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A professional development programme based on biomimicry to improve stem project creativity of science student teachers

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ABSTRACT
In Thailand, science, technology, engineering and mathematics (STEM) education is being promoted to support science student teachers by conducting projects to extend their learning skills and to turn them into innovators. This study aimed to develop a professional development programme (PDP) based on biomimicry to improve STEM project creation for science student teachers and to evaluate the implementation result of this programme. The 60-hour programme, designed for 29 science student teachers from a teacher training institute in southern Thailand, was collaboratively developed to align with stakeholders' needs. It comprised four main lessons incorporating biomimicry principles and an eight-step problem-solving approach. The design process included stakeholder input, expert validation, and iterative improvement. The PDP integrated a coaching approach to facilitate problem synthesis and enhance learning outcomes. It underwent multiple stages of design, drafting, and expert validation before finalization. The programme's effectiveness was evaluated through the creativity of resulting STEM projects using class observations, a creativity evaluation form, and interviews. Data analysis employed content analysis and interpretatiove methods. The implementation resulted in six innovative biomimicry-inspired STEM projects, demonstrating the programme's success in fostering creativity and innovation among future educators. This study contributes to the advancement of STEM education in Thailand by providing a structured approach to developing science student teachers' project creation skills.

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Introduction

Interdisciplinary STEM education refers to an education approach that integrates science, technology, engineering and mathematics. It encourages students to connect concepts across these disciplines, fostering a holistic understanding (Cinar et al., 2022). STEM education is increasingly vital across all educational levels, from primary through tertiary, as it develops critical thinking and problem-solving skills beneficial in various fields. While STEM careers, including healthcare, are projected to expand more rapidly than non-STEM jobs, the skills acquired through STEM education are valuable in all career paths. Hands-on projects in STEM courses teach time management and project breakdown skills, applicable to various life and career tasks (Yeti Academy, 2024). The importance of this integrated approach to STEM education (Sanders, 2009) is being increasingly recognised worldwide, including in Thailand. Recent shifts in STEM education have led science instructors and educators to focus more on design-based learning, which integrates scientific inquiry with engineering practices to promote meaningful learning experiences (Ladachart et al., 2022).

The Thai government's policy is to improve its manpower for STEM education (The Institute for the Promotion of Teaching Science and Technology [IPST], 2020; Office of the Basic Education Commission, 2008) by encouraging learners to conduct innovative projects and by training professional teachers for STEM education. Toward this end, the Ministry of Education is constantly promoting STEM education as a core component of the curriculum to drive innovations in science and technology and to develop society and the economy (IPST, 2020; IPST, 2022). The main challenge in delivering STEM education is the availability of suitable STEM teachers (Bybee, 2010). Professional STEM teachers with necessary skills are required to design learning activities that can increases a learner's potential. Therefore, STEM project management should contain high-quality professional development experiences to learn how to design learning activities (Capraro & Slough, 2013). Most previous projects by Thai students lacked interdisciplinary integration, often focusing on single subject areas rather than combining methods or tools from different sciences (Chongsrid, 2016).

Although the Thai government is promoting STEM education, insufficient training is available for both pre-service and in-service STEM teachers in universities (Pimthong & Williams, 2018). Therefore, comprehensive training is needed to ensure STEM teachers are proficient in STEM knowledge, teaching methods, and skills. This training should occur during student teacher preparation (Shernoff et al., 2017) and continue through in-service professional development for practicing teachers. Science student teachers play a significant role in constructing and publicizing STEM education for science teaching (Djulia & Simatupang, 2021). Preparing for STEM teaching in a given subject is one approach for ensuring that both student teachers and current educators have the necessary preparation to effectively implement STEM education in their classrooms (Mafugu et al., 2022).

Biomimicry is an important approach to encourage students' creativity and enable successful STEM projects; it involves emulating nature to create new things or processes to resolve complex real-world problems (Benyus, 2002). Biomimicry affords advantages that are suitable for STEM interdisciplinary learning (Pauls, 2017). Biomimicry involves selecting a problem, looking for a plant or animal that faces the same problem, and emulating its solution for solving the problem, thereby learning from nature (Nilsart, 2016). It is an educational revolution that integrates biological sciences, STEM education, creative solutions, designs and systematic thinking to inspire learners. Biomimicry can be incorporated into science education for many topics including STEM education and environmental studies (Baumeister, 2013). The learner can innovatively solve a real-world problem by emulating a natural process or discovering data from nature. By doing so, the learner will develop their knowledge and competencies in STEM and related fields, including creative disciplines such as design, architecture, and applied arts (Coban, 2019). This approach, especially when supported by scientific inquiry, is useful for developing a learner's design and systematic thinking skills (Qureshi, 2020). Thus, it allows learners to connect theories and scientific knowledge to daily life and to create learning for sustainable development. Further, it builds an understanding and awareness of the value of natural resources in terms of their benefits to and significance for humans, and it will contribute toward innovation and technological developments that are mindful of the environment (Putwattana, 2018).

