Thai undergraduate science, technology, engineering, arts, and math (STEAM) creative thinking and innovation skill development: a conceptual model using a digital virtual classroom learning environment

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Abstract

Qualitative and quantitative research methods were undertaken to examine and develop a digitally based virtual classroom learning environment (VCLE) for Thai undergraduate students' creative thinking and innovation enhancement in science, technology, engineering, arts, and math (STEM/STEAM) disciplines. The research methodology was divided into two phases, including the synthesis and then the design of the VCLE. Also, in addition to the study's authors, nine experts were used for the model's development and another ten for its assessment (19 total). From their in-depth interviews and subsequent content analysis, their input of the proposed STEAM-ification process was synthesized and the data analyzed. The results revealed that the VCLE design should begin with a face-to-face, classroom learning environment in which the '*gamification*' mechanisms were introduced and examined. This was then reinforced by moving the gamification process online outside of the classroom. Furthermore, five VCLE STEAM-ification steps were found to be particularly useful for enhancing creative thinking and student innovation. These included *investigation*, *discovery*, *connections*, *creativity*, and *reflection*. Moreover, we identified the gamification process as consisting of three main components. These were the '*game mechanics*,' the '*game dynamics*,' and '*player emotions*'. The ten experts agreed that the VCLE STEAM-ification creativity and innovation (C & I) process was appropriate at an '*excellent*' level ($\bar{x} = 4.68$, S. D. = 0.47), which has great potential in the development of Thai undergraduate student C & I skills. Also, when undertaken correctly, innovation and motivation to learn are also outcomes from both VCLE and gamification applications. Thus, when students undertook study with the VCLE STEAM-ification format, they were found to achieve higher levels of creativity and innovation than students who studied using the traditional teaching plan. These results were found to be statistically significant at the .01 level.

Keywords 21st Century education · Creative Thinking · Critical thinking · Digital Learning Environment · Gamification · Innovation skills · STEAM-ification · STEM · Thailand

1 Introduction

Education in the 21st Century has become more reliant on information and communication technology (ICT) (Alismail, 2015). Numerous new learning models have evolved, such as the *flipped classroom* and *blended learning* (Banyen et al., 2016; DeLozier & Rhodes, 2017; Ekici, 2021; Wannapiroon & Petsangsri, 2020). These new environments allow students to choose when and how they are learning content, and when they come to class, they can free the instructor for problem-solving exercises or content questions and answers (Eppard & Rochdi, 2017; Shih & Tsai, 2017). Therefore, the teacher's role has evolved as well within these new digitally-enabled environments to that of a '*knowledge facilitator*' (KF), in which each KF (teacher) arranges the appropriate circumstance for learning (Phuapan et al., 2016).

Also, Boholano (2017) has injected that 21st Century generation Z students expect and use ICT and social media like fish do to water. The author also points out how pre-service teachers and their respective institutions should be technically savvy and properly outfitted if they expect to engage this newer generation of students effectively. Moreover, students should have freedom of thinking capabilities created from the cognitive, affective, emotional, and psychomotor domains (CAP domains) (Chaffar & Frasson, 2012; Illeris, 2002). Also, Darling-Hammond et al. (2020) added that learner development of *higher-order thinking skills* (HOTS) could best be achieved through inquiry and investigation, knowledge application to new problems and situations, idea and solution production, and collaborative problem-solving. This is consistent with Laisema and Wannapiroon (2014), who also added the importance of problem-solving techniques, searching for new information, and having good morality and responsibility, critical thinking, creative thinking, and productivity. Furthermore, UNICEF has also reported that there are 12 core life skills. Of these, creativity is listed first, and critical thinking is second. Also, both are stated to be core life skills in which educators should begin developing in students at an early age (Carlile & Jordan, 2012; Dilley et al., 2015).

In Thailand, Techakosit and Wannapiroon (2015) designed research in which they used a connectivism learning environment to connect *augmented reality* (AR) with science laboratory students to increase their scientific literacy. Once again, science literacy development is seen as a process in which the students are tasked to understand and solve problems while searching for the necessary information to solve the problem. After that, reasoning is required to assess what has been discovered, at which point reflection is necessary to present what has been found. Also, in Thailand, Sarnok et al. (2019) explored a model or ecosystem for digital storytelling, which the authors concluded made use of a variety of digital media, including still images, short films, animations, audio, video games, applications, or content designed on a cloud-based website. This is consistent with another STEAM study from the US state of Pennsylvania in which girls were encouraged to use technology

to explore and create various types of digital art-making through activities involving storytelling, personal experiences, and technology literacy by making video games, animations, and machinimas (Liao et al., 2016).

