Stem-oriented Project-based Assignments in teaching Systems Thinking Subject for Engineering Students in Vietnam

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***Abstract*—Systems Thinking is a necessary subject for engineering students to develop their logical and systematic mindset. At Ho Chi Minh City University of Technology and Education, Vietnam, the Systems Thinking subject is implemented with many teaching methods including STEM approach. Through carrying out STEM-oriented project-based assignments (SPAs), students develop their technical/ professional competence and soft skills including communication skill, presentation skill and team work skill. Besides, their learning motivation/ learning interest is also improved. According to the survey results with 150 students who underwent the Systems Thinking subject in the school years from 2021 to 2023, the STEM skills as well as systems thinking of engineering students at Ho Chi Minh City University of Technology and Education have been better after the educational experiments. The paper also proposes some solutions for lecturers to overcome the challenges in implementing SPAs related to course time management, difficulty in choosing SPA topics, money cost and material costs for learning products, conflicts of students in teamwork. Recommendations are that lecturers should design SPA topics that are relevant to learning objectives linked with the socio-technical/professional context, limit the number of SPAs (no more than two or three projects for each subject per semester), use both large and small projects instead of only large projects, encourage the use of recycled materials. Lecturers should give fair support for different groups of students and restructure learning groups when necessary to create a favorable learning atmosphere. The STEM-oriented project-based assignments can be one of the forms of teaching organization, that brings benefits for implementing many other subjects in engineering education.**

***Keywords*— STEM; engineering education; project-based assignments; Systems Thinking; soft skills.**

***JEET Category*—Research.**

I. INTRODUCTION

THE contributions of Asia-Pacific countries to engineering education not only play an important role in promoting the development of worldwide engineering education but also engineering education research issues (Chou, 2023). Many countries in Asian have engineering education associations as well as accreditation organizations that promote the quality of engineering education, especially in Higher Education institutions. However, to promote engineering education in Asia in general and in Southeast Asian in particular, there is a need for virtuous research circles, initiatives of engineering education research based on relevant educational theories and especially the linking research findings to practice (Mohd-Yusof et al., 2016).

Engineering education in many countries in the Asia-Pacific region often focuses on the development of semiconductor and electronics manufacturing industries because of the influence of high-tech industrial trends (Chou, 2023). The 4.0 Industrial Revolution put human beings in challenges related to requirements of high quality human resources, especially in the field of Artificial Intelligence (AI), Internet of Things (IoT), Big Data, Digital, Biotechnology and Physics etc. The STEM approach in Higher Education with the integration of Science (S), Technology (T), Engineering (E) and Mathematics (M) is therefore very appropriate in preparing students for adapting with requirements of new era.

Systems Thinking is an optional subject for engineering students at Ho Chi Minh City University of Technology and Education, Vietnam. When implementing this subject with STEM-oriented project-based assignments, we recognize, that the influences on student's technical competence as well as on soft skills including communication skill, presentation skill and team work skill is very positive. The learning motivation/ learning interest of students is also improved.

Through this article, we would like to share some experiences from Ho Chi Minh City University of Technology and Education in utilization of STEM-oriented project-based assignments to help engineering students enhance their learning performance. It could be the example for using this approach in engineering education in general to foster the application of STEM in reality of education.

II. LITERATURE REVIEW

A. STEM education

STEM education is considered by many countries around the world to be the foundation for economic development (Lee, Chai, Hong, 20019). STEM stands for **S**cience, **T**echnology,

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Engineering and **M**athematics (Breiner et al., 2012). STEM education is understood as an interdisciplinary educational method that connects independent subjects to help students solve real problems in modern society (Sanders, 2009). Tsupros, Kohler, Hallinen (2009) claimed that STEM Education refers to a method of interdisciplinary learning, in which, students apply theories of Science (S), Technology (T), Engineering (E) and Mathematics (M) in specific context closely combined with reality of school, society, business etc. STEM education has the potential to motivate students to learn and participate in STEM fields in their future careers (Gomez & Albrecht, 2013; Margot K& Kettler, 2019).

STEM education has been successfully implemented in many countries, such as in the United States, in Australia, in Asian countries and other Western countries. According to White (2014), integrating the fields of Science, Engineering, Mathematics and Technology in STEM education can motivate learners to explore knowledge and improve learning efficiency. STEM education is said to be able to equip students with cross-disciplinary and interdisciplinary knowledge and skills to solve problems occurring in daily life as well as in the complex society of their future (Roegiers, 2004). Bybee (2010) believes that STEM education can create a qualified and highly skilled labour for the 21st century. Therefore, STEM education is considered as an inevitable trend of the modern education system to prepare future global workers.

According to Mooney and Laubach (2002), to solve problems related to STEM fields, theme-based learning as STEM-themed project can be developed as a pedagogical practice by integrating knowledge of Science, Technology, Engineering and Mathematics as cohesive components to solve real-world problems (Mooney & Laubach, 2002).

Ajay Krishnan and Deshpande (2021) in their effort to explore pedagogical approaches for implementing STEM education, introduced a disruptive teaching methodology using COMSOL Multiphysics® and COMSOL Applications to support laboratory learning in Transport Phenomena - a foundational course in chemical engineering. Their study showed that this approach increased student engagement, improved comprehension of complex equations, and doubled the number of research projects related to the subject, highlighting the potential of innovative methods to strengthen STEM education.

A study by Jiang et al. (2024) highlighted the need for increased efforts to enhance STEM career awareness based on enhancing learners' self-efficacy and meeting their expectations of outcomes in STEM courses. This study also showed that there are different STEM career concerns and different self-efficacy between male and female students in STEM courses.

Based on the above mentioned theories, in the educational experiment at Ho Chi Minh City University of Technology and Education in Vietnam, students participated in interdisciplinary STEM-oriented project-based assignments, in which, they employ knowledge and skills related to Science (S), Technology (T), Engineering (E) and Mathematics (M) to create learning products. These assignments were designed in accordance with student's (technical) majors aiming to enhance their STEM career awareness and to facilitate them to self-express, achieve learning efficacy, thereby meeting student learning outcomes expectations.

STEM-themed projects provide students with real-world context, foster their interest with real problem and improve their problem-solving and communication skills. While students explore STEM-themed projects, they participate in solving project problems individually and in groups (Breiner et al., 2012).

The integration of computational thinking (CT) into STEM education has recently attracted considerable attention, underpinned by the premise that CT and STEM are mutually reinforcing (Li; Oon, 2024). One of the pioneering studies of the impact of teamwork in STEM courses on neurodivergent undergraduate students by Salvatore et al. (2024) investigated the experiences of 22 neurodivergent undergraduate students with teamwork in STEM courses. The study identified seven themes that influenced the experiences of the participating students. Three themes were at the individual level: personal characteristics that students linked with their neurodivergence; strategies for academic success (related to time organization/management, adaptive communication, and self-advocacy); and beliefs about the value of teamwork. Four themes were at the group/classroom level: group dynamics; roles within group (including leadership roles); competitive culture in STEM; and recommendations for lecturers. Based on the study results, Salvatore et al. (2024) suggested that incorporating inclusive STEM team-based assignment design that includes lecturer reflection and articulation of anti-discrimination values can support neurodivergent students. In other words, lecturers need to support a stronger culture of inclusion in the classroom when organizing STEM team-based assignments

On that basis, in order to effectively develop students' communication skills and teamwork skills, as well as to support the fairness for students with different mental health backgrounds, STEM-oriented project assignments at Ho Chi Minh City University of Technology and Education are implemented in groups. Each group consists of 4-5 students working together towards a common goal, planning and managing the project themselves (i.e. having strategies for academic success), and sharing the value of teamwork.

