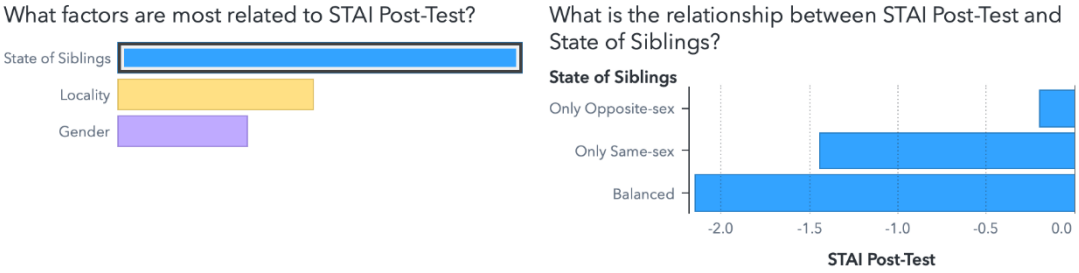


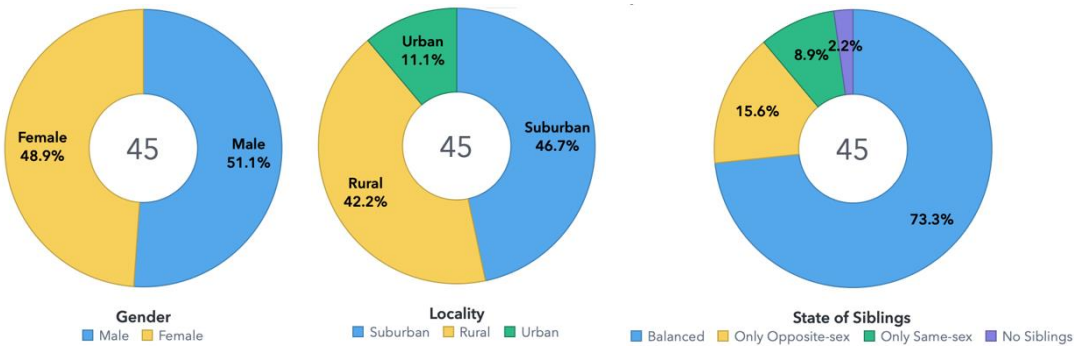
Fig. 14. The arrangement of the most related factors to the results of the STAI post-test in workshop A [Authors via SAS]

The influences of factors: gender, locality, and the state of siblings on STAI transformation of values led to the conclusion of their arrangement according to the most related factor. The most related factor is the state of siblings. As shown in Fig. 14, when the state is "Only Opposite-sex" the average of the values of the STAI pre-test is high. While low values are most common when the state is "Balanced" or "Only Same-sex". The second

related factor is the locality. When it`s "Rural" or "Urban" the average of the values of the STAI post-test is high, while in the case of a "Suburban" locality, the average of the values is low. Eventually, the least related factor is gender as the analysis of the values of the post-test implied greater improvements in the state of anxiety of female participants than males. When the gender is "Male", the average value is (-1.2), while the average value of the "Female" case is (-2).

7.2. Workshop B: "Biomimetic Lightweight Structure"

The second workshop was carried out between the 4th and 8th of September embracing 49 participants, 27 juniors, and 18 facilitators. As shown in Fig. 15, the gender distribution of the participants is 22 females and 23 males, 48.9 percent and 51.1 percent in order. While the study of their locality state has indicated a higher percentage of the suburban locality, as nearly half of them, 46.7 percent, have come from suburban spaces. On contrary, the urban locality appeared as the lowest percentage, only 11.1 percent, while the rest belongs to rural spaces around the countryside of the Fayoum government. Moreover, the common state of siblings is balanced, 73.3 percent, with a lower percentage of the state of only same-sex and only opposite-sex, 8.9 percent, and 15.6 percent in sequence. In addition to the three common states of siblings, the workshop has included one male novice with no siblings, who represents 2.2 percent of the participants.



