

Retraction Notice

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Correction: yes, date: yyyy-mm-dd X no

Comment:

The paper is withdrawn from "Creative Education" due to personal reasons from the corresponding author of this paper.

This article has been retracted to straighten the academic record. In making this decision the Editorial Board follows COPE's <u>Retraction Guidelines</u>. The aim is to promote the circulation of scientific research by offering an ideal research publication platform with due consideration of internationally accepted standards on publication ethics. The Editorial Board would like to extend its sincere apologies for any inconvenience this retraction may have caused.

Editor guiding this retraction: Anita LIU (Editorial Assistant of CE)



A Study on Bionic Design Approach to Sustainability of Product Design STEM Project-Based Learning

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Abstract

This study introduced biomimicry to the curriculum of the design department of a university in Tarwan. This study considered 168 students as its subjects and carried out a six-week sustainable bionic product design based n STEM & PBL activities. The activity design regarded STEM integrative thinking as the mainstay, combined PBL learning strategies, and offered an environmental protection course on sustainable bionic design to the students. Teachers assisted in promoting the study of the students. This study adopted both qualitative and quantitative analysis methods. It used qualitative content nalysis method to explain the performance of students and interviewed their felings. The conclusions were as follows: 1) The STEM & PBL curriculum integrated knowledge in science, technology, engineering, and mathematics; 2) the integration of STEM activities with the teaching of bionic design had a positive influence on the naturalist intelligence and bionic design ability of the undergraduates; 3) the STEM & PBL curriculum had a positive and significant impact on the learning effectiveness of environmental protection education; and 4) the teaching model for STEM & PBL curriculum had five major integrative characteristics, including STEM and PBL. Based on the conclusions, this study proposed suggestions on teaching and for future relevant studies.

Keywords

Bionic Design, Product Design, Project-Based Learning, STEM, Sustainable

1. Introduction

While enjoying the benefits of economy and technology, individuals face the dilemma of resource exhaustion from limited resources and increasingly serious problems of environmental pollution and climate change. The issues of global warming, resource depletion, and waste disposal are affected by commodity design (Packard & McKibben, 1960). Design aims to make life better. However, as more and more products are manufactured, rubbish, environmental damage, and resource depletion follow. Van der Ryn and Cowan (2013) argued that some environmental problems have arisen from design problems. Papanek and Fuller (1972) asserted that designers should shoulder the responsibility of global environmental protection. No designer can avoid the topics of how to establish the concept of environmental protection, import sustainable design, and maximize the value of products and resources. Therefore, environmental protection education that has sustainable design as the mainstay cannot be ignored by students majoring in design.

It has become a major policy for many developed countries to train students with science, technology, engineering, and mathematics (STEM) capabilities and encourage them to work in the field of science (Stets et al., 2017; Park et al., 2018). STEM integrative education has become an educational trend globally. STEM curricula are designated to provide students the knowledge, attitude, skills, and abilities to solve real-world problems and help them face the rapid changes in the 21st century (Bybee, 2013). The characteristics of STEM lie in that, through engineering design, it demonstrates the use of scientific exploration and mathematical analysis, and it provides students with the experience to solve interdisciplinary problems in a systematic manner (Kelley, 2010). The implementation of STEM curricula stresses discipline integration and connection with life experience (Bybee & McCrae, 2009). STEM curricula must focus on concerning and reflecting on real-world issues and triggering the deep thinking f students (Fan & Yu, 2016). This study centered on environmental protection education to design the curriculum and regarded STEM as the core of the integration. It regarded the life experience and problems of students as topics and sustainable bionic product design as the theme to prepare the curriculum, developed a teaching model based on problem-solving and discovery, encouraged students to actively participate, and made full use of existing environmental resources to find solutions to the problems.

In response to the current system and status quo of education, STEM curriculum design must maintain the original curriculum structure of all disciplines and focus on subject-oriented learning activities (Lou et al., 2017). PBL is an integrated curriculum. After learning relevant theories and having practiced via professional courses, students can receive the curriculum to learn abilities in organization, application, integration, innovation, and R&D (Lou et al., 2011). STEM curricula should provide students with meaningful and real learning scenarios. Through engineering design, students are guided to integrate systematic thinking of scientific exploration and mathematical analysis during prob-



lem-solving and apply scientific tools and techniques so as to achieve the objectives of the STEM curriculum (Fan & Yu, 2016).

In view of this, STEM curriculum design must pay attention to the connection with real-world problems or scientific and technological issues. This study combined STEM integrative education thinking with PBL strategies to conduct environmental protection education centering on sustainable bionic design, carry out sustainable bionic product design based on STEM & PBL activities, guide students to face and improve the issues in their daily lives, and cultivate their problem-solving abilities. It probed into the learning effectiveness of students majoring in design in STEM & PBL-based environmental protection education. Furthermore, it explored the improvement in naturalist intelligence and bionic design ability of undergraduates who received the bionic course integrated with STEM activities. Finally, it set up a teaching model for environmental protection education integrating STEM & PBL into sustainable design.