Castle et al.'s (2024) study of introductory lecture courses in STEM majors at six universities in the United States demonstrates that student's grade outcomes in STEM courses are affected by systemic inequalities related to gender, family's income, first-generation status, and race. This study, which involved more than 200,000 samples, found that the advantages in grades of 200,000 students at six universities increased in proportion to the amount of systemic advantages that students possessed. The study provides a basis for promoting solutions related to reducing social inequalities for students in the process of participating in STEM courses at universities. It can be seen that, in addition to the restructuring of STEM education to reduce barriers for disadvantaged students as proposed by the Castle group's research, we can consider the equal and unbiased support/ consulting of lecturers for all types of university students for STEM courses, the design of STEM learning assignments and topics that do not cost too much to support university students with different social backgrounds to study and achieve learning results regardless of their social backgrounds. In other words, we should support the equality in STEM education. This is also a theoretical basis for the STEM-oriented project-based assignments at Ho Chi Minh City University of Technology and Education in Vietnam.

B. Project-based learning

"Project" was first used in art academy Accademia di San Luca in Italy at the end of the 16th century. After that, this Italian training model was improved and developed in France (1671) and other European countries and America since the 18th century. John Dewey (1859 – 1952) played an important role in building the theoretical basis for the project-based learning (Knoll, 1997). Project-based learning is the process of simulating and solving real-life problems (Tan & Chapman, 2016). According to Nguyen & Meier (2011), project-based learning is a teaching method in which learners perform a complex learning task, combine theory and practice, create products that can be introduced. This task is performed by learners with high self-reliance throughout the entire learning process. Group work is the basic form of project-based teaching (Nguyen & Meier, 2011, p. 184).

The characteristics of project-based learning:

(1) Project-based learning is situation-oriented: The project topic needs to be related to practical situations of the profession, life, society. It gives students opportunity to apply knowledge into social practice (Nguyen & Meier, 2011, p.184-185; Gudjons, 2008, p. 79; Dewey & Kilpatrick, 1935, p. 79; Trinh, 2011, p.6).

(2) Project-based learning is learners' interest - oriented: Learners are involved in the process of choosing a project topic so that the topic is suitable to their own abilities and interests (Nguyen & Meier, 2011, p.185; Gudjons, 2008, p. 80-81; Trinh, 2011, p.5).

(3) Project-based learning is highly socially practical: The project needs to contribute to connecting in-school learning with real life and society. Through project-based learning, students can carry out rich and diverse activities associated with social practices and their career in the future, thereby developing complex competencies including social competencies, personal competencies etc. Through that, they have ability to improve the society in the future (Nguyen & Meier, 2011, p. 185; Gudjons, 2008, p. 82; Trinh, 2011, p.6).

(4) Project-based learning is goal-oriented and is the unity between theory and practice: The project must help students connect knowledge with practice, apply knowledge into practice, and achieve learning goals. According to Dewey/Kilpatrick (1935), projects must be planned and linked to the social environment (Dewey & Kilpatrick, 1935, p.162).

(5) Project-based learning is self-organized and self-responsible: In project-based learning, students are involved in all stages, from discussing project ideas, identifying projects to planning, implementation and evaluation. Students are self-organized and responsible, self-reliant in implementing projects, while teachers only play the role of consultant, guide, and helper (Nguyen & Meier, 2011, p.185; Gudjons, 2008, p. 83-84; Trinh, 2011, p. 6).

(6) Project-based learning involves all senses: Students must use a combination of all knowledge, experience, collaborative skill, communication skills and manual skills to implement project products (Gudjons, 2008, p. 84-85)

(7) Project-based learning is product - orientated: A project must create a final product. It can be a physical product or a linguistic/ verbal product that can be used, shared, introduced or presented (Nguyen & Meier, 2011, p. 186; Gudjons, 2008, p. 86 -89; Trinh, 2011, p. 7).

(8) Project-based learning is complex and interdisciplinary: The project content may require complex knowledge and skills from many different fields and specialties. In real life, to solve a complex problem, people often have to cooperate with each other and use a complex of interdisciplinary knowledge and skills. The project - based learning puts students in real-life situations, so it is also complex and interdisciplinary (Nguyen & Meier, 2011, p.186; Gudjons, 2008, p. 89-90).

According to Trinh (2011), projects in project-based learning can be classified in many ways. For example, based on the time-consuming criteria, project can be identified through three following types: (1) The *mini project* lasting from two hours to six hours, (2) the *average project* lasting from one day to seven days (or one week) and (3) the *big project* lasting at least one week to many weeks. Based on the task of project, a project can be identified through three following kinds: the *investigation project* (in which, students study/ investigat the actual status of the object/ phenomena), the *research project* (in which, students do research to find solutions for practical problem) and the *construction project* (in which, students create physical products or perform practical actions, or perform tasks such as decorating, displaying, performing, composing etc.).

Many authors discussed the efficiency of project-based learning in improving competence of student. Arisanty et al. (2020) state that using a project-based learning model can improve the student learning outcomes at Banjarmasin High School on the effective use of natural resources. Biazus et al. (2022) argue that Project-based learning has the positive impact on creative thinking skills of secondary students. Kordova (2020) considers that the systems thinking of engineering students can be enhanced through participating in multidisciplinary projects. According to Perrault& Albert (2018), a project-based learning assignment can make a significant positive shift in sustainability attitude of students.

Gou et al. (2020) conducted a study on how to evaluate the outcomes of project-based learning (PjBL) in higher education based on an analysis of Educational and Psychological Sciences databases. 450 articles were selected based on the following criteria: (1) The studies must be experimental and provide original data; (2) The studies must focus on student learning; (3) The learning projects must take place in higher education; (4) The impacts of the learning projects on student outcomes (cognitive, skill, and affective outcomes) must be measured; (5) The studies must demonstrate the characteristics of project-based learning. Gou et al. found that affective outcomes (related to perceptions of the benefits of PjBL and perceptions of the experience of PjBL) were the most commonly used, measured by questionnaires, interviews, observations, and self-reflection; Cognitive outcomes (i.e., knowledge and cognitive strategies) and skill outcomes were measured using questionnaires, criteria, tests, interviews, observations, self-reflection, artifacts, and diary data. Gou et al. recommended that future studies should further explore student learning processes and their learning products. This is also a reference for the research at Ho

Chi Minh City University of Technology and Education when measuring the effectiveness of STEM-oriented project assignments for engineering students by self-reflection through surveys, observations, interviews and analysis of students' learning products.

Crespí et al. (2022) conducted a quasi-experimental study, with a pre-test/post-test design to examine the effectiveness of project-based learning in promoting students' communication and teamwork skills in the context of interdisciplinary subjects in Spain. The sample consisted of 610 university students from the Community of Madrid, of whom 387 participated in PBL (experimental group) and 223 learned through traditional teaching methods (control group). The results of the study showed that project-based learning can effectively develop interpersonal communication and teamwork skills in the context of interdisciplinary subjects.

Pratama et al. (2023) investigated the development of soft skills among maritime cadets through project-based learning implemented within the Moodle learning management system. The study involved a sample of 80 cadets enrolled in four programs: Transportation, Maritime Transport Management, Marine Engineering, and Nautical Science. The findings indicated that project-based learning in the Moodle environment proved to be an effective approach for enhancing cadets' soft skills, particularly in the context of online learning during the COVID-19 pandemic. Notably, the cadets demonstrated significant improvement in essential 21st-century competencies relevant to the maritime profession, including responsibility, discipline, creativity, and problem-solving.