Currently, no guidelines have been established for an instructional process that contributes to encouraging innovation in learners' STEM education in response to existing problems. Many teachers struggle to integrate STEM education and the engineering design process into their daily instruction (Xue et al., 2023). Thus, teacher training institutes should study and develop the teaching profession to train effective STEM teachers who can conduct STEM projects and play new roles in our evolving society, contributing to the necessary developments in national education. This study aims to develop a Professional Development Program (PDP) to enable science student teachers to use biomimicry to improve their STEM project skills and to study the implementation results of this program.

Accordingly, the following research questions guided the study: What is the structure of a PDP that enables science student teachers to use biomimicry to improve their STEM project skills? What is the impact of the developed program on the STEM projects of science student teachers?

Literature Review

STEM Education and the Drive for STEM Education in Thailand

STEM education was first implemented by the National Science Foundation (NSF) in 1990. It is a teaching and learning approach in which STEM knowledge and skills are applied to solve real-world problems (Bozkurt et al., 2019; Sanders, 2009). In Thailand, the Ministry of Education is promoting STEM education through the Institute for the Promotion of Teaching Science and Technology (IPST), whose aim is to enhance the science, mathematics and computer skills of Thai teachers and youths. Since 2013, IPST has promoted STEM education by establishing the national STEM education centre, constructing the STEM cooperation network with the Office of the Basic Education Commission (OBEC) to develop teachers, and, in 2014, initiating the Outstanding Teacher Award for STEM Education. STEM education has been made a core component of the education curriculum for B.E. 2560–2579 (CE 2017–2036) (IPST, 2022). However, despite these efforts, STEM education in Thailand faces challenges in fully developing learners' critical thinking and problem-solving skills, as reflected in international assessments such as the Programme for International Student Assessment (PISA). For example, Thailand has scored lower than the international average in science and mathematics, which may indicate a need for more effective STEM instructional practices and resources (PISA Thailand, IPST, 2019).

STEM Education Project based on Engineering Design Process

Project-based learning has long been used in fields such as medicine, engineering, education, economics and business (Capraro & Slough, 2013). STEM-project-based learning is a learning approach that has been developed for delivering STEM education and preparing learners to keep up with technological advancements (Lou et al., 2011). It challenges and encourages learners' critical and analytical thinking skills and promotes advanced thinking through cooperation, communication, problem-solving, and self-learning (Baran et al., 2021; Capraro & Slough, 2013). A STEM project involves efficiently using STEM knowledge, methods, and resources to solve real-world problems and to achieve desired outcomes. The teacher's role in STEM-based instructional management is to guide the learner to find a solution. The teacher acts as a coach or instructor who monitors the progress of the project and ensures that everyone cooperates to achieve the common goal. Learners can independently discuss, experiment with, and apply their methods to solve the problem (Sahin, 2013). The STEM-project-based learning design process begins with clearly determining the expected outcome by establishing the objective and planning the project evaluation result summary. The learner is assigned tasks to present ideas for resolving complex problems, which is typically effective at the upper secondary level or higher, as it requires advanced problem-solving and critical thinking skills (Capraro & Slough, 2013).

Biomimicry as a New Approach to STEM education

The term "Biomimicry" has roots in ancient Greek; "Bios" means life, and "Mimesis" means emulation. Therefore, "biomimicry" means emulating organisms in nature (Wangtreesup, 2017). Biomimicry is an interdisciplinary field that combines ecology, technology and other fields to solve problems using knowledge of biology. Biologists, engineers, architects and designers in the educational and industrial sectors are adopting biomimicry for various design purposes (Jacobs et al., 2022). Biomimicry can be applied at three levels to solve problems: the organism level (emulating the form and function of specific species), the behavioural level (mimicking how organisms behave or interact), and the ecosystem level (replicating complex systems of interdependent species) (Pathak, 2019). Biomimicry has been observed, learnt from, and emulated in many cases to create innovations. For example, the structure of lotus leaf surfaces has inspired the development of water-repellent materials, and the shape of the spiral impeller, inspired by the structure of an apple snail shell, has been used to reduce energy consumption in impeller drives.

Scientists apply biomimicry through two main patterns. The first pattern involves identifying a problem, analyzing it, and then finding an organism that has developed a solution to a similar issue, which can be emulated for innovative problem-solving. This is called the top-down approach. The second pattern begins with a scientist gathering data from nature by identifying the features, behaviours, or functions of an organism or ecosystem. This leads to the construction of knowledge and understanding of the organism's self-adaptive mechanisms, ultimately resulting in the development of novel technology.This is called the bottom-up approach (Pathak, 2019). Many studies have applied biomimicry as an alternative to STEM education. For instance, Bilici et al. (2021) allowed students to work as engineers to design an ecofriendly vehicle prototype to mitigate air pollution; this was inspired by the human body system and the movement of the grasshopper, ant, spider, and red Japanese beetle. Coban and Costu (2021) applied biomimicry to allow students to select an organism and to then develop their ability to observe living things, understand the relationship between its structure and function, and design and create a model. Gencer et al. (2020) developed a STEM activity by using biomimicry in the design process to search for the relationship between the structure and function of organisms and to integrate a learning unit of organisms on earth. Pongsophon et al. (2021) examined the development of teachers' understanding of the engineering design process through a biomimicry workshop on design in consideration of environmental and social impacts (i.e., green design). Qureshi (2020) investigated biomimicry with undergraduate students who used it to create innovate designs for healthcare challenges.

