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How Do the Demographic Differences of Architectural Students Correlate to Their Performance in Multidisciplinary Fields?

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Abstracts: Architectural education needs creativity, critical thinking, and problem-solving skills. However, little research has looked into how demographic differences, especially gender and learning style, affect the performance of architecture students especially in multidisciplinary curricula. Therefore, the paper aims to investigate the relationship between learning styles and gender among architecture students and their academic performance in a biomimicry-based practice. A practice one-week workshop was employed with a sample of architecture students to identify their idea-generation style and creativity, through novelty, resolution, and elaboration. The study found that Learning styles greatly influence idea generation style preferences and creativity performance in teamwork. Females tend to be more collaborative idea-generators during the initial stages than males. Also, Scores of novelty and elaboration were more closely tied to learning styles, while resolution scores were more associated with gender. Despite many limitations such as the focus on a specific multidisciplinary field (the architectural articulation of biomimicry), the results contribute to the development of architecture teaching strategies and the broader field of biomimicry by providing insights into how different students approach biomimicry-based design challenges.

Keywords: Architectural Education, Learning Style, Gender, Biomimicry, Architectural Students.

1. INTRODUCTION

Educators worldwide have extensively studied the learning patterns of students in the field of architecture, recognizing that it is a complex variable influenced by various factors. These factors include cognitive ability, motivation, surroundings, familial and community circumstances, and quality of educational institutions and instructors [1]. All these factors interact with each other in complex ways. Therefore, a holistic approach that considers multiple aspects is essential for effective education. Among these factors, learning styles [2] and gender have a significant direct impact on how individuals comprehend information that should be taken into account to meet learners' needs, especially for a multidisciplinary application like biomimicry [3, 4].

To analyze the learning patterns of architecture students, several theories and models have been utilized, including the Keirsey Temperament Sorter [5], Johnston's Learning Combination Inventory [6], Grasha-Reichmann's Learning Styles [7], Myers-Briggs Type Indicator [8], Kolb's Learning Style Inventory [9, 10, 11], and Honey and Mumford's Learning Styles Questionnaire (LSQ) [12]. However, it is important to note that gender differences also play a role in how students learn as females tend to excel in memorization and social skills, while males often perform better in spatial and mathematical skills. These differences may stem from fundamental disparities in how males' and females' brains process information, emotion, cognition, and language [13].

2. LITERATURE REVIEW

2.1. Relationship Between Learning Styles, Gender, And the Architectural Academic Performance

Research on the correlation between the learning style and the gender of architectural students and their performance has always been of interest to many researchers [14]. The foundation of learning style classification started with the theory of experiential learning raised by David Kolb in 1984 balancing the process of experiential learning into two different moods of acquiring knowledge and two others of transforming it [15].

Later, the results of two case studies conducted using samples of architectural undergraduates, 83 novices from Bilkent University, and 81 second and third-year students from Chongqing University, [16] [17] indicated that learning style differences have a remarkable influence on students' performance scores in conventional architectural programs. Simultaneously, in 2007 a three-group study, with samples of 111, 88, and 74 freshmen, was conducted at Bilkent University to explore the relationship between architectural students' learning styles, gender, and their performance scores in different courses. The study indicated the impact of gender differences on students' scores, as males were higher in technical-based courses, while females were higher in basic and artistic courses. Moreover, the study showed that both gender and learning styles are independent and have no impact on each other [18]. A further study conducted using a sample of 90 architectural students at Bahçeşehir University found that learning styles of diverging and assimilating were more successful in the process of concept development and spatial configuration, while those with the converging or assimilating styles were more successful in unconstrained and concept generation tasks [19].

The independence of gender impact on architectural students' performance appeared clearly during the study of this impact on the employment of different design processes, using a sample of 69 seniors from Ahmadu Bello University. Females were more likely to navigate the technical and confluent process, while males were able to deal with all the design processes, the precise, the technical, the confluent, and the sequential [20] which agrees with the results of the experimental study of Fulani that proved the capability of males to go through the learning processes in design studio without spending a much effort as females [21].

More recently, in an attempt to associate learning styles with architectural students' performance in the design studio, a sample of 50 second and fourth-year students, notably 78 percent were males, were administered Kolb's learning style questionnaire. The descriptive analysis of their performance indicated that although most of the sample were assimilating and converging students, the accommodating students had better performance in the design studio [11].

2.2. Creativity and Idea Generation Styles of Architectural Students

Architectural students seek inspiration to generate new ideas but may face challenges in producing original concepts without relying on past solutions [22]. Despite the prevalence of computer-generated designs in architecture, many students still rely on freehand sketching as a way to brainstorm and visualize unique ideas. It remains an important tool in the initial stages of the design process [23]. The choice between hand drawing and computer use in architecture is often linked to students' learning styles and preferences. Hand drawing can be seen as a form of art, but practical students may prefer the efficiency of computers [24].

According to a study conducted at Middle East Technical University, independent idea generators may struggle with initiating projects and devising plans to accomplish tasks, but they exhibit genuine concern for their colleagues' efforts. Collaborative idea generators work together to create unique ideas. They consist of individuals with different backgrounds and viewpoints, allowing for a range of knowledge and experiences. Those who are over-sensitive idea generators may approach idea generation with more caution and apprehension, resulting in more thoughtful solutions. However, this approach may also undermine their confidence and self-esteem. Effective idea generators possess a talent for rapid learning, excel at presenting ideas, and utilize strategies to generate a variety of concepts. They possess exceptional problem-solving abilities and outstanding communication skills to effectively convey their ideas to others [25]. This study aligns with a study conducted in the Arab Academy for Science, Technology and Maritime in Cairo considering five themes that students tend to follow during idea generation: Skeptical Nature, Willingness to Initiate, Flexible Attitude, Generative Behavior, and Self-Criticism. Generative Behavior is the most effective method for generating ideas as it allows for solution verification and unique ideas. The other themes describe different techniques with their advantages and disadvantages [26].

Around the idea of determining the idea generation style of architectural students, assessing their creativity has gained a lot of interest since the early days of modern architecture where originality was seen as a key factor in evaluating a student's creative achievement. However, measuring creativity in architecture has become more complex, with subjectivity playing a major role. While originality is still an important factor, the notion of generative potential/resolution has emerged as equally significant, evaluating a student's ability to generate innovative insights and new concepts. Other factors include flexibility, fluency, and elaboration, which together give an integrated picture of a product's creativity [27]. In the 20th century, the focus on originality in architecture shifted to the Generative Potential/Resolution which involves identifying individuals who can think creatively and "outside the box" [28, 29].

In evaluating creativity, other factors include Flexibility, Fluency, and Elaboration. Flexibility refers to the ability of a student to approach existing issues in new or different ways or to generate multiple innovative solutions to a particular problem. Fluency is the quantity of innovative ideas an individual can produce while working on a specific subject. Elaboration assesses whether the individual expands upon their thoughts in a meaningful way, going beyond the fundamental concept to explore new angles and possibilities. When these five criteria are combined, they provide a comprehensive understanding of the level of creativity present in the end product. In evaluating creative products, various methods are used, each with its strengths and weaknesses. These methods include the Consensual Assessment Techniques (CAT) [30], the Creative Product Analysis Matrix (CPAM) [28], and the Creative Product Semantic Scale (CPSS) [31]. When it comes to evaluating the teamwork of architectural students in terms of creativity, the CPSS is the most updated tool considered as a further development for the CPAM. Also, it offers a structured and comprehensive approach to assessing creative products by breaking down the assessment into three dimensions, novelty, solution, and elaboration, and facilitating a more objective analysis. Moreover, it considers the multiple perspectives of the panel of experts and uses a Likert-type scale scoring system for each item to quantify creativity, making it a subjective tool for assessment [32].

2.3. Implementation of Biomimicry in Architectural Education

Architectural curricula have been the gateway for inspiring architectural students since their first day in the design studio. Architectural students often face challenges when it comes to nurturing their creativity and generating new ideas. However, biomimicry is a promising approach that has emerged to enhance the creativity [33] and the overall learning experience of architectural students [34, 35]. According to a study conducted at The Hague University, by drawing inspiration from the natural world, biomimicry offers two approaches: solution-based and problem-based [36]. Implementing biomimicry in design studios not only encourages open-ended discussions and puzzles but also allows for multiple solutions to be explored for the same problem [37].

