Development of a Virtual Learning Environment with the Engineering Design Process to Enhance Students' Creative Thinking Skills

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***Abstract*—This research aimed to 1) develop a Virtual Learning Environment with the Engineering Design Process (VLEEDP) to enhance students' creative thinking skills, and 2) study the results of using this VLEEDP to enhance students' creative thinking skills. The sample group consisted of ninth grade students from Benchamarachuthit Pattani School. The sample group included one classroom with 39 students, selected through cluster random sampling. The research tools included a VLEEDP and lesson plans. The data collection tools comprised an evaluation form to assess the quality of the VLEEDP and a creativity skill evaluation form. Data analysis involved descriptive statistics, including mean, standard deviation, and percentage. Additionally, the research employed a one-way repeated measures analysis of variance to analyze variables, and pairwise comparisons using the Bonferroni test. The research results indicated that: (1) the development of the VLEEDP was of high quality, and (2) the results of utilizing this VLEEDP showed that a statistically significant increase in creative thinking skills across the three assessments (64.76%, 75.14%, and 91.19%, respectively) at the 0.01 significance level.**

***Keywords*—virtual learning environment, engineering design process, creative thinking skills**

I. Introduction

The 21st century global social context is the digital age, where technology has advanced significantly and plays a crucial role in education. It also has an impact on both teachers and learners. There is a need for a transformation in learning format to develop learning skills that align with the global context and keep pace with rapid changes. One crucial component in promoting learning skills among learners is creating a conducive and appropriate learning environment. Therefore, teachers need to transform their roles into facilitators, both in managing teaching and organizing the learning environment. In addition to arranging the physical learning environment in the regular classroom, teachers should also pay attention to organizing the virtual learning environment. This way, teachers can integrate information technology tools for communication, collaborative work, and knowledge exchange, both in synchronous and asynchronous formats. Teachers can leverage technology to create a virtual learning environment that allows learners to choose based on their interests, along with generating motivation for critical thinking and stimulating hands-on activities. This approach contributes to the development of more effective learning skills in learners. Therefore, teachers should plan, design, and develop teaching methods to enhance learners' abilities to adapt to changes in a timely manner.

In the current teaching environment, teachers need to develop a diverse learning environment for learners. A virtual learning environment is an innovative tool that significantly impacts learners' skill development [1]. It plays a vital role in promoting motivation [2], facilitating collaborative work [3], and integrating various technological tools for communication, collaboration, and knowledge exchange both in synchronous and asynchronous formats [4]. These learning experiences take place within a virtual learning environment. The virtual learning environment is an educational innovation that enhances teaching efficiency and provides more flexible learning opportunities for all students [5, 6], aligning with the research of Tang *et al*. [7], which demonstrates that technology tools have transformed traditional teaching methods. They enable learning through portable devices and immediate feedback. Smooth connectivity is possible and has positive impacts on learners; these include increased motivation, creative thinking, and improved abilities and skills. Additionally, they contribute to creating a virtual learning environment conducive to developing students' creative thinking skills.

The development of creative thinking skills is at the core of learner development, which the Ministry of Education of Thailand highly emphasizes and focuses on. This is because learners with creative thinking skills actively seek innovative ideas, approaches, and tools to enhance efficiency in their work. Therefore, it benefits organizations significantly. This aligns with the World Economic Forum's report [8], which discusses the changing skill requirements in various future jobs. This leads to a higher tendency of skill gaps by the year 2027. The approach to teaching and skill development is being increasingly shifted to online formats. Therefore, learners need to possess outstanding creative thinking skills to meet organizational needs and future work trends. However, currently, learners possess low levels of creative thinking skills. This issue arises from teaching methods that emphasize lectures and memorization as crucial elements. These methods lack opportunities for learners to practice their thinking skills. The teaching approach often guides learners to learn within the framework set by the teachers without promoting essential learning processes for creative thinking skills [9]. Therefore, teachers must design a suitable learning environment along with a learning format that allows learners to achieve their full learning potential. This involves promoting effective technology use to enhance learners' readiness for learning.

One learning format that helps enhance learners' creative thinking skills is learning with the engineering design process,

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which is a cycle of systematic problem-solving. It helps learners solve problems with limited resources and analyze the situations and impacts, which leads to the design of the most suitable solution. Learners can continuously go back and improve their designs through testing, analysis, and repeated redesigning until they achieve the most suitable concept [10]. The ideas generated through each step of the engineering design process demonstrate the creative thinking skills of each individual learner [11, 12]. This aligns with the research conducted by Aini and Aini [13], which found that learners enhance their creative thinking skills through learning using the engineering design process. The most crucial step in this process is creating prototypes. Learners create prototypes with solutions and present them. In addition, they can choose prototypes to further develop suitable solutions. Hence, this activity can enhance learners' creative thinking skills. This is consistent with the ideas of Arık and Topçu [14], who stated that the engineering design process has a structured iterative working mechanism in the design, development, and testing stages, allowing learners to iterate and redesign. This iterative learning process helps learners exercise creative thinking through repetition. Repetition in learning can transform skills or knowledge from conscious to subconscious awareness. It enables learners to apply what they have learned in real life knowingly and achieve success.

From the above key points, the researchers believed that learners should receive knowledge, skills, and abilities development to become a vital force for the nation's growth. This could be achieved by cultivating and developing creative thinking skills, giving learners opportunities to create items, produce works, and invent various things from childhood. This is because creative thinking skills are crucial for coping with the constant changes in the dynamic world. Therefore, the researchers were interested in developing a Virtual Learning Environment with the Engineering Design Process (VLEEDP) to enhance learners' creative thinking skills. Additionally, the researchers aimed to study the effects of this virtual learning environment on students' creative thinking skills. The research questions were: 1) what are the components and steps of the VLEEDP to enhance students' creative thinking skills; and 2) can the VLEEDP effectively enhance students' creative thinking skills, and how?