Research Design and Methods

This study employed an interpretative paradigm and a qualitative research method. The primary aim was to develop and evaluate a professional development program (PDP) based on biomimicry to enhance STEM project creativity among science student teachers. The research design focused on the program development process, its implementation, and assessment of its effectiveness. The study comprised three main phases:

1. Program Development: Designing the PDP based on biomimicry principles and stakeholder input.
2. Implementation: Conducting the program with science student teachers at a teacher training institute in southern Thailand.
3. Evaluation: Assessing the impact of the PDP on the STEM projects created by participants.

This approach emphasizes the program's development and efficacy rather than treating it as a conventional study on learners and learning outcomes. For reference, student teacher teams and individual student members are represented using the abbreviations T and S, respectively, along with numbers (e.g., T1 for the first team, S1 for the first student teacher).

Programme Development

The proposed PDP was designed to align with the needs and expectations of multiple stakeholders: the university supervisor, supervising teacher, and student teachers, as well as the new state education policy. Its primary goal was to improve the STEM project creativity of science student teachers. The programme's objectives, content, main activities, and structure were developed collaboratively, incorporating input from all these stakeholders. Information gathered from focus group discussions with them was instrumental in shaping the program design. The programme was designed and delivered using a constructivist approach, with key components including pedagogical theory, content knowledge, activity practice sessions, discussion, reflection, and action (Loucks-Horsley et al., 1998). It was designed to allow science student teachers to participate for 60 h. It consisted of four main lessons: (1) basic knowledge about biomimicry; (2) a case study of strategy development for creative designs inspired by nature and natural patterns; (3) biomimicry innovation: a challenge of designing a flying machine; and (4) biomimicry innovation: being inspired by nature for engineering problem-solving and innovative product design in STEM projects. The researcher applied a biomimicry principle based on "biology to design a spiral" (Macnab, 2012) and modified it to suit Coban's (2019) approach to solve problems. It included eight reversible steps:

(1) Identifying the problem: Identify a need to satisfy or problem to solve, and then find living things facing similar problems and imitate their methods for solving the problem.

(2) Obtaining data from nature: Link the observed relationships between the processes and functions of living things and discovered data to gain knowledge and understanding of the adaptation mechanisms of living things, and use these as inspirations for design.

(3) Emulating: Students are inspired by living things to find technological design ideas.

(4) Designing: Students create designs inspired by living things through drawings and three-dimensional models.

(5) Exchanging: Students share design ideas through simulations with fellow students and STEM subject matter experts, including engineers, mathematicians, scientists, technologists, and materials scientists.

(6) Prototyping: Students create a prototype, which is a model or preview of the final product, and forward it to the development team for the next step in the development process.

(7) Testing: Students test the use of the prototype to solve problems. The test results may be used to improve and develop the prototype to solve the problem more effectively.

(8) Evaluating: Students evaluate the use of the prototype to solve problems.

The evaluation results may also be used to improve and develop the prototype to solve the problem more effectively. The program incorporated a coaching approach for synthesizing problems. A coach participated in the problem-solving process or promoted learning to enable the success of the STEM project. The PDP was developed through design, draft, and quality validation (by experts) stages; improved; and finalized.

Description of Biomimicry STEM Lessons and Implementation

Twenty-nine science student teachers from Rajabhat University in southern Thailand voluntarily participated in the PDP. The study was conducted for 60 h during the science method course (4 h per day, 1 day per week) in the first term of academic year 2022. This structure was based on the university's standard credit system and curriculum design guidelines. Each participant received three graduate credits from the university for participating in the PDP, aligning with the institution's credit allocation policy. The programme was conducted through discussions, collaborative group work, hands-on activities, problem-solving opportunities, reflections, and presentations by the participants (Loucks-Horsley et al., 1998). The lessons on using biomimicry for solving problems were divided into four major parts, as described below.

Part 1: Basic Knowledge about Biomimicry (8 h)

The first part of the lesson aimed to introduce basic knowledge of biomimicry and how nature inspires humans to design products and technologies.

Activity 1: Reflect on design by observing the structures and functions of specific organisms, such as the vein patterns in leaves, and encourage thinking through questions such as (1) What do you see from this pattern? (2) What is the specific purpose of the venation? (3) Where else can we find this pattern in nature and why? (4) How does the water transport system in plants differ from the systems designed by humans?