Zhang & Ma (2023) conducted an in-depth quantitative analysis based on 66 experimental or quasi-experimental research articles on project-based learning over 20 years. The research results showed that project-based learning significantly improved student learning outcomes and made positive contributions to student's learning performance, emotional attitudes, and thinking skills compared to traditional teaching. The test results showed that: (1) In terms of national geography, the impact of project-based learning in Asia, especially Southeast Asia, was significantly better than that in Western Europe and North America; (2) In terms of curriculum, project-based learning fostered student learning outcomes more significantly in engineering and technology subjects, and was better employed in practical classes than in theoretical classes; (3) Pedagogically, project-based learning is better suited to small learning group, where a group size of 4-5 people gives the best results. The study on STEM-oriented project-based learning at Ho Chi Minh City University of Technology and Education in Vietnam continues to provide empirical evidence on how effective the application of STEM project-based learning for engineering students in Southeast Asia for small learning groups (from 4-5 students) is in improving students' professional-technical competencies, soft skills including communication skills, presentation skills, teamwork skills, systems thinking as well as their learning interests.

C. *Systems Thinking for engineering students*

Kriz (2010) believes that systems thinking refers to a comprehensive approach, considering as many different factors as possible to avoid interpreting the problem from a single perspective. Ramage & Shipp (2009) defined that systems thinking is a way to understand the complexity of the world by looking at it in terms of wholeness and relationships rather than by breaking it down into parts. Systems thinking is often used as a way to explore and develop effective action in complex contexts (GSE & GORS, 2012). Senger (2006) identifies systems thinking as the principle of reviewing to see the whole. It is a framework of seeing the interrelationships between things rather than the things themselves and seeing the interacting pieces in change (Senger, 2006). Richmond (2000) compares systems thinking as the view of the whole forest than focusing on a tree. As argued by Sterman (2000), systems thinking refers to the way of see the world as a complex system, in which, "everything is connected to everything else" (Sterman, 2000, p.4).

At Ho Chi Minh City University of Technology and Education, Systems Thinking is a subject that guides engineering students in a comprehensive approach to consider problems, objects and phenomena from multidimensional and multiple perspectives considering the mutual interactions in a continuous movement as well as in their development process, avoiding interpreting problems, things, and phenomena from a single point of view.

An engineer needs an interdisciplinary understanding of "the various science disciplines, math, and technology to support and provide context for their engineering designs and applications" (Breiner, 2012, p. 5). Alok and Saipriy (2020) claimed that traditional engineering education often suffers from limitations such as insufficient real-world exposure, lack of soft skills, and weak alignment with industry needs. To address these gaps, they introduced Design Thinking as a complementary pedagogical tool to foster systems thinking, strategic thinking, creativity, and practical problem-solving. Students engaged in project-based learning structured around five stages of Design Thinking: (1) Empathize (observing, experiencing, and interviewing users to identify authentic need)s; (2) Define (analyzing and prioritizing needs and translating them into technical specifications); (3) Ideate (generating diverse solutions through methods such as mind mapping, morphological charts, and the Six Thinking Hats); (4) Prototype (developing trial models using low-fidelity mockups and rapid prototyping labs); and (5) Test (validating solutions with users, gathering feedback, and iterating designs). The findings revealed that this approach not only bridged theory and practice through experiential learning but also enhanced students' creativity, interdisciplinary problem-solving abilities, and practical project outcomes, with several student projects receiving further support and investment.

Engineering systems thinking is a higher ordered thinking that helps individual "to accomplish system-related tasks successfully" (Kordova, 2020, p.65). Kordova (2020) also accessed the ability termed Capacity for Engineering Systems Thinking (CEST) by Frank (2007). It relates to the capacity to understand the whole without the need to understand all of the details in advance based on the combination of knowledge, professional skills and behaviour components to solve problems in an engineering system with various systems components. On this basis, the application of STEM-oriented project-based assignments is very appropriate for engineering education in general and for implementing the Systems Thinking subject for engineering students in particular.

III. RESEARCH METHOD

This study uses the following methods:

- *Theoretical research method* with document analysis and synthesis to identify the concepts related to STEM education, project-based learning and Systems Thinking as well as to suggest the process to apply STEM-oriented project-based assignments into teaching subject Systems Thinking in particular and into engineering education in general.

- *Educational experiment* with the application of STEM-oriented project-based assignments (STEM PjbA) for teaching subject Systems Thinking at Ho Chi Minh City University of Technology and Education in the school years from 2021 to 2023. This is an uncontrolled educational experiment evaluated by surveying the opinions of students who participated in the experiment using questionnaires, interviews combined with pedagogical observations and analysis of learning products. The research hypotheses are: (1) STEM PjbA can develop professional/ technical competence of students; (2) STEM PjbA can improve student's soft skills including communication skill, presentation skill and team work skill; (3) STEM PjbA can enhance STEM skills of students; (4) STEM PjbA can foster systems thinking of students; (5) STEM PjbA can promote learning interest of students.

- *Survey method* with questionnaires through Google Form to collect opinions from 150 students of the school years from 2021 to 2023, who took part in educational experiment, to determine the results of the experiment. The questionnaire was designed with a 4-level Likert scale and statistically processed by percentage, average score, and standard deviation. Link of the survey: https://docs.google.com/forms/d/e/1FAIpQLSfO8NsI6tuPpW5ZXUm7fFJmgaVefOJ284V8QAgz-zoGRH_EjA/viewform?usp=sf_link

- *Interview method* used to collect feedback of students on the effectiveness of STEM-oriented project-based assignments beyond the results predicted in research hypotheses.

- *Observation method* and *Learning product analysis method* applied to find supplementary information to prove the research hypotheses. Besides, to minimize the potential biases (e.g., self-reporting bias from students with their answers for questionnaires and for interview, i.e. their self- assessment), the integration of *Observation method* and *Learning product analysis method* is helpful and necessary for lecturer/ researcher in collecting the more objective information for assessment (i.e. external assessment). The students' professional/ technical competence as well as their soft skills related to communication skill, presentation skill and team work skill etc. can be reflected and assessed more exactly through their action (which can be observed) and through their learning products (which can be analyzed and assessed).

IV. RESEARCH RESULTS AND DISCUSSION

A. Process of implementing the Systems Thinking subject with STEM-oriented project-based assignments

The Systems Thinking subject at Ho Chi Minh City University of Technology and Education includes the following contents:

- Chapter 1 (Overview of System) relates to concepts of system, description of system, features of system, types of system, steps of developing a system, system analysis and design, approaches and methods of doing research on system.
- Chapter 2 (Thinking and Technical Thinking) provides students with definition of thinking, characteristics of thinking, laws of thinking, structure of technical thinking.
- Chapter 3 (Systems Thinking Methodology) focuses on distinguishing Mechanistic Thinking and Systems Thinking, the characteristics of Systems Thinking.
- Chapter 4 (Creative Thinking methods) introduces some creative methods, such as Focal Object, DOIT, Cause- and-effect diagram, 5W&1H etc.

In order to teaching the Systems Thinking subject for engineering students effectively, besides the traditional teaching methods (e.g. presentation/ verbal conveying and conversation), we design the STEM-oriented project-based assignments for students according to the following process:

- ***Step 1***: Determining the learning objectives (learning goals) related to subject Systems Thinking, which is linked with social/ professional/ technical context.