Virtual classrooms are also learning methods that facilitate learners gaining twenty-first century skills in the ‘Four Cs’ which once again includes *creative* and *critical* thinking skills, *communication* skills, and *collaboration* (Liao et al., 2016; Riegel & Kozen, 2016), which also enhances twenty-first-century in learning and *innovation* for higher education learners (Songkram, 2017). Moreover, Songkram (2017) suggests that the learning process consists of four steps: material introduction, student learning, creation and innovation, and finally, the evaluation phase.

Also, numerous studies have been undertaken to find which digital education methods are most effective in student STEAM development skills. One example is Ortiz et al. (2016), which conducted a literature review of how gamification in STEM subjects affected higher education (HE) students. From the results the authors determined that game element combinations (e.g., leaderboards, badges, points, etc.) positively affect a student’s attendance, goals, attitude, and performance towards computer science-related subjects. In Canada, Bertrand and Namukasa (2020) evaluated multiple STEAM curriculums and reported that each was involved in critical thinking and problem solving, collaboration and communication, and finally, creativity and innovation, which can be transferred to other disciplines (Liao et al., 2016). Furthermore, it was noted from the Canadian programs that each had an initial stage that built on a student’s curiosity and interest in the material presented.

In summary, from this overview, we propose a more in-depth literature review concerning the STEAM-ification of a digitally based virtual classroom learning environment (VCLE) for Thai undergraduate students’ creative thinking and innovation enhancement. We intend to focus on how gamification features can be applied in STEAM education and the available methods in the virtual classroom..

1.1 Research problem

Globally, numerous studies have addressed what has been called ‘core values’ of a 21st Century citizenry and workforce; critical thinking and creativity skills. Moreover, the crucial nature of science, technology, engineering, arts, and math (STEM/STEAM) disciplines has risen from a faint whisper to a loud roar. Therefore, educators and institutions have sought out new ways to develop these skills in their student curriculums. Methods are numerous, but most agree that information and communication technology (ICT) using the Internet as a transmission medium is a good foundation from which to start. When added to a growing plethora of software and media-based systems and environments, discerning which process, processes, or combination is difficult to ascertain for most educators and institutional administrators. This study, therefore, set out to identify through multiple panels of experts which factors have the potential to have the most significant positive impact on STEAM education, critical and creative thinking, and innovation using a digitally-enabled VCLE.

1.2 Research objectives

1. From the qualitative research, we intend to synthesize the literature and determine which factors can play the most significant role in STEAM education in a digitally-enabled VCLE.
2. From the factors selected, we then examine each in combination with two panels of experts to develop a STEAM-ification model for Thai undergraduate students' creative thinking skills, their critical thinking skills, and their ability to innovate thinking (Wannapiroon & Petsangsri, 2020).
3. Develop a framework to assess the model's appropriateness using the VCLE.
4. Finally, we will develop and efficiently evaluate the VCLE STEAM-ification use.

2 Review of the literature

2.1 Virtual classroom learning environment (VCLE)

The concept for a VCLE today lies in the combination of a virtual classroom (VC) and a digital learning environment (DLE) which allow teachers to connect with their students outside the classroom through a variety of online platforms using social media such as Facebook, Line, and WhatsApp (Moto et al., 2018), to cloud-based learning management systems (LMSs) such as Moodle or Schoology (Banyen et al., 2016). Also, VCs are now using interactive video conferencing tools such as Zoom, especially since the beginning of the Covid-19 pandemic and the shutdown of physical school campuses worldwide (Joia & Lorenzo, 2021). Moreover, VCs are highly customizable and accessible to users through various digital devices, including smartphones, tablets, and laptops. However, Internet access and bandwidth constraints are frequently mentioned limitations to a VC's implementation and use.

Furthermore, undergraduate education is being transformed from digital technology integration in the classroom (Kadambaevna et al., 2021), where the importance of each teacher's learning activities is of essential importance in assisting students in building their comprehension and learning stimulation. Moreover, Thailand's ICT use in education has been prioritized under Thailand's 12th National Economic and Social Development Plan (Baxter, 2017) and precepts outlined under Thailand's 4.0 visions for a 21st Century, critical thinking, and digitally-enabled workforce.

2.2 STEAM education

According to English (2017), STEAM education is a teaching method that focuses on heightening each student's interest in each discipline by increasing their expression, innovation, and aesthetic perception capabilities (Taylor, 2016), of which innovation is the most important (Hsiao & Su, 2021). In the United States, STEM became a national priority initiated by the National Science Foundation for all levels of secondary education (Sanders, 2009), whose goal was to provide students with

critical thinking skills that had the potential to make students creative thinking problem solvers who would eventually be marketable in the workforce (White, 2014). Today, an ‘A’ for arts has been added, and STEAM education is now helping students to comprehend their world better through diversity in knowledge and perspectives, which is conducive to their innovation capability cultivation (Connor et al., 2015; Miller & Knezek, 2013). Finally, Ogunleye (2018) has stated that the key to STEAM education is the word, ‘*integration*.’