The proposed work is innovative as it integrates the VLEEDP to enhance students' creative thinking skills. This approach is advanced in terms of educational techniques as it fuses technology at its best with a structured problem-solving base. As opposed to traditional settings that are heavy on passive content delivery, this model puts students at the center with interactive simulations and problem-solving tasks. From classrooms that use multiple modes of media to lecture capture and streaming, this method allows teachers to create a learning experience that is engaging through built-in interaction tools for students while leveraging the resource-rich environment of virtual platforms. The integration of engineering design principles also encourages a tactile and iterative problem-solving approach, getting students to think in multiple solutions and creatively. This novel combination is revolutionary to teaching and learning, empowering a new wave of creative educational strategies that are necessary for guiding students into an increasingly complex modern world.

The objectives of the study were as follows:

1) To develop the VLEEDP to enhance students' creative thinking skills.
2) To study the results of using the VLEEDP to enhance students' creative thinking skills.

The research hypothesis stated that students' creative thinking skills will significantly increase after each of the three learning sessions in the VLEEDP at the 0.01 level.

II. Literature Review

A. Virtual Learning Environment with the Engineering Design Process (VLEEDP)

Managing the educational environment to promote learners' learning is crucial in developing their thinking skills. This consists of various aspects, including organizing the physical learning environment in traditional classrooms, as well as creating a virtual learning environment for online classes. The virtual learning environment is particularly significant, especially during situations like the COVID-19 pandemic, where the integration of technological tools becomes essential in managing online teaching. This involves preparing delivery methods, tracking learner progress, evaluations, and accessing information sources. In general, a virtual learning environment typically incorporates tools that can support learners' learning in several ways, including communication, evaluation, collaboration, and other facilities [15]. Both learners and teachers can use these tools for presentations, resource sharing, collaborative activities, and interaction with each other. Additionally, these tools serve as a way to manage the learning experience, enabling learners to achieve their objectives, providing convenience, supporting the active participation of both learners and teachers for a collaborative learning experience. It also helps create relationships between teachers, learners, and schools by using the internet as a medium for knowledge transfer [16, 17]. In summary, a virtual learning environment is an online learning space systematically designed and developed to create lessons. It incorporates technology tools that encourage learners to interact with each other and exchange knowledge through learning activities designed to be accessible anytime, anywhere. In the 21st century, the development of virtual learning environment has had a significant impact on fostering creative thinking skills, which are crucial for learner development. Teachers must seek ways to develop learners' creative thinking skills, and the engineering design process is one approach that can contribute to enhancing these skills [18, 19].

The engineering design process is a systematic problem-solving approach with an iterative working mechanism to address problems with limited resources. It involves analyzing the situation and impacts, leading to the design of the most suitable solution. The engineering design process can develop learners' creative thinking and help them explore detailed problem-solving approaches, understand the operation easier, address potential future issues, and apply their own ideas to create tangible and beneficial innovations [11, 20]. For the steps of the engineering design process, various organizations, educational institutions, and scholars have proposed diverse frameworks. For instance, the International Technology Education Association [21] has presented seven steps of the engineering design process, comprising: 1) identifying the problems, 2) generating ideas, 3) selecting a solution, 4) testing the solution, 5) making the item, 6) evaluating it, and 7) presenting the results. Massachusetts Department of Education [22] has presented eight iterative steps of the engineering design process, comprising: 1) identify the need or problem, 2) research the need or problem, 3) develop possible solutions, 4) select the best possible solutions, 5) construct a prototype, 6) test and evaluate the solutions, 7) communicate the solutions, and 8) redesign. Precharattana *et al*. [11] have presented seven steps of the engineering design process, comprising: 1) identify problem and need, 2) determine possible solution, 3) design a solution, 4) drawing presentation, 5) developing prototype, 6) testing and evaluating, and 7) final product presentation. The notable steps include identifying the problems and needs, designing, and developing prototype. These are steps where learners will have to use creative thinking skills and create the work. This ignites fun, challenges, and allows learners to choose topics according to their interests. In this research, the researchers used the Virtual Learning Environment with Engineering Design Process model (VLEEDP model) from Thammaariyasakun *et al.* [23], as shown in Fig. 1. This VLEEDP model can foster learners' creative thinking skills.

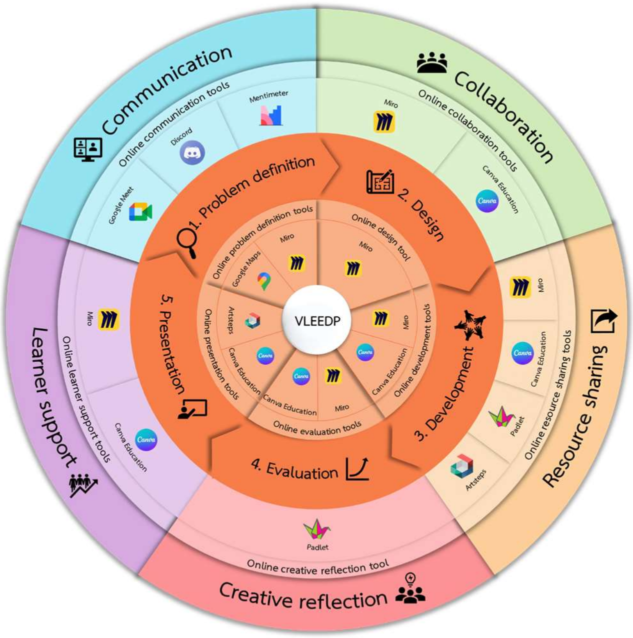

Fig. 1. VLEEDP model to enhance creative thinking skills.