In 2011, a study conducted at Texas Tech University involving a group of early design students throughout an academic semester aimed at incorporating the principles of nature-inspired metaphors into their projects by utilizing the solution-based approach. However, the emphasis on analogs and metaphors resulted in an oversimplified understanding of natural systems [38]. Moreover, the study conducted in 2012 at Uludag University aimed to enhance the three-dimensional thinking of first-year architectural students. Students were asked to create a biomimetic-based design for a mobile space inspired by arthropods. With a sample of 48 students, the study lasted for three weeks embracing a teamwork project. However, the study found that three weeks was not enough time for the majority of them, except for one team [39].

With a larger sample, a study was conducted at Karadeniz Technical University with 100 second-year architectural students. Students used the problem-based approach of biomimicry to create an architectural project called Life Under the Sea. Despite their commitment, the individual practice limited their creativity by imitating only one natural organism in their designs [40]. Two years later at Izmir University of Economics, a study was conducted on 15 teams of second-year architectural students for two weeks integrating the problem-based approach to foster the problem-solving skills of students. The study results showed how biomimicry positively impacted students' critical thinking abilities [41].

In Egypt, two separate studies were conducted one at Port Said University and another at MSA University. The former study was conducted with six teams of third-year architectural students to promote creativity by observing structural systems in Nature using the problem-based approach that helped foster creativity but lacked information on participants and comparison to other methods [42]. The later study demonstrated that the integration of biomimicry in an elective course for 18 senior architecture students provided students with an inspiring learning experience helping students merge parametric design with their projects [43]. More recently, the Architecture Department of the University of California offered a master's program in 2019 that spanned two semesters and was divided into four teams of post-graduates. The course focused on modern design and fabrication techniques while exploring natural models from a different perspective. At the end of the project, students' achievements varied from 2D sketches and digital 3D models to physical models presenting multidisciplinary projects with creative solutions brought to the real world [44].

Overall, incorporating biomimicry into architectural education encourages students to think creatively, develop algorithmic reasoning and comprehensive design skills, and foster imaginative thinking and unconventional problem-solving. This interdisciplinary approach also equips students with 21st-century skills such as innovation and teamwork. According to (Table 1), teaching integrating biomimicry into architectural students is advised to be integrated for multiple academic levels, preferably, through teamwork, encouraging adventurous and unconventional experiences, followed by more advanced and interdisciplinary practices in higher education.

Table 1: Case studies of integrating biomimicry into the practice of architectural students

Case Study	Strategy	Approach	Duration	Participation
Case Study 1 Biomimicry Studio for Early Design Students [54]	An academic course for early design students focuses on using analogies and metaphors to explore nature	Biology inspiring design (Solution-based)	A whole semester	NOT MENTIONED (Individual submission)
Case Study 2 Biomimetic Design in Architectural Education for First-year Students [55]	An Exercise for beginners to solve architectural problems through analyzing the behavior, form, and movement of arthropods	Design looking for biology (Problem-based)	Two weeks	44 Students (11 Teams)
Case Study 3 Using Inspiration from Nature [56]	Novices designing a house under the sea inspired by sea creatures	Design looking for biology (Problem-based)	Not mentioned	100 Students (Individual submission)
Case Study 4 A Course on Biomimetic Design Strategies [51]	Applying algorithmic thinking and problem-solving inspired by Nature in design projects of undergraduates	Biology inspiring design (Solution-based)	15 weeks	19 Students (Individual submission)
Case Study 5 Mission Mars 2024: Biomimetic Structural Organism [57]	Teaching second-year students digital and fabrication skills through biomimicry-inspired design.	Design looking for biology (Problem-based)	Two weeks	15 Teams (six to seven students in each)
Case Study 6 Biomimetic to help Architecture Students Understand Construction Systems [58]	Enhance the understanding of biomimetic construction systems among third-year students by studying natural organisms.	Design looking for biology (Problem-based)	A whole semester	Six Teams (participation was NOT MENTIONED)
Case Study 7 Biomimicry and Architecture [59]	Seniors applying biomimicry to design sustainable building envelopes using Rhino and Grasshopper.	Biology inspiring design (Solution-based)	A whole semester	18 Students (Individual submission)
Case Study 8 Studio One: Discovering Bio-Inspired Design and Fabrication [60]	A course for post-graduates that collaborates with industry partners and museums to explore fabrication.	Biology inspiring design & Design looking for biology	Two Semesters	Four Teams (participation was NOT MENTIONED)

Source: Authors' Computation

3. MATERIAL AND METHODS

Previous literature shows that research on architecture students has explored their learning styles, creativity, and use of biomimicry in education. However, there has yet to be an experimental study combining all of these approaches to provide a comprehensive understanding of the challenges and opportunities faced by students in adopting biomimicry in their architectural practice. This information would be valuable for educators seeking to enhance students' creative performance in this field. The research utilizes the case study methodology focusing on understanding the possible impacts of the differences in learning style and gender on each student's idea generation style using a descriptive method [45, 26], and teamwork creative performance using a quantitative assessment method [32]. Adopting cooperation and teamwork practice is intended to open the way for students to an ultimate creative environment of visibility and communication [46].

Therefore, students can expand their knowledge and accomplish their ambitious projects in a relatively short time. On top of that, by separating the biomimicry practice of architectural students from their traditional courses, the case study targeted to use of summer vacation to guarantee the elimination of any potential preoccupation or distraction felt by students. The study was guided by the following research questions:

RQ1. How do individual differences in learning style and gender among architectural students relate to their idea generation style?

RQ2. How do learning style and gender affect teamwork creativity scores in the realm of biomimicry?

3.1. Sample Design

The study embraced two separate one-week workshops by inviting all students of the Architectural Engineering Department at Fayoum University, even novices who were preparatory-year graduates about to enter their first year in the architecture department. In total, the main participation was 18 first-year graduates in Workshop A, 27 novices in Workshop B as shown in (Figure 1), and 34 facilitator participants, 10 second-year graduates, 17 third-year graduates, and 7 fresh graduates. The targeted sample in this experiment is the architectural novices with little or no experience in architecture so their original learning style inclinations are not yet affected by their perceived academic education. Additionally, enthusiasm and excitement supported the nature of the experiment settings with limited duration. However, the states of far or rural localities for most of them made the extension of the workshop time to more than one week seem unfeasible during summer.

3.2. Instrument and Data Collection

The quantitative study adopts several implements. On the first day of the workshop, participants took Kolb's Learning Styles Inventory (KLSI) (version 3.1) of 2005, revised by Peter Honey and Alan Mumford [12]. This part was accompanied by additional academic and demographic information such as gender, year of study, and home locality. Regarding the idea generation style, participants were asked to individually submit their conceptual sketches for the project idea on the first day of the workshop program. Through the observation of their behavior and analysis of their strengths and weaknesses, their idea-generation styles were determined [25].

Additionally, the creativity assessment model of the Creative Product Semantic Scale (CPSS) was administered by six experts separately by scaling each item of the assessment using a Likert-type scale of five points. Originality and surprise are the items of the **Novelty** dimension. Logic, usefulness, value, and understandability are the items of the **Resolution** dimension. Organic qualities, craftsmanship, and elegance stand for the **Elaboration** dimension [32].

