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Research Article

Virtual Studio Learning Environment Based on STEAM Education Concept Integrated With Socio-Scientific Issues to Enhance Learner's Scientific Creativity

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Abstract

The objective of this research was to develop learners' scientific creativity by incorporating a virtual studio learning environment based on the STEAM education concept integrated with socio-scientific issues. The learning environment highlighted features such as a showcasing space where learners can gain feedback, which could be useful for any revisions to increase the efficiency of their projects. This created room for learners' trial and error while engaging in the activities. Moreover, the STEAM education concept integrated with socio-scientific issues was utilized in the activities. Using purposive sampling the sample consisted of 75 secondary school students. During the 8-week experiment, these students were assessed before (week 1), during (week 4), and after studying (week 8). The evaluation tools included a student self-assessment form and a teacher project evaluation form. Statistical analysis was conducted using mean, standard deviation, and repeated measure ANOVA. The results from the self-assessment form revealed that students had a higher average score for divergent thinking after studying (M = 4.66, SD = 0.22) than during (M = 3.31, SD = 0.23) and before studying (M = 3.02, SD = 0.36). For convergent thinking, the average score after studying (M = 4.65, SD = 0.23) was found to be higher than during (M = 3.32, SD = 0.22) and before studying (M = 3.02, SD = 0.37) at the .05 statistical significance level. The results from the teachers' project evaluation form showed that the learners' scientific creativity average after learning (M = 21.97, SD = 0.15) was higher than during (M = 18.23, SD = 0.15) and before learning (M = 12.53, SD = 0.11) at the .05 statistical significance level.

Keywords: virtual studio learning environment, STEAM education, socio-scientific issues, scientific creativity, secondary school students

Introduction

Creativity resides as a highlighted 21st century skills for its role in preparing learners for the challenges of sustainably developing and creating innovations (Haim & Aschauer, 2022). This aligns with SDGs' education targets to adjust learning for knowledge and skills towards innovation as well as resilience and creativity for sustainable development (Gabriel et al., 2023). The education framework 2023 promoted creativity that shall enhance learners' knowledge application skills to tackle unfamiliar situations by employing diverse skills and thinking processes. Learners shall be able to think and develop new items, knowledge, innovation, services, works, processes, or methods that are beneficial and valuable. Also, they must cooperate and acquire practical skills such as handling information or technological tools (OECD, 2018). Additionally, creativity belongs to the future skills category alongside the ever-changing landscape of the 21st century which ignited alterations both in the social and technological aspects as well as learning disruptions (Khlaisang & Koraneekij, 2024). As a result, the quality of learners needs to be developed to match the demands on future skills, body of knowledge, and careers. Likewise, Thailand's Ministry of Education classifies creativity among the future skills for learners ranging from early childhood, adolescence, and working age (Office of the Education Council, 2021).

Surrounding the context of science education, creativity is crucial to the scientific process (Ozkan & Umdu Topsakal, 2021). This is because the creative process can be integrated into the scientific method to help uncover problems, create concepts and deliverables, or seek alternative solutions (Dwikoranto et al., 2021; Sun et al., 2020; Cook, 2020; Yildiz & Guler Yildiz, 2021). In terms of STEAM education, it incorporates comprehension in science, technology, engineering processes, arts, and mathematics, which are utilized to enhance learners' higher-order thinking skills such as creativity, problem-solving, and critical thinking. Also, it involves innovating via activities that are designed to engage learners in tackling complications, collaborating, and connecting creativity processes to their work (Chun & Heo, 2019; Wannapiroon & Petsangsri, 2020; Conradty et al., 2020; de Vries, 2021). Moreover, once socio-scientific issues become the activity's setting alongside STEAM, it allows learners to efficiently understand how to apply knowledge to their daily context. Thus, learners' scientific creativity skills development can be achieved (Sadler et al., 2004; Yoon et al., 2019;

Hodson, 2020; Kim et al., 2020).

In the aforementioned context, a virtual studio learning environment (VsLE) is among the suitable solutions. It is an online learning environment that highlights the exchange of ideas and reflections between learners as well as learners and teachers while they are conducting the activities. This can assist learners with feedback that can be used for them to adjust their work or learning processes (McDonald et al., 2020; Nespoli et al., 2021). Loudon (2019) mentions that the fear of mistakes when completing activities can hinder creativity development. Therefore, a learning environment that unlocks opportunities for learners' trial and error while learning can address creativity development as learners can be more open-minded and acquire greater learning motivation.

This research incorporated a virtual studio learning environment (VsLE) with STEAM education concepts and socio-scientific issues. It offered a learning environment that permits learners to present perspectives, exchange ideas, and practice while encouraging trial and error via a series of activities that involve engineering knowledge and design processes. In the process, learners are guided to develop deliverables or provide solutions. The research question, therefore, was what outcomes on the scientific creativity were observed among secondary school students when learning via a virtual studio learning environment based on STEAM education concept integrated with socio-scientific issues. This was to address the needs to enhance scientific creativity and STEAM Education, as a focus in Thai education, in the hope that it could equip students with integrated skills in arts, science, and technology which incorporates creative thinking and knowledge, implying the improvement of problem-solving skills and creative innovation in daily life and workplaces (Ministry of Education, 2022).

Objectives

The objective of this research was to develop learners' scientific creativity by incorporating a virtual studio learning environment based on the STEAM education concept integrated with socio-scientific issues.

Hypothesis

After studying through VsLE, according to STEAM Education, with the socio-scientific issues, students have higher scientific creativity scores compared with during and before studying at the .05. statistical significance level.

Literature Review

Virtual studio learning environment

The studio learning environment gained recognition in architectural and industrial design education as an assistant to enhance learners' creativity. It accentuates exchanges of ideas and reflections between peers and among learners and teachers whilst completing pedagogical activities. The process allows learners to access feedback that is used to alter their working or learning methods (McDonald et al., 2020). It also highlights openness in thinking via the learning by doing concept. These interactions help learners visualize feedback and use it to develop their work as well as their creative potential (Fleischmann, 2021; Jones et al., 2021). The elements of VsLE were synthesized and summarized in the table below.

Table 1

Elements of Virtual Studio Learning Environment

Elements/Studies	Fleischmann (2020)	Walker et al. (2019)	Loudon (2019)	Ramey and Stevens (2019)	Walker and Kafai (2021)	Iranmanesh and Onur (2021)	Nespoli et al. (2021)	Jones et al. (2021)	Summary
Learning space	✓	✓	✓	✓	✓	✓	✓	✓	✓
Space for learners' personal activities	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 1
(continued)

Elements/Studies	Fleischmann (2020)	Walker et al. (2019)	Loudon (2019)	Ramey and Stevens (2019)	Walker and Kafai (2021)	Iranmanesh and Onur (2021)	Nespoli et al. (2021)	Jones et al. (2021)	Summary
Space for collecting learners' works or portfolio	✓			✓		✓		✓	✓
Learner-to-learner and learner-to-instructor sharing of ideas	✓	✓	✓	✓	✓	✓	✓	✓	✓
Organizing learning activities based on learners' interests	✓	✓		✓	✓		✓	✓	✓
Instruments for learners' collaborative work	✓								
Showcase	✓		✓	✓	✓	✓		✓	✓
Evaluation, reflection, and feedback	✓	✓		✓		✓	✓		✓

According to Table 1, the learning environment consists of 1) a personal learning and activity space, 2) a group activity space to exchange ideas among peers and with teachers, 3) activities that focus on learning from authentic situations that relate to the learners' daily lives according to the learners' preference, 4) a space for showcasing learners' work, and 5) evaluation that involves reflections and feedback from peers and teachers (Walker et al., 2019; Loudon, 2019; Fleischmann, 2021; Iranmanesh & Onur, 2021; Jones et al., 2021).