- ***Step 2***: Select the learning contents which are appropriate to be conveyed by learning projects which can lead to *STEM learning products* relating to technical major of students as well as their interest. Through making these products, students could reach the learning goals. To create such a STEM product, students must do a project in group, thereby they have to use the *scientific* (S) knowledge, apply technical and engineering mindset and skills (T, E) and calculate with *mathematics* knowledge and skills (M), called STEM activities.

- ***Step 3***: Let students do STEM-oriented project-bases assignments (SPAs) in group. Students take part in all phases of implementing the project: collecting information, planning, carrying out the project (with STEM activities), controlling and evaluating the project result. Lecturer play the role of consultant, guide, and helper.

- ***Step 4***: Students share/ present/show their STEM learning products.

- ***Step 5***: The STEM learning products are openly evaluated.

This proposed process can be easily adapted to non-engineering subjects for engineering students. To ensure the quality of undergraduate engineering training curriculum, the non-engineering subjects in the engineering training curriculum should still have learning objectives linked to the social/professional context. Therefore, in order to design SPAs for a certain non-engineering subject, the lecturer must first identify the learning objectives of the subject linked to social/professional context (in step 1). Next, the lecturer designs learning contents in accordance with the identified learning objectives, in which, selecting learning contents that can be illustrated by STEM learning products to design SPAs (step 2). For example, one of the learning objectives of the *Philosophy subject* for engineering students is that students can explain the relationship between theory and practice in the context of industrial society (step 1). A learning content corresponding to this objective could be "The relationship between engineering theory and practice", which can be illustrated by a STEM-oriented project-based assignment, such as: Students work in groups to conduct a project to design a device/a toy related to their major, then present the learning product and analyze the relationship between engineering theory and engineering practice to be able to create this product, analyze its meaning in modern life context (step 2). The remaining steps (step 3, step 4, step 5) can be implemented similarly to what was explained in the proposed process above. As can be seen, the scope of use of SPAs is very flexible in engineering training in both engineering and non-engineering subjects.

B. Examples for designing STEM-oriented project-based assignment for the Systems Thinking subject

In the Chapter 1 (Overview of System), in terms of content "System analysis and design", a STEM-oriented project-based assignment as following was allocated to the students:

"Doing a three-week project in group to create a technical material system/ physical system (e.g. equipment, toys, items, decorations etc.) with familiar materials (e.g. ice cream sticks/ cardboard/ iron/ aluminum/ wood/ paper/ reusable materials etc.) Students should relate your project products to your (technical) major/ discipline".

The requirements:

- Present the product in front of class.
- Have a video clip describing the process of doing project (3-5 minutes).
- Summary of the process of project management, teamwork.
- Briefly describe the elements and subsystems of the system (product), the relationships between them, the dominance, the constraints and the function of the designed system.
- The system created is creative and interesting.

In this project, students work together in small group including about four-five students who are majoring in the same technical field (for example, electronics/ mechanics/ IT/ wooden technology etc.). Firstly, they need to find an idea related to an appropriate system as a target to achieve. It is best to choose a system that is related to the technical field they are studying. Students choose a (technical) system to build/ to create based on their technical knowledge and skills as well as their interdisciplinary competence and experience. In order to successfully create this system, they must calculate with **m**athematic skill (M), apply **s**cientific reasoning (S), exploit their **t**echnical skills (T) and use **e**ngineering knowledge (E) to handle relevant materials and make the product. In reality, students often make a small robot/ an automatic electronic toy/ an intelligent decoration item etc. In other words, they develop their STEM competence through making products. Students take comprehensive actions from planning, choosing the best solution, implementing, controlling and evaluating to create project product (a material system). Through these actions, they develop teamwork competence, know how to solve conflicts in their group, how to make plan and manage the time and the risks. They also develop their *systems thinking* through determining the structure of their product with identifying its elements, its subsystems, the relationship between these elements, the dominance and the constraint of their system. They also have opportunity to present the product of their project in front of class and improve their presentation skill.

Some examples of successful projects of students are presented below:

(1) Handheld vacuum cleaner: Students carried out a STEM – oriented project – based assignment producing a mini vacuum cleaner in group. This group included five sophomore students from electrical and mechanical engineering majors. In this project, students incorporated elements of STEM into project-based tasks in the following way.

- They explained the scientific basis (S- Science) of their product based on physics knowledge. The suction force of the vacuum cleaner is caused by the pressure difference between the two ends. How is this pressure difference generated? There is an electric motor inside the vacuum cleaner, which drives the fan blades to rotate at high speed, and the fan blades also make the air move. After the air moves, the air velocity also changes, and the pressure immediately drops, while the air pressure on the outside of the vacuum cleaner is still 0.1 megapascal; therefore, there is a pressure difference between the dust suction side and the exhaust side. Under the effect of the suction force caused by the pressure difference at the two ends, dirty objects are sucked in one after another.
- They applied Electrical Technology (T – Technology) knowledge to draw the product's circuit diagram and prepare the materials (illustrated in Figure 1).
- They employed Engineering knowledge and skills (E-Engineering) to assemble the parts of the mini vacuum cleaner and operate their product (illustrated in Figure 1).
- They used mathematical knowledge to calculate the size of the plastic tubes used to make the mini vacuum cleaner (M-Mathematics).

After finishing the product, students presented their mini vacuum cleaner in front of class and analyzed their product using Systems Theory. They determined the subsystems of this product including the covering (with elements of suction nozzle, dust box, engine box and machine handle), engine (with elements of motor, battery, electric circuit, switch), exhaust fan and filter. Then they analyzed the constraint of their system with the strict connection between all elements from the input signal to output signal. They proved the engagement of all members of learning group through a video clip. The students also operated their mini vacuum cleaner successfully in front of their classmates. The mini vacuum cleaner worked well and can can suck up scraps of paper and small trash inside.

Besides, the students also clarified the project management process with making plan based on resource, risk management, project execution and control as well as the conflict resolution in teamwork. Based on the educational observation, it can be seen that their professional/ technical competence, their soft skills and their systems thinking were developed at the same time.

In terms of the role of lecturer, the lecturer provided equitable support to all students when they were doing their project by giving them advising, explaining the requirements, the assessment criteria, helping them resolve the conflicting if necessary and asked them to make report once a week. After the students completed their project, the lecturer organized a learning product reporting session for students. In this session, students presented their learning product, used Systems Theory to analyze the product. Especially, the lecturer required all group members to take part in the presentation, so each student had the opportunity to improve her/his presentation skills. Then all students and lecturer assessed the learning product as well as their presentation openly. So, there were the peer-assessment, self- assessment and the assessment from the lecturer in this session. The assessment criteria related to: (1) Product functionality and aesthetics; (2) The correct application of systems theory to analyze the product; (3) Teamwork ability demonstrated through the explanation of students about the project management process, the video clip and the quality of their presentation.