(a) (b) (c)

Fig. 15. Factors distribution in the second workshop, (a) the distribution percentage of students' gender, (b) the distribution percentage of students' locality, and (c) the distribution percentage of students` state of siblings [Authors via SAS]

7.2.1. The procedure of the solo practice

The initial step on the first day of the workshop is to assess students' performances before incorporating the biomimetic practice. Therefore, the workshop conducted a discussion about the biomimetic lightweight structure and then followed the same sequence as the first workshop process on the first day. After brainstorming, the preliminary hand drawing for any imaginative space with a biomimetic structure and the STAI pre-test covering the quantitative study were inserted into the individual practice. As shown in Fig. 16, each participant was obligated to a selected drafting table in the design studio. After four

hours of sketching, students turned in their design work and the answers to the STAI pre-test while the authors' participation concluded in the tutoring and supervision role.

(a) (b)

Fig. 16. The solo practice on the first day of workshop B, (a) the separation between males and females in the seating positions, and (b) part of the individuality between the same gender [Authors]

7.2.2. The procedure of the teamwork practice

The practice of cooperative biomimetic architecture started in teams early on the second day of the workshop. Before instructing them towards the translation phase that has been guided by authors to help them search for solutions from Nature, their cooperative research on the biomimetic structure enabled them to the identification phase with plenty of structure system alternatives to mimic. The authors noticed that juniors had a common affinity to joining teamwork with facilitators from higher levels more than joining with their peers at the same academic level. Principally, the cooperation between participants from different gender faced many difficulties in the initial steps of identification and translation. However, the abstraction, as well as the discovering phase, helped students to express their thoughts freely without feeling uncomfortable. Consequently, the emulation process has been integrated as a combination of different abstracts and different translations to the language of Nature's lightweight structure systems. The analogy between this workshop and the first one is the STAI post-test on the third day (after starting the discovering and translating processes).

As shown in Fig. 17, participants were spontaneously divided into six groups concerning their personal preferences without any directed distribution from the authors. The highest number of group members has been formed from ten students in group "2" with five novices and five facilitators, while the lowest number of group members have been found in group "4" and group "6" with six participants in each. Both have been noticed with the priority of the affiliation of novices over facilitators. Group "4" included only one facilitator working with five novices and group "6" integrated two facilitators with four novices. Similarly, the majority of novices in group members` distribution has been remarked in group "3" with five novices cooperating with three facilitators. Conversely, the

two remaining groups, “1” and “5”, have been observed to have a higher or similar number of facilitators than novices. Group “1” included eight participants with four facilitators, while group “5” involved seven participants with only three novices.

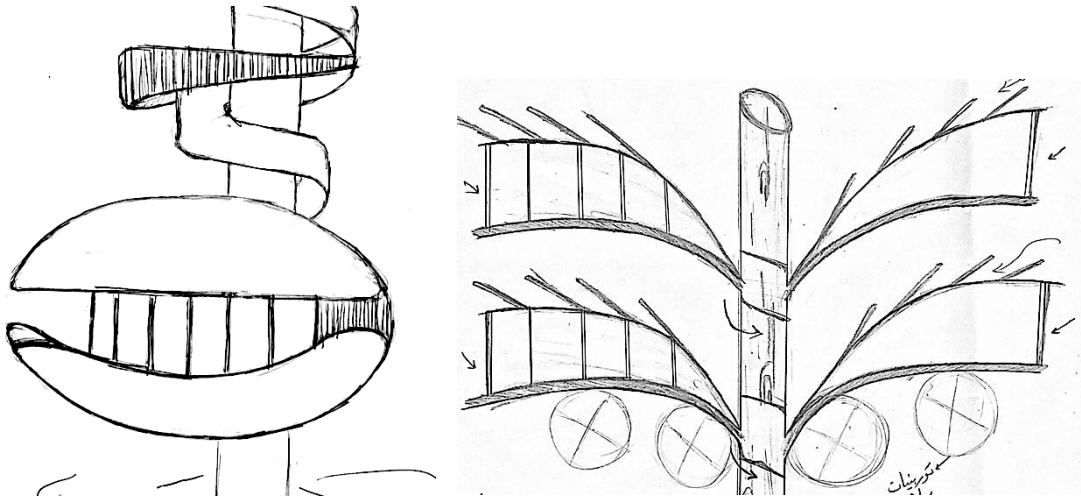
(a) (b) (c)

Fig. 17. Types of cooperation in workshop B, (a) peer tutoring of G1, (b) peer learning of G6, and (c) peer learning among novices of G2 [Authors]

7.2.3. Results

The results include two main approaches as the previous workshop as both follow the same methodology. The qualitative study of assessing students’ architectural design work showed that the practice of cooperative biomimetic design in the architectural studio is the major influencing factor on students’ academic performance. In this context, the assessment of the solo practice showed the following:

- Participants claimed that solo practice was not appropriate for such a practical-analytical design.
- The preparation process of identifying and discovering failed to apply to most solo practice participants.
- Translating and abstracting steps depended on a one-way thinking method with full reliance on self-inclination and spontaneous solutions.
- Emulating Nature in architectural articulation was never a success of biomimetic lightweight structure for any participant. Nevertheless, few tried to emulate the appearance of Nature and maintained the concept of connectivity with Nature by integrating curved lines and natural ventilation, as shown in Fig. 18.
- Each student, including novices and facilitators, verified their drafting sketches without discussions.
- Most cooperative engagement between participants showed in the form of curious general conversations containing no explanations or debates (verification process).



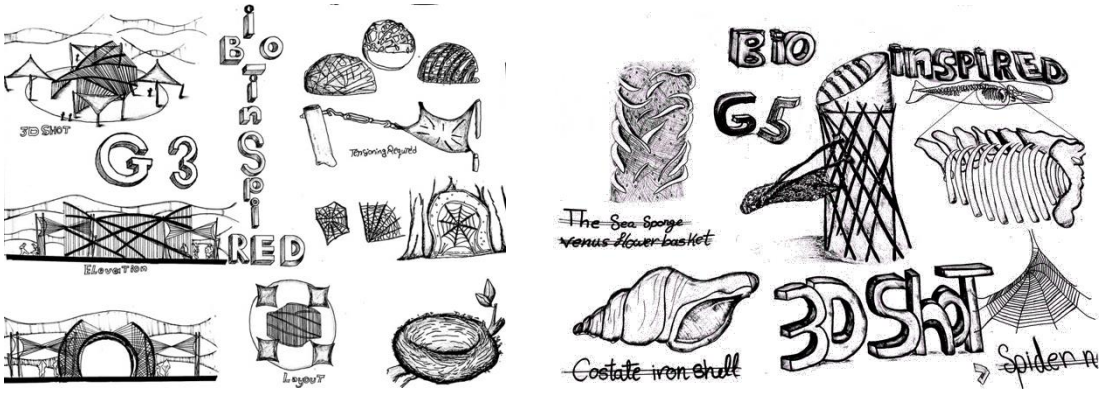
(a) (b)

Fig. 18. Samples of the individual practice Workshop B, (a) the output of a female novice (ID: A10), and (b) the output of a male novice (ID: A03) [Novices of Workshop B]

Quite the opposite, the assessment of teamwork practice starting from the second to the last day implemented a practical preparation process through grouping six teams and starting the research work with a clear identification of the problem statement (identifying process), how natural organisms solve the issue of lightweight structure system. In addition, each group organized a translation perspective of the selected examples from nature and discovered the schemes necessary for imitation (translating and discovering processes). However, as shown in Fig. 19, the translation process took place as verbal reflections inside each group without presenting the considerable formula of analysis (abstract process). Sequentially, some of the emulating biomimetic structure systems appeared as confused attempts partly depending on the characteristics of biomimetic structure with many examples of mimicking the shape, not the structure system, in their architectural projects (emulating process). The verification process flourished on the fourth and the last day of the workshop except for group "2" members who spent much more effort than other groups without reaching any practical solutions. The authors noticed repeated separations and disagreements between group members, despite their close friendship, which were later explained due to the huge number of group members, ten participants, and the equality of novices and facilitators' numbers.

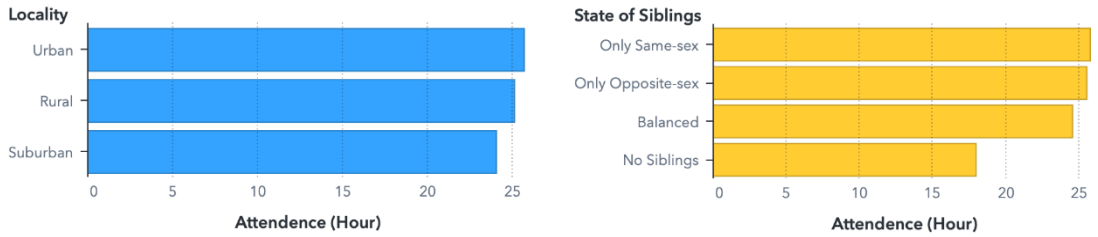
As in workshop "A", workshop "B" has integrated five design studio days each containing six hours of architectural practice. The results of correlating attendance hours to the factors, gender, locality, and state of siblings indicated the direct relativity of locality factor with the higher average attendance hours. As shown in Fig. 20, attendance ranged from 12 to 30 hours with an average of 25 hours, as when the locality is urban or rural the average attendance is a high value and when it`s suburban it is a low value. The second relative factor is the state of siblings as when it is only same-sex, only opposite-sex, or balanced the attendance average is a high value, although the state of no siblings is

combined with a low value of attendance average. Though, gender didn`t imply any influence on attendance hours of workshop B.