STEAM education concept integrated with socio-scientific issues

STEAM education integrates five disciplines namely science, technology, engineering, art, and mathematics. Chu et al. (2019) explained that the application of STEAM education alongside socio-cultural contexts could help learners acknowledge the significance and connections of science to their everyday lives. For instance, when topics about global warming are incorporated, it encourages learners' curiosity which leads to further inquiry for answers in their areas of preference. This is because learners are in control of stating the problems and feel a sense of ownership over the topic they have chosen. Furthermore, the inclusion of art education while accomplishing the activities guides learners to better comprehend scientific conceptions because such knowledge was required when designing. Thus, they are provided with the opportunity to develop creativity, problem-solving skills, and autonomous learning. Therefore, the advantage of STEAM education is that learning relates to authentic situations with the involvement of art in the pedagogical process. This generates spaces for learners to design their learning process while spotlighting social contexts as well as promoting trial and error. This openness to welcoming diverse experiences, learning mistakes, exchanging of peers' perspectives, and feedback, all contribute well to learners' creativity development (Chun & Heo, 2019; Wannapiroon & Petsangsri, 2020; Conradty et al., 2020; de Vries, 2021). The synthesized stages of learning were presented in the table below.

Table 2

Synthesized Stages of Learning Model

Stages of learning	Wannapiroon and Petsangsri (2020)	Jia et al. (2021)	Khamhaengpolet al. (2021)	Ozkan and Umdu Topsakal (2021)	Summary
Analyzing problems and needs	✓	✓	✓	✓	✓
Gathering ideas related to the problematic situations	✓		✓	✓	✓
Researching, designing, and planning to solve the problems	✓		✓	✓	✓
Evaluating solutions to address the problems		✓		✓	
Considering further possible solutions		✓			
Connecting and integrating knowledge	✓				
Developing innovations or works from the knowledge and plans	✓	✓	✓	✓	✓
Reflecting, giving feedback of, and evaluating the results of what the learners learn	✓	✓	✓	✓	✓
Presenting the results		✓	✓	✓	✓

According to the synthesized stages of learning model, ultimately, when socio-scientific issues are introduced as the context for STEAM education, the "STUDIO" learning process is constructed with the approaches as follows: 1) researching the socio-scientific situation to state the problem, 2) researching additional information on the task to seek solutions, 3) planning unique solutions by integrating multiple disciplines via exchanges of information and discussions, 4) designing innovation, work or concepts, 5) illustrating to showcase the work, and 6) conducting open-minded reflections and evaluations.

Scientific creativity

Scientific creativity is the personal ability to think and develop new work that is beneficial or valuable to oneself and society. This can include both concepts and tangible works that apply knowledge and skills specifically in the areas of science, scientific process, and the creativity of general contexts which are then used to state problems, uncover solutions, and create innovation (Yang et al., 2019; Oh, 2021; Wiyanto & Hidayah, 2021; Atesgoz & Sak, 2021; Zhou, 2021). Documents pertaining to elements of scientific creativity could be summarized in Table 3.

According to Table 3, the elements of scientific creativity consist of such concepts as divergent thinking which involves 1) fluency, which is the number of answers or ideas that the learners generate, 2) flexibility, which is the number of criteria or groupings that the learners can categorize, and 3) originality of the learners' ideas. Moreover, the process consists of convergent thinking which consists of 1) analysis and synthesis, and 2) evaluation and selection to discover appropriate solutions and problem statements.

According to the rationale of the study, literature review, along with the theoretical framework of constructivist learning and self-directed learning research framework was presented as follows.