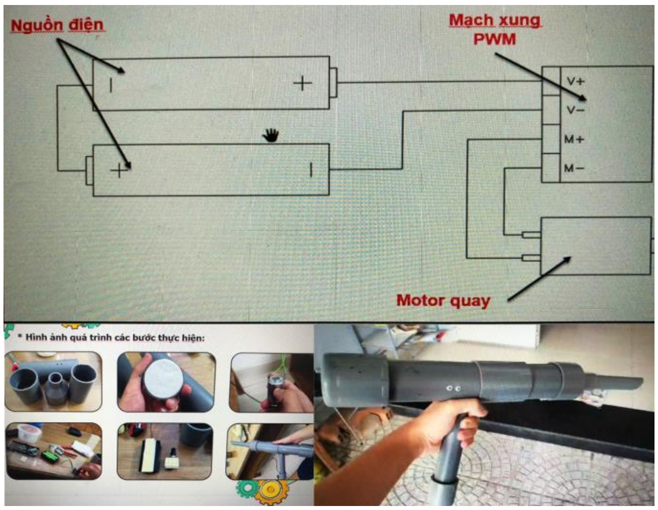

Fig.1. The process of making a mini vacuum cleaner by students.

(2) Spring-powered motor toy car: Students undertook a STEM-oriented project-based assignment producing a spring-powered motor toy car (or a wind-up toy car) in group. This group consisted of five sophomore students from automotive and mechanical engineering majors. In this project, the students applied STEM elements into their project as following:

- They explained the scientific basis for the operation of a spring-powered toy car based on physics knowledge (S-Science): A spring-powered motor allows the toy car to move on its own without the need for electricity or batteries. When the spring is pulled, mechanical energy is stored in the spring in the form of elastic potential energy. When the spring is released, the spring slowly stretches, releasing this energy and converting it into kinetic energy, making the toy car move.
- They applied technological knowledge and skills (T-Technology) related to materials, car structure assembly to select and prepare appropriate materials. Materials include used wooden popsicle sticks and cardboard for the car frame, springs and gears for the engine, plastic wheels and axles for the wheel system (illustrated in Figure 2). The materials chosen are recycled materials (such as used wooden popsicle sticks, cardboard for the car frame) that are cheap. The lecturer encouraged the use of recycled materials to educate students about environmental protection. In addition, using cheap materials facilitates students from different socio-economic backgrounds to participate in STEM courses in a fair and favorable way (as mentioned earlier in the theoretical framework in the Literature Review section).
- They used the knowledge of mechanical engineering (E-Engineering) to draw the structural design drawings of the toy car and assemble the toy car (illustrated in Figure 3).
- They employed mathematical knowledge (M-Mathematics) to calculate the size parameters of their toy car expressed on the structural design drawings (illustrated in Figure 3).

Students worked in group and managed their project until they completed the final product (illustrated in Figure 4).

Fig. 2. Students determined the materials for their product based on Systems Diagram and technological knowledge and skills.

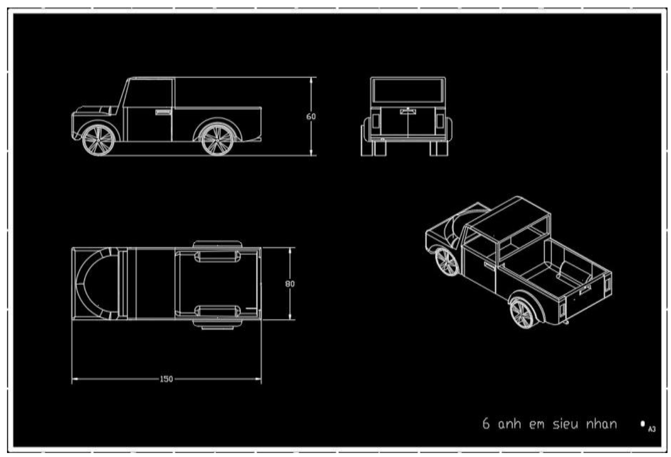

Fig.3. The structural design drawings of the car toy drawn by students based on engineering knowledge.

Lecturer helped, advised, and supported students throughout the project implementation process, required weekly project progress reports. After students completed the project, the lecturer organized a project report session, in which all group members participated in a presentation introducing the project and product. Students clarified the project management process from defining goals, resources, planning implementation, risk management, conflict resolution to controlling, adjusting, and perfecting the product. Students also used Systems Theory to analyze the structure of a wind-up toy car, including: (1) Frame system (including components such as the chassis made of used wooden popsicle sticks, and the toy car body made of cardboard); (2) Engine system (including components such as springs, gears); (3) Transmission system (including components such as wheels and axles). Students presented the advantages or the dominance of this system as helping children develop their thinking (e.g. children can learn about simple physics principles, such as friction, kinetic energy and energy) and encouraging creativity (e.g. The toy car can be decorated or customized, allowing children to express their creativity). In addition, the cars use mechanical energy (energy from springs) without batteries and are made from recycled materials, which helps protect the environment. The students also explained the technical compulsion (or the constraint) of this system. Accordingly, the spring-driven vehicle works by storing energy in the mainspring when it is wound up. When released, this energy is released, creating motion for the vehicle. The compulsion ensures that the vehicle continues to move until the energy runs out.

Fig.4. The spring-powered motor car toy made by students based on their design.

The students' teamwork skill was demonstrated through a short video clip about their project implementation process. The learning product was also evaluated through three forms (student self-assessment, peer-assessment and lecturer assessment) at the project results reporting session based on criteria such as successful product, which can operate well, the right and appropriate application of Systems Theory to analyze the product, presentation skills (demonstrated through the presentation) and teamwork skills (demonstrated through the video clip).

There were many other diversified learning products made by students. The project reporting sessions can take place in directly in class or Online (synchronous Online Learning). Some of them are illustrated by the figures below.

Fig.5. Electrical Engineering students presented Mini DC Generator in a synchronous online class in Systems Thinking subject.

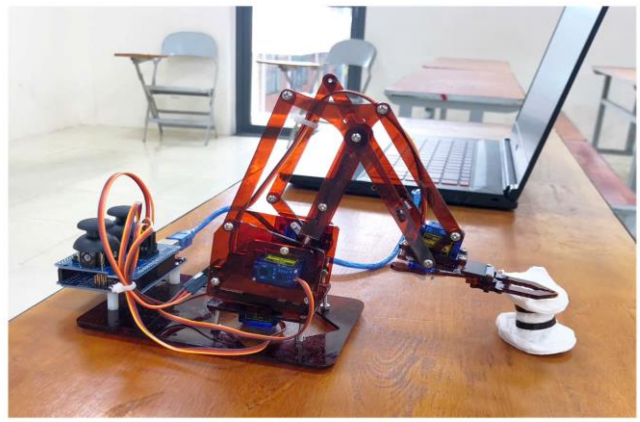

Fig.6. Robotic Arm Product made by a group of second-year Mechatronics students in Systems Thinking subject.

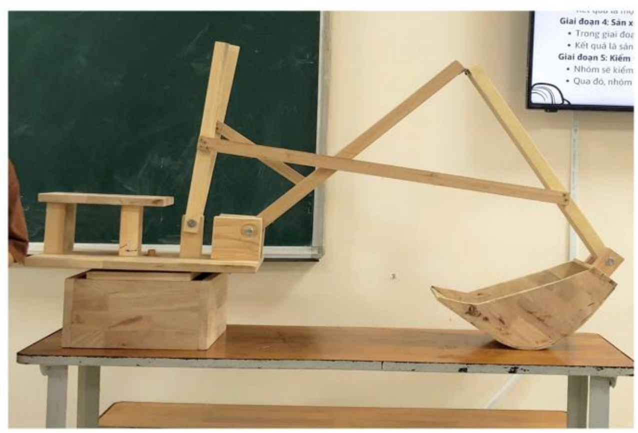

Fig. 7. A wooden toy crane product made by a group of second-year students majoring in Wood Engineering in Systems Thinking subject.