The model comprises five stages of the engineering design process, as follows. In the problem definition step, each student group must comprehend the issues or needs arising within the Pattani provincial community, including occupational challenges faced by the community members. This involves conducting surveys and analyzing problem situations to help each student group clearly understand the conditions and framework of the problems. This aligns with Watkins *et al.* [24], who state that the problem definition step is a crucial part of the engineering design process. To achieve effective problem-solving approaches that meet the objectives, it is necessary to consider defining the characteristics and scope of the problem, exploring feasibility, identifying constraints faced in problem-solving, as well as weighting and using criteria for prioritization. In the design step, students collaboratively brainstorm to conceptualize solutions for community issues in Pattani province. This stage involves gathering relevant problem-solving information from credible sources and establishing a work plan to determine the most appropriate and feasible solution within given conditions and constraints. This aligns with research by Syukri *et al.* [25], which found that work planning helps students discover detailed problem-solving approaches and facilitates easier understanding of operational processes. Moreover, it enables the anticipation and resolution of potential future issues. Correspondingly, research by Precharattana *et al.* [11] indicates that the design phase is most favored by students, as it allows for the application of creativity and hands-on practice. In the development step, students engage in the creation of their project, utilizing information gathered during the design phase as a foundational concept for developing innovative, beneficial, and optimally suitable outcomes within their capabilities. The process begins with drafting to visualize the general shape of the project. During this stage, students must collaboratively discuss to produce the most novel, beneficial, and appropriate draft for their group. The teacher encourages students to create multiple innovative drafts and refine them for greater completeness. This aligns with research by Zainuddin and Iksan [26], which indicates that drafting stimulates students to express ideas visually, examine prior knowledge, facilitate communication, practice collaboration, and actively engage in the learning process. In the evaluation step, teachers assess students' continuous behaviors, encompassing both their work processes and observable outcomes from activities conducted within the engineering design process. Teachers provide feedback, offer guidance, and identify weaknesses, strengths, and areas for improvement in the projects. This enables each student group to refine and enhance the creativity of their work. This approach aligns with research by Erol [27], which emphasizes the crucial role of teachers in supporting students' failure analysis and continuous improvement processes. Teachers strive to assist students in problem-solving by encouraging them to reconsider issues, demonstrate patience and determination, and facilitate communication and collaboration among peers. These strategies aid students in comprehending problems and engaging in failure analysis and continuous improvement. In the presentation step, which is the final stage of each week, members of each group present their problem-solving methods and artifacts to other student groups and teachers. Each participant can provide feedback, critiques, and suggestions regarding the projects. Subsequently, each group showcases their work in a virtual exhibition. This aligns with research by Precharattana *et al.* [11], who state that project presentations offer learners the opportunity to receive expert feedback for future improvements and developments. Thus, the presentation of student-created projects is fundamentally derived from the students' own knowledge constructs [28].

The quality of the VLEEDP is assessed according to the Analyze, Design, Develop, Implement, and Evaluate (ADDIE) model, which is a widely recognized and accepted instructional design model [29]. The ADDIE model can also be used for designing and developing virtual learning environments. It consists of five stages: Analysis, Design, Development, Implementation, and Evaluation. Each stage acts as a flexible guideline for creating instructional tools effectively [30–32].

B. Creative Thinking skills

Creative thinking skills are crucial for learners. Learners need to possess outstanding creative thinking skills to align with organizational needs and support future work requirements [8]. Creative thinking skills are an expertise in the thought process that can generate diverse and innovative perspectives, whether evolving from existing ideas or innovating. This leads to practice to achieve concrete success, resulting from a quick response to problem-solving, identifying what is missing, not through imitation but by collecting ideas, making assumptions, testing assumptions, refining, and disseminating the work [33]. The components of creative thinking, in the form of divergent thinking, involve thinking broadly from various perspectives, in multiple directions, and are divided into four elements: originality, fluency, flexibility, and elaboration [34]. There was an evaluation of the quality of the work in order to be used as an indicator of the developmental level of creative thinking skills [12, 13].

III. Research Methodology

The research on the development of the VLEEDP to enhance students' creative thinking skills was a research and development study. The researchers proceeded as follows.

A. Research Methodology

1) Investigate and analyze theories, principles, concepts, and studies related to the development of the VLEEDP to enhance creative thinking skills.
2) Designed the VLEEDP to enhance creative thinking skills based on VLEEDP model [23].
3) Developed the VLEEDP to enhance creative thinking skills by following the steps of the ADDIE model, which comprises five steps: analysis, design, development, implementation, and evaluation.
4) The quality of the VLEEDP was evaluated by experts in educational technology, educational measurement, and education. The evaluation used criteria based on a 5-level scale media quality evaluation form. Data was collected, analyzed, and adjustments were made accordingly.
5) Conducted an experiment using the VLEEDP to enhance creative thinking skills.
6) Collected data using a creative thinking skills evaluation form and proceeded to analyze the data.

B. Research Design

This research utilized quasi-experimental research design. It was an equivalent time-series design, as proposed by Campbell and Stanley [35]. The research design could be elaborated as follows.

XO_1	XO_2	XO_3

X represented the implementation of lessons using the VLEEDP (Treatment).

O_1 represented the 1st observation of creative thinking skills.

O_2 represented the 2nd observation of creative thinking skills.