Table 3

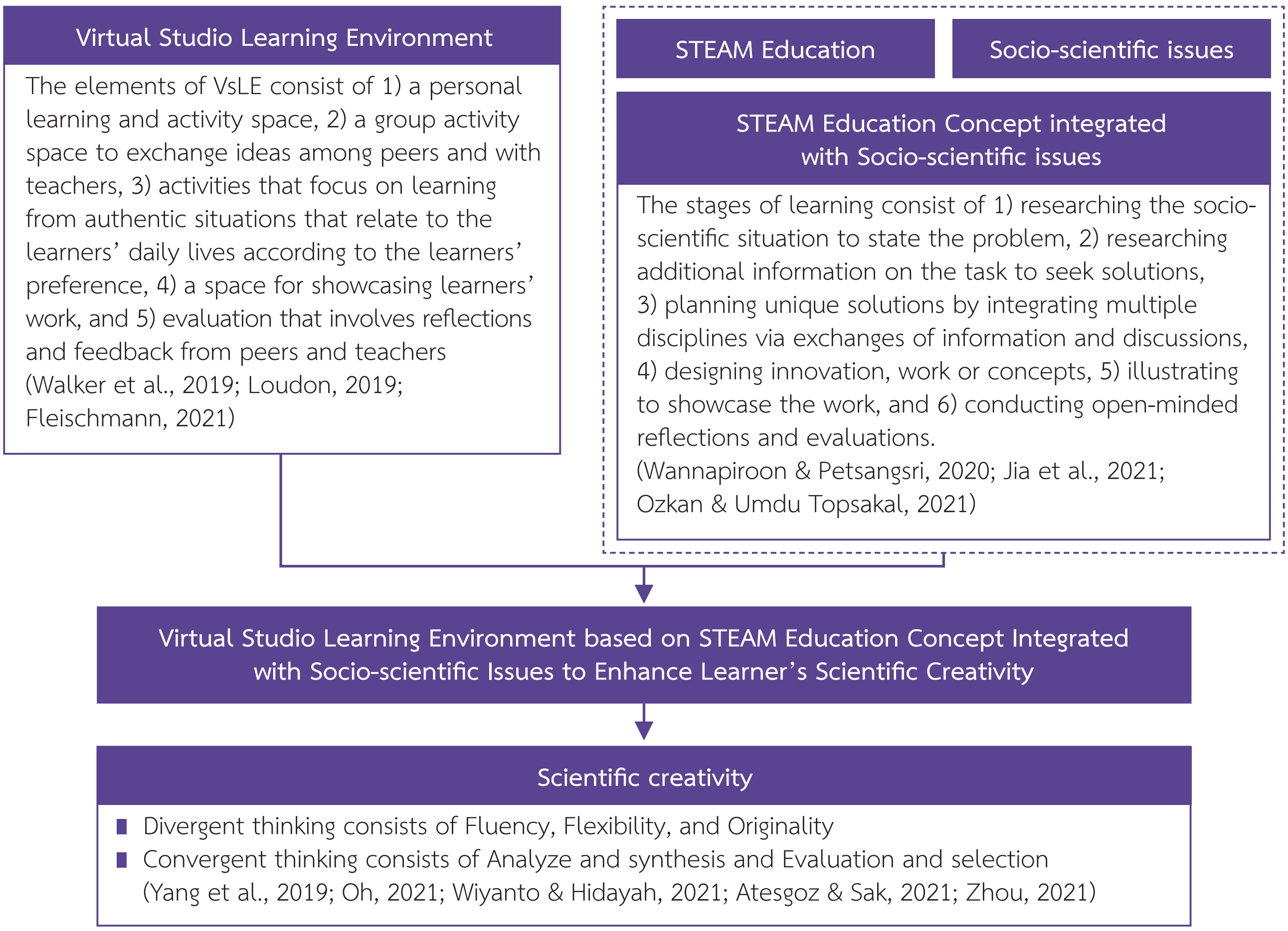
Elements of Scientific Creativity

Elements of scientific creativity	Hu and Adey (2002)	Oh (2021)	Wiyanto and Hidayah (2021)	Atesgoz and Sak (2021)	Yang et al. (2019)	Zhou (2021)	Summary
Divergent thinking: fluency, flexibility, and originality	✓	✓	✓	✓	✓	✓	✓
Convergent thinking: analyzing approaches to identifying and solving problems		✓	✓		✓		✓
Selecting useful and innovative ideas		✓	✓				
Creative process and scientific imagination	✓		✓				

Research Framework

Figure 1

Research Framework



Methodology

The study used a quasi-experimental design with a one-group time series. The objective of the current research was to observe the effects of using STEAM-oriented VsLE with socio-scientific issues to develop secondary students' scientific creativity.

Participants

Using purposive sampling, the sample of the study consisted of 75 grade-12 secondary students from different parts of Thailand, including 36 female (48%) and 39 male students (52%) who were in the science-mathematics major. The recruitment criteria were as follows. 1) The students were capable of using technological devices. 2) Their institutions provided consent and were technologically ready. 3) The teachers were prepared for and capable of using technology.

Ethical consideration

In this study, the researchers obtained consent from the participants to give their responses. The researchers ensured the anonymity of the participants as well as their freedom to withdraw from the study anytime with no need to give reasons. The data were kept during the study and were destroyed upon completion of the study. Only researchers would have access to the data. All research protocols and procedures were reviewed and approved by the Research Ethics Review Committee for Research Involving Human Subjects at Chulalongkorn University (224/66).

Experimental Design

This was a learning innovation research and development study that designed the virtual studio learning environment based on the STEAM education concept integrated with socio-scientific issues to enhance the scientific creativity of secondary school students. It emphasized on-demand learning wherein learners followed their needs or interests within the socio-scientific concept in order to design concepts or innovations for problem-solving. The virtual studio learning environment encapsulated spaces for completing activities as follows. The first feature was 1) My Studio, where learners carried out activities (both individual and group tasks). This was where learners could exchange ideas while working. Also, group work activities featured STEAM tools that they could use to design the works such as Tinkercad (Autodesk), Spatial, and SketchUp. In this space, learners could display their work in progress to collaboratively exchange ideas and reflections in a metaverse platform. The feedback could be used for better group work adjustments. The second feature was 2) My Modules, which was the learning space with related resources and information that were accessible anywhere and anytime. The third feature was 3) Showcase, which was where the group could display their work and fellow students could give likes and comments. Further details were provided in Table 4.

Table 4

The Relationship between the Learning Process in the Virtual Studio Learning Environment and Scientific Creativity

STUDIO	Features in the virtual studio learning environment	Scientific creativity
S (Situation) Research on socio-scientific issues to state the problem in a situational format	My Studio feature: learners' personal learning and activity space (Figure 1)	Divergent thinking
T (Task) Further research to seek solutions for the group discussion tasks	■ My Module feature: information related to the activity's topic (Figure 2) ■ Group activity space with peer-to-peer ideas exchange (divergent thinking and convergent thinking)	Divergent thinking and convergent thinking to state the problem and seek problem-solving options
U (Uniqueness) Design and plan to solve problems by integrating knowledge from diverse disciplines that are used to generate multiple, unique ideas for discussions	My Studio feature: a group activity space for peer-to-peer ideas exchange	Divergent thinking

Table 4
(continued)

STUDIO	Features in the virtual studio learning environment	Scientific creativity
D (Design) Collaboratively analyze and synthesize information to design the best solution	My Studio feature: a group activity space with examples of STEAM tools that learners can choose to help with their design such as Tinkercad (Autodesk), Spatial, SketchUp, etc. (Figure 3)	Convergent thinking
I (Illustration) Illustrate innovative work or concept development that is beneficial to oneself and society by applying specific scientific knowledge and skill with creativity	My Studio feature: a group activity space	Convergent thinking
O (Open-minded) ▪ Draft presentation in the metaverse platform to open-mindedly receive comments from teachers and peers that can be guidelines for better revisions ▪ Finalized students' works are displayed for collaborative learning opportunities	Showcase feature: a space for display and evaluation as well as for reflection and feedback (Figure 4)	Divergent and convergent thinking

Figure 2
Identifying the Learners' Activity Topic in "My Studio" and Using Online Concept Maps to Assist Learners in Stating as Many Problems as Possible About Resources