Moreover, the addition of art to STEM is reinforced due to follow-on studies indicating the importance of art in helping learners develop their capability for innovation as various forms of technologies and mediums are used (Catchen, 2013; Conradty & Bogner, 2018; Liao et al., 2016; Yuktirat et al., 2018). Bazler and Sickle (2017) have also commented that adding art to STEM increases student systematic thinking skills, creativity development, and student motivation enhancement. Furthermore, it is widely recognized that art stimulates cognitive skills such as problem-solving, critical thinking, listening, and decision-making in addition to other areas such as observational skills, listening skills, collaboration, and communications (Lynch, 2019; Thuneberg et al., 2018). Catchen (2013) has also added that in STEAM education, creativity is vital, and students can learn things about themselves they did not know before.

STEAM education also enables ‘learning by doing’ collaboration at solving real problems with actual processes. This allows students to connect their knowledge with their real-life (Patterson & Muna, 2019). In Thailand, Chujitarom and Piriyasurawong (2018) examined gamification’s use in STEAM education and reported that games are becoming more critical in Thai education. Moreover, gamification is a process that allows students to participate in learning. It also helps inspire and promote learning, solve problems, and drive behavior and is easily accessible through social media or web-based platforms.

Moreover, Conradty and Bogner (2018) have stated that creativity as a construct is broad and complex and challenging to define and quantify. Fortunately, after an analysis of 2,713 European students, the authors reported that STEAM might help develop critical thinking, solve real-world problems (investigation), help make learning science easier, and finally, support a student’s motivation. However, Sosa (2011) has added that social distancing can inhibit creativity.

How and Hung (2019) have also investigated STEAM in the context of artificial intelligence (AI) learning and suggested that this process could enhance learning by challenging humans to interpret new findings from the machine-learned discovery (investigation) of hidden patterns in the data. The authors also felt that an underlying foundation in Industry 4.0 was AI principles and their integration through STEAM education. In Indonesia, Rahmawati et al. (2019) also reported that a STEAM approach helps develop chemistry students’ problem-solving skills, critical thinking skills, and collaboration (connection). Interestingly, Perignat and Katz-Buonincontro (2019) have added that creativity is rarely assessed or measured as part of STEAM education and that there is great confusion about how art pedagogies are integrated into STEAM. This is also consistent with Baharin et al. (2018), who lamented that STEM integration could be challenging due to the requirements for educators with skills in STEM fields.

Therefore, we summarized the STEAM learning process of our model using a VCLE as consisting of five elements, including the student's ability to *investigate*, their *discovery* process, how they collaborate or *connect* with others, how they *create*, and finally, how they *reflect* on what they have learned.

2.3 Gamification

According to Smiderle et al. (2020), gamification education can enhance student levels of engagement, improve specific skills, and optimize their learning. However, students' personality traits and characteristics can directly affect gamification lessons' effectiveness (Jia et al., 2016; Sanchez et al., 2019). Other studies have also stated that gamification can be a tool for optimizing learning, behavioral change reinforcement, and a socialization mechanism (Krause et al., 2015; Dichev & Dicheva, 2017).

Specifically, gamification student stimulation is accomplished most often through a process referred to as '*game mechanics*' (GM) (Hakulinen & Auvinen, 2014), which is also known as '*verbs of gamification*' (Nielson, 2017). GM is also how students engage with the program, the next steps to undertake, and what form of accomplishment feedback is received, which usually takes place in forms such as *points, badges, AND leaderboards* (PBL) (Werbach & Hunter, 2015), mission levels, and progress (*observations* and *rewards*). Moreover, of the 24 GM characteristics listed in 2017 by Nielson (2017), the author stated that they could be divided into three distinct categories or attributes: the GM type, boosts or benefits, and finally, types of personalities (Nielson, 2017).

Furthermore, although there is a thin line between GM and '*game dynamics*' (GD), GD is interpreted to be understood as the tools within the game that creates satisfaction in the player (Werbach & Hunter, 2015). This is consistent with Hamari and Koivisto (2015), who noted that hedonic motivations are positively associated with a user's gamification continued use. In Finland, Hassan et al. (2019) also reported that gamification is positively associated with a player's experiences of affective feedback. There is more GM than GD, with GM acting as the tool helping the player move forward within the simulation. Specifically, Werbach and Hunter (2015) outlined five GDs, including *constraints, emotions, the narrative, progression, and progression*. Moreover, '*emotions*' come from the positive or negative results from the game's simulation.