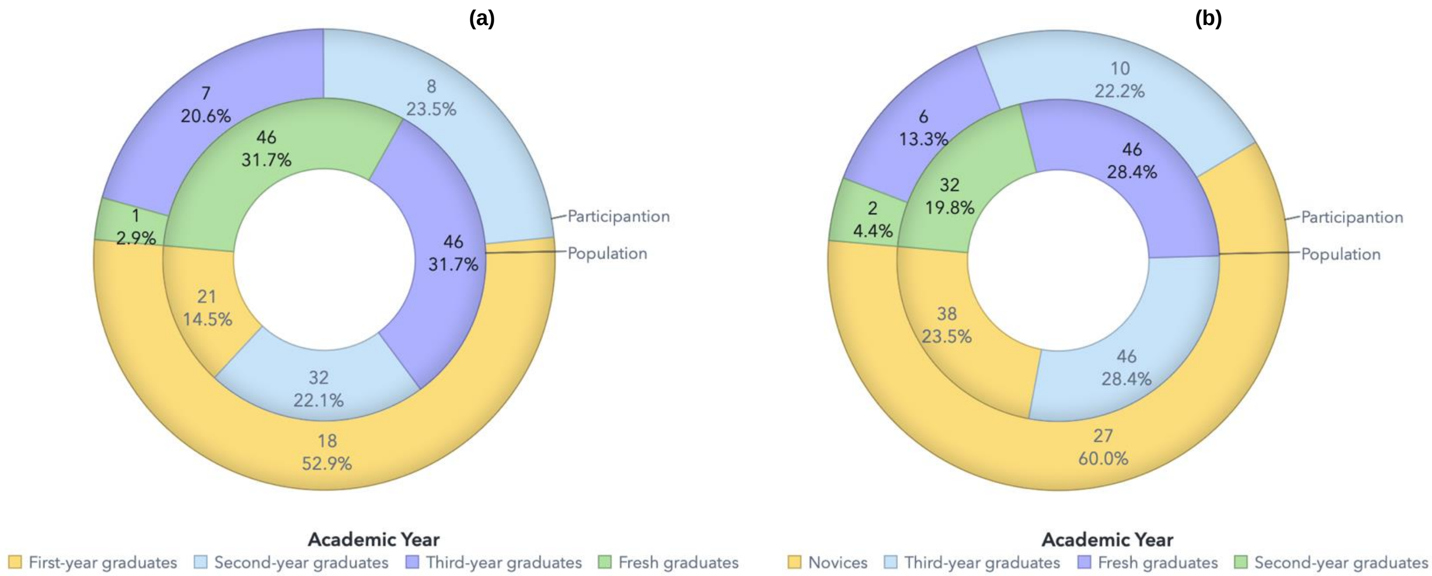

Figure 1: Population and participation sample of the experiment. (a) the sample of Workshop A. (b) the sample of Workshop B. Source: The Authors' Creation via SAS.com

3.3. Curriculum Content

Both architectural workshops have been dedicated to drawing inspiration from Nature to improve the design of structural systems by creating lightweight deployable buildings using the solution-based approach. This approach is based on the design spiral process of biomimicry [47], which involves observing and defining natural elements to enhance students' architectural design skills. Within this framework, students have researched and proposed the use of various types of biological structures [48] such as tension structures [49], skeleton structures [50], bamboo structures (hollow tubes) [51], woven structures inspired by the reciprocal weaving techniques used in bird nests, [52], tree structures [53], and deployable structures using kinematic systems to create lightweight and dynamic buildings that can deform using various positions [54].

3.4. Procedure

During the summer of 2022, at the Department of Architectural Engineering of Fayoum University two biomimicry-based workshops were conducted each for five continuous days. These workshops were open to novices and facilitators who volunteered to participate. Workshop A occurred from July 23 to 27 including a total of 34 participants (18 first-year graduates and 16 facilitators). Workshop B took place from September 4th to September 8th and had a total of 49 participants (27 novices and 18 facilitators). Each commenced with the administration of Kolb's Learning Styles Inventory test (KLSI). During the event, (Figure 2) demonstrated a two-hour open discussion on biomimicry. This interesting topic explored ways to mimic Nature's functionality in various design aspects. Students were given the task of creating a conceptual idea for a deployable lightweight structure. They submitted their sketches and received feedback from the instructors. On the second day, Teams collaborated to integrate natural elements into their designs through sketches and presented their concepts and research findings. They gave feedback, redesigned, and presented physical models to apply biomimicry in architecture.

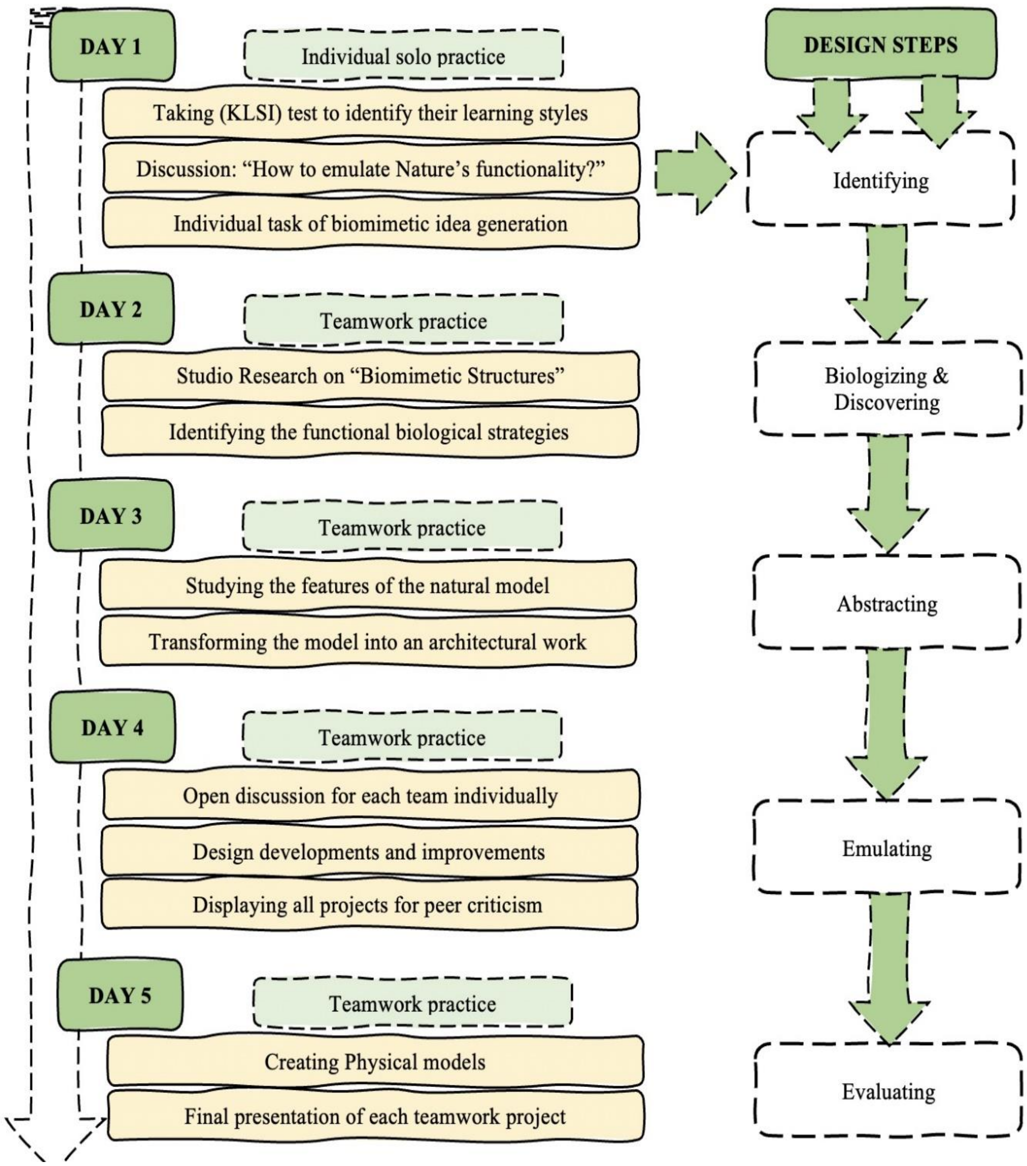

Figure 2: Program of the biomimicry-based experimental workshops.

Source: The Authors' Creation

3.5. Data Analysis

The demographics of the participants by learning style and gender were presented using descriptive statistical analysis, including frequencies and percentages. Using the automated explanation method of Statistical Analysis Software (SAS.com) using data from (Table 4), Appendix A, and (Table 5), Appendix B, the study was intended to find out whether there are correlations between the learning styles and gender of students and their idea generation styles as well as their creativity scores in both workshops. Also, the consistency and reliability were checked for the score results of the CPSS model for the six raters using Cronbach's Alpha value.