2. Literature Review

2.1. Science, Technology, Engineering and Mathematics (STEM)

STEM (science, technology engineering, and mathematics) refers to the integration of scientific exploration, technology engineering design, and mathematical analysis (Lou, 2017).Science refers to the exploration of principles of nature. Engineering stands for commodity design based on scientific knowledge. Technology means the production of commodities through science and technology. Mathematics refers to analysis and statistics with scientific methods (Lou et al., 2013). STEM curriculum planning generally has several significant characteristics. 1) It considers real-world issues or problem scenarios as the background; 2) curriculum design is mainly subject- and problem-oriented and inquiry-based; 3) it has clear curriculum objectives, scope of content, and competence indicators; 4) it provides a learner-centered learning experience; 5) it emphasizes knowledge integration and application of the disciplines of STEM; 6) it stresses the cultivation of high-level thinking abilities such as logical thinking, problem-solving, and critical thinking; and 7) it pays attention to the connection between curriculum and workplace (Fan & Yu, 2016).

As a result, this study regarded STEM integrative education as the framework for the curriculum design of environmental protection education. It employed a cooperative learning model that considered two to three students as a group, guided students to apply science and technology and scientific thinking to solve environmental problems in their daily lives, assisted students in learning with a variety of IT tools, and adopted multiple assessments to evaluate the students' learning outcomes in order to achieve the objectives of environmental protection education.

2.2. Project-Based Learning (PBL)

Project-based learning (PBL) is a model that organizes learning around projects



(Thomas, 2000). PBL allows students to turn real-world problems into cases for interpretation and resolution (Barrows, 2000). PBL is student-centered and holds that there is no correct answer to a problem. The definition of a project (for students) must "be crafted in order to make a connection between activities and the underlying conceptual knowledge that one might hope to foster." (Barron et al. 1998). In a collaborative group, students work and learn independently and apply their new knowledge to solve problems (Hmelo-Silver, 2004). A teacher plays the roles of course designer, learning facilitator, and process evaluator in PBL (Chen, 2002).

During the design of the environmental protection education course, this study referred to PBL, developed the sustainable bionic product design program from the perspective of a learner, and emphasized strengthening and training the students' problem-solving abilities, with teachers providing assistance to students only if necessary.

2.3. Environmental Protection and Bionic Design

The core problem-solving concept of biomimicry stems from learning from organisms which adapt to the environment and survive. It then skillfully applies the underlying scientific principles to improve or invent products (Benyus, 2002; Chou, 2013). Bionic design capability can be regarded as the ability to solve environmental problems. Environmental education should enhance bionic design (Cattano et al., 2010). Lucas (1980) proposed that environmental education has three parts: learning from the environment in person, learning relevant environment, and learning for the environment, all of which begin with naturalistic observation.

Bionic inventors' design ability and inspiration come from long-term and in-depth naturalistic observations (Eggermont, 2011) and bionic analogy and association. Staples (2005) suggested that teachers should provide appropriate examples to students, and regarded the introduction to bionic cases as a scaffolding. Students conduct a case study, while teachers provide course resources in order to cultivate bionic analogies and associations, as well as the students' product design abilities. Bionic design can serve as a bridge between design and other relevant sciences. Thus, it plays a prominent role in the development of product design (Neurohr & Dragomirescu, 2007). This paper integrated STEM activities into bionic design and explored how to improve the academic performance in the environmental protection education of students majoring in design with STEM activities and the procedures of the biomimicry curriculum.

In a nutshell, this study, through sustainable bionic product design based on STEM & PBL activities, hoped to raise the awareness of environmental issues of students and lay a solid foundation for the view of environmental protection based on sustainable design. In addition to environmental knowledge, it aimed to cultivate the students' attitude toward and value of use and choice of sustainable products and facilitate students to develop a correct attitude of environmental protection and sustainable development.



3. Research Methodology

3.1. Research Process

This study considered 168 freshmen who attended the course titled Introduction to Design of the design department of a university in Taiwan as its subjects, planned the STEM & PBL environmental protection education curriculum, and designed sustainable bionic product designs based on STEM & PBL activities. The research process is shown in **Figure 1**.

This study introduced STEM & PBL and guided students to apply knowledge in environmental protection education to carry out sustainable bionic product design. Lastly, it implemented a questionnaire on academic performance and presented the works of the students so as to learn the design concepts and experience of each group and promote peer exchange and learning.

3.2. Research Method and Tools

This study mainly employed a qualitative and quantitative research design consisting of interviews and questionnaires, as well as the content analysis method



Figure 1. Research flowchart.

for qualitative analysis to explore the process files written by the students, including process file A on the students' selection and analysis of bionic design cases and process file B on the students' hands-on bionic design. It referred to and revised the process files A and B of Chow and Wang (2016). The questions in the student process files were consistent with the checklist. By viewing the process files, it was possible to check the students' knowledge in biomimicry and application of bionic knowledge and skills. In terms of the practice files, three teachers scored the process files rated by the three evaluators was 0.35 (p < 0.00), 0.14 (p < 0.05), and 0.17 (p < 0.01), respectively, indicating that the evaluation results of the three evaluators were highly correlated, significant, and consistent.