In the Chapter 2 (Thinking and Technical Thinking), in terms of Technical Thinking, a STEM -oriented project-based assignment named "Egg drop" was assigned to students:

"Making the system of covering egg with papers and glue in the class within 45 minutes with material including 15-20 sheets of A4 paper, glue, 01 fresh egg, which are prepared by the lecturer. This system of covering egg must keep the egg unbroken when being dropped from the 2nd floor to the ground".

The requirements:

- The covering system (box) of eggs is creative, impressive.

- Briefly present the basic theory and technical drawings of the design on a piece of paper.
- The fresh egg within the covering system does not break when being dropped from the 2nd floor to the ground.

In this project, the students had to find information in group, make the plan (how to make this paper system), decide the solution (choose the feasible option), make the product (the paper system covering the fresh egg) based on scientific knowledge (S), technical skills (T), engineering mindset (E) and calculating (M). They have to use knowledge regarding to gravity (belonging to physics – the natural science) and calculate with respect to gravity with mathematic skill. They design the model of the system by sketching the technical drawing of this system with technical and engineering mindset, so that their system can resist the ground reaction force, reducing the falling velocity. By discussing in group, students develop their teamwork ability, the problem – solving competence and increase learning interest. The fact that students weigh the pros and cons of multiple options to choose the one that fits their goals can foster their systems thinking as they look at the problem from multidimensional perspectives while still focusing on the main goal. The cost of this assignment is low, so it is appropriate for all students with different social and economic background. It can contribute to the equality of STEM education, which was pointed out in the theoretical framework above.

Through this Egg Drop project, students incorporated the STEM elements as the following:

- They explained the phenomenon of egg drop in the viewpoint of physics (S- Science). E.g. Egg falls freely under the influence of gravity. Gravitational potential energy: Ep = m.g.h, where m is the weight of the egg (kilogram or gram), g is the gravitational acceleration vector (which is a constant of approximately 9.81 or g is approximately 10m/s²), h is the height (meter). When the egg falls from the 2nd floor, the potential energy is converted into kinetic energy. Kinetic energy: Ek = (1/2).m.v^2, where m is the weight of the egg and v is the speed (or velocity) of the egg. This energy creates impact when the egg hits the ground. The paper covering system should help reduce v, thereby reducing Ek before collision.
- They used technological skills (T- Technology) to make the covering system by paper with cutting, pasting, shaping products.
- They applied engineering knowledge (E-Engineering) to create the design drawing of their products.
- They used mathematical knowledge (M – Mathematics) to calculate and prove the average force acting on the egg as it hits the ground. E.g. The explanation based on calculation of one student at X University in our System Thinking course was as following: The distance of the egg from the drop point to the ground is about 10 meters (m), the egg weighs about 50 grams (≈ 0.05 kg), collision time is 0.01 seconds (s). To calculate the falling speed, ignoring air resistance, using the formula to calculate the velocity when hitting the ground: $v^2 = 2gh$ (with g = 10m/s², h = 10m), we can have v ≈ 14.14 m/s. The force acting on the egg when colliding is equal to the change in momentum: F = Δp/Δt. Momentum before collision: p = m.v = 0.05 kg X 14.14 m/s ≈ 0.707 kg.m/s. Momentum after collision: p' = 0 (because the egg stops). Momentum change: Δp = |p' – p| = 0.707 kg.m/s. So, the average force acting on the egg: F = Δp/Δt = 0.707 kg.m/s / 0.01 s ≈ 70.7 N. Thus, with an impact force of approximately 70N, the egg will break immediately. So there are two solutions to solve the problem: (1) Need a protective layer of paper to absorb some of the impact force on the egg; (2) Need to create a "wing" of paper to block the air, reducing the falling speed of the egg.

How can such STEM-oriented project-based assignments influence the learning interest of students, their teamwork skill, their communication and presentation skills as well as their STEM competence? The survey below conducted with the students who experienced these assignments can present some results of these pedagogical experiments.

C. Results of educational experiment

Using survey method (questionnaires) with **150 students** who underwent courses of Systems Thinking with STEM-oriented project-based assignments (SPA) in the school years from 2021 to 2023 to record the self-evaluating from the students. The study used a 4-level Likert scale (from 1 to 4) to measure the level of factors related to the effectiveness of SPA in developing students' competencies. The conventional scale is as follows:

TABLE I
CONVENTIONAL SCALE TABLE

Score	Level of improvement of competence/skill	Level of usefulness	Level of effectiveness
1	Does not help improve competence /skills	Not helpful	Inefficient
2	Helps improve competence/ skill at a low level	Useful at a low level	Effective at a low level
3	Helps improve competence/ skill at a high level	Useful at a high level	Effective at a high level
4	Helps improve competence/ skill at a very high level	Useful at a very high level	Effective at a very high level

Note: The 4-point Likert scale here is conventionally averaged as follows:

1.00 – 1.75: No improvement/ Not useful/ Ineffective.

1.76 – 2.50: Low improvement/ Low usefulness/ Low effectiveness.

2.51 – 3.25: High improvement/ High usefulness/ High effectiveness.

3.26 – 4.0: Very high improvement/ Very high usefulness/ Very high effectiveness.

Using statistical processing by percentage, average score (mean), standard deviation, combined with observation method, learning product analysis methods and interview method, we determine the efficiency of SPA as following:

(1)In terms of ***learning interest***, 99.3% of students (149/150) think that SPA has helped enhance their learning interest, just 0.7% of students (1/150) have the opposite opinion (see Fig. 8)

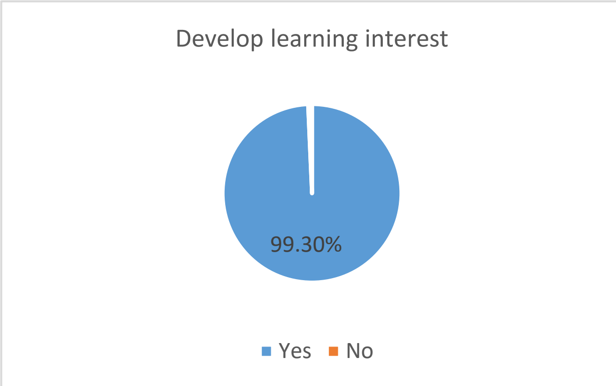

Fig.8. SPA develops learning interest.

Since 99.3% of students (group 1) believe that SPA increased their interest in learning, and only 0.7% of students (group 2) had the opposite opinion, the difference related to other factors between group 1 and group 2 was completely statistically insignificant. It can be seen that SPA can increase the learning interest of engineering students in general.

The next quantitative variables in this study are the proportions related to students' teamwork skills, communication and presentation skills, technical/professional competence, STEM skills, and systems thinking. While the qualitative variable related to students' learning interest has two values (group 1 - interested in learning and group 2 - not interested in learning), and these two values (two groups) are very different (group 1 accounts for 99.3% and group 2 accounts for 0.7%), therefore, the difference between the quantitative variable and the qualitative variable in this case is not statistically significant. For this reason, the study did not use Independent Samples T-Test to test the difference between these two groups in the next factors.