4. RESULTS

4.4. Workshop "A"

Out of 34 participants, 58.8 percent were female and 41.2 percent were male. Regarding learning style distribution, the workshop included 13 diverging associates, 10 assimilating associates, 9 accommodating associates, and 2 converging associates. Additionally, the participants' home locality indicated their status of residence outside the city of Fayoum, as illustrated in (Figure 3). The workshop on incorporating a biomimicry solution-based approach into architectural articulation was attended by a diverse group of first-year graduates and facilitators each subjected to the idea- generation task that showed their inclination toward a specific idea-generation style from the four styles, Independent, Effective, Over-Sensitive, and Collaborative.

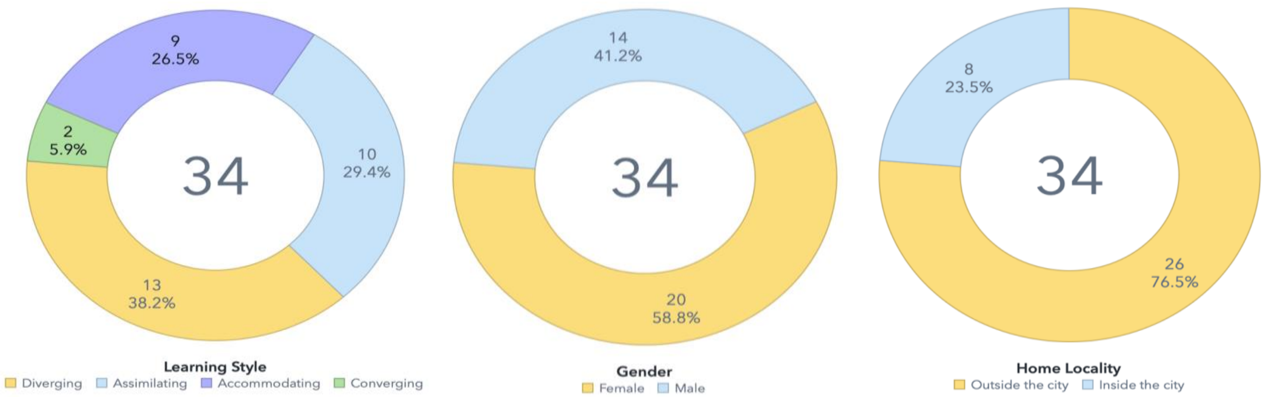

Figure 3: The demographics of Workshop "A" sample. (a) distribution of learning style differences. (b) distribution of gender differences, and (c) distribution of home locality status.

Source: The Authors' Creation via SAS.com

The analysis in (Figure 4) shows how the learning style factor is strongly related to the tendency of idea-generation style. Whereas, most of the diverging participants showed a preference for the over-sensitive idea-generation style, accommodating students used the collaborative idea-generation style even during their individual practice, most assimilating students were observed as effective idea-generators, while the two converging participants used the independent style. On the other hand, the analysis of gender correlation with idea-generation style showed no relevance.

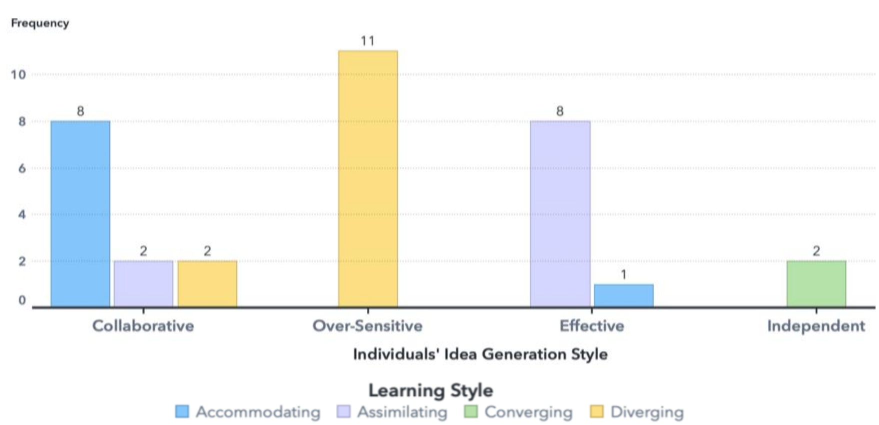

Figure 4: Distribution of learning styles correlation with idea-generation styles in Workshop "A". Source: The Authors' Creation via SAS.com

During their teamwork practice, students formed five groups, as illustrated in (Figure 5). They regularly held both formal and informal meetings to review and discuss potential improvements with one another. The observation made over the four days of teamwork practice showed that the team structure played a vital role in analyzing the design phase and the groups. The letters in the participant's ID indicate their academic level, with "A" representing first-year graduates, "B" representing second-year graduates, and so on. The CPSS scores for the five groups in the workshop indicated that the average CPSS score (45) ranges from 35 to 39, with an overall average of 37. Group 5 scored the highest average of creativity. While the lower score averages were accompanied by the performance of Groups 2 and 4.

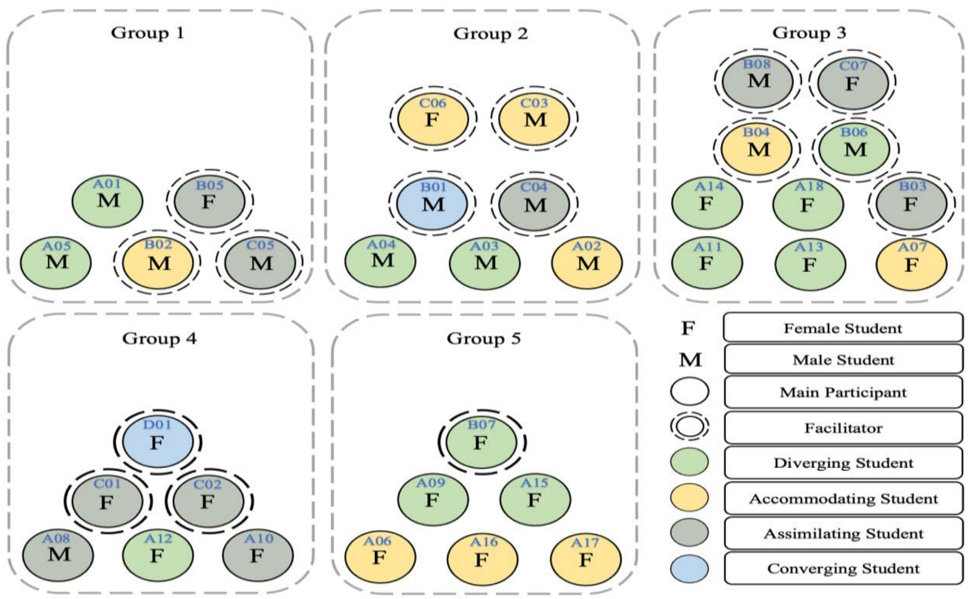

Figure 5: Distribution of participants of Workshop "A" between five groups.

Source: The Authors' Creation

The CPSS average score of Group 5 is (39 out of 45) with a novelty average score of (8 out of 10), a resolution average score of (18 out of 20), and an elaboration average score of (13 out of 15). While each of Group 2, and Group 4 average score is (35 out of 45) with a novelty average score of (7 out of 10), a resolution average score of (16 out of 20), and an elaboration average score of (12 out of 15). Table 2 shows the detailed scores of each group according to six expert raters with a Cronbach's Alpha 0.88, indicating a high level of consistency and reliability in the scores. Furthermore, the study correlating learning styles and gender to the creativity assessment results showed that learning style differences are more related to the CPSS scores than gender differences. However, females had higher scores, with an average score of 37, than males with an average score of 36. (Figure 6) illustrates the correlation between learning style and creativity score. When the learning style is diverging or accommodating the CPSS score is of higher value than assimilating or converging.