O_3 represented the 3rd observation of creative thinking skills.

C. The Research Population and the Sample Group

1) The population

The population used in this research consisted of ninth grade students from Benchamarachuthit Pattani School. This comprised 10 classrooms and 350 individuals in the second semester of the academic year 2022.

2) The sample group

The sample group comprises ninth grade students. The sample size was determined using G*Power [36], with a medium effect size of 0.3, a significance level (α error probability) of 0.05, and a power level (1-β error probability) of 0.95, yielding a minimum sample size of 31 students. The sample was chosen through cluster random sampling, followed by a lottery method, resulting in a classroom with 39 students. For the purpose of analysis, these 39 students were then divided into 7 subgroups.

D. Developing and Evaluating the Quality of Research Tools

1) Virtual learning environment with engineering design process to enhance students' creative thinking skills

The VLEEDP to enhance students' creative thinking skills was developed following ADDIE model as follows:

a) Analysis

1) Curriculum analysis was an analysis on indicators and core curriculum content of the Science and Technology (Revised version from 2017) based on the Basic Education Core Curriculum of 2008. The researchers studied the curriculum. The learning standards and indicators were in Content Area 4, specifically focusing on technology.
2) Content analysis was an analysis on each subject that aligned with the VLEEDP. The results included content of each subject, design, and technology in learning unit 3, problem-solving technology. It consisted of four main topics, including 1) Agriculture, 2) Fisheries, 3) Food, and 4) Tourism, totaling nine lesson plans.
3) Learner analysis focused on ninth grade students, categorized based on their abilities into high, moderate, and weak groups.
4) Context analysis focused on students' technological readiness, including smartphones and internet access, required for using the VLEEDP.

b) Design

1) Designing lesson plans for the VLEEDP to enhance creative thinking skills had the following elements: 1) developing a concept map; 2) naming the learning unit; 3) defining the learning content and indicators; 4) defining the key content in the learning unit; 5) specifying learning content in terms of knowledge, process skills, and attributes; 6) defining tasks and workload; 7) setting topics and criteria for evaluating tasks and workload; 8) setting the learning duration for the learning unit; and 9) planning lessons for the learning unit—totaling 10 lesson plans as follows:

- Plan 1: Orientation and preparation;
- Plan 2: Problems and needs of the Pattani Province

Community;
- Plan 3: Designing concepts to solve problems for the Pattani Province Community;
- Plan 4: Researching and gathering data about how to solve problems in the Pattani Province Community;
- Plan 5: Developing prototype for the 1st time;
- Plan 6: Developing prototype for the 2nd time;
- Plan 7: Developing prototype for the 3rd time;
- Plan 8: Having the prototype evaluated for the 1st time by teachers;
- Plan 9: Having the prototype evaluated for the 2nd time by experts;
- Plan 10: Presenting the work.

2) Designing the VLEEDP that aligned with lesson plans included following details:
   - The process of determining the content to be presented in the VLEEDP involved dividing the content into main components. These included content within the learning activities through the engineering design process, comprising a total of 10 activities. Additionally, online tools were utilized to enhance the value of the VLEEDP. This system involved network-based lessons in the form of a website, and it gathered essential tools for learning. There were two types of tools: 1) Tools within the virtual learning environment, including communication tools, collaborative tools, resource-sharing tools, creative thinking reflective tools, and learner support tools; and 2) tools in the engineering design process, such as problem-setting tools, design tools, development tools, evaluation tools, and presentation tools.

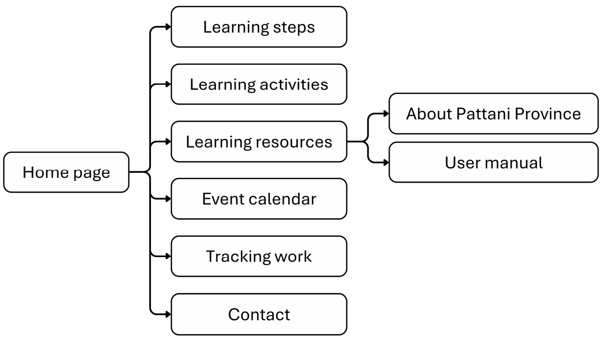

Fig. 2. Organizing the site structure.

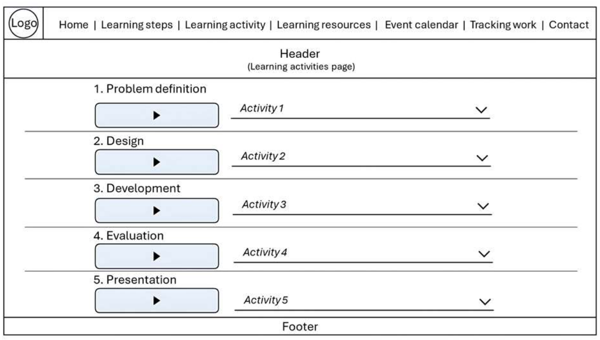

Fig. 3. Example of website design.