Activity 2: Recognise the design principle and key strategy used in nature through a case study of biomimicry and conduct the biomimicry mix and match activity (CERES, 2024) to match the invented product inspired by nature (plants or animals). Reflect through questions such as (1) What is the matching biomimicry project, and which organism inspired the product (e.g., the shape of a kingfisher's beak inspires the design of bullet trains)? (2) What is the positive environmental impact? (3) What is the positive impact on individuals and society? (4) Can the design be improved, and if so, how?

Activity 3: Survey the natural environment in the university to observe the characteristics or patterns of designs and analyse their purpose.

Part 2: Case Study of Strategy Development for Creative Design Inspired by Nature and Natural Patterns (20 h)

The second part of the lesson aimed to develop strategies to produce creative designs inspired by nature (STEM Learning Ltd., 2018).

Activity 1: Apply morphing, a special technique that involves changing an image to a material or practice, as a strategy for creative thinking (8 h). Study the case of Alessi, an Italian company that makes houseware and kitchen utensils by using morphing. The sample is the student's project of using the pattern of a large honeycomb and a glass with a pipe to develop a new product, namely, a 2-in-1 pipe glass for drinking in which the pipe is a handle or straw (Figure 1).

Activity 2: Concept of creative textile/fabric design inspired by nature (8 hours) to explore how biomimicry influences textile design and practice. The sample is a student project based on a textile/fabric design inspired by a peacock (Figure 2), demonstrating how natural patterns and forms can serve as a source of inspiration for creative textile designs.

Activity 3: Creative architectural design inspired by nature (4 h) to understand how biomimicry inspires architecture via shapes and patterns through a video.

Figure 1

Pipe glass morphing design (S26)

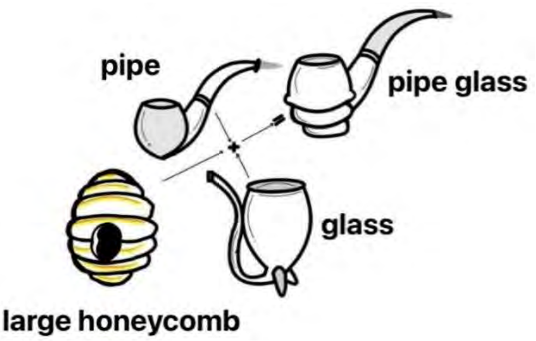


Figure 2

Textile/fabric design from peacock pattern (S3)

Part 3: Biomimicry Innovation: A Challenge of Designing a Flying Machine (12 h)

The third part of the lesson aimed to enable students to perform biomimicry by creating a flying machine based on the eight reversible steps of biomimicry: (1) identifying the problem, (2) obtaining data from nature, (3) emulating, (4) designing, (5) exchanging, (6) prototyping, (7) testing, and (8) evaluating.

Activity 1: Review the biomimicry lesson. Learn the work background of Leonardo da Vinci, who tried to invent a flying machine by observing a flying bird. Students will work in small groups of 4–5 and must research information about suitable flying animals to emulate, design a sketch, and build a model. For example, figure 3 shows how a student team created a flying machine by emulating a flying greater coucal and tested its performance for prolonged flight duration.

Figure 3

Flying machine emulating a flying greater coucal (T3)

Part 4: Biomimicry Innovation: Inspiration from Nature for Engineering Problem-Solving and Innovative Product Design in STEM Project (20 h)

The fourth part of the lesson aimed to enable students to create biomimicry STEM projects inspired by nature to solve engineering problems and to develop innovative product designs.

Activity 1: Students are divided into six teams of 4–5 to create STEM projects. The activity is conducted according to the biomimicry guidelines. First, students identify the problem to solve or need to satisfy. Then, students work as a team to find an inspiration to solve this problem by observing a plant or animal, understanding the function of its structure, and using its structure and function to produce a product blueprint to solve the real-world problem. Finally, students propose the solution to experts from various disciplines and answer questions reflecting STEM knowledge: (1) What scientific knowledge do you apply to emulate the organism’s structure, and what is the structure’s function? (2) What equipment, tools, materials, or processes do you use to solve the problem? (3) What are the problems that the invented innovation can solve? How does the innovation better solve the problem compared with the existing solution? (4) Did you apply a creative scientific principle to design and develop the innovation based on the purpose of use, worthiness, and safety? (5) Did you use mathematics to explain and study the relationship, and if so, how?

Evaluation of PDP

The effectiveness of the PDP can be evaluated through the STEM project creativity of the science student teachers. Data were collected through the observation and STEM project creativity evaluation form and semistructured interviews of selected participants. The form was used to evaluate the creativity as a result of their participation in the program. This form was improved based on the study by Gencer et al. (2020). It focuses on eight categories that represent students' progression from level 1 to 3, and it provides an analysis of the engineering design process. The form was created to evaluate the prototype biomimicry models developed by students to solve a human problem. The students should be able to explain how they design the STEM project, structures of the organisms that inspire them, and how the structure’s function is used to solve the real-world problem. Further, they have to answer questions that reflect their STEM knowledge. Finally, the participants were interviewed. The interview questions focused on factors that support and obstruct the programme implementation.