Table 2: CPSS scores by six raters for the five groups of Workshop "A"

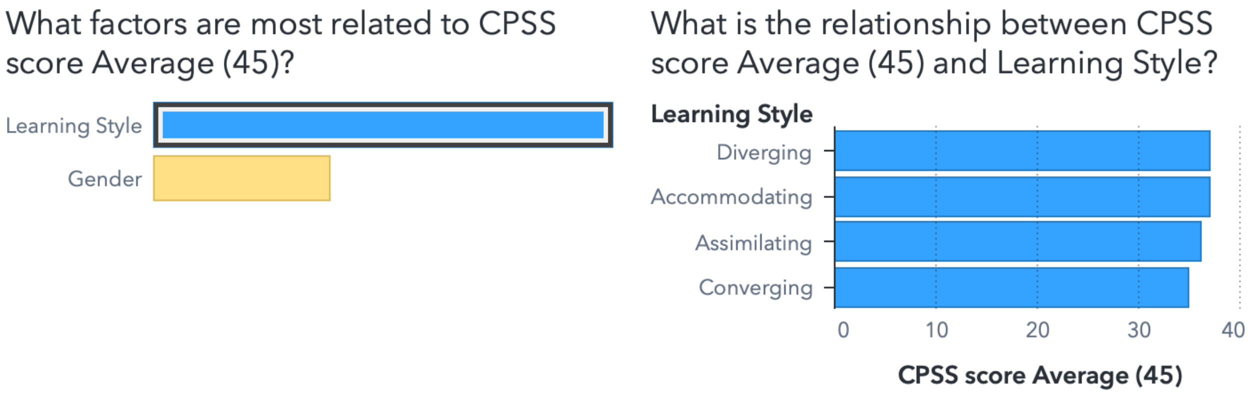

Figure 6: Relating learning style and gender variances to the CPSS score in teamwork in Workshop "A".
Source: The Authors' Creation via SAS.com

Groups	Assessment Dimensions																								
	Novelty						Resolution						Elaboration						Total Score						
	r1	r2	r3	r4	r5	r6	r1	r2	r3	r4	r5	r6	r1	r2	r3	r4	r5	r6	r1	r2	r3	r4	r5	r6	total
g1	8	7	8	9	7	7	17	17	19	18	17	16	14	12	12	12	13	12	39	36	39	39	37	35	225
g2	7	7	6	6	6	7	17	16	16	18	16	17	12	11	11	12	12	13	36	34	33	36	34	37	210
g3	6	6	8	9	7	7	16	17	18	17	16	17	12	12	13	13	12	12	34	35	39	39	35	36	218
g4	7	6	6	7	8	9	14	17	18	17	14	16	11	12	11	13	12	10	32	35	35	37	34	35	208
g5	7	8	9	9	7	9	18	19	19	18	17	17	12	12	14	13	12	14	37	39	42	40	36	40	234

Source: Authors' Computation

4.2. Workshop "*B*"

Out of 45 participants, 51.1 percent were female and 48.9 percent were male. The learning style distribution integrated 19 diverging associates, 14 accommodating associates, 10 assimilating associates, and 2 converging associates. Moreover, the participants' home locality indicated their status of residence outside the city of Fayoum, as illustrated in (Figure 7).

The workshop was attended by a diverse group of novices and facilitators each subjected to the idea-generation task that showed their inclination toward a specific idea-generation style from the four styles, Independent, Effective, Over-Sensitive, and Collaborative. The analysis in (Figure 8) shows how the learning style factor is likely similar to the results of Workshop "A". The study indicated the correlation between idea-generation style and learning style distribution. Whereas, most of the diverging participants showed a preference for the over-sensitive idea-generation style, accommodating students used only the collaborative idea-generation style even during their individual practice, most assimilating students were observed as effective idea-generators. However, some of them administrated the collaboration idea-generation style. While the two converging participants only used the independent style.

Likewise, the analysis of gender correlation with idea-generation style showed no relevance. During their teamwork practice, students formed six groups, as shown in (Figure 9), following the solution-based biomimicry.

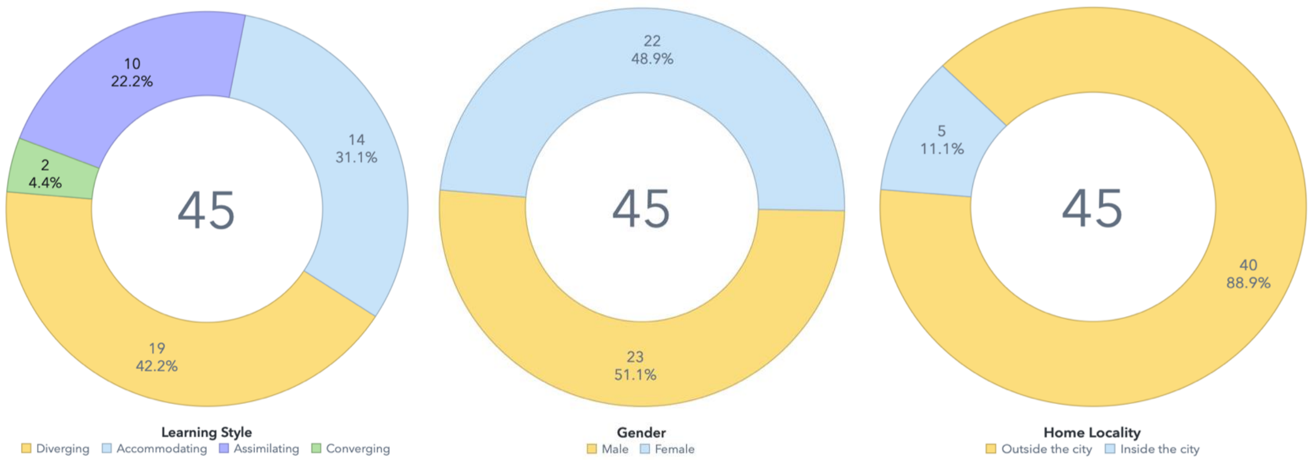

Figure 7: *The demographics of Workshop "B" sample. (a) distribution of learning style differences. (b) distribution of gender differences, and (c) distribution of home locality status.*
Source: The Authors' Creation via SAS.com

The CPSS scores for the six groups in the workshop indicated that the average CPSS score (45) ranges from 32 to 38, with an overall average of 35. Group 5 scored the highest average of creativity. While the lower score averages were accompanied by the performance of Group 6.

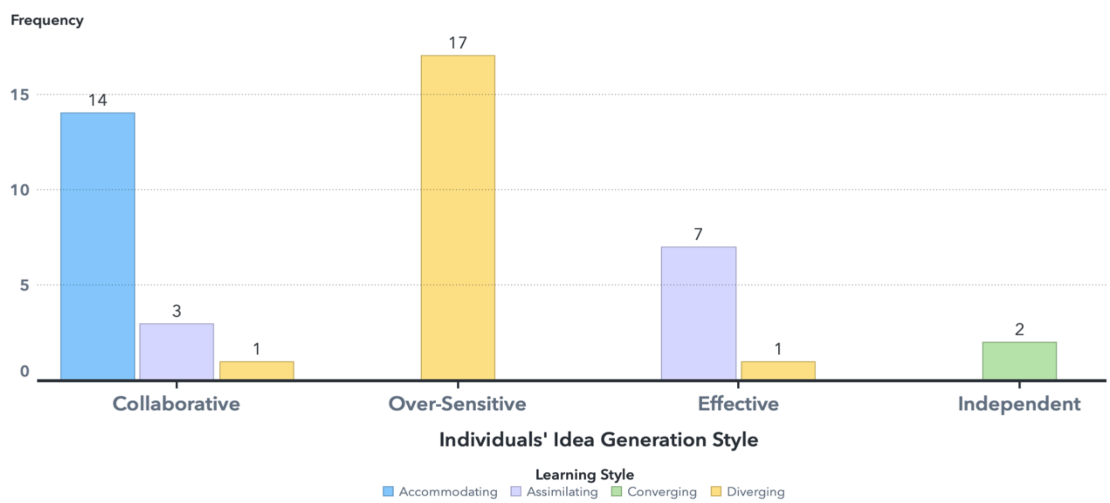

Figure 8: Distribution of learning styles correlation with idea-generation styles in Workshop "B".