   - The process of organizing the website structure involved structuring the content to create a data structure on the website. It included arranging the presentation sequence of content by creating a site structure diagram, specifying the format of links on the website, and defining the layout format of the navigation system, as shown in Fig. 2.
   - The process of website design involved using content to design the layout on each web page. It included designing the graphical display characteristics of the web page and website, as shown in Fig. 3.

c) Development

1) Developing 10 lesson plans by writing plans and presenting them to the experts in order to evaluate the quality, accuracy, identify mistakes, give suggestions for improvement, and define the quality level of the plans. It was found that the quality of lesson plans was of high quality (Mean = 4.49, S.D. = 0.50) and could be implemented in lessons.
2) For the development of a VLEEDP, the researchers used Google Sites to create and manage content on a website, along with using supporting tools including Miro, Canva Education, Padlet, Artsteps, Discord, and Google Meet [23].
3) Presented the developed VLEEDP to experts specializing in virtual learning environments, as well as those with expertise in the engineering design process and creativity to evaluate their accuracy using a quality evaluation form. The evaluation form utilized a Likert-type rating scale with 5 levels. The evaluation form had an Index of Item Objective Congruence at the level of 1.00 and could be used to collect data. The results of the evaluation for the VLEEDP from three experts showed that it was of high quality (Mean = 4.38, S.D. = 0.58) and could be implemented in lessons.

d) Implementation

1) One-to-One Evaluation. This was implemented with ninth grade students from Benchamarachuthit Pattani School during the academic year 2022. The students had varying levels of academic performance, including high, moderate, and weak. There was one student representing each level, totaling three students. Students were asked to express opinions on the VLEEDP. Then, improvements were made.
2) Small group evaluation. This was implemented on ninth grade students from Benchamarachuthit Pattani School during the academic year 2022. Each level of academic performance was represented by three students. The total nine students provided feedback in many aspects such as content, system design, and lesson support. Students were asked to express their opinions on the VLEEDP. Then, improvements were made.
3) Field testing. This was implemented by using the VLEEDP to experiment with a sample group of 39 ninth grade students from Benchamarachuthit Pattani School during the academic year 2022.

e) Evaluation

Evaluating creative thinking skills by using a creative thinking skill evaluation form, which was structured with a rubric scoring system. It comprised four elements, including originality, fluency, flexibility, and elaboration (Fig. 4).

2) Evaluation form for creative thinking skills

Created an evaluation form for creative thinking skills derived from utilizing the VLEEDP. The evaluation form was structured with a rubric scoring system, adapted from the evaluation criteria developed by Aini and Aini [13], Hirsch *et al.* [37]. It defined elements of creative thinking skills that needed to be evaluated into four elements as follows. 1) Originality, 2) Fluency, 3) Flexibility, and 4) Elaboration. The form was then presented to an expert in educational measurement to evaluate content accuracy. It was found that the index of Item Objective Congruence was at the level of 1.00 and the evaluation form could be used to collect data. The criteria for evaluating overall creative thinking skills could be elaborated as follows:

Mean score 80–100 meant creative thinking skills of a student were of very high level.

Mean score 70–79 meant creative thinking skills of a student were of high level.

Mean score 60–69 meant creative thinking skills of a student were of immediate level.

Mean score 50–59 meant creative thinking skills of a student needed to be improved.

Mean score 0–49 meant creative thinking skills of a student were of failing level.

In the opinion of Kemp [38] a level of precision that can be tolerated as a measure of the effectiveness of achieving the goal is if 80% of students achieve a score of 75 or above on the minimum criteria to achieve the goals set.

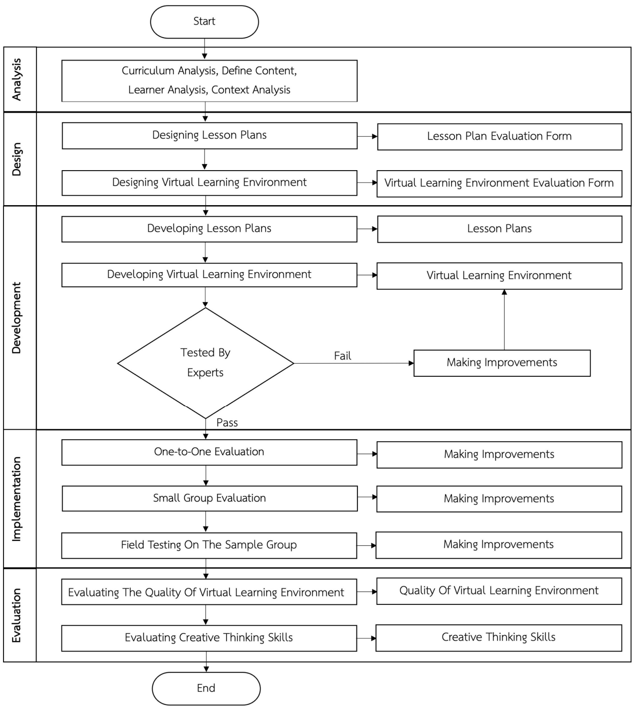

Fig. 4. The diagram for the design and development of the VLEEDP based on the ADDIE model.

E. Data Collection

The researchers experimented and collected data from students who learned in the VLEEDP to enhance creative thinking skills. Data collection processes could be listed as follows:

1) Preparation stage

1) Orientation: Teacher provided learning guidance using the VLEEDP, engineering design process activities, and methods for evaluating creative thinking skills.
2) Students conducted practical exercises using the VLEEDP: registration, login, use of online communication tools, online collaboration tools, online resource sharing tools, online creative reflection tools, online learner support tools, online problem definition tools, online design tools, online development tools, online evaluation tools, and online presentation tools.

2) Experimental stage

Students studied by using the VLEEDP for 18 weeks. The duration was divided as follows. For week 1–6, students studied by using the VLEEDP. Then, they were evaluated on creative thinking skills for the 1st time. For week 7–12, students studied by using the VLEEDP. Then, they were evaluated on creative thinking skills for the 2nd time. For week 13–18, students studied by using the VLEEDP. Then, they were evaluated on creative thinking skills for the 3rd time.