Data Analysis

The observation and STEM project creativity evaluation form was analysed and scored using a key created for this study. The form was used for assessing students and their STEM project creativity after each group presented. Content analysis was conducted to analyse the data obtained from the form. All data were classified. The data were interpreted to obtain an inductive summary classified by the content before comparing the contents.

The interview data were aggregated based on the response homogeneity or heterogeneity (Patton, 2002). Structural coding and inductive analysis were used to analyze the data arising.

Trustworthiness of Findings

To make the research reliable based on the concept suggested by Lincoln and Guba (1985), the researcher took the following steps: engagement with the participants was prolonged to 60 h to ensure that useful data were acquired, and methodological triangulation was performed to recheck whether different data collection methods provide the same or different results. The data were interpreted after they were validated by an expert.

Result of PDP Implementation

The implementation of the Professional Development Program (PDP) demonstrated successful outcomes, as evidenced by the engagement of participants in creating STEM projects using a biomimicry model. The participants could engage in a STEM project with a biomimicry model. The researcher assigned students to work in six teams of 4–5, with each team creating one STEM project. The results revealed that each team created inventions derived from biomimicry principles: Team T1's a hydropower plastic bottle compressing machine, Team T2's a plant nursery, Team T3's an automatic trash can – EM trash can, Team T4's SCTH drone – simulating the transport of a first-aid kit, Team T5's fish stool suction, and Team T6's an oxygen pump in a fish tank. Each innovation was designed by imitating living things to solve different human problems. The participants began by analysing the problem to solve and then finding an organism facing a similar problem to emulate its solution. Then, they obtained data from nature to link the structure and function of the organism to acquire knowledge and understand the adjustment mechanism that inspired their design. They emulated the selected organism to look for technological design concepts and designed the work creatively by using drawings and 3D models. They exchanged and shared their idea via the model with peers and STEM experts, including biologists, mathematicians, technologists, materials scientists, and engineers. Then, they created the final model and tested whether it could solve the problem. The test result was applied to improve and develop a more efficient solution. The participants also evaluated the use of the model. The innovation projects produced by each team are summarized in Table 1, which provides an overview of the biomimicry-based solutions and the corresponding inspiring organisms, structures, and functions that were emulated.

Table 1

Innovation projects or STEM-based solutions developed using biomimicry

Team	Innovation/Problem-Solving method	Inspiring organism	Organism structure and function	Solution
T1 Hydropower plastic bottle compressing machine		Python	Python's body – Prey behavior by squeezing with the body.	Minimize the storage space required before recycling.
T2 Plant nursery		Mangrove and Snapper	Mangrove's root supports the trunk. Snapper scale prevents concentrated minerals in the ocean from permeating to the body.	Control and set an appropriate environment for plant growth.
T3 Automatic trash can - EM trash can		Nepenthes	Trap and digest insects – when insect sits on a bag mouth, it will drop into the bag and be digested by the digestive juice.	Reduce the littering problem and use food waste to produce organic fertilizer.
T4 SCTH drone – simulating the transport of first-aid kit		Dragonfly	Flying – vertically by lifting up or down and forward.	Control a drone to transport a first-aid kit in various situations.
T5 Fish stool suction		Sucker catfish	Mouth – small teeth scratch animal tissues or moss from surfaces to eat.	Remove moss and fish stool in a fish tank.
T6 Oxygen pump in a fish tank		Mudskipper	Tail fin – jump on the water surface by rolling the lower tail and springing. Movement - use a pectoral fin to crawl on sludge to support itself.	Solve the problem of insufficient oxygen in water, save water by reducing need for changing water in a fish tank, and save electricity.

For evaluating the creativity of each team's biomimicry-based STEM project, the researcher evaluated the engineering design process in terms of eight components, each scored with 1–3 points, by using the evaluation form adapted from Gencer et al. (2020). The results showed that the students achieved a moderate average score of 2.41, which accounted for 80% of the total possible score (Table 2).

Table 2

Results of designing innovative inventions to solve problems.