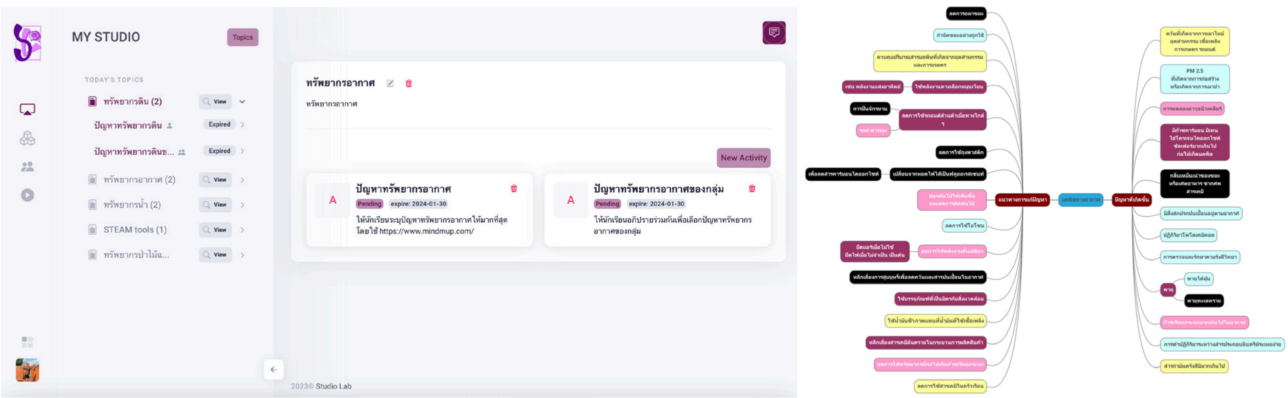


Figure 3
"My Module" Learning Space

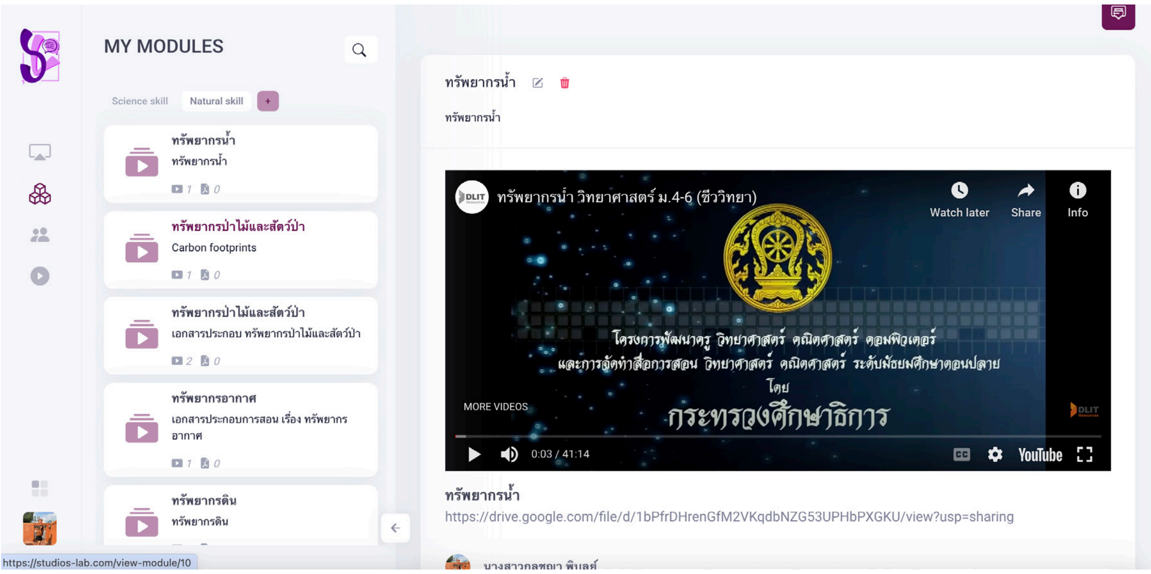


Figure 4
STEAM Tool to Assist Learners' Design with Tinkercad and SketchUp Programs

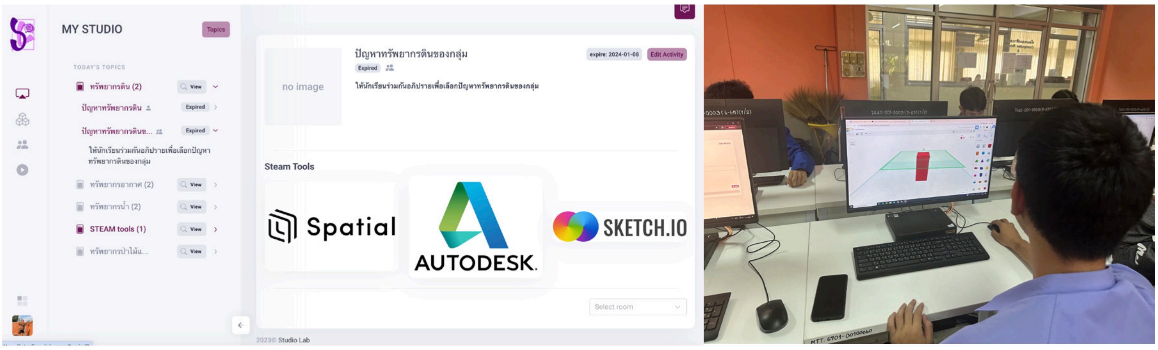
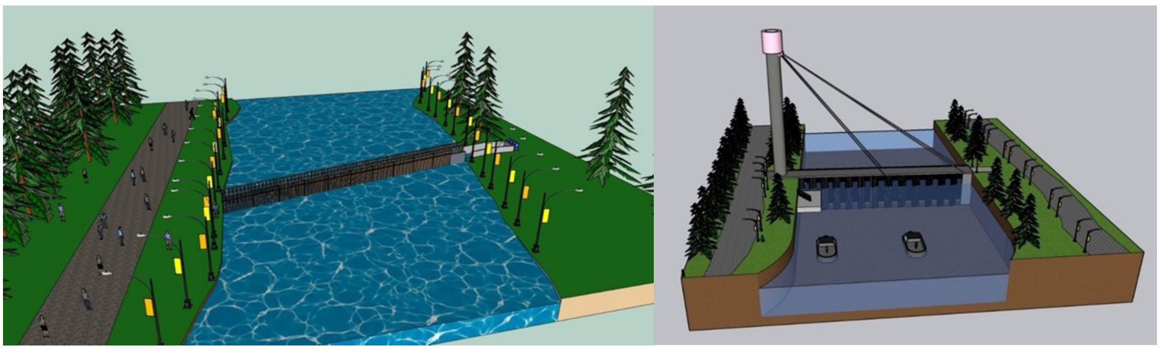


Figure 5
(Left) First Draft and (Right) Second Draft of the Water Waste Collection Innovation Design