2.4 Creative and critical thinking

Discussions concerning critical thinking (CT) are nearly as old as civilization itself, with Plato 2,500 years ago in his lectures concerning logic believed that CT was a tool from which people could find solutions or answers to confusion or problems (Thayer-Bacon, 1998). Socrates, Plato's teacher, also believed that CT and discussion with knowledge reside in an individual's mind, instead of with the transmission of knowledge from teacher to student (Ornstein & Levine, 2006). After 2,500 years,

countless scholars have written and lectured on the processes, importance, and outcomes of CT skills (or lack thereof) (Changwong et al., 2018).

In the U.S., the National Association of Colleges and Employers (NACE) (2016) highlighted the importance CT skills after their survey of employees found that the respondents felt that CT skills were the most importance skill in a new hire. Similarly, Bassham et al. (2013) reported that university educators have a responsibility to develop student CT skills, which in turn lead to *higher-order thinking skills* (HOTS). Additionally, HOTS uses concept formation, CT, creativity and brainstorming, problem-solving, mental representation, rule use, reasoning, and thinking logically (Srikan et al., 2021). This is also consistent with other studies in which CT skills are consistently included as a requirement for university and career readiness (Costa & Kallick, 2014; National Council for Excellence in Critical Thinking, 2017).

However, unfortunately in Thailand CT skills seem to be a missing element in secondary skill school children, as recent evaluations of 6,235 students across 10 Thai provinces on their logical thinking and analytical skills discovered that only 2.09% could pass the exam (Rujivanarom, 2016). Comments and speculation as to why these scores are so low are numerous, but the reality of the problem is there for all to see.

Fortunately, numerous scholars from their STEM and STEAM research have come to the conclusion that both initiatives are an excellent way in which students gain knowledge, creatively and solve problems across disciplines, both in the classroom and out (Gess, 2017; Henriksen, 2014; Liao, 2016; Rahmawati et al., 2019; Ugras, 2018). Moreover, Holm-Hadulla (2010) has added that scientific thinking requires creative ability, while Henriksen (2014) has also found that STEM curricula benefit from the arts' creative aspects and solutions. Other scholars have established connections between ICT and innovation and the need to possess 21st Century skills such as creativity and critical thinking, problem-solving abilities, research and questioning skills, and finally, collaboration skills to be successful (Morrison, 2006; Wai et al., 2010). Finally, most importantly according to Conradty and Bogner (2018), thinking creatively is paramount in solving problems..

3 Research methodology

The investigation into how a VCLE affects the STEAM education process of Thai university students and their creative skills, critical thinking skills, and innovation skills used a mix-method research approach, which included both quantitative and qualitative methods. Moreover, we undertook a systematic review to investigate which factors affect the STEAM-ification process in a VCLE (Wahono et al., 2020).

3.1 Qualitative review

In the qualitative analysis, we set out first to find the most recent studies (five years or less) concerning STEAM and STEM education using the following steps:

Step 1: The researchers synthesized the model after a review of 170 documents.

Step 2: The primary researcher developed the VCLE STEAM-ification model after consultation with his advisor. After that, the model was presented to a Focus group of 19 experts for their comments, suggestions, model quality assessment and suitability (Nyumba et al., 2018; Ruenphongphun et al., 2021; Srikan et al., 2021; Tremblay et al., 2012).

Step 3: The researcher then used the proposed VCLE STEAM-ification model to experiment with students (This data is not included in this article due to its extensive and supplemental nature).

Keyword searches combined with STEAM included creativity, critical thinking, innovation, gamification, virtual classroom, virtual learning, and learning environment. According to Lawrence et al. (1999), keywords research is necessary for finding articles. This was then repeated using these terms combined with STEM. This is consistent with Cohen et al. (2007), who have suggested that meta-analysis-type methods are an excellent way to synthesize findings from separate studies and allow researchers to compare, combine, and subsequently evaluate quantitative data taken from these studies to obtain more complete and convincing results.

3.2 Ethics clearance

Ethics approval for the study was obtained from our university's Human Ethics Committee before consultation with the two groups of 19 experts relating to the questionnaire's design and assessment (Pimdee, 2020). Before the Zoom meeting with each panel of experts, each individual was sent via email a simple and clear explanation about the purposes of the research and informed that the information obtained was confidential and no identities would be disclosed. Email confirmation and agreement were then noted from each individual. Furthermore, all data obtained from the respondents was stored in a password-protected computer and secure location.