Source: The Authors' Creation via SAS.com

The CPSS average score of Group 5 is (38 out of 45) with a novelty average score of (9 out of 10), a resolution average score of (15 out of 20), and an elaboration average score of (14 out of 15). Each Group 6 average score is (32 out of 45) with a novelty average score of (6 out of 10), a resolution average score of (15 out of 20), and an elaboration average score of (11 out of 15). Table 3 shows the detailed scores of each group according to six expert raters with a Cronbach's Alpha 0.81, indicating a high level of consistency and reliability in the scores.

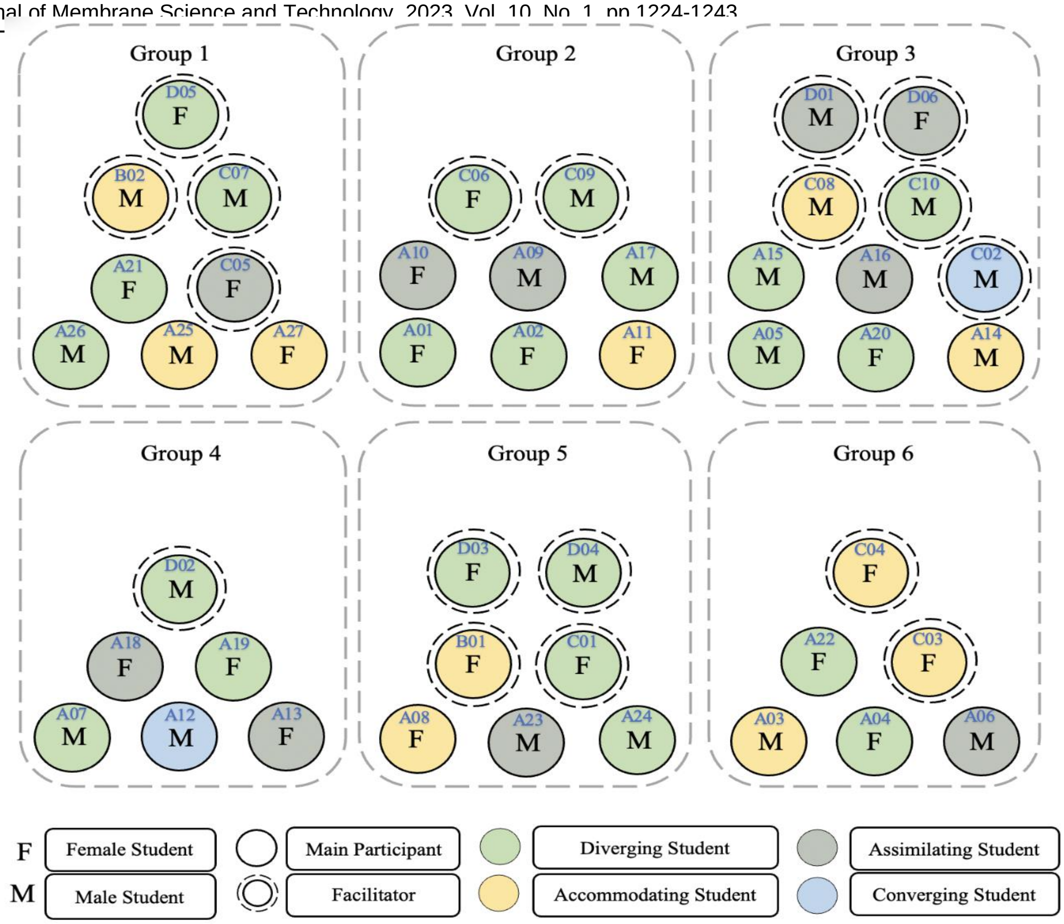

Figure 9: Distribution of participants of Workshop "B" between five groups.
Source: The Authors' Creation

Furthermore, the study correlating learning styles and gender to the creativity assessment showed the same results as the results of Workshop "A". Learning style differences are more related to the CPSS scores than gender differences. Females had higher scores, with an average score of 36 than males with an average score of 35. (Figure 10) illustrates the correlation between learning style and creativity score when the learning style is diverging or assimilating the CPSS score is of higher value than accommodating or converging.

Table 3: CPSS scores by six raters for the six groups of Workshop "B"

Groups	Assessment Factors																								
	Novelty						Resolution						Elaboration						Total Score						
	r1	r2	r3	r4	r5	r6	r1	r2	r3	r4	r5	r6	r1	r2	r3	r4	r5	r6	r1	r2	r3	r4	r5	r6	total
g1	4	8	6	3	8	3	14	17	17	17	16	14	13	13	14	11	12	13	31	38	37	39	36	30	211
g2	5	8	7	8	9	7	16	16	18	19	18	13	14	11	15	14	15	11	35	35	40	41	42	31	224
g3	6	7	6	8	6	8	15	14	14	18	14	13	12	13	10	12	12	14	33	34	30	38	32	35	202
g4	4	7	9	10	9	6	16	15	16	18	18	17	10	12	11	13	15	12	30	34	36	41	42	35	218
g5	9	9	10	9	10	7	14	13	15	16	17	15	14	13	14	14	15	12	36	37	42	39	42	34	230
g6	5	7	6	5	6	4	14	13	16	16	15	14	11	13	11	13	11	12	30	33	33	34	32	30	192

Source: Authors' Computation

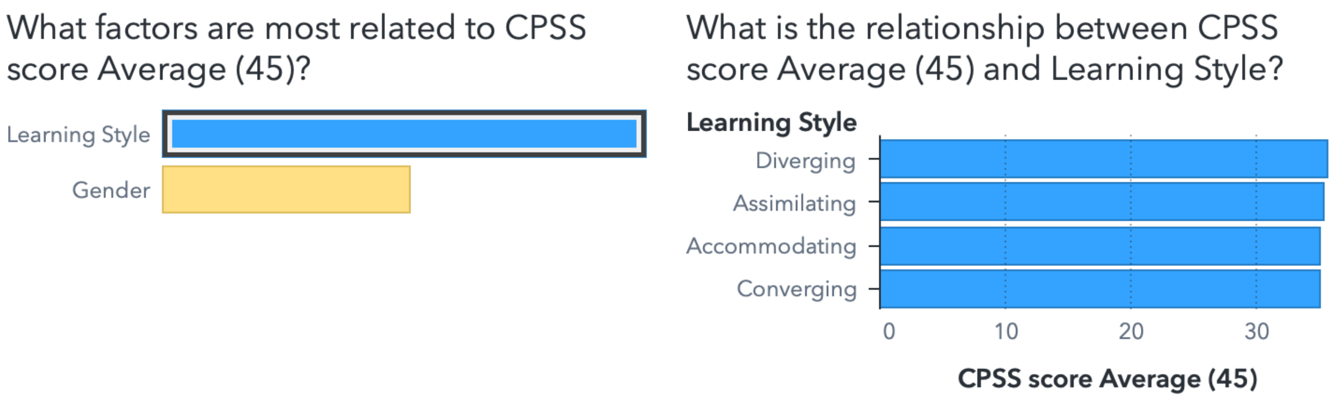

Figure 10: Relating learning style and gender variances to the CPSS score in teamwork in Workshop "B".

Source: The Authors' Creation via SAS.com

3.3. Overall Findings

The analysis based on the case study, containing 79 participants in total, shows a direct correlation between architectural students' learning styles and their idea-generation styles as diverging students tend to be over-sensitive idea-generators, accommodating students tend to be collaborative idea-generators, assimilating students mostly tend to be effective idea-generators and converging students tend to be independent idea generators, as shown in (Figure 11). On top of that, regarding gender correlation with idea-generation style, the analysis indicated a slight relevance of gender to the idea-generation style as females showed more tendency to be collaborative idea-generators on day one of each workshop. As shown in (Figure 12), When the gender is "Female", the total count of collaboratives is 19. When the gender is "Male", the total count of collaboratives is 11.