(a) (b)

Fig. 19. Posters from the teamwork practice of biomimetic design during Workshop B, (a) the presentation of the final poster for G3, and (b) the final poster of G5 [Participants of Workshop B]

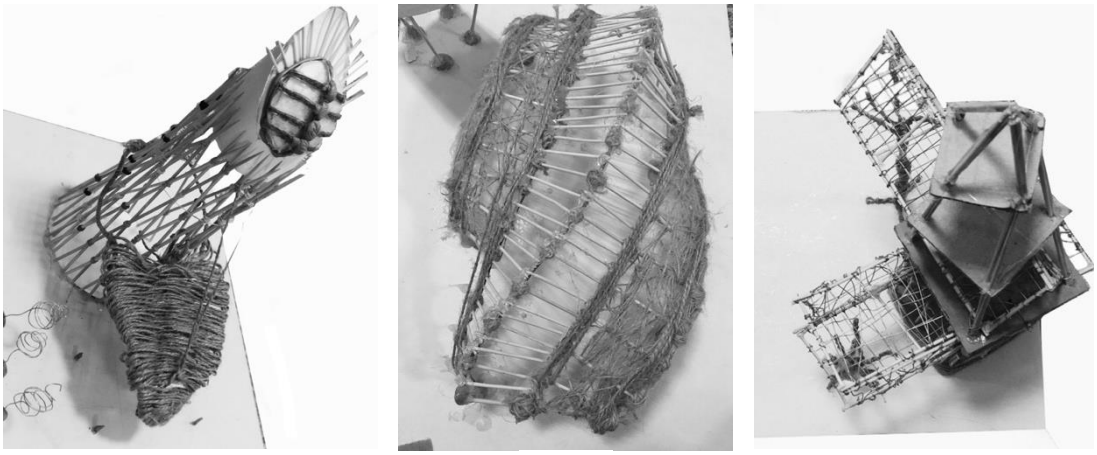


(a) (b)

Fig. 20. The relationship between attendance in workshop B and participants' classifications, (a) students' localities as the most influencing factor on attendance, and (b) the state of siblings as the second most influencing factor on their attendance [Authors via SAS]

The assessment of the final model declared three degrees of engagement in the experience of a cooperative biomimetic workshop. The most optimum degree is (1) creating a new architectural perspective of biomimetic structure, (2) applying comes in the second place of emerging biomimetic concepts to an already-existing architectural project by adding details or independent elements. For most of the workshop groups, creating or applying levels have managed to make their way to the final presentation of the poster, as shown in Fig. 19, and the 3D model, as shown in Fig. 21. The bottom level of the hierarchical assessment is (3) engagement to the language of the biomimetic structure systems by creating analytical theories without proof. The only case shown in the third level is group "2" with an incomplete project of an imaginative pavilion depending on representing the biomimetic tension structure without enough analyses. remarkably, the condition of their group arrangement, as mentioned before, led to the division of group unity

into three or four inside teams with dozens of failed trials and wasted materials before presenting the 3D model.



(a) (b) (c)

Fig. 21. the output of the cooperative practice of biomimicry in workshop B, (a) the creating level of G5 emulating woven (reciprocal) and tension structure systems, (b) the creating level of G3 using reciprocal structure system, and (c) the creating level of G4 abstracting woven (reciprocal) and tree structure systems [Authors]