Component	Criteria	$\bar{X}$	SD	Skill Level	%
Identifying demand or problem	Understand real-world problem and identify needs	2.83	0.37	Good	94
	Determine the criteria and limitations	1.83	0.37	Moderate	61
Researching demand or problem	Identify necessary information for a solution or demand	2.67	0.47	Good	89
	Determine the use of acquired information to solve a problem	2	0	Moderate	67
Developing a possible solution	Propose solution guidelines	2.67	0.47	Good	89
	Draft blueprint of the proposal	2.5	0.5	Good	83
Selecting the best solution	Consider pros and cons of proposed solution	2	0.82	Moderate	67
	Explain reasons (positive or negative criteria and limitations) for selecting the best solution	2	0	Moderate	67
Creating a model	Create a model or prototype of the solution by explaining and giving the details	2.5	0.5	Moderate	83
	Use materials that meet the criteria and limitations of the model or prototype	2.33	0.73	Moderate	78
Testing and evaluating solution	Test how the model or prototype solves the problem or need	2.17	0.69	Moderate	72
	Scientific language is used to explain the experiment	2.5	0.5	Good	83
Communicating approach of solution	Explain how the design solves the real-world demand or problem	2.83	0.37	Good	94
	Identify the organism's structure and function	2.83	0.37	Good	94
Improving the design	Explain the necessary improvement	2.5	0.5	Good	83
	Improve the design based on the information and evaluation acquired from the test and solution exchange	2.33	0.47	Moderate	78
		2.41	0.45	Moderate	80

Note. 1 - Low (1–1.49), 2 - Moderate (1.50–2.49), 3 - Good (2.50–3.00)

Each aspect of the evaluation results of the engineering design process is discussed below.

Identifying Demand or Problem

The average evaluation result for identifying the needs or problems was good ($\bar{X}$ = 2.83, SD = 0.37, 94%), and that for specifying the criteria and limitations was moderate ($\bar{X}$ = 1.83, SD = 0.37, 61%). Students could understand the problems encountered in daily life by clearly specifying needs or problems and presenting details to determine the scope of the problem before creating innovations or solutions. Students can also specify criteria and limitations, as shown in Table 3.

Table 3

Identifying demand or problem

Team	Identifying demand or problem	Criteria and limitation	Developing a possible solution
T5 Fish stool suction	Aquarium fish keepers normally find it difficult to clean moss and fish stool. The solution is to imitate a sucker catfish for fish stool suction.	Budget under 1,500 THB. The fish stool suction device needs to be moved manually, and thus, cleaning may take time.	Developed an innovative fish excrement vacuum cleaner that imitates the mouth of a sucker fish to solve the problem of large amounts of algae and fish excrement scattered in fish tanks.

Researching Demand or Problem

The average evaluation result for specifying necessary information to solve needs or problems was good ($\bar{X}$ = 2.67, SD = 0.47, 89%), and that for how to use the obtained information to solve human needs or problems was moderate ($\bar{X}$ = 2, SD = 0, 67%). Students could research and collect information related to a problem or need, find STEM ideas and knowledge from various sources, and clearly identify information necessary to solve problems or needs. In addition, they could determine how to collect the information required to solve needs or problems. For example, team T4 used knowledge about dragonflies (which inspired the solution), speed calculations, and drone technology as well as calculations of the area of the first aid equipment model for helping accident victims to control the drone in various simulated missions.

Developing a Possible Solution

The average evaluation result for proposing solutions to needs or problems was good ($\bar{X}$ = 2.67, SD = 0.47, 89%), and that for drafting blueprints of the solution was good ($\bar{X}$ = 2.5, SD = 0.5, 83%). Students could propose solutions to needs or problems according to the criteria and limitations by specifying existing limitations and criteria in the context of the problem, as in the example of team T3 (Table 3). Additionally, students could draft a detailed blueprint of the proposed solution.

Selecting Best Solution

The average evaluation result for considering the advantages and disadvantages of the proposed solutions was moderate ($\bar{X}$ = 2, SD = 0.82, 67%), and that for explaining the reasons (positive or negative, criteria, and limitations) for selecting the best solution was moderate ($\bar{X}$ = 2, SD = 0, 67%). Students could determine the pros and cons of most solutions and explain the rationale for the chosen solution, as seen in the example of team T3's selection of the best solution (Table 4).

Table 4

Selecting best solution

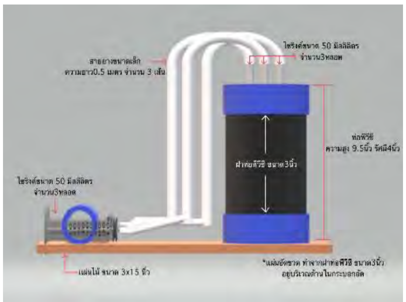
Team	Identifying demand or problem	Selecting Best Solution	Advantages	Disadvantages
T3 Automatic Trash Can – E.M. trash can	Exposure to trash while opening the trash can. Hand contaminated by germs.	Develop an automatic trash can that digests organic trash to minimize exposure to trash, reduce the risk of pathogens, and emulate nepenthes to trap and digest insects.	- A trash can opens and closes automatically to minimise exposure to trash and pathogens. - Organic trash can be used to produce biofermented water, which is useful for plants.	- Trash can does not open or close quickly because of the timing. - Speed of producing biofermented water depends on type and quality of organic trash. - Trash can uses a battery that needs frequent replacement.