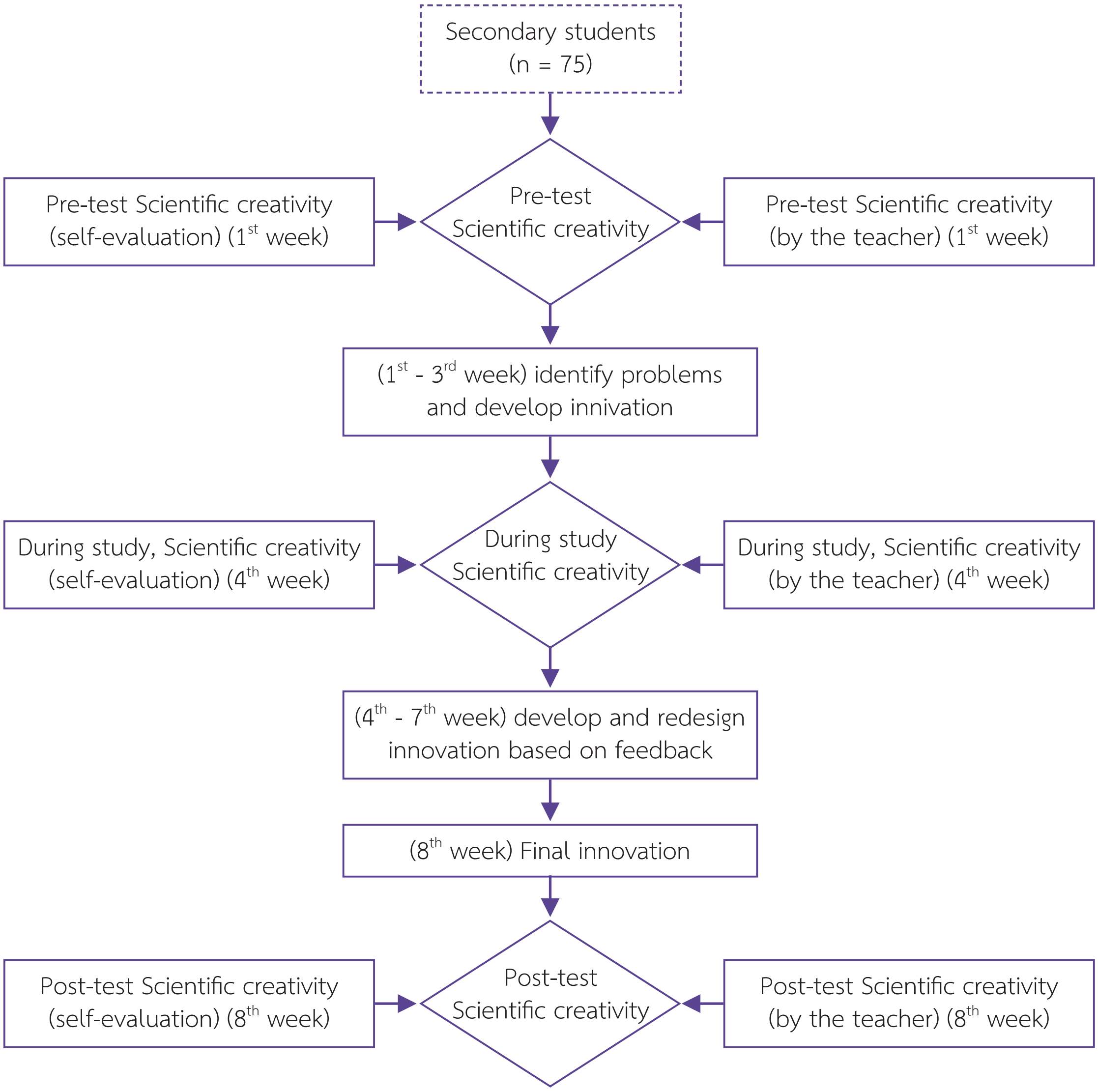


Experimental procedure

Learners could log in to the website via http://studios-lab.com and complete the individual activity of stating the problem and introducing their interest to the group. The group then chose the problem that they were mutually interested in to discuss, sought solutions, and further developed the group's work. The students performed self-assessment before (1st week), during (4th week), and after (8th week) studying. Moreover, the teacher engaged in evaluating the working process and completed work which was assessments before, during, and after studying as well. The experimental design is elaborated in Figure 6.

Figure 6

Diagram of the Experimental Design



Instruments

Usability Assessment

The platform "Virtual Studio Learning Environment based on STEAM Education Concept Integrated with Socio-Scientific Issues" was designed and developed using responsive web technology. Its validation process involved five experts in educational technology and science education, utilizing the usability assessment platform of a 5-point Likert scale. The result showed an average rating of 4.00, which underscores its effectiveness and suitability for implementation.

Questionnaire

The current study employed two research instruments. The first one was the work and process evaluation form in the format of a teacher graded scientific creativity rubric. With the total score of 24, this four-level rubric includes three items dealing with divergent thinking and the other three with convergent thinking. The tools were validated by five experts in educational technology and science education. For the internal consistency analysis, Cronbach's alpha coefficient was .92. The second instrument was a scientific creativity self-assessment form for learners in the format of a 5-point Likert scale. Having 64 items in total, the form included two factors with five aspects. The first factor was divergent thinking, which involved 1) fluency, 2) flexibility, and 3) originality, covering 30 items. The second factor was convergent thinking, which were 1) analysis and synthesis and 2) evaluation and selection, covering the rest 34 items. Before being used, the instruments were validated by five experts in educational technology and science education. In the internal consistency analysis, Cronbach's alpha coefficient was .72.

Data analysis

In studying the system usage, the research was designed by collecting data in weeks 1, 4, and 8. For the analysis, the average, standard deviation, and repeated measure ANOVA were used to analyze the mean difference in scientific creativity before, during, and after studying.

Results

Analysis of the mean difference in scientific creativity in secondary school students before, during, and after studying

Divergent thinking

The results revealed that the students had an overall statistically significant ($p \leq .05$) mean difference of divergent thinking (F = 619.134, p = .00) with the highest mean in the post-test (M = 4.66, SD = 0.22) followed by during studying evaluation (M = 3.31, SD = 0.23) and pre-test (M = 3.02, SD = 0.36) respectively.

In exploring the individual elements of divergent thinking namely fluency, flexibility, and originality, the details are shown in Table 5.

Table 5

The Level of Divergent Thinking from the Pre-test, During Study, and Post-test Evaluations (Full Mark is 5 Points)

Divergent thinking	Evaluation								
	Pre-test			During study			Post-test		
	M	*SD*	Level	*M*	*SD*	Level	*M*	*SD*	Level
Fluency	3.05	0.38	medium	3.30	0.23	medium	4.67	0.23	highest
Flexibility	2.98	0.06	low	3.31	0.03	medium	4.65	0.03	highest
Originality	3.04	0.06	medium	3.32	0.03	medium	4.66	0.03	highest

Convergent thinking

The results revealed that the students had an overall statistically significant ($p \leq .05$) mean difference of convergent thinking (F = 594.652, p = .00) with the highest mean in the post-test (M = 4.65, SD = 0.23) followed by during studying evaluation (M = 3.32, SD = 0.22) and pre-test (M = 3.02, SD = 0.37) respectively.

For the individual elements of convergent thinking namely analysis and synthesis as well as evaluation and selection, the details are shown in Table 6.

Table 6

The Level of Convergent Thinking from the Pre-test, During Study, and Post-test Evaluations (Full Mark is 5 Points)

Convergent thinking	Evaluation								
	Pre-test			During study			Post-test		
	M	*SD*	Level	*M*	*SD*	Level	*M*	*SD*	Level
Analysis and synthesis	3.00	0.04	medium	3.30	0.03	medium	4.67	0.03	highest
Evaluation and selection	3.03	0.05	medium	3.33	0.03	medium	4.63	0.03	highest

Table 7

The Level of Scientific Creativity from the Pre-test, During Study, and Post-test Evaluations (Full Mark is 5 Points)

Scientific creativity	Evaluation								
	Pre-test			During study			Post-test		
	M	*SD*	Level	*M*	*SD*	Level	*M*	*SD*	Level
Divergent thinking	3.02	0.36	medium	3.31	0.23	medium	4.66	0.22	highest
Convergent thinking	3.02	0.37	medium	3.32	0.22	medium	4.65	0.23	highest

Analysis of the scientific creativity level in secondary school students before, during, and after studying that derives from the scientific creativity work and learning process rubric

Results showed that the students had an overall statistically significant ($p \leq .05$) mean difference of scientific creativity (F = 5760.412, p = .00) with the highest mean in the post-test (M = 21.97, SD = 0.15) from the total mark of 24 points followed by during studying evaluation (M = 18.23, SD = 0.15) and pre-test (M = 12.53, SD = 0.11) respectively.