3) Evaluation stage

After students studied by using the VLEEDP, the evaluation was conducted as follows, evaluating creative thinking skills in four areas: (1) fluency, (2) flexibility, (3) originality, and (4) elaboration. The evaluation involved using the creative thinking skills assessment form using 4-level scoring rubric criteria. The data were analyzed by using descriptive statistics, including mean, standard deviation, and percentage, as well as a one-way repeated measures analysis of variance and pairwise comparison using the Bonferroni test.

F. Data Analysis

1) Data analysis employed descriptive statistics for evaluating and validating the quality of research tools, including mean and standard deviation.
2) One-way repeated measures analysis of variance.
3) Pairwise comparisons using the Bonferroni test.

IV. Research Results

A. Results of the Quality Assessment on the Virtual Learning Environment with Engineering Design Process

Results of the quality assessment on the VLEEDP are elaborated in Table 1.

Table 1. Results of the quality assessment on the VLEEDP ($N = 3$)

Assessment Items	Mean	S.D.	Level of Quality
1. Content	4.50	0.67	Very high
2. Screen design	4.53	0.52	Very high
3 The design of VLEEDP	4.19	0.60	High
4. Technique and representation	4.40	0.51	High
Sum of the means	**4.38**	**0.58**	**High**

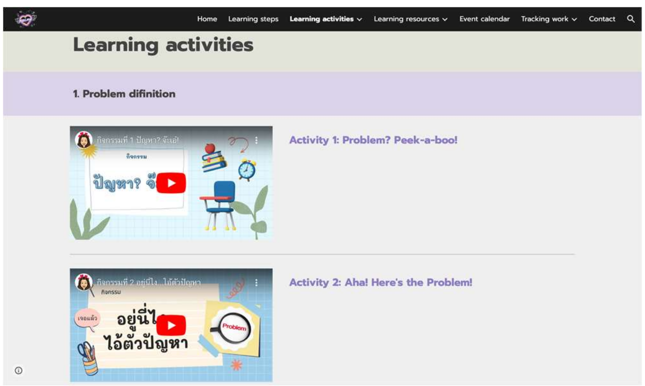

Fig. 5. The VLEEDP to enhance creative thinking skills.

From Table 1, it was found that the sum of the means from the evaluation by three experts was of high level in overall (Mean = 4.38, S.D. = 0.58). When considering each aspect individually, the results were as follows: screen design (Mean = 4.53, S.D. = 0.52), content (Mean = 4.50, S.D. = 0.67), technique and representation (Mean = 4.40, S.D. = 0.51), and the design of the VLEEDP (Mean = 4.19, S.D. = 0.60), respectively. The VLEEDP is presented in Fig. 5.

B. The Results of Using the Virtual Learning Environment with Engineering Design Process

1) The results of using the VLEEDP to enhance students' creative thinking skills

The results of using the VLEEDP to enhance students' creative thinking skills for the 1st time, 2nd time, and 3rd time could be elaborated in Table 2.

Table 2. The results of using the VLEEDP to enhance students' creative thinking skills for the 1st time, 2nd time, and 3rd time

Time		Originality	Fluency	Flexibility	Elaboration	Sum of the Means
1st time	Mean	17.71	15.29	27.29	65.00	**31.32**
	S.D.	1.70	1.38	3.55	10.82	**4.03**
	%	63.27	76.43	56.85	62.50	**64.76**
2nd time	Mean	21.29	17.29	32.86	72.43	**35.96**
	S.D.	1.89	0.76	4.53	9.85	**3.98**
	%	76.02	86.43	68.45	69.64	**75.14**
3rd time	Mean	26.43	20.00	42.14	85.86	**43.61**
	S.D.	0.79	0.00	3.80	10.49	**3.63**
	%	94.39	100.00	87.80	82.55	**91.19**
Sum by Each Aspect	**Mean**	**21.81**	**17.52**	**34.10**	**74.43**	**36.96**
	S.D.	**1.15**	**0.69**	**3.88**	**10.28**	**3.84**
	%	**77.89**	**87.62**	**71.03**	**71.57**	**77.03**

From Table 2, the sum of creative thinking skills was 77.03%. When considering each time individually, it was found that the percentage in the 1st time was 64.76%, the percentage in the 2nd time was 75.14%, and the percentage in the 3rd time was 91.19%. This resulted in students having higher creative thinking skills with evaluation. Creative thinking skills in the 3rd time were higher than those the 2nd and 1st times. When considering the sum of each aspect individually, it was found that the highest score belonged to fluency, with 87.62%, followed by originality, with 77.89%, followed by elaboration, with 71.57%, and finally followed by flexibility, with 71.03%.

2) The result of one-way repeated measures analysis of variance for the results of creative thinking skills of students

The result of one-way repeated measures analysis of variance for the assessment of creative thinking skills of students is elaborated in Table 3.

Table 3. The result of one-way repeated measures analysis of variance for students' creative thinking skills results

Variable	1st time		2nd time		3rd time		F (2,12)	η_p^2
	Mean	S.D.	Mean	S.D.	Mean	S.D.		
Creative thinking skills	31.32	4.03	35.96	3.98	43.61	3.63	545.83**	0.99

** $p < 0.01$

From Table 3, it presented the means, standard deviations, and F-value for consecutive creative thinking skills development. The results indicated a statistically significant difference in the means of creative thinking skills. F (2,12) = 545.83, MSE = 0.49, p = 0.000, n_p^2= 0.99. The research findings showed that the levels of creative thinking skills after studying in the VLEEDP for the 1st time (Mean = 31.32, S.D. = 4.03) became higher later during the period of studying for the 2nd time (Mean = 35.96, S.D. = 3.98) and the 3rd time (Mean = 43.61, S.D. = 3.63). Pairwise comparisons using the Bonferroni test revealed statistically significant differences ($p < 0.01$) between all pairs of scores obtained during the first, second, and third assessments in the VLEEDP.