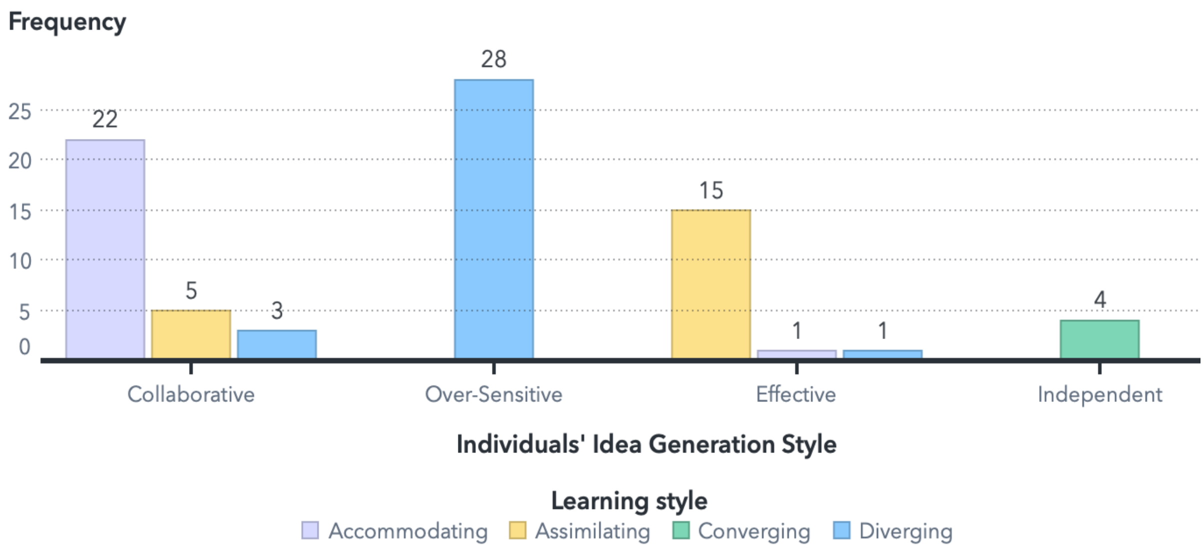

Figure 11: Distribution of learning styles correlation with idea-generation styles in the overall case study.
Source: The Authors' Creation via SAS.com

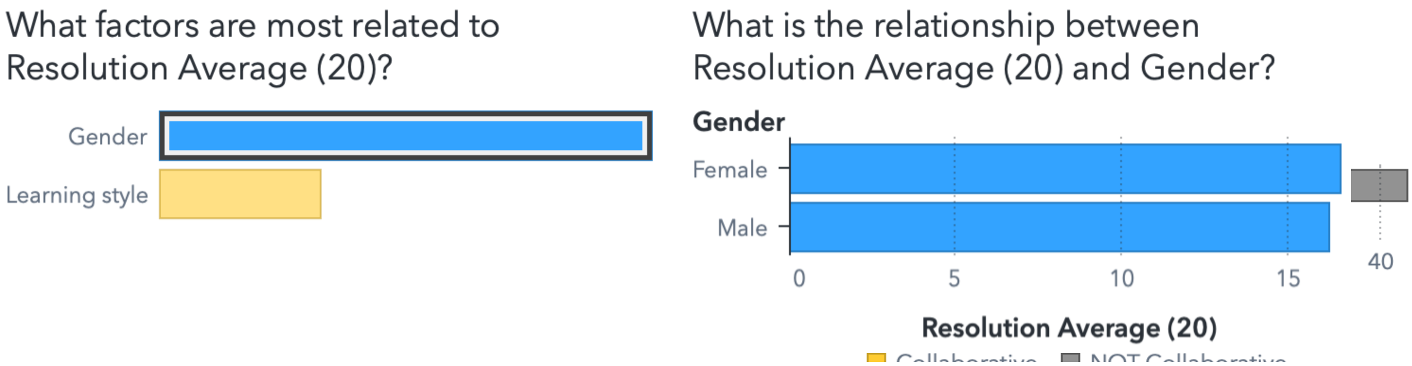

Figure 14: Relating learning style and gender variances to the resolution average score.

Source: The Authors' Creation via SAS.com

On the other hand, the in-depth analysis of the correlation between learning styles and gender of architectural students and their creativity scores in teamwork showed different relevance to each of the creativity dimensions, novelty, resolution, and elaboration. The novelty scores average ranges from 5 to 9 (out of 10) with a mean average of 7. Learning style best differentiates the highest and the lowest scores of the novelty. When the learning style is assimilating, converging, or diverging, the average novelty score is a high value. However, the average novelty score is a low value when the learning style is accommodating, as shown in (Figure 13). Although gender showed much lower relevance to the idea-generation style than learning styles, females remain the ones with higher values than males in all creativity dimensions.

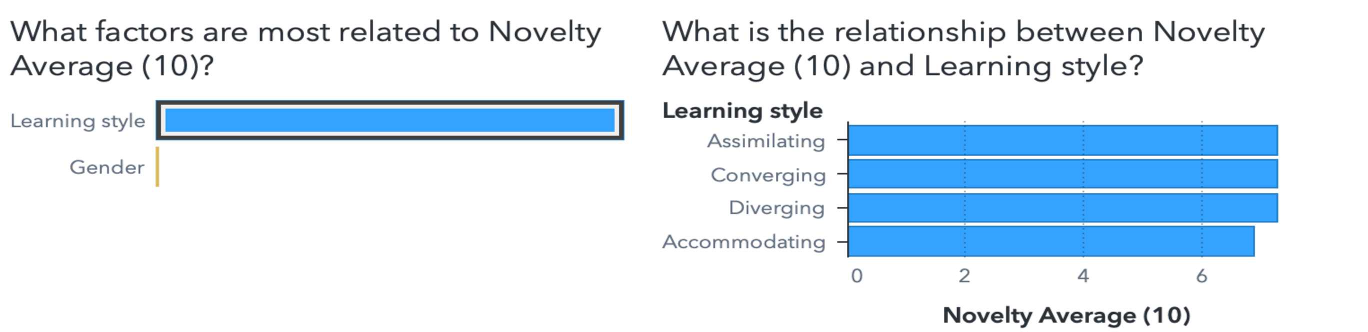

Figure 13: Relating learning style and gender variances to the novelty average score.

Source: The Authors' Creation via SAS.com

The resolution scores average ranges from 15 to 18 (out of 20) with a mean average of 16. Gender best differentiates the highest and the lowest scores of the resolution. When the gender is female, the average resolution score is a high value. However, the average resolution score is a low value when the gender is male, as shown in (Figure 14). Although learning style showed lower relevance to the idea-generation style than gender when learning style is diverging or accommodating, the resolution score average is a high value and when learning style is converging or assimilating, the average is a low value.

The elaboration scores average ranges from 12 to 14 (out of 15) with a mean average of 16. Learning style best differentiates the highest and the lowest scores of the elaboration. When the learning style is accommodating or diverging, the average resolution score is a high value. However, the average elaboration score is a low value when the learning style is assimilating or converging, as shown in (Figure 15). Although gender showed lower relevance to the idea-generation style than learning style, when gender is female, the elaboration score average is a high value and when gender is male, the average is a low value.

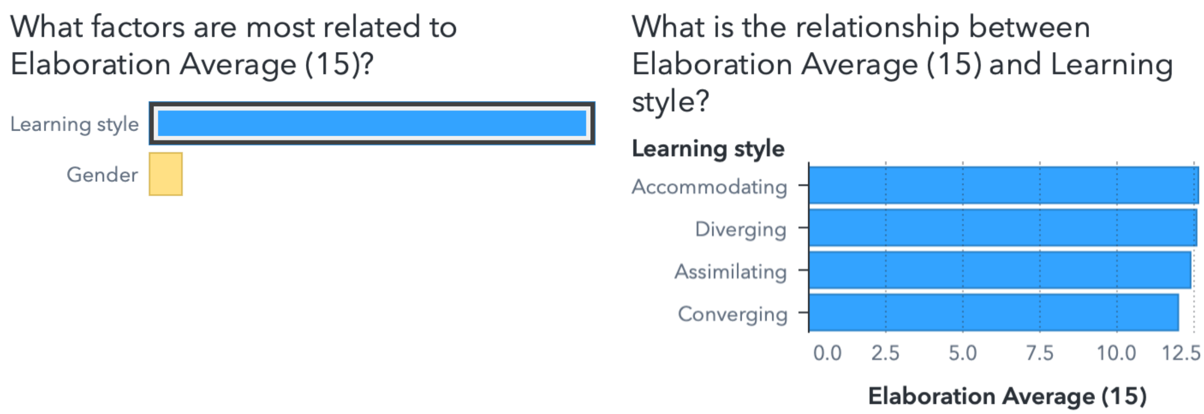

Figure 15: Relating learning style and gender variances to the elaboration average score.