A questionnaire was adopted for quantitative analysis. The Questionnaire on the Learning Effectiveness of Energy-saving Education Based on STEM & PBL developed by Lou (2017) which was revised into the Questionnaire on the Learning Effectiveness of Environmental Protection Education Based on STEM & PBL. The questionnaire contained three dimensions, namely, STEM learning (six questions), PBL learning (eight questions), and environmental protection learning (six questions). There was a total of 20 questions. The Scale for Self-inspection of Naturalist Intelligence and Bionic Ability of Students of Chow and Wang (2016) was referred to and revised by this study. The questionnaire covered two dimensions, that is, naturalist intelligence (seven questions) and bionic design ability (16 questions). There was a total of 23 questions. After the activities were completed, all the students involved filled in the questionnaire. In this way, this study could determine their learning effectiveness. Additionally, this study adopted the semi-structured interview method. It randomly sampled and interviewed the students to discover their learning process during the STEM & PBL environmental protection education activities and group interactions.

The teaching plan was designed in line with the STEM & PBL environmental protection education curriculum developed by this study. It guided the students to learn the environmental protection education curriculum from the three dimensions of cognition, affection, and skill so as to reach the objectives of each unit, as shown in Table 1. In this way, it enhanced the academic performance of the environmental protection education of the students.

In addition, this study extended skill-based courses and designed sustainable bionic product design based on STEM & PBL activities to cultivate the knowledge and abilities of students related to environmental protection education, as shown in **Table 2**. Accordingly, it designed STEM activity tasks that requested the students to complete design in line with the objectives and find the best design plan. Finally, the drawings, presentations, and evaluations of the sketches of bionic design were completed. This study conducted qualitative and quantitative analysis and discussion as the reference basis for the establishment of a teaching model for the STEM & PBL environmental protection education curriculum.

In regard to the collection of process data, in order to fully record the learning process of each group of students, this study utilized the iLMS integrated digital



Aspect	Unit Objective	Behavioral Objective
	1-1 Understand the relationship between individuals and the environment	1-1-1 Explain the relationship between individuals and the environment 1-1-2 Explain the definition and development of sustainable design
	1-2 Understand sustainable product design	1-2-1 Explain the relationship between sustainable design and product design
Cognition	1-3 Understand bionic design	 1-3-1 Explain the types and corresponding definitions of bionic design 1-3-2 Explain the relationship between bionic design and applied biological characteristics 1-3-3 Analyze the biological characteristics used in product design
	1-4 Understand bionic design	 1-5-1 Identify the mechanisms and principles of biological adaptation 1-5-2 Observe and analyze bionic products and biological adaptations 1-5-3 Describe the problems to be solved via bionic design
	1-5 Understand the composition of aesthetic principles of product design	1-6-1 Explain the proportion of bionic design 1-6-2 Explain practical aesthetics (function, structure, interface, and texture)
Affection	2-1 Raise the awareness of sustainable product design	2-1-1 Recognize the importance of sustainable product design to sustainable environmental development
	2-2 Develop students' independent thinking abilities	 2-2-1 Propose one's own opinions and views in the case study of bionic product design 2-2-2 Identify the characteristics of species and make analogies and associations of corresponding relationship by observing the structure of organisms
Skill	3-1 Cultivate sustainable bionic product design abilities	 3-1-1 Correctly choose outstanding life characteristics and integrate them into sustainable product design 3-1-2 Design and develop products based on the analogy and association of biological characteristics to solve problems

 Table 1. Teaching plan and objectives of environmental protection education curriculum.

Table 2. Process file B on students' hands-on bionic design (independently selected bionic design) for student B38.

Process fi	e B on students' hands-on bionic design (independently selected bionic design)
Title	Seahorse buoy
Design purpose	Most buoys are practical rather than decorative. It is common to see a buoy with a broken string floating at the seaside. Via this design, such lost buoys can become decorations rather than waste. As they are made of PHI, they are naturally degradable.
Biological properties	A seahorse moves upright in the sea.
Adaptive mechanism and principle	A seakorse often moves upright in the sea, and so does a buoy. A buoy maintains balance by its center, while a seahorse has a raised and filiform structure.
Design description	Because it is an artificial seahorse buoy, some weight must be added to the bottom of the center, like a regular buoy, so that it can maintain balance and remain upright in the sea.
Drawing	Draw a sketch on product improvement or innovation. Some weight must be added to the bottom of the center so that it emain upright in the sea. Hipp ocam pus buoy

campus learning system to offer a student-centered real-time collaborative learning environment. It also provided the teachers with a complete curriculum management mechanism. Via the system, the teachers could collect and upload data on student interaction and discussion, correct the students' homework, and offer timely guidance and assistance to the students.