3) The results of the comparison of the mean scores of creative thinking skills

The results of the comparison of the mean scores of creative thinking skills from three evaluations is presented in Table 4.

Table 4. The results of the comparison of the mean scores of creative thinking skills from three evaluations

(I) Time Point	(J) Time Point	Mean Difference (I–J)	Std. Error	Sig.	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1	2	–4.643**	0.331	0.000	–5.732	–3.554
	3	–12.286**	0.387	0.000	–13.559	–11.012
2	1	4.643**	0.331	0.000	3.554	5.732
	3	–7.643**	0.404	0.000	–8.971	–6.315
3	1	12.286**	0.387	0.000	11.012	13.559
	2	7.643**	0.404	0.000	6.315	8.971

** $p < 0.01$

From Table 4, The results of comparing creative thinking skills across three evaluations indicated that the mean scores at each time point differed significantly ($p < 0.01$).

V. Discussion

From investigating, analyzing, and synthesizing related documents and research to use in the development of the VLEEDP to enhance students' creative thinking skills, the following conclusions could be drawn based upon the objectives.

A. Development of the VLEEDP to Enhance Students' Creative Thinking Skills

From quality evaluation, the result of the development of the VLEEDP to enhance students' creative thinking skills was of high quality (Mean = 4.38, S.D. = 0.58). The VLEEDP was systematically and orderly developed following the ADDIE model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation. The model gained global acceptance and can be used to develop a virtual learning environment effectively. This aligns with the research by Cárdenas and Estrada [39], who designed a learning model that integrated digital resources into a virtual learning environment. Upon following the ADDIE model in the development, it was found that the learning format could enhance digital literacy skills, support interactive processes, collaborative learning, and independent learning.

Additionally, the researchers had incorporated principles into the VLEEDP, resulting in students having creative thinking skills. This aligned with Alina [40] who stated that having a virtual learning environment using computers as a medium and integrating various learning formats, such as e-learning, u-learning, f-learning, blended learning, along with tools for group discussions in visual formats like Padlet, Miro, Mentimeter, enabled learners to learn by themselves while having continuous feedback and suggestions. It also enabled them to create virtual groups and utilize online social network. These could lead learners to develop creative thinking skills.

In addition, the results of this study can be effectively applied to formulate educational policies and sustainable social development initiatives, particularly in curriculum development. Educators can utilize these insights to enhance secondary education curricula by incorporating design activities and group projects into classroom settings, thereby providing students with opportunities to cultivate these skills in real-world environments. This aligns with Shafie, Majid, and Ismail [30], who posit that integrating Technological Pedagogical Content Knowledge (TPACK) can lead to curriculum improvements that enhance the quality of secondary education and better address the needs of the digital era.

In terms of educational policy formulation, support for technology-enhanced learning should be prioritized, including budget allocation for the development and maintenance of virtual learning platforms. This would enable schools to access essential resources for creating effective learning environments. This aligns with Neifachas, Butvilas, and Kovaitė [41], who discuss approaches to developing virtual learning environments that allow students to access education anytime and anywhere, unrestricted by time and location constraints. This technological implementation responds to evolving educational needs. Such technological support is crucial as it broadens access to quality learning resources for all students.

Moreover, investment in technological infrastructure, encompassing system development, maintenance, and teacher training for effective technology utilization, is essential for long-term stability in the education system and maximizing the benefits of technology-enhanced learning for students. This aligns with Rashid *et al.* [42], who emphasize that teacher preparedness in technology use can mitigate challenges in implementing virtual learning environments and facilitate smooth technology-enhanced learning experiences. This aligns with Putra *et al.* [18], who indicate that developing teachers' technological competencies and engineering design process skills plays a crucial role in enhancing students' skills, particularly in prototype development. This approach fosters student learning through problem-solving and innovative activities.

Therefore, educational policies should emphasize the importance of developing teachers' skills and investing in technological infrastructure. This aligns with Koley [43] insights on enhancing workforce skills in the construction industry and investing in innovation. Both perspectives highlight the significance of human resource development alongside technological advancement to create sustainable change. These parallel approaches in education and industry underscore the critical role of skill development and technological investment in fostering long-term societal progress and adaptability. Prioritizing both human capital and technological resources can create more resilient and innovative systems capable of addressing future challenges in both educational and industrial contexts.

B. Study the Results of Using the VLEEDP to Enhance Students' Creative Thinking Skills

Regarding the results of using the VLEEDP to enhance students' creative thinking skills, it was found that overall creative thinking skills were at a high level (Mean = 36.96, S.D. = 3.84). This was because students learned through the engineering design process. Students were able to repeat steps multiple times as necessary and make improvements simultaneously. In other words, when students learned from failures and discovered new design possibilities, it led to better problem-solving methods. The engineering design process thus emphasizes open-ended problem-solving and allows students to learn from failure, improving their work until they achieve the most appropriate outcome. This process of iteration and repetitive learning ultimately leads to skill development [11, 13, 25].

This aligned with the research of Sopapradit [44], who demonstrates the STEM learning system with the internet of things through cloud learning, which was tested using a one-way repeated measures analysis of variance. An examination was conducted to test students' digital literacy knowledge before starting the class. After completing the class, the researcher tested the students' digital literacy knowledge again. Then, after a 1-month interval, the same test series was executed once more to compare the results. The research findings revealed that students had higher digital literacy scores both immediately after completing the class and after the 1-month interval compared to their scores before the class.