Besides, all "Systems Thinking" courses have students from many different technical majors (e.g. electronics, mechanics, automobiles, wood engineering, construction, mechatronics, etc.). Hence, the students between these courses have almost no difference in terms of professional competence components, social characteristics. In other words, the students participating in these courses are fairly similar in terms of learning characteristics. All students in these pedagogical experimental courses underwent the same teaching methods and approaches, especially the experiential learning with STEM-oriented project-based assignments (SPAs). Therefore, the study does not aim to compare the SPA learning outcomes of different courses but only evaluates the development of teamwork skills, communication and presentation skills, technical/professional competence, STEM skills, and systems thinking of students (in general) from all surveyed courses.

(2)In terms of ***teamwork skill***, 68.7% of students (103/150) suppose that SPA has helped them improve their teamwork skill *at a high level*, even 23.3% of students (35/150) believe that SPA has helped them increase their teamwork skill *at a very high level*, just 12.7% of students (19/150) is of the opinion, that SPA has helped them improve this skill just *at a low level*, and just 1.3% of students (2/150) think that SPA could *not* help them reinforce this skill. The reason for these results is understandable, when the students had the opportunities to work in group to create learning products with SPA (sse Fig. 9)

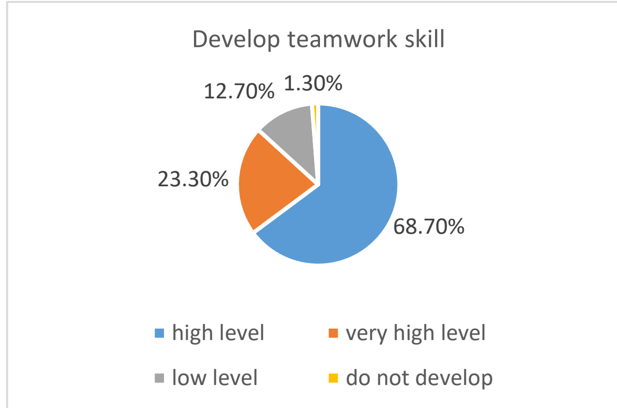

Fig.9. SPA develops teamwork skill.

TABLE II
EXTENT TO WHICH SPA HELPS STUDENTS IMPROVE TEAMWORK SKILLS

N	Min.	Max.	Mean	Std. Deviation
150	1	4	3.12	0.591

Compared with the conventional scale, the mean score of 3.12 and standard deviation of 0.591 shows that students rate SPA as helping them improve their teamwork skills at a high and very high level.

Using the *method of learning product analysis*, it can be seen that the students participated in group work very actively. They demonstrated this through a short video clip describing the process of all group members collaborating together during the project implementation. Through the *method of pedagogical observation*, this teamwork skill was also confirmed through the presentation of each group, in which all members of the group participated in the presentation. The students planned the presentation, divided the tasks, and each student was responsible for presenting a certain content in the overall presentation. Through the *interview method*, a student confided: "I really like this Systemic Thinking course because the lecturer is enthusiastic, willing to answer questions and create opportunities for students to work in groups".

(3) In terms of ***communication and presentation skills***, 59.3% of students (89/150) trust that SPA has helped them increase their communication and presentation skills *at a high level*, even 24.7% of students (37/150) think that SPA could help them improve these skills *at a very high level*, just 15.3% of students (23/150) suppose that it could foster these skills *at a low level*, and 0.7% of students (1/150) is of the opinion, that SPA could *not* help him/her cultivate these skills. The students had to communicate with each other while doing project. They had to solve the conflict in group and learn to negotiate, exchange their ideas when making the learning product. After finishing the project, they had to present their project result in front of class. That why they can improve their communication and presentation skills (see Fig. 10)

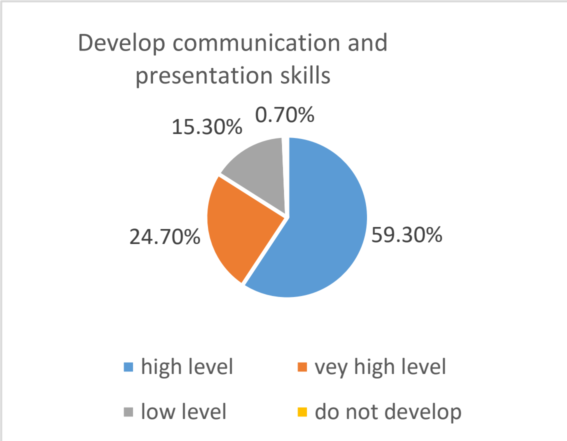

Fig.10. SPA develops communication and presentation skills.

TABLE III
EXTENT TO WHICH SPA HELPS STUDENTS IMPROVE THEIR COMMUNICATION AND PRESENTATION SKILLS

N	Min.	Max.	Mean	Std. Deviation
150	1	4	3.08	0.650

The mean score of 3.08 and standard deviation of 0.650 shows that basically, students rate SPA as helping them improve their communication and presentation skills at a high and very high level.

Using the *method of pedagogical observation*, it can be seen that through the presentations in the SPA, students become more and more confident with their presentation skills. They are also less shy and communicate, interact with their classmates more boldly during the presentation sessions. Through the *interview method*, a student shared: "In the Systems Thinking subject, we have the opportunity to present and introduce our project products, so we feel that our presentation skills have been improved. The classroom atmosphere is fun and open."

(4) In terms of ***technical/ professional competence***, 61.3% of students (92/150) suppose that SPA has helped them train their technical/ professional competence *at a high level* and 22% of students (33/150) believe that it could help them promote this competence *at a very high level*. Just 16% of students (24/150) think it just help them improve this competence *at a low level* and 0.7% of students (1/150) is of the opinion that SPA could *not* help him/her strengthen this competence. The project product is linked with their major and their interest, so through making the product, they can improve their technical/ professional competence (see Fig.11)

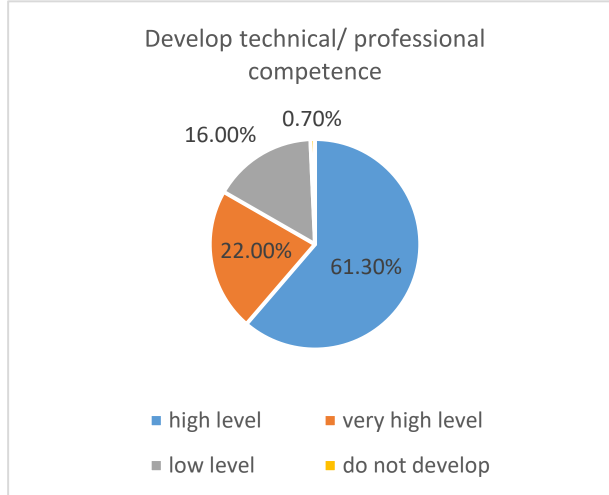

Fig.11. SPA develops technical/ professional competence.

TABLE IV
EXTENT TO WHICH SPA HELPS STUDENTS IMPROVE THEIR TECHNICAL/PROFESSIONAL COMPETENCIES

N	Min.	Max.	Mean	Std. Deviation
150	1	4	3.05	0.638

The mean score of 3.05 and standard deviation of 0.638 showed that basically, students rate SPA as helping them improve their technical/ professional competence at a high level and very high level, Besides, there is a small ration of students (16%) underrated the usefulness of SPA in improving this competence.

Using the *method of learning product analysis*, it can be seen that students from different majors (mechatronics, electronics, mechanics, automotive technology, wood technology, etc.) have applied technical/professional theories well to make project products. The technical products in the projects are diverse and all operate well and successfully. SPAs are opportunities for students to practice. Through the *interview method*, a student expressed: "Through these learning projects, we can apply technical theories to our majors in a profound and practical way". Another student also said: "Many assignments are related to reality, so we can apply our expertise to real life".