4. Data Results and Analysis

1) Analysis of the STEM & PBL environmental protection education course

a) Science-PBL: This study used scientific knowledge to guide the students to understand the principles of outstanding biological characteristics to solve actual problems.

The students applied their basic knowledge of environmental protection to discuss the topic of sustainable bionic product design and propose several directions for thinking, such as the use of recycled materials, solving the problem of water shortage, and reducing marine litter. The students of different groups started to design, learn or apply various scientific principles, such as control, chemical, and mechanical biomimicry. Overall, in the activities for STEM & PBL environmental protection education, the learning of science and the ability goals set up by this study were consistent. In addition, after they selected and analyzed bionic design cases by themselves and created a bionic design, the students better understood science principles. During production, they also gained empirical knowledge which they could apply to their daily lives.

B61: Although I had knew that a honeycomb was hexagonal, I did not know about its principles or associate it with products. I am delighted to attend the bionic product design activities so that we can apply the principles to design environmentally friendly products and better understand the principles and connotations of biological characteristics.

B12: A scarab probe can control electricity consumption and improve overloads. The characteristic of protective coloration was applied to the design of a socket. The socket can change color along with the current so as to effectively control electricity consumption and ensure safety. In case of an overload, the socket will change color and sound an alarm to remind users to lower the current.

b) Technology-PBL: Through hands-on design, the students identified and selected outstanding life strategies for bionic product design and set raw materials for products.

After the students discovered problems, the teachers adopted PBL teaching strategies to allow the students to observe, identify, select, and apply solutions. Lastly, by practical strategies, the teachers promoted the students to propose and draw sketches of bionic product design. Thus, the students learned techniques of bionic design. For instance, they could understand the mechanisms and principles of the biological adaptation features used and describe their idea of bionic product design. Moreover, during bionic product design, the students discovered the problems of current eco-friendly product designs and materials and ap-



plied their experience to solve the problems.

*B*38: Octopus sucker bathroom appliance: The suction principle of octopus tentacles was applied to design an environmentally friendly bathroom product. The product is both interesting and easy to store. The application of PLA can reduce the environmental pollution caused by toothbrushes, as shown in Figure 2.

A15: Allochroic and invisible winter clothes: Such clothes can protect divers from being mistaken by predatory fish such as sharks as their prey and prevent them from being attacked. Hence, we utilized the principle of discoloration of chameleon skin and the structure of shark skin and adopted recycled and blended polyester fiber to produce the elastic and anti-cold clothes, as shown in Figure 3.

550



Figure 2. Octopus sucker bathroom appliance.



c) Engineering-PBL: Through the innovative design and development of works, the students were inspired to solve problems.

During sustainable bionic product design, the students created designs by considering the function and structure of products, such as application scenarios and product styling. The students collected materials, conducted innovative design, and drew and compared sketches to make sustainable bionic products that were beautiful and stylish. For instance, they drew appearance sketches or corrected the selected materials. During the design process, the students collected data from the Internet, had group discussions, drew structure charts and designed product appearances based on biological characteristics. They gave full play to their creative thinking, drew sketches of bionic products, and wrote process file B on the students' hands-on bionic design (independently selected bionic design), as shown in Table 2 and Table 3

d) Mathematics-PBL: Diversified mathematic problem design to enhance the students' abilities in analysis and inference

Mathematical principles were applied to the project. The students used their experience of using products in daily life and the proportion principle (function and structure) for product design. For example, they needed to mark the size of the product and that of each functional structure. However, this study found

 Table 3. Process file B on students' hands on bionic design (independently selected bionic design) for student A61.



that the students of the design department were not proficient in making specification marks on their product sketches, because the curriculum lacked content on mathematical analysis and scientific exploration. Merrill et al. (2008) pointed out that in order to incorporate concepts of engineering into science and technology curricula, teachers must guide students to apply mathematics and scientific knowledge and improve their hands-on engineering design abilities.

A06: The honeycomb mobile cover utilizes the hexagonal structure of a honeycomb. The hollow structure can disperse pressure and impact, as shown in Table 3.

A16: Leaf cutlery: It takes at least 73,000 days for a general plastic plate to be degraded in nature. However, the leaf cutlery can automatically decompose and be converted to fertilizers that nourish the earth within 28 days.

2) Analysis of the Questionnaire on the Learning Effectiveness of STEM & PBL Environmental Protection Education

A total of 168 students participated in the course and filled in the Questionnaire on the Learning Effectiveness of STEM & PBL Environmental Protection Education. After invalid feedback was excluded, a total of 125 valid responses were recovered. The details are described below.