This aligned with the research of Ayaz and Sarikaya [45], who demonstrates the effectiveness of repetitive and continuous learning in skill development, particularly in the context of engineering design-based science teaching. This study examined the impact of such teaching methods on decision-making skills, scientific creativity, and design skills of teacher candidates. The results show a significant improvement in skills, with the mean scores for engineering design-based process skills of teacher candidates in the experimental group increasing from 11.17 in the first design to 20.50 in the final design. Throughout the research process, students participated in six different engineering design activities. Performance evaluation of the students utilized an engineering design process evaluation rubric, and a one-way repeated measures analysis of variance was employed to analyze the differences in mean scores. The analysis results indicated a significant skill improvement throughout the study.

This also aligns with the findings of Ritter and Mostert [46], who specifically explored the context of brainstorming and idea generation. Their study employed a one-way repeated measures analysis of variance to examine the impact of four specific idea generation techniques: Silence, Evolution, Random Connections, and Scamper. The key finding of their research was that generating ideas in a group setting after an initial phase of individual idea generation has a beneficial effect on the quality of the ideas produced. This sequential approach to brainstorming-individual ideation followed by group brainstorming-proved to be more effective than group brainstorming alone.

This aligned with the research results of Aini and Aini [12], who found that students who learned through engineering design process possessed very high levels of creative thinking skills. Creative thinking skills consisted of originality, fluency, flexibility, and elaboration. Students possessed very high levels of creative thinking skills in every area. This aligned with the research of Precharattana *et al*. [11], who found that organizing learning using the engineering design process in Blended Learning, which integrated group activities through online learning and hands-on practical activities through independent study at home could lead to students developing higher creative thinking skills through the engineering design process. Moreover, the process of identifying the problems and needs, designing solutions, and developing prototype were the students' favorite engineering design processes because students could use their creative thinking skills and do the work. It was fun, easy, and challenging. Additionally, it opened opportunities for them to choose based on their interests. Therefore, the VLEEDP could enhance four areas of students' creative thinking skills, including originality, fluency, flexibility, and elaboration.

These research findings may lead to the development of community-based learning initiatives for youth that focus on design and invention, providing opportunities for young people to enhance their creative thinking and collaborative skills. This aligns with Sudrajat, Ardianto, and Permanasari [47], who employed the engineering design process to foster students' creativity in the context of alternative energy. Their approach can serve as a guide for developing community learning projects that emphasize hands-on learning connected to local issues and promote sustainable skills such as analytical thinking, problem-solving, and collaboration. This community-focused approach resonates with Koley [43] findings on the importance of engaging local communities in industry projects. The construction sector has recognized the need to create social value through community engagement. Similarly, these educational initiatives can foster community development through youth empowerment and skill-building.

Furthermore, this corresponds with Abdurrahman *et al.* [48], who highlight the significance of integrating the engineering design process into STEM makerspaces focused on renewable energy units. This integration is crucial for developing sustainable solutions to energy and environmental challenges. Students are afforded opportunities to innovate and design renewable energy devices applicable to daily life. Such projects foster community engagement in innovative problem-solving and effectively promote community adaptability for the future. The focus on sustainable solutions and community adaptability aligns closely with Koly [43] emphasis on the construction industry's role in creating sustainable value for Aboriginal communities. Both approaches highlight the importance of integrating local knowledge and needs into technological and educational advancements, fostering resilience and long-term community development.

Consequently, applying these research findings in real-world contexts, particularly in developing virtual learning environments and implementing engineering design processes, will enhance educational policies and social development initiatives that prioritize sustainability. Moreover, this approach can effectively cultivate essential skills for students' future success. This holistic approach to education and skill development echoes Koley [43] recommendations for comprehensive policy reforms in the construction industry. Both perspectives underscore the need for integrating technological advancements with social value creation, whether in educational settings or industry practices, to address evolving societal needs and challenges in the post-COVID-19 era.

VI. Conclusion

The research concluded that the VLEEDP to enhance students' creative thinking skills had a high level of quality (Mean = 4.38, S.D. = 0.58). Therefore, it is effective in improving students' creative thinking skills. The results showed that the total creative thinking skills of students reached 77.03%. When considering each evaluation separately, the 1st evaluation totaled 64.76%, the 2nd evaluation totaled 75.14%, and the 3rd evaluation reached 91.19%, which was significantly higher at the 0.01 statistical significance level.

For the suggestions on implementing the VLEEDP, there must be preparation in terms of technological basic skills, devices such as computers, smartphones, and the internet. This is to ensure teaching and learning activities are conducted efficiently. Additionally, there should be orientation before learning. Teachers should prepare a manual and demonstrate the five steps of using the tools in the VLEEDP through modern social media. Therefore, students will have the opportunity to practice and thoroughly understand how to use the tool before the actual use. More importantly, they can use the tools effectively. As learning activities in the VLEEDP require tools to use in group activities, teachers should define the learning format such as 40/60, 50/50, hyflex learning, or blended learning. teachers are responsible for controlling the online classroom, closely providing advice on how to use the tools, and facilitating the activities. Teachers should also create an atmosphere that enables students to interact with each other, which leads to the achievement of goals. For further research, there should be an application of the virtual learning environment to other subjects or skills that students need in the future.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Phongampai Thammaariyasakun performed conceptualization, methodology, data collection, formal analysis, and writing—original draft; Wichai Napapongs contributed to conceptualization, methodology, validation, and writing—review & editing; Jirawat Tansakul was responsible for methodology, validation, and writing—review & editing; Chamaiporn Inkaew handled conceptualization, project administration, supervision, and writing—review & editing. All authors had approved the final version.

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