Table 8

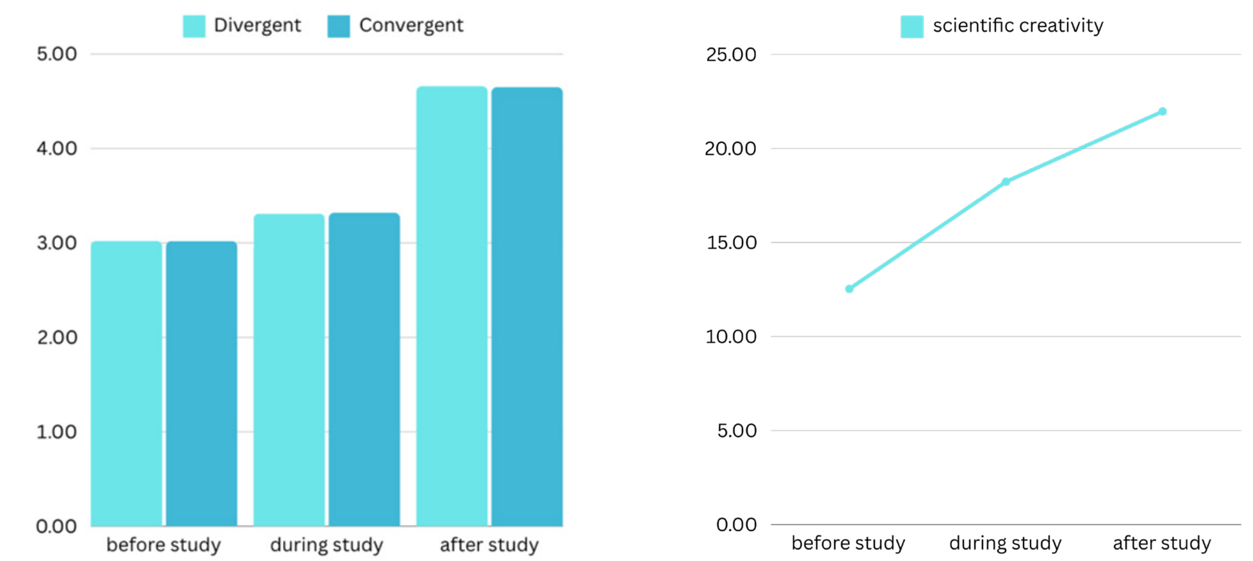
The Scientific Creativity Difference Analysis from Students' Final Work Evaluation

Scientific creativity	Variables	*SS*	*df*	*MS*	*F*	p	Summary
Scientific creativity	Evaluation	3389.13	2	1694.56	5760.412	<.001*	Post-test>
	Error	43.54	148	0.294			during> pre-test

*p < .05

Figure 7

(Left) Self-assessment (Right) Work Evaluation



Discussions

Based on the analysis, both from the self-assessment and work evaluations, the results showed that learners had a statistically significantly higher scientific creativity in the divergent and convergent thinking elements, when compared with during and before studying. This was observed in both the self-assessment by the student and work evaluations by the teacher. This was owing to the VsLE design that offered a flexible learning environment and activities wherein learners had access to the contents anywhere and anytime. The results went in accordance with self-directed learning theory which allows learners to identify the topic, design, and plan for the learning activities of their interest. As supported by Lee's (2024) study on the factors affecting creativity development, self-directed learning seemed to enhance learners' creativity. Moreover, the group activity space, My Studio, incorporated a variety of STEAM tools that learners could select to help with their designing process. The integration of STEAM tools into pedagogy enhanced learners' scientific creativity (Samamiego et al., 2024). This aligned with Mebed et al. (2022) who involved e-learning techniques with the virtual design studio. In their design, digital tools were used for designing which assisted in creativity skill development. Additionally, the learning activities that offered designing, drafting, and drawing, helped learners deliver innovation and promoted their creativity (Sharma & Kumar, 2023). Furthermore, with reference to the table presenting synthesized elements of learning environment, VsLE highlighted the space for learners to showcase their progress or works so that they receive feedback for more efficient development or revision of their works or processes. This opened trial and error opportunities while learners were completing their tasks, which addressed pedagogy that developed creativity. This was also supported by constructivist learning theory where students learned through collaboration, social interaction, and teacher-provided scaffolding, which helped relate learners' experiences and promote their creativity (Kiesler, 2022). Interestingly, divergent and convergent thinking are related thinking processes. To illustrate, the task to identify the topic was categorized as a divergent thinking process while deciding on the interested topic belongs to convergent thinking (Pinkow, 2023). Therefore, requiring learners to present their work in progress could help enhance both skills as learners were asked to think of various problem-solving options (divergent thinking) and evaluate the appropriate path (convergent thinking) that could lead to improvements. This coincided with Obeid and Demirkan (2023) who utilized the virtual design environment to aid the learners' design process. Their findings revealed that it was more efficient when compared to non-immersive methods while also increasing learning motivation.

When spotlighting the scientific creativity factors, the results showed that, after studying, learners had higher divergent thinking, in all three skills of fluency, flexibility, and originality when compared to during and before studying. According to Table 3, Hu and Adey (2002) referred to fluency, flexibility, and originality as important elements of divergent thinking. This went in accordance with Torrance, but in the context of scientific creativity, scientific knowledge was applied. This was accomplished through activities where fluency and originality were practiced by identifying the highest number of socio-scientific issues. Then together, learners categorized the problems that assisted flexibility. This supported Lu et al. (2022) who mentioned activity settings where learners could achieve both individual and group work. They explained that group work via brainstorming activities could enhance fluency as learners were open to diverse perspectives from peers. Furthermore, activities, wherein learners could design and develop works, alongside the tasks, identified by teachers, could contribute to divergent thinking development (Bulut Ates & Aktamis, 2024). In terms of convergent thinking, the results showed that learners acquired higher skills in analysis and synthesis as well as evaluation and selection after learning when compared to during and before learning. It was found that providing opportunities for the learners to analyze and select issues as well as finding solutions using scientific knowledge could promote their scientific creativity (Yang et al., 2019). It could be observed that the Showcase space promoted learning exchange to help them improve their work, build motivation for adjustments, and enhance creativity (Putri et al., 2023). The analysis and synthesis as well as evaluation and selection from ideas exchange was a crucial element in the innovation and creativity development process (Baruah & Green, 2023).