a) Analysis of STEM learning

In terms of STEM learning, the average score for each question was above 3.40 and reached a significant level. The average of the overall dimension was 3.59, implying that most of the students agreed that the activities could help them improve their STEM learning outcomes. The top three questions with the highest scores included A3: after participating in STEM activities, I have a different opinion of and attitude toward STEM (M = 3.77, SD = 0.75); A4: I think that the STEM program can enhance my learning motivation of and interest in the theme activities (M = 3.68, SD = 0.75); and A1: I think that STEM activities are interesting (M = 3.62, SD = 0.84). The findings indicated that most of the students felt that the curriculum could improve their quality of STEM, as well as their learning motivation of and interest in the curriculum activities. Specifically, the implementation of the STEM curriculum with learner-centered teaching strategies could help students more specifically detect the connection between scientific & mathematical knowledge and engineering design (Clark & Ernst, 2008; Merrill et al., 2008; Schnittka & Bell, 2011).

b) Analysis of PBL learning

Terms of PBL learning, the average score for each question was above 3.43 and reached a significant level. The average of the overall dimension was 3.63, indicating that most of the students agreed that the activities could help them improve their PBL learning outcomes. The top three questions with the highest scores included B5: I think that the activity design is very interesting and associated with the actual situation of life (M = 3.78, SD = 0.71); B8: The teaching materials have given me a very important learning experience (M = 3.77, SD = 0.77); and B2: The tasks of each unit allow me to have deeper understanding of relevant knowledge (M = 3.73, SD = 0.79). The findings demonstrated that most



of the students believed that sustainable bionic product design based on STEM & PBL activities could stimulate their learning motivation. With respect to the design of teaching materials, the teachers explained the cases, and the students then selected cases by themselves and had hands-on design practice so as to acquire knowledge and application related to adaptive mechanism and bionic design, as well as engage in important practical learning experiences. A STEM curriculum should focus on concerning and reflecting on real-world issues and triggering the deep thinking of students (Fan & Yu, 2016). Real situation learning is a core concept of integrated curriculum and key to promoting students to participate in interdisciplinary curricula (Bybee & McCrae, 2009).

c) Analysis of environmental protection learning

In regard to environmental protection learning, the average score for each question was above 3.57 and reached a significant level. The average score of the overall dimension was 3.74, indicating that most of the students agreed that the activities could help them improve their environmental protection learning outcomes. The top three questions with the highest scores included C2: I can understand what environmental protection is (M = 4.56); C5: I know how to apply sustainable design effectively to design (M = 4.44), and C6: I can understand the relationship between sustainable design and environment. (M = 4.50). The issues caused by scientific advances such as resource depletion and environmental pollution are common topics of STEM curricula.

STEM * PBL learning activities based on actual problems could indeed facilitate most of the students to learn the connotation of environmental protection and the relationship between sustainable design and environment. In addition, the students could better effectively integrate environmental protection with design to achieve the purpose of sustainable design.

In summary, the STEM teaching activities raised the students' recognition of the concept of environmental protection and demonstrated that, through hands-on sustainable bionic product design, the students could integrate environmental protection with sustainable design in their future design works and assume the due responsibility of designers for global environmental protection (Papanek & Fuller, 1972). A STEM curriculum should focus on concerning and reflecting on real-world issues and the triggering deep thinking of students (Fan & Yu, 2016).

d) Influence of STEM & PBL environmental protection education on naturalist intelligence and bionic design ability

In regard to naturalist intelligence and bionic design ability, the pre-test and post-test of the specific observations of naturalist intelligence, as well as the bionic knowledge, analogy, association, design improvement or new invention abilities had significant differences, as shown in **Table 4** and **Table 5**. This study revealed that, in terms of naturalist intelligence, through the activities, the students' abilities to make observations were strengthened. Such activities also had a positive influence on the students' identification of species, keen observations of changes in the natural environment, and bionic design abilities. Naturalist



Table 4. T-test of the differences	between the	e pre-test an	d the post-test	of naturalis	t intel-
ligence (N = 119).					

Dimension	Average (Stand	Degree of	T V.L.			
Dimension	Pre-test	Post-test	Freedom	1 value	р	
Feeling	2.42 (0.66)	2.41 (0.70)	118	0.162	0.871	
Specific observation action	1.91 (0.71)	2.17 (0.72)	118	-4.2	0.00	

Table 5. T-test of the differences between the pre-test and the post-test of self-assessment of bionic design ability (N = 108).

Dimension	Aver (Standard I Pre-test	rage Deviation) Post-test	Degree of Freedom	T Value	р
Bionic knowledge	2.25 (0.63)	2.55 (0.61)	107	-5.68	0.00
Bionic analogy and association skills	2.44 (0.60)	2.18 (0.72)	107	-5.39	0.00
Design improvement or new invention ability	2.18 (0.70)	2.57 (0.64)	107	-6.80	0.00

intelligence and environmental education stress environmental awareness and sensitivity (Leeming et al., 1997). Bionic design capability can be regarded as the ability to solve environmental problems, and environmental education should enhance bionic design (Cattano et al., 2010).

3) Teaching Model for STEM & PBL Environmental Protection Education Curriculum

This study regarded the results of the qualitative analysis of the learning process and the results of the quantitative analysis of the learning effectiveness after the implementation of sustainable bionic product design based on STEM & PBL activities as its basis to establish the teaching model for STEM & PBL environmental protection education curriculum, as shown in **Figure 4**. It effectively integrated environmental protection education and STEM into PBL, and included five major teaching characteristics, which are described as follows.

a) The students' learning began with actual environmental protection and sustainable design problems. Their STEM integrative knowledge was deepened.