(5) In terms of ***ability of integrating of Science, Technology, Engineering and Mathematics for solving problem*** (called STEM skill), 58% of students (87/150) believe that SPA has helped them develop their STEM skill *at a high level*, 29.3% of students (44/150) think that it could help them improve this skill at *a very high level*, just 11.3% of students (17/150) suppose that it could stimulate this skill at *a low level*. And just 1.3% of students (2/150) believe that SPA is *inefficient* for improving this skill (see Fig.12)

TABLE V
EXTENT TO WHICH SPA HELPS STUDENTS IMPROVE THEIR STEM SKILL

N	Min.	Max.	Mean	Std. Deviation
150	1	4	3.15	0.663

The mean score of 3.15 and standard deviation of 0.663 showed that basically, students rated SPA as helping them improve their

STEM skill at a high level and very high level. The percentage of other opinions is very low (total 12.60%).

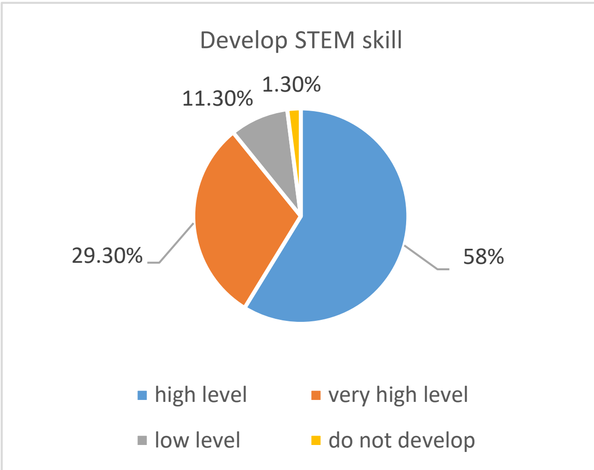

Fig.12. SPA develops STEM skill.

Using the *method of learning product analysis* (mentioned in section 4.2), it can be seen that through SPA, students develop the ability to apply STEM elements to perform project-based tasks and solve learning problems.

(6) In terms of ***systems thinking of engineering students (ST)***, 59.3% of students (89/150) think that SPA could stimulate the ST *at a high level*, 30% of students (45/150) trust that SPA could help them develop their ST *at a very high level*. Just 8.7% of students (13/150) suppose that it could trigger their ST *at a low level*, and 2% of them (3/150) think that SPA could be *useless* in improving their ST.

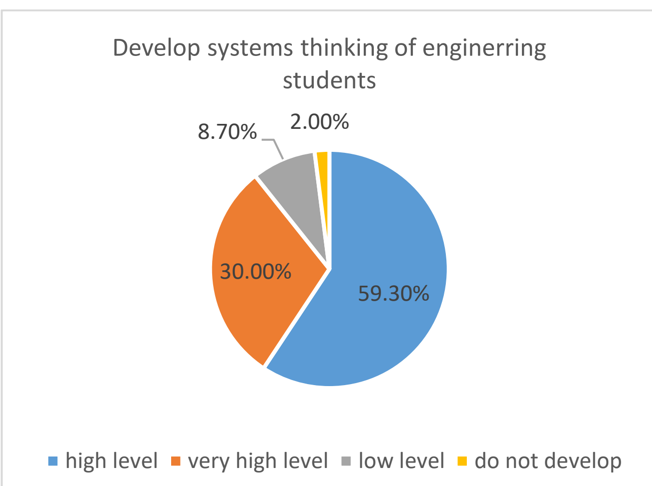

Fig. 6. SPA develops systems thinking of engineering students

TABLE VI
EXTENT TO WHICH SPA HELPS STUDENTS IMPROVE THEIR SYSTEMS THINKING

N	Min.	Max.	Mean	Std. Deviation
150	1	4	3.17	0.663

The mean score of 3.17 and standard deviation of 0.663 showed that basically, students rated SPA as helping them improve their systems thinking at a high level and very high level. The percentage of other opinions is very low (total 10.70%).

Using the *method of learning product analysis* with the consideration of the quality of students' presentations, it can be seen that through the presentations, the students have applied the Systems Theory well to analyze their project products (subsystems, elements, dominance of the system, the constraint and principle of the system, relationships between elements, evaluation of the advantages and disadvantages of the system and proposal of improvement measures). This is also evidence for the development of students' systems thinking. In addition, applying the *interview method*, many students have appreciated the role of SPA in improving their systems thinking ability. For example, one student expressed: "Knowledge of systems thinking can be applied very well in practice, helps to develop my thinking ability", or another student shared: "The project assignments in Systems Thinking are not only theoretical but also highly applicable, helping us to understand more deeply how to look at problems comprehensively and systematically".

D. Challenges and limitations

Some of the challenges and limitations when implementing the Systems Thinking subject with STEM-oriented project-based assignments include:

- Not all learning content of the subject is suitable for designing STEM-oriented projects;
- Project implementation takes a lot of time and costs a certain amount of money for the project products;
- Sometimes students encounter conflicts during the project implementation process when working in groups and sometimes cannot resolve these conflicts by themselves;

Some solutions that can be recommended to address these challenges are as follows:

- Lecturer should choose appropriate content to design SPAs for a subject. The content should link with social/ professional/ technical context and stimulate students' learning interest. The number of SPAs should not be too much to overload students. The number of projects (including large and small projects) should be from two to three projects for each subject per semester.
- Lecturer should design both large and small projects instead of only using large projects. For example, in this paper, the system design project (equipment, toys etc.) is a large project, while the Egg Drop project is a small project. This avoids the loss of control over the time to implement projects in the subject. In addition, lecturers should set projects that are not too costly in terms of materials and encourage students to use recycled materials. This is also a cost-effective solution for STEM-oriented projects, facilitating students from different socio-economic backgrounds to participate in STEM learning in an equitable manner and contributing to environmental protection.
- Lecturer should regularly support and advise students throughout the process of implementing their learning projects. In case of too much conflict in the group, lecturer can arrange for students to change groups or restructure the group to create a more favorable learning atmosphere for students.

CONCLUSION

Implementing learning projects to combine academic knowledge at university with real-world is one of the effective forms in STEM education. It is to realize the practicality and application of theoretical technical knowledge combined with the process of exploration and discovery, engineering design in solving practical problems. Here, there is no longer a barrier between learning academic knowledge and practical application. With the pedagogical experiments at Ho Chi Minh City University of Technology and Education, it can be realized, that STEM–oriented project-based assignments are very helpful for engineering students in increasing their learning interest, their team work skill, their communication and presentation skills. Besides, the technical/ professional competence and STEM skill of them are also improved. Especially, STEM-oriented project-based assignments appropriately applied can stimulate the systems thinking of engineering students. These pedagogical practice could be applied in other subjects/ other field of engineering education. In the future, there should be other studies on the application of SPAs in different subjects in training engineering students in different countries to identify more clearly the other effects of SPAs in engineering training as well as to see whether there are differences when applying SPAs to students in different countries with different socio-economic backgrounds. Besides, the lack of a control group limits the ability to compare their effectiveness with traditional teaching methods in this research. In the future, other studies could exploit the more holistic research approaches/ methods to collect the more comprehensive results. The proposed solutions to overcome the challenges in implementing SPAs in engineering education might also be tested for their effectiveness and their impact in further studies. They may be the next potential future research directions of this research topic.

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