Conclusion

The virtual studio learning environment enhanced learners' scientific creativity via activities that integrate STEAM education and socio-scientific issues. It provided the opportunity for learners to incorporate knowledge from multiple disciplines for work design and development to solve problems that are of learners' interest. Aside from the space, another significant aspect was the activity design that helped learners practice thinking. It could be accomplished by introducing topics that learners preferred and allowing for trial and error during the process which could lead to the development of learners' scientific creativity.

Recommendations

Firstly, educational institutions are recommended to integrate STEAM Education with socio-scientific issues and use it to promote active learning. VsLE is suggested to be integrated in such teaching context to develop scientific creativity, as a part of scientific literacy.

Secondly, the use of STEAM Education with socio-scientific issues (STUDIO) is regarded as an integration of scientific knowledge and skills along with related fields of study such as mathematics, engineering, technology, and art, under socio-scientific contexts. Therefore, teachers could adapt this approach to the context they are working in to improve scientific creativity or literacy by integrating such scientific knowledge and skills to activities.

Thirdly, learners could bring VsLE and STEAM tools to develop scientific creativity. This is because it offers ways to participate in learning activities based on their interest, which meet the differences in terms of learning style.

Acknowledgement

This study was part of the research project titled "Virtual Studio Learning Environment based on STEAM Education Concept Integrated with Socio-scientific Issues to Enhance Scientific Creativity of Secondary School Students". This current paper was situated in phase three of the total of 4 phases as follows: 1) phase one aimed to examine the conditions of teaching and learning as well as the users' experience to develop secondary school students' scientific creativity, 2) phase two, a model of the virtual studio learning environment was developed, 3) phase three was the implementation of the developed virtual studio learning environment, and 4) phase four was a presentation of the results evaluated by experts in the field of educational and technology and science education.

References

Atesgoz, N. N., & Sak, U. (2021). Test of scientific creativity animations for children: Development and validity study. *Thinking Skills and Creativity, 40*, Article 100818. https://doi.org/10.1016/j.tsc.2021.100818

Baruah, J., & Green, K. (2023). Innovation in virtual teams: The critical role of anonymity across divergent and convergent thinking processes. *Journal of Creative Behavior, 57*(4), 588-605. https://doi.org/10.1002/jocb.603

Bulut Ates, C., & Aktamis, H. (2024). Investigating the effects of creative educational modules blended with cognitive research trust (CoRT) techniques and Problem Based Learning (PBL) on students' scientific creativity skills and perceptions in science education. *Thinking Skills and Creativity, 51*, Article 101471. https://doi.org/10.1016/j.tsc.2024.101471

Chu, H., Son, Y., Koo, H., Martin, S. N., & Treagust, D. F. (2019). The potential of arts-integrated STEM approaches to promote students' science knowledge construction and a positive perception of science learning. In Hsu, Y. & Yeh, Y. (Eds), *Asia-pacific STEM teaching practices: From theoretical frameworks to practices* (pp. 17-38). https://doi.org/10.1007/978-981-15-0768-7_2

Chun, B. A., & Heo, H. J. (2019). *Toward creative convergence: A free learning semester class with mobile device 'making an ecological map of our schoolyard'* [Paper presentation]. 5th International Conference on Education and Training Technologies, Seoul, Republic of Korea, https://doi.org/10.1145/3337682.3337698

Conradty, C., Sotiriou, S. A., & Bogner, F. X. (2020). How creativity in STEAM modules intervenes with self-efficacy and motivation. *Education Sciences, 10*(3), Article 70. https://doi.org/10.3390/educsci10030070

Cook, A. B. (2020). Scientific creativity through the lens of art. *Matter, 2*(5), 1072-1074. https://doi.org/10.1016/j.matt.2020.03.021

de Vries, H. (2021). *Space for STEAM: New creativity challenge in education.* Frontiers in Psychology, 12. https://doi.org/10.3389/fpsyg.2021.586318

Dwikoranto, Jatmiko, B., Hariyono, E., Lestari, N. A., Prahani, B. K., & Suyidno. (2021). MobLen model for enhancing scientific creativity of physics students: An alternative in the covid-19 pandemic. *Journal of Physics: Conference Series, 1805*(1), Article 012006. https://doi.org/10.1088/1742-6596/1805/1/012006

Fleischmann, K. (2021). Hands-on versus virtual: Reshaping the design classroom with blended learning. *Arts and Humanities in Higher Education, 20*(1), 87-112. https://doi.org/10.1177/1474022220906393

Gabriel, F., Marrone, R., & van Broekhoven, K. (2023). Chapter 27-teaching and learning for creativity in science and mathematics. In R. Reiter-Palmon & S. Hunter (Eds.), *Handbook of Organizational Creativity* (Second Edition) (pp. 393-405). Academic Press. https://doi.org/10.1016/B978-0-323-91841-1.00001-4

Haim, K., & Aschauer, W. (2022). Fostering scientific creativity in the classroom: The concept of Flex-based learning. *International Journal of Learning, Teaching and Educational Research, 21*(3), 196-230. https://doi.org/10.26803/ijlter.21.3.11

Hodson, D. (2020). Going beyond STS education: Building a curriculum for sociopolitical activism. *Canadian Journal of Science, Mathematics and Technology Education, 20*(4), 592-622. https://doi.org/10.1007/s42330-020-00114-6

Hu, W., & Adey, P. (2002). A scientific creativity test for secondary school students. *International Journal of Science Education, 24*(4), 389-403. https://doi.org/10.1080/09500690110098912

Iranmanesh, A., & Onur, Z. (2021). Mandatory virtual design studio for all: Exploring the transformations of architectural education amidst the global pandemic. *International Journal of Art and Design Education, 40*(1), 251-267. https://doi.org/10.1111/jade.12350

Jia, Y., Zhou, B., & Zheng, X. (2021). A curriculum integrating STEAM and maker education promotes pupils' learning motivation, self-efficacy, and interdisciplinary knowledge acquisition. *Frontiers in Psychology, 12*. https://doi.org/10.3389/fpsyg.2021.725525

Jones, D., Lotz, N., & Holden, G. (2021). A longitudinal study of virtual design studio (VDS) use in STEM distance design education. *International Journal of Technology and Design Education, 31*(4), 839-865. https://doi.org/10.1007/s10798-020-09576-z

Khamhaengpol, A., Sriprom, M., & Chuamchaitrakool, P. (2021). Development of STEAM activity on nanotechnology to determine basic science process skills and engineering design process for high school students. *Thinking Skills and Creativity, 39*, Article 100796. https://doi.org/10.1016/j.tsc.2021.100796

Khlaisang, J., & Koraneekij, P. (2024). Future skillset of higher education learners: Confirmatory factor analysis. *International Journal of Mobile Learning and Organisation.* https://doi.org/10.1504/IJMLO.2025.10058392

Kiesler, N. (2022, October 8-11). *Reviewing Constructivist theories to help foster creativity in programming education* [Paper presentation]. 2022 IEEE Frontiers in Education Conference (FIE), Uppsala, Sweden. https://doi.org/10.1109/FIE56618.2022.9962699