This teaching model was set up for teachers to teach environmental protection-related knowledge to students. The teachers explained the relationship between humans and the environment (sustainable design and biological properties), bionic design (morphology and application of biological properties and bionic analogies and associations), design aesthetics (practical aesthetics), and bionic cases to guide the students to observe and think via open-ended questions. For instance, the students were asked to consider the following: In the face of possible resource depletion in the future, please list the products available in the market which have sustainable design and discuss how to design environmentally friendly and sustainable bionic products. While exploring meaningful problems, the students were motivated to discuss, identify, select, and verify real







problems from the perspective of STEM integrative thinking so as to achieve the learning objectives or solve problems. For instance, the students could explore the relationship between sustainable design and bionic product design and the possible technological limits on the application of bionic design and biological properties to product design.

b) The teachers provided and analyzed bionic cases and guided the students to solve problems from the perspective of STEM integrative thinking.

This teaching model aimed to enhance the students' analogy and association abilities. This study referred to Holyoak and Koh (1987) and Staples (2005), who suggested that teachers should provide bionic cases to cultivate students' abilities in bionic analogy, association, and product design to solve problems. Through applying the scaffolding strategy to bionic cases, the students could learn faster and better. This teaching model stressed the interest of students and encouraged them to conduct naturalistic observations. For example, it guided the students to identify and learn species characteristics in actual cases. The students compared the structure of living organisms with bionic product design to identify similarities and environmental protection problems that they could solve. Lastly, the students were expected to think about the correlation between creatures and commodities and apply such correlations to sustainable design.

c) This teaching model allowed the students to select bionic cases by themselves, explored process files, and stressed the performance of students in STEM integrative learning.

This teaching model required the students to choose existing bionic design products for bionic design analysis. By observing the actual cases and writing process files, the students compared the similarities and differences of biological properties and products, summarized the underlying scientific principles and structures of living organisms required for bionic design, and drew an analogy



with bionic product design. For example, the biological property of the closely arranged hexagonal cylinder of honeycomb was utilized to design honeycomb tire with strong suction and vibration reduction functions. From the scoring results of Process file A on the students' selection and analysis of bionic design cases (as shown in **Table 6**), it was possible to see that the scores on the students' selection and analysis of bionic design cases were between 4.11 and 3.83. The evaluators believed that the students had good performance in questions A1-4, and their scores were above four, indicating that the activities had a positive effect on the naturalistic observation, analogy, and association abilities of the students. However, the students needed to improve their problem-solving abilities, as reflected in A5. Additionally, the activities stressed that the students should actively explore, analyze products from STEM integrative thinking, and stress the learning of high-level STEM knowledge.

d) Through the implementation of student-led bionic design practice, the students acquired knowledge in STEM and environmental protection education.

This teaching model emphasized the students' learning experience with initiative construction and sharing. The students defined problems by themselves, observed the features of biological adaptations, made analogies, and drew bionic product sketches. For example, the students clarified what kinds of environmental protection problems they were to solve via group discussions, and pointed out environmental problems that had been ignored by others. They then selected species with the adaptive features that could solve the problem. They needed to describe the mechanisms and principles of biological properties, explain their product design, and draw bionic design sketches. Through collaborative learning and sharing responsibilities, the students were expected to learn the knowledge and STEM connotations of sustainable bionic product design required to solve problems. Lastly, the students shared their experience to gain solutions to problems so as to achieve the goals of joint construction of knowledge nd cultivation of critical thinking abilities. From the scoring results of Process file B on the students' hands-on bionic design (as shown in Table 7), it was possible to see that the scores were between 4.18 and 4.30. The evaluators deemed that the students had good performance in questions B1-5, and their



	Practical Abilities Scored (N = 63 Groups)	Score
	A1 Topics of bionic cases	4.03 (0.66)
Naturalistic observation	A2 Description biological and product characteristics	4.04 (0.71)
A 1 1 1	A3 Similarities and differences	4.11 (0.62)
Analogy and association	A4 The most important principles and mechanisms	4.06 (0.68)
Problem-solving	A5 Resolution of problems in which field	3.83 (0.73)

Note: 1. The evaluators rated the bionic design ability of students based on their practice. The full score was 5. 2. The figures in the table are averages. Those in brackets are standard deviations.