Creating a Model

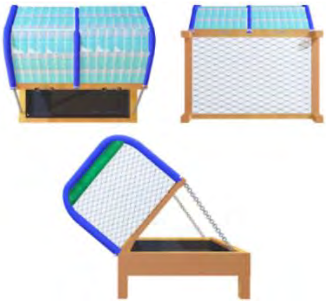
The average evaluation result for creating models or prototypes of solutions was good ($\bar{X}$ = 2.5, SD = 0.5, 83%), and that for using materials that meet the criteria and limitations of the model or prototype was moderate ($\bar{X}$ = 2.33, SD = 0.73, 78%). Most teams could create a fully suitable 3D model or 3D prototype for their solution by clearly specifying the dimensions of and materials used in the prototype while using materials that meet most of the model's criteria and constraints. Examples include team T1's prototype of a water-powered plastic bottle compressor that mimics the digestive system of a python and fluid energy transfer and team T6's water oxygenator for an aquarium that mimics a mudskipper (Figure 4). Team T2 developed a tree nursery with a structure based on mangrove tree roots and a roof imitating sea bass scales. However, they did not specify the size and materials used in the initial drawings. After expert feedback, they specified the size and type of materials used to build the tree nursery prototype to create a more complete and detailed model.

Figure 4

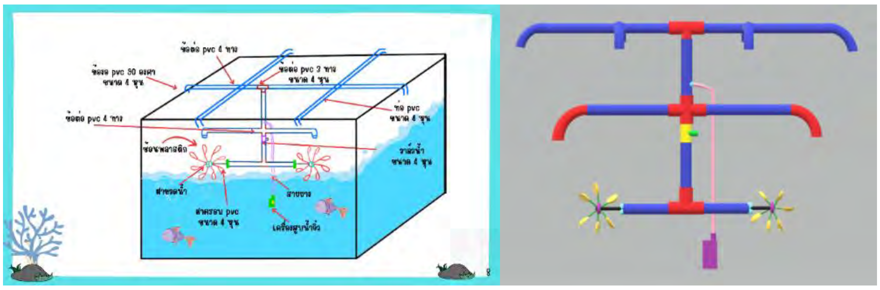
Sample of model or prototype of proposed solution



Team T1's prototype of a hydropower plastic bottle compressing machine emulating the digestive system of python and fluid energy transfer



Team T2's prototype of a plant nursery, where the structure imitates a mangrove root and the roof imitates a snapper's scale



Team T6's prototype of an oxygen pump for a fish tank that imitates a mudskipper

Testing and Evaluating Solution

The average evaluation result for testing how the model or prototype solves problems or needs was moderate ($\bar{X}$ = 2.17, SD = 0.69, 72%), and that for explaining test results using scientific language was good ($\bar{X}$ = 2.5, SD = 0.5, 83%). Once the prototype was complete, each team tested and evaluated the solution. Most teams tested the model for how it solves a need or problem and analysed only a portion of the test results. Students could explain the test results by using detailed scientific language. For example, team T1 studied the efficiency of bottle compression by comparing the change in shape of plastic bottles before and after compression and the time required by the machine to compress one bottle until its shape changes. They studied the number of plastic bottles that the machine can compress in 5 min, tested the efficiency of increasing the plastic bottle disposal space, recorded the results, and compared the storage volume before and after compression (Figure 5). Team members could explain and express their opinions by using scientific principles and concepts that were communicated to others to understand the test results correctly.

Figure 5

Team T1 's a test of compression efficiency and increasing plastic bottle dumping area

Communicating Approach of Solution

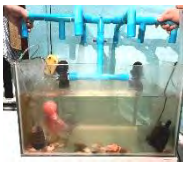
The average evaluation result for explaining how the design can solve human needs or problems was good ($\bar{X}$ = 2.83, SD = 0.37, 94%), and that for identifying the structures of living things and the functions of these structures used in design was moderate ($\bar{X}$ = 2.83, SD = 0.37, 94%). Students could clearly explain the design, including the structure of living things and its use as a model, and how it can solve human problems. For example, team T3 described the structure of the Nepenthes plant, consisting of the lid, peristome, wax zone, and digestive zone. This plant adjusts its leaves into colorful pot-like bulbs that attract and lure insects. The lid has nectar glands that attract insects. The inside of the pot is coated with wax so that insects fall into the pot, and the digestive juices produced by the plant digest the insects to obtain nutrients that the plant can absorb. The team imitated the adaptation mechanism of the Nepenthes plant to develop a biocomposting trash can whose lid closes and opens automatically using a sensor. In addition, EM microorganisms are used to increase the fermentation efficiency. This device produces nutrients for use as fertilizers.

Improving the Design

The average evaluation result for describing improvements needed for the design was good ($\bar{X}$ = 2.5, SD = 0.5, 83%), and that for improving the design based on test information and evaluation and exchanging solutions was moderate ($\bar{X}$ = 2.33, SD = 0.47, 78%). For example, team T6 identified the need to improve their design and then optimized the design based on the data, test results, and discussion of solutions (Table 5).