Kim, G., Ko, Y., & Lee, H. (2020). The effects of community-based socioscientific issues program (SSI-COMM) on promoting students' sense of place and character as citizens. *International Journal of Science and Mathematics Education, 18*(3), 399-418. https://doi.org/10.1007/s10763-019-09976-1

Lee, G. H. (2024). Mediating effects of creative home environment and self-directed learning ability on the relationship between personality and creative achievement intention. *Creativity Studies, 17*(1), 178-191. https://doi.org/10.3846/cs.2024.15551

Loudon, G. (2019). Integrating ideas from design disciplines into the STEM curricula. *Higher Education Pedagogies, 4*(1), 284-286. https://doi.org/10.1080/23752696.2019.1599688

Lu, S. Y., Lo, C. C., & Syu, J. Y. (2022). Project-based learning oriented STEAM: the case of micro–bit paper-cutting lamp. *International Journal of Technology and Design Education, 32*(5), 2553-2575. https://doi.org/10.1007/s10798-021-09714-1

McDonald, J. K., West, R. E., Rich, P. J., & Hokanson, B. (2020). Instructional design for learner creativity. In M. J. Bishop, E. Boling, J. Elen, & V. Svihla (Eds.), *Handbook of Research in Educational Communications and Technology.* Springer. https://doi.org/10.1007/978-3-030-36119-8_17

Mebed, Y. A., Shatta, N. Y., & Zahra, N. N. (2022, June 6-7). E-learning techniques in the virtual interior design studio [Conference session]. Engineering and Technology for Sustainable Architectural and Interior Design Environments, Manama, Bahrain. http://dx.doi.org/10.1109/ETSAIDE53569.2022.9906342

Ministry of Education. (2022). *STEAM Education.* Education news. https://www.moe.go.th/360steam-education/

Nespoli, O. G., Hurst, A., & Gero, J. S. (2021). Exploring tutor-student interactions in a novel virtual design studio. *Design Studies, 75,* Article 101019. https://doi.org/10.1016/j.destud.2021.101019

Obeid, S., & Demirkan, H. (2023). The influence of virtual reality on design process creativity in basic design studios. *Interactive Learning Environments, 31*(4), 1841-1859. https://doi.org/10.1080/10494820.2020.1858116

OECD. (2018). *The future of education and skills: Education 2030, The future we want.* OECD. https://repository.canterbury.ac.uk/download/96f6c3f39ae6dcffa26e72cefe47684172da0c93db0a63d78668406e4f478ae8/3102592/E2030%20Position%20Paper%20%2805.04.2018%29.pdf

Office of the Education Council. (2021). *Future skills to prepare for the development of the quality of Thai people of all ages. Support the rapid change (disruption) of the 21st century world.* Open-D. https://opendata.nesdc.go.th/en/dataset/research-0306-2564-11

Oh, J. (2021). *Understanding the scientific creativity based on various perspectives of science.* Axiomathes. https://doi.org/10.1007/s10516-021-09553-8

Ozkan, G., & Umdu Topsakal, U. (2021). Exploring the effectiveness of STEAM design processes on middle school students' creativity. *International Journal of Technology and Design Education, 31*(1), 95-116. https://doi.org/10.1007/s10798-019-09547-z

Pinkow, F. (2023). Creative cognition: A multidisciplinary and integrative framework of creative thinking. *Creativity and Innovation Management, 32*(3), 472-492. https://doi.org/10.1111/caim.12541

Putri, A. S., Prasetyo, Z. K., Purwastuti, L. A., Prodjosantoso, A. K., & Putranta, H. (2023). Effectiveness of STEAM-based blended learning on students' critical and creative thinking skills. *International Journal of Evaluation and Research in Education, 12*(1), 44-52. https://doi.org/10.11591/ijere.v12i1.22506

Ramey, K. E., & Stevens, R. (2019). Interest development and learning in choice-based, in-school, making activities: The case of a 3D printer. *Learning, Culture and Social Interaction, 23*, Article 100262. https://doi.org/10.1016/j.lcsi.2018.11.009

Sadler, T. D., Chambers, F. W., & Zeidler, D. L. (2004). Student conceptualizations of the nature of science in response to a socioscientific issue. *International Journal of Science Education, 26*(4), 387-409. https://doi.org/10.1080/0950069032000119456

Samaniego, M., Usca, N., Salguero, J., & Quevedo, W. (2024). Creative thinking in art and design education: A systematic review. *Education Sciences, 14(*2), Article 192. https://doi.org/10.3390/educsci14020192

Sharma, G. V. S. S., & Kumar, S. (2023). Thinking through art – A creative insight into mechanical engineering education. *Thinking Skills and Creativity, 49*, Article 101341. https://doi.org/10.1016/j.tsc.2023.101341

Sun, M., Wang, M., & Wegerif, R. (2020). Effects of divergent thinking training on students' scientific creativity: The impact of individual creative potential and domain knowledge. *Thinking Skills and Creativity, 37*, Article 100682. https://doi.org/10.1016/j.tsc.2020.100682

Walker, E. B., Boyer, D. M., & Benson, L. C. (2019). Using studio culture to foster epistemic change in an engineering senior design course. *IEEE Transactions on Education, 62*(3), 209-215. https://doi.org/10.1109/TE.2019.2898151

Walker, J. T., & Kafai, Y. B. (2021). The biodesign studio: Constructions and reflections of high school youth on making with living media. *British Journal of Educational Technology, 52*(3), 1116-1129. https://doi.org/10.1111/bjet.13081

Wannapiroon, N., & Petsangsri, S. (2020). Effects of steamification model in flipped classroom learning environment on creative thinking and creative innovation. *TEM Journal, 9*(4), 1647-1655. https://doi.org/10.18421/TEM94-42

Wiyanto, W., & Hidayah, I. (2021). Review of a scientific creativity test of the three-dimensional model. *Journal of Physics: Conference Series, 1918*, Article 052088. https://doi.org/10.1088/1742-6596/1918/5/052088

Yang, K., Hong, Z., Lee, L., & Lin, H. (2019). Exploring the significant predictors of convergent and divergent scientific creativities. *Thinking Skills and Creativity, 31*, 252-261. https://doi.org/10.1016/j.tsc.2019.01.002

Yildiz, C., & Guler Yildiz, T. (2021). Exploring the relationship between creative thinking and scientific process skills of preschool children. *Thinking Skills and Creativity, 39*, Article 100795. https://doi.org/10.1016/j.tsc.2021.100795

Yoon, S. A., Shim, J., & Noushad, N. (2019). Trade-offs in using mobile tools to promote scientific action with socioscientific issues. *TechTrends, 63*(5), 602-610. https://doi.org/10.1007/s11528-019-00408-z

Zhou, C. (2021). The effectiveness of 5E model to improve the scientific creativity of teachers in rural areas. *Thinking Skills and Creativity, 41*, Article 100900. https://doi.org/10.1016/j.tsc.2021.100900