Table 7. Scoring results of Process file B on the students' hands-on bionic design.	
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	Practical Abilities Scored (N = 63 Groups)	Score
Problem identification	B1 Resolution of problems in which field	4.29 (0.32)
Naturalistic observation	B2 Adaptive properties	4.34 (0.43)
Analogy and according	B3 The most important principles and mechanisms	4.18 (0.38)
Analogy and association	B4 Design what kinds of bionic products	4.18 (0.50)
Sketch design	B5 Draw a sketch on product improvement or innovation	4.30 (0.57)

Note: 1. The evaluators rated the bionic design ability of students based on their practice. The full score was 5. 2. The figures in the table are averages. Those in brackets are standard deviations.

scores were above 4, indicating that the activities had a positive effect on problem identification, naturalistic observation, analogy, association, and sketch design.

e) Teachers play the role of facilitator of STEM and environmental protection learning

This teaching model considered that teachers play the role of facilitator in the curriculum, provide STEM learning guidance, remind environmental protection-related knowledge, and promote the learning activities among students so that students can accumulate rich environmental protection knowledge from exploration and problem-solving by themselves.

5. Conclusions and Suggestions

5.1. Conclusion

1) The STEM & PBL environmental protection education curriculum integrated knowledge in science, technology, engineering, and mathematics.

The results of this study implied that the students' study and application of the STEM program included learning scientific principles, sketch design, the selection of raw materials, the adoption of technologies for production, engineering internal structures, commodity modeling design, mathematical applications, and actual evaluation and calculation. They effectively adopted scientific principles to enhance their STEM integrative applications.

2) The STEM & PBL environmental protection education curriculum had a positive and significant impact on the learning effectiveness of environmental protection education.

By participating in the STEM program, the students agreed on the importance of environmental protection and learned the connotations of environmental protection, as well as the positive and significant correlation between sustainable design and the environment. By learning environmental protection knowledge through the STEM program, the students could more effectively combine environmental protection and design to reach the goal of sustainable design and improve their understanding of concepts and connotations of environmental protection education.

3) The teaching model for the STEM & PBL environmental protection education curriculum included five major integrative characteristics, including STEM



and PBL.

This study analyzed the teaching results and student activity process as the basis for the set-up of the teaching model for the STEM & PBL environmental protection education curriculum. This teaching model could effectively integrate environmental protection education and STEM into PBL and included the following six major characteristics: 1) The students' learning began with actual environmental protection and sustainable design problems; 2) it focused on subject-oriented learning activities; 3) it deepened the STEM integrative knowledge of the students; 4) through the implementation of student led bionic design practice, the students acquired knowledge in STEM and environmental protection education; 5) it stressed the performance of students in STEM integrative learning and requested the students to draw sustainable bionic product design sketches; and 6) teachers played the role of facilitator. Student-centered learning, teachers playing the role of learning facilitator, adoption of practical observations and hands-on strategies, and guidance to students to solve real-world environmental problems were all components of the teaching model.

5.2. Suggestions

Based on the teaching experience of the STEM & PBL environmental protection education curriculum, this study proposed the following suggestions on teaching and for future relevant studies:

1) Design of student-centered STEM activities through which students can have hands-on experience

The design of STEM activities should be student-centered, combine life experiences and issues, and allow students to have hands-on experiences. It is suggested that, during each stage of learning, students can guide others to think about the connotations of STEM at all levels.

2) Promotion of the teaching model for the STEM & PBL environmental proection education curriculum

Through the process files and works of the students, this study found that, after receiving the STEM program, the students had improved their abilities in environmental protection-related cognition, skills, and affection, and could create innovative design works in line with themes. Hence, it is important to promote the teaching model for the STEM & PBL environmental protection education curriculum.

3) Future Research

This study probed into the influence of the STEM program on the learning effectiveness of environmental protection education of undergraduates majoring in design, adopted qualitative and quantitative methods, proposed a STEM learning process, and analyzed the results. Due to research ethics, this study failed to adopt a quasi-experimental design or compare the differences in teaching of different groups of students. It is suggested that future researches refer to this teaching model to design teaching models based on STEM & PBL for dif-



ferent curricula so as to conduct deeper researches.

State of the Literature

- STEM Project-based Learning is a teaching model which guides students via meaningful and realistic learning scenarios by combining the interdisciplinary and integrated thinking model of STEM (Science, Technology, Engineering, and Mathematics) and PBL (Project-based Learning) curriculum design.
- Project-based Learning is a problem-solving and learning process that centers on students, guides students to form cases based on real environmental problems, helps them to analyze problems and adopt STEM thinking, and propose designs.
- The proposed STEM-PBL teaching model includes the scaffolding approach for teachers and learning by doing for students.

Contribution of This Paper to the Literature

- The STEM-PBL approach focuses on preparation, case scaffolding, case study, and students' hands-on design and evaluation, which can enhance students' naturalistic observation and design skills.
- The learning objectives of STEM-PPL can enhance students' abilities in interdisciplinary STEM thinking and application.
- STEM-PBL can further improve students' bionic design abilities, such as bionic knowledge, bionic associative skills, and the ability to improve existing designs or design new inventions.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this pa-

References

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- Barron, B. J. et al. (1998). Doing with Understanding: Lessons from Research on Problem- and Project-Based Learning. *Journal of the Learning Sciences*, *7*, 271-311.
- Benyus, J. M. (2002). Biomimicry: Innovation Inspired by Nature. New York: Perennial.
- Bybee, R. W. (2013). The Case for STEM Education: Challenges and Opportunities, National Science Teachers Association.
- Bybee, R. W., & McCrae, B. (2009). *PISA Science 2006: Implications for Science Teachers and Teaching.* NSTA Press.
- Cattano, C. et al. (2010). Teaching Systems Thinking and Biomimicry to Civil Engineering Students. *Journal of Professional Issues in Engineering Education & Practice, 137,* 176-182. https://doi.org/10.1061/(ASCE)EI.1943-5541.0000061
- Chen, Y. (2002). Research on the Development & Application of Mathematics Project-Based Learning in Elementary Schools.
- Chou, W.-R. (2013). Learning from Nature: Bio-Inspired Design. *Design Journal Shih Chien University*, 7, 114-127.