Table 5

Improvement of design

Team	Innovation	Improvement
T6 Oxygen pump in a fish tank		- Innovation from the PVC tube. Other types of tubes can be used to reduce the weight and accommodate movement. However, the strength will be compromised. - Six top beams adhering to the tank edge can be made adjustable for use with tanks of other sizes.

All 29 participants agreed that the PDP was beneficial in the creation of their STEM projects. Eight randomly selected participants were interviewed about the supporting factors and limitations of the program. They identified the following supporting factors: (1) technological adaptation skills to develop the model or prototype; (2) efficient communication skills and exchange of opinions; (3) teamwork skills to assist and brainstorm and to exchange knowledge about innovative designs; (4) good planning skills using the whole engineering design process; (5) key role of the advisor in successful innovation creation; (6) actual practice, pursuing knowledge, skills practice, self-learning to form knowledge, and knowledge propagation via the project; (7) understanding about STEM education projects based on knowledge of different fields; and (8) use of knowledge obtained from nature through observations and studies of organism structures and functions to determine the characteristics, qualities, and benefits, and observation of an organism with a similar problem that develops a structure and function to adjust itself to live in nature. The main limitations were the budget of the STEM education project, proficiency in each field, understanding of the engineering design process, and integration skills. All teams did not consider the inclusive integration of knowledge, and they required different knowledge fields to find the solution for a STEM project.

Discussion

The PDP successfully promoted STEM projects because biomimicry affords unique advantages that are suitable for interdisciplinary fields in STEM education. Natural processes can motivate a learner's imagination regardless of their age, interest, or cultural background (Pauls, 2017). The biomimicry approach adopted by scientists to realise innovative designs is incorporated into STEM education by using the biological theory obtained from observations of nature as well as mathematical and physical calculations as a foundation for the engineering design process. These were used to develop the required thinking and problem-solving skills and to create an understanding and awareness of natural resources in terms of their benefits to technology and innovation while being mindful of the importance of ecological balance (Putwattana, 2018). Biomimicry is a form of reversible engineering. The researcher identifies the problem, searches for biological sources to develop a natural solution to solve the problem, tries to understand the natural solution, and designs a solution for the benefit of humans (Gardner, 2012). Thus, the use of biomimicry in this study corresponds to the engineering design process based on STEM education guidelines.

Although students could successfully create biomimicry-based STEM projects by following the engineering design process, the results revealed some limitations. Students needed time to design and develop the innovation and learn about the difficulties during the design steps. Pongsophon et al. (2021) correspondingly found that science student teachers who joined a workshop to develop an understanding of the engineering design process learned about the design challenges. They had to consider the limitations during the design step. The innovator must work based on the prototype, test and improve it, and then create the final product. The design process was repeated, which was very complicated. Further, successes and failures allowed the learner to understand the biomimicry method (Qureshi, 2020). Further, the researchers found that students creating a biomimicry-based STEM project via the engineering design process had a moderate average score of 2.41, which accounts for 80% of the total possible score. In the problem identification step, most teams understood the problem and clearly stated it; however, they did not clearly state the criteria and limitations. The average score was not lower than those of other steps. Gencer et al. (2020) similarly reported that the scores of students in the problem identification step and the criteria and limitations identification step were lower than those in other steps. Further, the supportive factors for the success of the program were knowing that diverse technologies provide more choices, and innovations from the alternative subtechnologies can work together the best and can be extended (Prasertsan, 2015). Further, advisors, especially those who were enthusiastic and open-minded and sacrificed their time, played a crucial role in the success of STEM projects in Thailand. In addition, observations of the environment and surrounding nature can stimulate and initiate the concept of a solution. Close observations are likely to help construct the understanding of new concepts of nature (Chongsrid, 2016).

Conclusion and Implications

The PDP based on biomimicry was considered a success, and the researcher added a coaching strategy to support the programme by acting as a coach to advise students to exercise their and their team's potential via the practice and thinking processes to improve upon and develop their proposal constantly. They also meet a STEM expert to get feedback, which helped them to complete their quality innovation based on the prototype. The program participants can engage in the STEM project based on biomimicry by analysing a problem, obtaining data from nature, emulating, designing, exchanging, developing the prototype, testing, and evaluating. This process is reversible. The students can explain the structure and functions of the organism that inspired them to create the innovation and identify how it solves their problem. Moreover, they engage in the engineering design process and reflect on the STEM knowledge applied to the STEM project. Students also learn about the limitations and success during the program implementation.

Study Limitations and Recommendations

This study developed a PDP to improve STEM education projects and studied the implementation result of the programme with science student teachers in only one teacher training institute, which might not be adequate for interpretation or generalisation. The result is applicable to this study only. Although the program is successful, some student teachers do not have adequate knowledge about STEM education and misunderstand the emulation method, which is an obstacle to innovation creation via STEM projects. Therefore, further research may implement other development approaches, such as having professional mentors from various fields to accommodate the development of creative STEM projects.

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