Source: The Authors' Creation via SAS.com

5. DISCUSSION

The aforementioned results, by investigating the correlation between the learning styles and gender of architectural students and their performance in biomimicry-based architectural practice considering their individual idea generation style as well as their teamwork creativity score, provide valuable insights into the field of understanding architectural students' tendencies in their architectural education. These insights have been exposed by analyzing the study results according to the research questions.

RQ1. How do individual differences in learning style and gender among architectural students relate to their idea generation style?

In light of the findings of day one in both workshops, the study clearly stated the direct relevance of a student's learning style to his idea-generator style. First and foremost, although the most direct correlation appears in the converging students' tendency to be independent idea-generators, the limitation of the small sample of converging students in the case study (only four students) questions the reliability of this result. On the contrary, the sample of diverging students, which represents 41 percent of the case study sample, indicated their tendency to mostly be over-sensitive idea generators. Assimilating students are effective idea generators while accommodating students prefer collaborative idea generation. These findings align with a study conducted in Turkey indicating the following description for each idea-generation style. Participants in the study fell into four categories when it came to generating ideas: independent, collaborative, over-sensitive, and effective. Independent idea generators were highly motivated and explored their ideas. Collaborative generators were open to others' ideas but still came up with their own. Over-sensitive generators struggled to initiate the process and were too concerned with their peers. Effective generators use the studio setting to generate and communicate ideas [25].

Unlike the more evident correlation between learning styles and idea-generation styles, it is difficult to determine a clear connection between a student's gender and his/her preferred idea-generation style except for the tendency of females to be collaborative idea generators. This exception supports the idea that females require more time and effort to develop their architectural ideas [21]. However, the exception made by the tendency of females to be collaborative idea generators differs from the findings confirmed by a study conducted using a sample of 230 students from the University of Queensland which indicated that gender bias has no relevance in generating ideas [14].

RQ2. How do learning style and gender affect teamwork creativity scores in the realm of biomimicry?

The overall analysis of students' creativity scores according to the CPSS technique revealed the diversity of the results according to three dimensions, novelty, resolution, and elaboration. Each included a separate case. In the cases of novelty and elaboration, students' learning styles were found to be more related to the scores than gender which barely has any dominance over the novelty scores. In the case of resolution, gender was found to be more related to scores than learning style. However, the study indicated the higher scores of females in all cases.

In addition, the learning styles of diverging or accommodating were combined with higher scores in resolution and elaboration which aligns with the findings of the literature studies conducted on the performance of diverging students [2] and the four learning styles [19], while the learning styles of assimilating or converging were combined with the higher scores in novelty which completely agree with the previous study findings that indicated how the two learning styles are more successful in unconstrained tasked and interested in creating new ideas [19]. Also, the findings intersect with the study indicating how accommodating students adopted better performance than converging and assimilating students as the effect of the novelty score on the overall creativity score in the CPSS technique is limited, 10 points out of 45 [11].

Further research is needed to explore the link between learning styles, gender, idea-generation styles, and creativity scores of architectural students. A larger sample size from various universities would provide more reliable results. Longitudinal studies could monitor changes in learning and idea-generation styles and their impact on creativity. This could lead to educational interventions to foster and enhance students' creative achievements throughout architectural education.

CONCLUSION

This research investigated the correlation between architecture students' learning styles, gender, and academic performance in biomimicry's architectural articulation. To fill the gap in the literature of overlooking the implications of students' differences on their creativity responses to the multidisciplinary practice of biomimicry. Through a case study approach with a sample of 79 architectural students, it was found that learning styles greatly influence idea generation style preference and creativity performance in teamwork. Specifically, diverging learners demonstrated sensitivity, accommodating learners exhibited collaboration, assimilating learners displayed effectiveness, and converging learners preferred independence. Additionally, the analysis explored the relationship between gender and idea generation style. While gender showed a slight association with idea-generation style, females exhibited a higher inclination towards being collaborative idea-generators during the initial stages of each workshop than males. This finding suggests that gender might have some influence on the preference for idea generation style, although to a lesser extent than learning style.

The study also found that the three factors of creativity, novelty, resolution, and elaboration scores differed based on learning style. Notably, the novelty scores displayed the most substantial differentiation based on learning style. Assimilating and converging earning styles were associated with higher novelty scores while the accommodating learning style correlated with lower novelty scores. Besides, gender exhibited a stronger association with creativity scores in resolution. Females consistently achieved higher resolution scores, whereas males obtained lower scores in this aspect. Similarly, when it came to elaboration scores, learning style had a greater impact, with accommodating and diverging styles showing higher scores, while assimilating and converging styles correlated with lower scores.

The findings of this study have significant implications for educators and practitioners in the field of architecture. Firstly, it highlights the importance of understanding the different learning styles of architecture students and how they impact their preferences for idea-generation style and creative responses to interdisciplinary practices in architecture such as biomimicry. Therefore, educators should take into consideration the learning styles of their students when designing tasks and facilitating teamwork, as it greatly influences their idea generation style preference and creativity performance. Furthermore, when engaging in collaborative idea generation, it is critical to take gender differences into account.

Research has demonstrated that female participants tend to display greater collaboration during the initial stages of workshops. This finding underscores the importance of educators being mindful of such differences when working to promote teamwork among students. Furthermore, the study revealed that creativity scores in novelty and elaboration were more closely tied to learning styles, whereas resolution scores were more strongly associated with gender. As a result, a more inclusive and personalized approach to creativity and biomimicry learning in architecture education is necessary considering both learning styles and gender to assess and encourage creativity in their students effectively.

Limitations And Future Research

Although significant results were found, there are some limitations to this research. The data was collected only from one university, and the sample size was small. Additionally, creativity assessment relied on teamwork, which may have affected the study's reliability. The self-reported KLSI questionnaire used in the study may also have an impact on the validity of the findings. To improve the external validity of the results, future research should include larger, more diverse samples, longer durations, and separate assessments of individual performance. In Summary, the study has comprehensively analyzed the relationship between learning styles, gender, and biomimicry performance among architectural students.

The findings of this study provide valuable insights into how architectural curricula for biomimicry can be tailored to better support diverse populations. By addressing a range of learning styles and gender differences, educators can create a more inclusive and effective learning environment for architectural education. These insights can help to inform the development of more personalized and effective curricula that can support the success of students from all backgrounds.

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Author Contributions

The authors designed the protocol, collected specimens, followed up on cases, took history, analyzed results, and fulfilled inclusion/exclusion criteria together.

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

Data Availability

Data will be made available on request.

CONCLUSIONS

The current-voltage curves were obtained from the chronotenograms and the values of the limiting current density of the membrane-solution systems were determined. Also, the difference between the transport number of the counterion in the membrane and in solution were studied. The apparent fraction of conductive area of the CEM was determined. (ε = 0.7955) in 0.01 M NaCl solution using chronopotentiometry, confirming that not all of the MIC surface participates in counterion transport. Finally, for the CaCl2 0.02 M - CEM (MK-40) system, the limiting current density was determined. (1.42 mA/cm2) and the transport numbers of Ca2+ in the solution (ts 2+ = 0.437) and in the membrane (tm 2+ = 0.976). It is concluded that the fraction of electric current density carried by Ca2+ in solution is lower than that carried by Cl-, but it is much higher in MIC. According to Sarapulova et. al. [22] the transport number for a CaCl2 0.02 M - CEM (MK-40) system is close to 0.98 which is in agreement with the present study.

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