The results of the quantitative study, illustrated in Fig. 22, prove the improvement of participants' state of anxiety after engagement with the procedure of the cooperative biomimetic practice. Most values of the STAI post-test are lower than these of the pre-test except for 29 percent who had a different experience of cooperative practice caused a higher value of anxiety in the pre-test. Including three students, seven percent, (ID: A13, C06, and C10) with constant values of anxiety in the pre and post-test, ten students, 22 percent, implied their preference for the solo practice. Eventually, the study of relating the factors, gender, locality, and the state of siblings, explained the unexpected results of the qualitative study. Similar to workshop A, the state of siblings is the most related influencer of the post-test value. As shown in Fig. 23, when the state is "Only Opposite-sex" or "No Siblings" the average of the scores on the STAI post-test is a high value (high level of experiencing anxiety). However, when the state is "Balanced" the average participants` scores are low value which means blending in the atmosphere of teamwork practice and utilizing peer learning and peer tutoring, even the only novice (ID: A26) with a state of "No siblings" showed a lower score on the post-test than this on the pre-test. The second effective factor in the scores of the post-test is the locality. Unlike the previous workshop, when the locality is "Urban" or "Suburban" the average of the scores is high, while the "Rural" locality is accompanied by lower scores. Although the gender factor is not the same relativity as the state of siblings and locality, the average of the scores of the "Male" is (-1.6) and (-1.8) for the "Female".

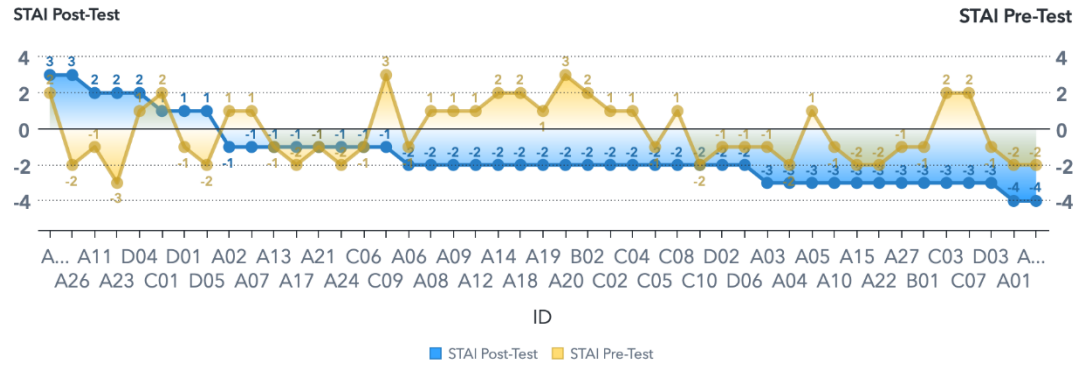


Fig. 22. The transformation of participants' state of anxiety in workshop B [Authors via SAS]

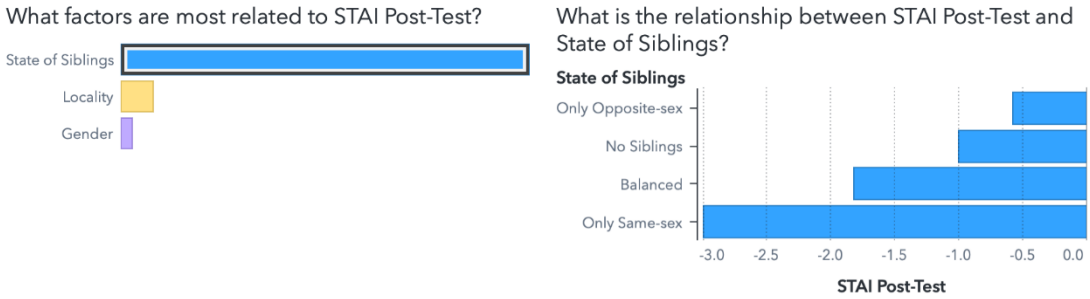


Fig. 23. The arrangement of the most related factors to the results of the STAI post-test in workshop B [Authors via SAS]