- Chow, H.-T., & Wang, S.-M. (2016). Investigating the Effectiveness of Guided Biomimicry Teaching on Naturalist Intelligence and Biomimicry Design for Environmental Engineering Students. *Journal of Environmental Education Research, 12,* 1-39.
- Clark, A. C., & Ernst, J. V. (2008). STEM-Based Computational Modeling for Technology Education.
- Eggermont, M. (2011). Biomimetics as Problem-Solving, Creativity and Innovation Tool. *Proceedings of the Canadian Engineering Education Association.* <u>https://doi.org/10.24908/pceea.v0i0.3767</u>
- Fan, S.-C., & Yu, K.-C. (2016). Core Value and Implementation of the Science, Technology, Engineering, and Mathematics Curriculum in Technology Education. *Journal of Research in Education Sciences*, 61, 153-183.
- Hmelo-Silver, C. E. (2004). Problem-Based Learning: What and How Do Students Learn? *Educational Psychology Review, 16*, 235-266. https://doi.org/10.1023/B:EDPR.0000034022.1647013
- Holyoak, K. J., & Koh, K. (1987). Surface and Structural Similarity in Analogical Transfer. Memory & Cognition, 15, 332-340. <u>https://doi.org/10.3758/BF03197035</u>
- Kelley, T. (2010). Staking the Claim for the "T" in STEM.
- Leeming, F. C. et al. (1997). Effects of Participation in Class Activities on Children's Environmental Attitudes and Knowledge. *The Journal of Environmental Education*, 28, 33-42. <u>https://doi.org/10.1080/00958964.1997.9942821</u>
- Lou, S.-J. et al. (2011). The Impact of Problem-Based Learning Strategies on STEM Knowledge Integration and Attitudes: An Exploratory Study among Female Taiwanese Senior High School Students. *International Journal of Technology and Design Education, 21*, 195-215, https://doi.org/10.1007/s10798-010-9114-8
- Lou, S.-J. et al. (2013). Effect of Using TRIZ Creative Learning to Build a Pneumatic Propeller Ship While Applying STEM Knowledge. *International Journal of Engineering Education*, 29, 365-379.
- Lou, S.-J. et al. (2017). A Study of Creativity in CaC₂ Steamship-Derived STEM
 Project-Based Learning. *Eurasia Journal of Mathematics, Science and Technology Education*, 13, 2387-2404.
- Lucas, A. M. (1980). The Role of Science Education in Education for the Environment. *The Journal of Environmental Education, 12,* 33-37. https://doi.org/10.1080/00958964.1981.10801898
- Merrill, C. et al. (2008). Delivering Core Engineering Concepts to Secondary Level Students. *Journal of Technology Education, 20,* 48-64.
- Neurohr, R., & Dragomirescu, C. (2007). Bionics in Engineering-Defining New Goals in Engineering Education at "Politehnica" University of Bucharest. In *International Conference on Engineering Education*.
- Packard, V., & McKibben, B. (1960). The Waste Makers.
- Papanek, V., & Fuller, R. B. (1972). *Design for the Real World*. London: Thames and Hudson.
- Park, H. et al. (2018). Do Single-Sex Schools Enhance Students' STEM (Science, Technology, Engineering, and Mathematics) Outcomes? *Economics of Education Review*, 62, 35-47. <u>https://doi.org/10.1016/j.econedurev.2017.10.007</u>
- Schnittka, C., & Bell, R. (2011). Engineering Design and Conceptual Change in Science: Addressing Thermal Energy and Heat Transfer in Eighth Grade. *International Journal* of Science Education, 33, 1861-1887. <u>https://doi.org/10.1080/09500693.2010.529177</u>



- Staples, H. (2005). *The Integration of Biomimicry as a Solution-Oriented Approach to the Environmental Science Curriculum for High School Students.*
- Stets, J. E. et al. (2017). The Science Identity and Entering a Science Occupation. *Social Science Research*, 64, 1-14. <u>https://doi.org/10.1016/j.ssresearch.2016.10.016</u>
- Thomas, J. (2000). *A Review of Research on Project-Based Learning*. Autodesk Foundation PBL.
- Van der Ryn, S., & Cowan, S. (2013). *Ecological Design* (10th Anniversary Edition). Washington DC: Island Press.