3.3 Design of the STEAM education process

The design of the study's model was undertaken by a panel of nine experts in which in-depth interviews were used to assess each participant's opinions concerning the study's quantitative results related to STEAM education, creativity, critical thinking, innovation, and how all this is affected by the use of a VCLE. Furthermore, each expert selected via purposive sampling had a minimum of a Ph.D. and five years of related teaching expertise in their field. The disciplines of each individual were related to the fields of ICT, education technology, gamification, teaching design, virtual classrooms, or organizational learning concepts. Due to the ongoing global Covid-19 pandemic in 2020 at the time of the study, all meetings related to the study were undertaken using Zoom video-conferencing software (Li et al., 2021).

3.4 Development and evaluation of the VCLE STEAM-ification model

3.4.1 Development of VCLE STEAM-ification model

The second group of 10-panel education experts was selected via purposive sampling in late 2020 to review the appropriateness of the STEAM education model from both our input and that of the last panel of nine experts. Once again, the second group of experts had a minimum of a Ph.D. and five years of teaching experience in their respective disciplines. Their fields of expertise included ICT, education technology, teaching design with gamification, organizational learning environments, virtual classrooms, curriculum development, and measurement and evaluation.

Each was given a survey of items in which a five-level scale was used to determine their level of agreement in their assessment. The questionnaire scale interpretation made use of '5' as a *very positive* response (4.50 - 5.00), '4' indicated a *positive* response (3.50 - 4.49), '3' was *somewhat positive* (2.50 - 3.49), '2' was a *negative* response (1.50 - 2.49), and finally, '1' was determined to be a *very negative* (1.00 - 1.49) response (Pimdee, 2020; Rajaram, 2021).

3.5 Data collection

The researchers collected the data by following the following three steps in sequence:

3.5.1 Preparation before the expert panel discussion

The researchers first discussed with the panel of experts on how to deliver a simplistic learning process using a flipped-classroom environment which would foster creativity and innovation among Thai undergraduate students. A creativity assessment form and a form to assess the suitability of the creative innovation process were developed.

3.5.2 Discussion proceedings

A small group meeting was held on August 22, 2019, from 10:00-16:00, in meeting room 212 at the Science and Technology Research Office within the King Mongkut's University of Technology North Bangkok campus to provide feedback on the learning process using a flipped-classroom online learning environment to foster creativity and innovation among Thai undergraduate students. Also, the meeting had a goal to create forms to assess student creativity and creative innovation.

3.5.3 Post-conversation and expert check

In this phase, we assessed the consistency of the creativity assessment scale and the consistency of the creative innovation assessment form.

3.6 Data analysis

The analysis of the level of suitability of the model (VCLE STEAM-ification) used the following steps:

3.6.1 Evaluation of suitability of the VCLE STEAM-ification model

The population were second semester undergraduate students in the third year of studies in the Faculty of Science and Technology at Rajamangala University of Technology Suvarnabhumi, Thailand in 2019. At this time, there were 820 students spread across six disciplines. The sample was obtained by using multistage random sampling in the following manner:

1st time: Cluster random sampling was done by specifying disciplines in the Faculty of Science and Technology at Rajamangala University of Technology Suvarnabhumi as a random unit with a lottery method, which became the sample group of 'Multimedia Technology'.

2nd time, Systematic random sampling was then used from the list of students in the multimedia technology department in which the odd numbers became the study's experimental group and the even numbers became the control group of 30 students who continued to study using traditional methods.

3.7 The tools used in the research

The tools used in the research consisted of:

3.7.1 Creativity assessment form

The creativity assessment form used concepts adapted from Guilford. (1991) and Nitko (2004) and consists of four sub-skills including originality, fluency, flexibility, and elaboration. A Rubrics scoring criterion was also used which contained a 4-level scale which was determined to have a consistency index between 0.80 - 1.00, a difficulty between 0.27-0.79, and a power of discrimination of 0.82.

3.7.2 Creative Innovation Assessment Form

Developed from the concepts outline by the OECD and Eurostat (2005), Smith (2006) and Weyrauch and Herstatt (2016), the creative innovation assessment form consisted of five parts. There were 1) being novel and unique 2) solving

objectives 3) efficiency 4) feasibility of use (Possibility) and 5) cost. The outcome from the experts's input using a Rubrics score on a 4-level scale, was a consistency index score from 0.80 - 1.00, a difficulty level form 0.23-0.77, and a clas-sification power of 0.81.

3.8 Data collection

The experiment was conducted with students in the course titled *Courseware Design and Development* during the Academic Year 2019 for 8 weeks.

4 Research findings

4.1 The STEAM education process using a VCLE

From the quantitative method analysis and the selection of aspects frequently associated with creativity, critical thinking, and innovation in the scholarly literature, we found that multiple researchers in Table 1 discussed *investigation*, *discovery*, *connections*, *creativity*, and *reflection* as five primary steps. Moreover, these five steps are shown in Figure 1.