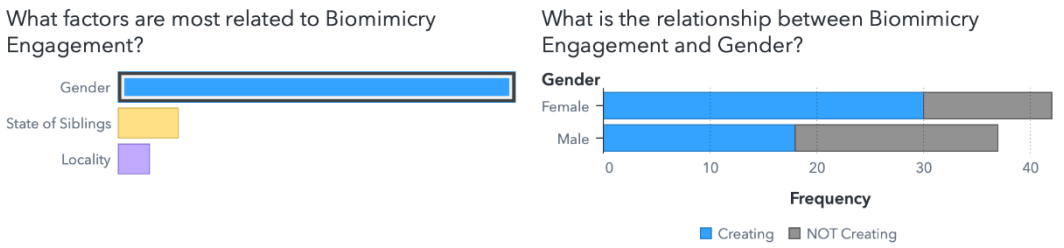
8. Conclusion

The study used the experimental-analytical methodology to measure the impact of the cooperative practice of biomimicry on the productivity of architectural students and their state of anxiety during a project-based workshop in the architectural design studio. Following the principles of biomimetic structure systems, the experiment tended to hold two architectural design workshops in two different design studios at the Department of Architectural Engineering at Fayoum university. Both workshops considered first-year graduates and juniors as the main participants in the experiment. However, for the implementation of peer tutoring, volunteering for the experiment was open to all levels in the architectural department. Thus, three different levels participated as facilitators in both Workshop A: "Biomimetic Deployable Structure" as well as workshop B: "Biomimetic Lightweight Structure". Considering the population of novices (main participants), the sample that volunteered for the experiment represented 86 percent and 71 percent, in sequence, in project-based workshops each for five days of solo and teamwork architectural practice. The workshops equally followed the same procedure of starting the first day with an open discussion (two hours) and biomimetic solo practice for the rest of the day (four hours) while measuring the score of students` state of anxiety by using a short version of the STAI test. The second day embraced the start of the biomimetic teamwork practice by

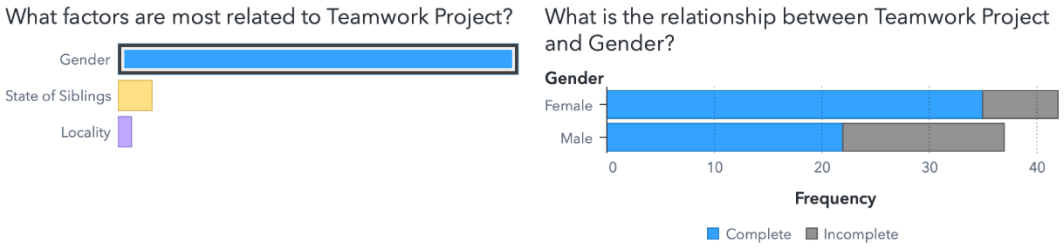
giving the chance for all participants to affiliate freely without any constraints. In the middle of the third day of the workshop (the second day of teamwork) the authors tested the anxiety state of participants by giving them individually the STAI post-test. Hereinto, the qualitative and quantitative study tend to measure the impact of the experiment relating to three factors sorting architectural students according to their gender, locality, and their state of siblings.

From the beginning of the opening discussion, participants in both workshops were advised to follow the sequence of the design spiral to achieve the best product quality. Therefore, the qualitative assessment depended in the first place on evaluating (1) the preparation process (including identifying, translating, discovering, abstracting, and emulating) in addition to (2) the verification process. Handling both processes, the preparation and the verification, reflected on the level of engagement with biomimicry (biomimicry understanding) as well as the accomplishment of the teamwork project. Moreover, the study involved (3) the attendance calculation out of the full 30 hours of each workshop, over the five days. The results of the experimental qualitative study remarked the following conclusions:

- Most participants improved their performance in the architectural biomimicry-based workshop when they switched to the cooperative practice.
- The influencing factors that affected the productivity improvements are gender, state of siblings, and locality, as shown in the automated explanation in Fig. 24(a) and Fig. 24(b).
- Creating is the most common result of biomimicry engagement level representing 60.76 percent (48 of 79) of experiment participants.
- Considering gender, females showed engagement with the creating level more than males, while students of the only same-sex and balanced state of siblings revealed blending with the top level of biomimicry engagement more than others.
- Participants of the suburban locality, followed by the rural, were combined by the creating level more than the urban locality.
- The relativity of the three factors showed the same orderly influences on the accomplishment of the teamwork project as on the biomimicry engagement level.
- Unlike the arrangement of factors relativity on the biomimicry engagement and the teamwork project, the attendance calculation related to the state of siblings is more effective than gender, as shown in Fig. 24(c).
- The average attendance is 24 hours and, in most cases, (63 of 79 participants) 79.74 percent attended between 19 and 29 hours.
- Females who came from rural or suburban localities with a balanced or only the same-sex state of siblings showed greater obligement of design studio attendance during the five days of their workshop than other participants with different circumstances.



(a)



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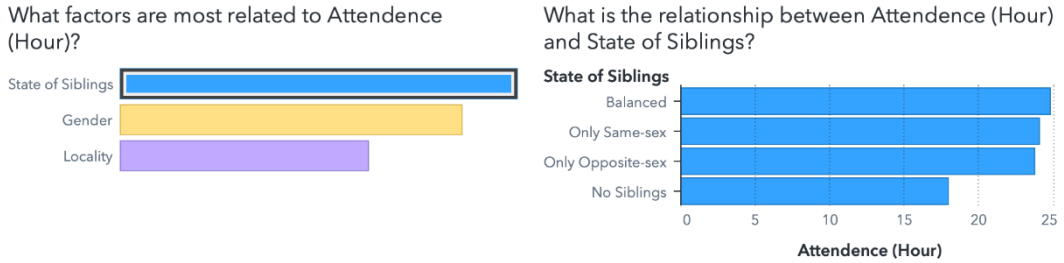

(c)

Fig. 24. Relating study factors to the qualitative assessment, (a) the arrangement of influencing factors on the creating level of biomimicry engagement, (b) the arrangement of the influencing factors on the accomplishment of the teamwork project, and (c) the arrangement of the influencing factors on attendance hours [Authors via SAS]

The quantitative study articulated by the results of the STAI pre and post-test comparing the transformation of participants' scores, as shown in Fig. 25, revealed that most participants scored noticed with lower scores in the post-test than the pre-test. The average score on the STAI post-test is (-1.7) which reflects the positive impact of biomimetic teamwork practice on reducing anxiety and creating a more comfortable learning environment for architectural students. Contrasting with the qualitative study, the relativity of the state of siblings as an influencing factor gets over the factors of locality and gender, as shown in Fig. 26. Regarding this, the study indicates the same result as the performance study, females who came from rural or suburban localities with a balanced or only the same-sex state of siblings were more impressed by the experiment and showed the lowest scores in the STAI post-test.

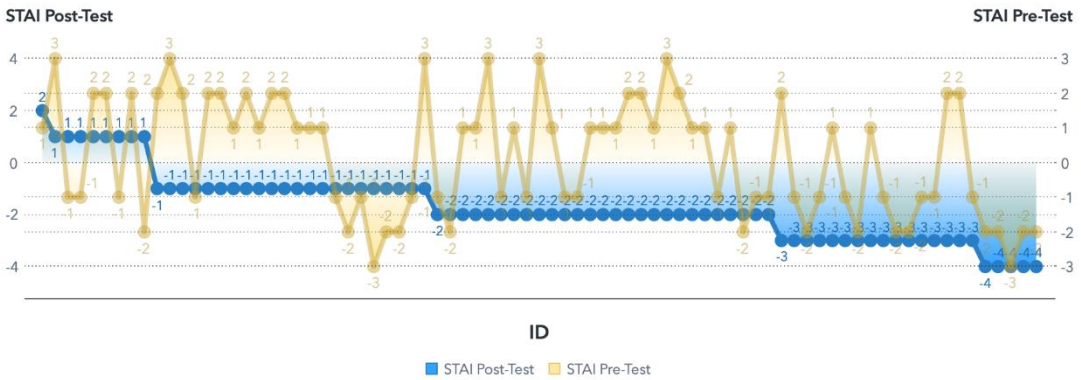

Fig. 25. Comparison between participants' scores in the STAI pre and post-test [Authors via SAS]

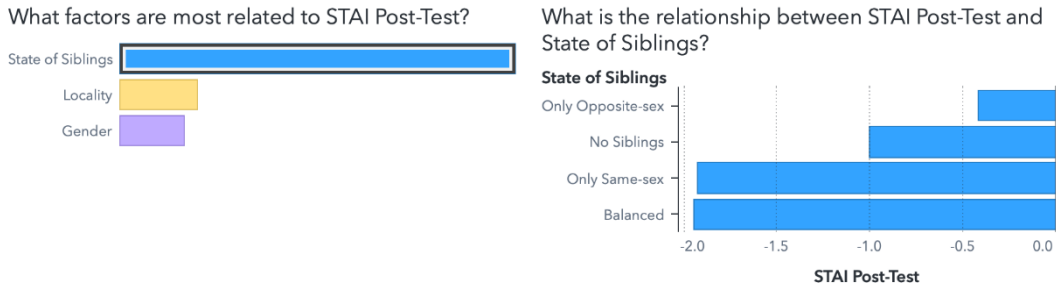

Fig. 26. The arrangement of the most related factors to the results of the quantitative study of STAI post-test scores [Authors via SAS]

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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