Table 2 further details the synthesis of the results of the gamification components. We find that there are three primary elements: the GM, the GD, and the player's emotions (Jia et al., 2016; Ortiz et al., 2016; Werbach & Hunter, 2015). Also, from the input from Toda et al. (2019), the study's specifics were drawn from a single classroom test case of 40 programming course class members. Ding (2019) undertook a gamification study with 70 online students, moving out of the realm of STEAM into the social science discipline of political science. The author concluded, like others, that student gamification familiarity was a factor in the success of the exercise and that in this test case, promoting a student's sense of community was not successful. This is somewhat similar to Sanchez et al. (2019), who took an even larger sample group of 473 university undergraduates and noted that their

Table 1 A representative overview of the quantitative method analysis of the STEAM education process

STEAM Education Process	(Rahmawati et al., 2019)	(Perignat & Katz-Buonincontro, 2019)	(How & Hung, 2019)	(Baharin et al., 2018)	(Ugras, 2018)	(Ogunleye, 2018)	STEAM Education Process
Investigation	✓	✓	✓	✓	✓	✓	✓
Discover	✓	✓	✓	✓	✓	✓	✓
Connect	✓	✓	✓	✓	✓	✓	✓
Create	✓	✓	✓	✓	✓	✓	✓
Reflect	✓	✓	✓	✓	✓	✓	✓

Fig. 1 The STEAM education process

gamification exercises were not sustainable after the novelty wore off for their students. Also, higher achievers did better than lower achievers overall (Table 6).

Furthermore, Koivisto and Hamari (2019) undertook a comprehensive review of 819 gamification studies and reported that while results generally were favorable, it was remarkable to find a wide array of mixed results. They also added that badges, points, and leaderboards persisted as the most common contexts and ways of implementing gamification (Table 2). Additionally, Hakaket et al. (2019) addressed the specifics of using gamification within the ‘cloud’ and further elaborated on subject areas that the authors felt were conducive to gamification through cloud services. Finally, Rodrigues et al. (2019) similarly examined 50 gamification studies and, from the Leximancer text mining tool, diagramed 28 gamification concepts, which were then grouped as eight themes. Figure 2 shows this study’s gamification components including the *game mechanics*, the *game dynamics*, and *game emotion*.

4.2 The creative thinking and creative innovation STEAM education process using a VCLE

Figure 4 details the results from quantitative analysis and the panels of experts’ input into the STEAM education process for Thai undergraduate creative thinking and creative innovation development using a VCLE. The model determined that there were five primary elements: investigate, discover, connect, create, and reflect. Furthermore, Fig. 3 details both the GMs and the GDs associated with each step’s element. Game mechanics involve determining goals, collecting points, enhancing levels, gaining badges and the leaderboard, whereas game dynamics involve demanding rewards, desiring the achievement, and competition and challenges (Table 3). Finally, a gamified VCLE consists of both the concrete and abstract environments

Table 2 The synthesis of the gamification components

Gamification Components	(Toda et al., 2019)	(Sanchez et al., 2019)	(Hakak et al., 2019)	(Chen et al., 2019)	(Koivisto & Hamari, 2019)	(Ding, 2019)	(Özer et al., 2018)	(Rodrigues et al., 2019)	Gamification Component
Game Mechanics									
Goals	✓	✓		✓	✓	✓	✓		✓
Points	✓		✓	✓	✓	✓	✓	✓	✓
Badges	✓	✓	✓	✓	✓	✓	✓	✓	✓
Levels	✓	✓		✓	✓	✓	✓		✓
Leaderboards	✓	✓	✓	✓	✓	✓	✓	✓	✓
Virtual good				✓	✓	✓	✓		
Roles	✓	✓			✓			✓	
Times	✓		✓						
Feedback	✓		✓			✓			
Reward	✓		✓	✓	✓	✓	✓	✓	✓
Status				✓		✓	✓		
Achievement	✓		✓	✓		✓		✓	✓
Self-expression				✓		✓	✓		
Challenge	✓	✓		✓		✓		✓	✓
Conflict		✓							
Competition	✓	✓			✓		✓	✓	✓
Cooperation	✓		✓			✓			
Game Emotion	✓	✓	✓	✓	✓			✓	✓

Fig. 2 The gamification components

Fig. 3 The STEAM education process step GMs and GDs

concerned with face-to-face classroom learning and the out-of-class, online learning process, respectively (Table 4 and Figure 4).

4.3 The evaluation of the appropriateness of the STEAM-ification process using a VCLE

Table 5 details the results from the panel of 10 experts who gave input on the appropriateness of the STEAM-ification learning process using a VCLE. We note that the conceptual model’s digital support to support learning and the application of the

Table 3 The synthesis of The STEAM-ification education process

STEAM Education Process	Gamification									
	Game Mechanics					Game Dynamics				
	Goals	Points	Badges	Leaderboards	Levels	Rewards	Achievements	Challenges	Competition	
Investigate	✓	✓	✓	✓		✓	✓	✓		
Discover	✓	✓	✓	✓	✓	✓	✓	✓		✓
Connect	✓	✓	✓	✓	✓	✓	✓	✓		✓
Create Creative Innovation	✓	✓	✓	✓	✓	✓	✓	✓		✓
Reflect	✓	✓	✓			✓	✓	✓		✓

Table 4 Synthesis of the VCLE gamification process

Virtual classroom Learning Environment (VCLE)	Gamification		Game Dynamics						
	Game Mechanics								
	Goals	Points	Badges	Leaderboards	Levels	Rewards	Achievements	Challenges	Competition
Concrete Environment	✓	✓	✓	✓	✓				
Face-to-Face Classroom	✓	✓	✓	✓	✓				
Abstract Environment						✓	✓	✓	✓
Online Learning Out of Class						✓	✓	✓	✓

Fig. 4 The VCLE's concrete and abstract aspects

Table 5 Conceptual model appropriateness determination from the panel of experts ($n=10$)

Content	$\bar{x}$	S.D.	Appropriateness Level
The STEAM-ification education learning process	4.70	0.48	Excellent
VCLE	4.70	0.48	Excellent
Digital technology to support learning	4.80	0.42	Excellent
Promoting creativity	4.40	0.52	Very good
Promoting creative innovation development	4.70	0.48	Excellent
Applying STEAM-ification processes in a VCLE	4.80	0.42	Excellent
Overall appropriateness	4.68	0.47	Excellent

STEAM-ification process in a VCLE were both ranked as the highest and 'excellent' in from the five-level agreement scale use. However, the conceptual model's ability to promote creativity was at the bottom of the scale, which was still ranked as 'very good.' Overall, the six aspects identified from the experts' evaluation study were ranked as 'excellent' ($\bar{x} = 4.68$, S. D. = 0.47) (Chujitarom, 2020).

4.4 VCLE STEAM-ification student assessment

Table 6 shows the results from both the experimental and control groups on student creative thinking and creative innovation.

From Table 1, it was determined that the experimental group using the VCLE STEAM-ification model had an average score of creativity. However, the researcher could not conclude whether it was a statistically significant increase or not, therefore, the One-Way MANOVA statistic had to be tested further.

Table 6 Mean and standard deviation of creativity and creative innovation

Groups	n	Creative Thinking			Creative Innovation		
		Total score	$\bar{x}$	SD	Total score	$\bar{x}$	SD
Experimental	30	16	14.53	0.94	20	18.40	1.04
Control	30	16	12.87	1.92	20	14.86	1.62

Before conducting the One-Way MANOVA statistical test, the researchers conducted a preliminary agreement test as follows (Bray & Maxwell, 1985).

1. Test the normal distribution of the data (Normality) with the Shapiro-Wilk test. It was found that the data for both dependent variables had a normal distribution ($\text{Sig} > \alpha$).
2. Testing the variance-covariance metrics (testing homogeneity of covariance matrices) with Box's M Test statistic found that the variance metrics of the two groups were not different ($\text{Sig} > \alpha$).
3. Test the relationship between the dependent variables (multi-linearity: multicollinearity) by using Barlett's Test of Sphericity, From this evaluation it was found that the dependent variables were statistically significantly related ($\text{Sig} < \alpha$).

From Table 7, it was found that the experimental group using the VCLE STEAM-ification model had an average score for creativity but for creative innovation it was higher than the control group that used the normal learning management plan. It was also found that the creativity of the experimental group was higher than the control group. The statistical significance was at the .01 level

Table 7 Results of multiple variance analysis to compare creativity and creative innovation of students in experimental and control groups

variance source	Multivariate tests	Value	F	Sig.		
Group	Pillai's Trace	0.69	63.36**	.00		
	Wilks' Lambda	0.31	63.36**	.00		
	Hotelling's Trace	2.22	63.36**	.00		
	Roy's Largest Root	2.22	63.36**	.00		
Test of Between-Subjects Effects						
Source	Dependent Variable>	SS	df	S	F	Sig.
Group	creativity	188.43	1	88.43	128.94**	.00
	creative innovation	38.37	1	8.37	25.39**	.00
Error	creativity	84.76	58	.46		
	creative innovation	87.63	58	.51		
Total	creativity	16862.95	60			
	creative innovation	11388.49	60			

**Sig. < .01

($df=1$, $F=128.94$, $p=.00$) and the creative innovation of the experimental group was higher than the control group. It was also statistically significant at the .01 level ($df=1$, $F=25.39$, $p=.00$).

Fig. 5 The final conceptual model of a VCLE being used for STEAM education creative thinking and innovative thinking process development

4.5 Final conceptual model

Figure 5 details the final results of the study. We can see the five elements and their associated aspects and sub-steps used within the VCLE.

5 Discussion

The STEAM education process in a VCLE consisted of five steps: investigate, discover, connect, create, and reflect. Moreover, gamification consisted of two main elements: game mechanics (e.g., goals, point, level, badges, and leaderboards) and game dynamics (e.g., rewards, achievement, challenges, and competition). Furthermore, from the panel of ten experts' input, it was determined that the proposed STEAM education model was an excellent foundation in the development of tools necessary for use in a digitally-based education LMS, flipped classroom, or blended learning environment (Banyen et al., 2016; DeLozier & Rhodes, 2017; Wannapiroon & Petsangsri, 2020).

5.1 VCLE

In New Zealand, VCLE student research by Gedera (2014) added that the use of digital platforms to connect with the Internet to websites where VCLEs are being used in blended learning environments is an excellent way for a student and teacher interaction which mimics an actual physical classroom. This study's conceptual model is also consistent with Fukuda et al. (2018), who in *Japan* developed a model for a VCLE in which the authors detailed their model's use of the need for student-centered ICT use, collaboration and social networking, and the site's ability for interactivity use.

The authors also suggested that the teaching and learning process is therefore not a journey to study in the cclassroom but rather a way to access the lesson's content through ICT and digital devices. In the *United States*, Hou et al. (2017) also investigated the cloud-based use of VCLEs, from which they detailed the complexities and calculations of Internet bandwidth capability and lesson streaming. Their suggestion was that to overcome bitrate requirements, VCLEs should employ hyper-cast approaches for cloud-based applications.

5.2 STEAM education

Based on the research results by Morrison (2006) in the United States, STEM was found to enhance student creativity, their ability at creative design, and the production of solutions based on current needs. This is consistent with Bakar and Mahmud (2020), who detailed the national government's stated importance of STEM and TVET education in Malaysia.

Moreover, the findings suggested that it was in the government's best interest to expose students to these educational tracts as early as the lower secondary school

level and to provide counseling services in career development programs for both fields. Also, the authors suggested that STEAM education can help learners solve problems in their daily lives while enhancing their experiences, life skills, and creativity. STEAM education also motivates students to take up later industry positions that employ their science, mathematics, and technology skills. Thus, they can use this knowledge to create innovation (Ogunleye, 2018; Parmin et al., 2020; Techakosit & Wannapiroon, 2015). Finally, STEAM education encourages learners to do activities that allow them to apply these skills to design processes or work to solve problems in daily life (Baharin et al., 2018; Rahmawati et al., 2019).

5.3 Gamification

In Thailand, Chujitarom (2020) found that collaborative gamification was a highly useful method in promoting innovative student creativity in digital art classes, with a knock-on effect of knowledge creation and innovation, which could be applied in the workplace. This is consistent with Santosa et al. (2020) in Indonesia, who also found that mobile digital devices used in ICT-supported collaborative learning were excellent at improving learning outcomes and solving problems. Once again, learners who were self-motivated at learning achieved better results.

Furthermore, in *Taiwan*, Hsu et al. (2017) noted the critical nature of website design in gamification's successful outcome. They also indicated that the site's utilitarian and hedonic features significantly affected a player's experience. In *Cyprus*, Hursen and Bas (2019) discussed the use of gamification in science education and found that within their class of 16 science students, motivation was increased and there was a joint approval from both the students and their parents.

5.4 Creative, critical thinking and innovation skills

The study's inclusion of creative thinking, critical thinking, and innovative skills as an output from a well-developed VLCE used in STEAM education was well supported in the literature from around the world (Choolarb et al., 2019; Chujitarom, 2020; Chujitarom & Piriyaasurawong, 2018; Ding, 2019; Jantakoon et al., 2019; Kankaew & Wannapiroon, 2019; Perignat & Katz-Buonincontro, 2019; Ruangvanich & Nilsook, 2018; Santosa et al., 2020; Sayavaranont & Piriyaasurawong, 2019).

6 Conclusion

Significant and global support was found for the study's investigation and conceptual model into how a VCLE affects a Thai undergraduate student's creative thinking, critical thinking skills, and innovation from the STEAM education or 'STEAM-ification' process. Furthermore, although there are also extensive global studies on gamification, the success of gamification is dependent on a variety of factors, including technological (e.g., bit rates and streaming), site design, the method and use of game mechanics and game dynamics, and the emotional

aspects which contribute most to a highly pleasurable, hedonic experience. Finally, when undertaken correctly, innovation and motivation to learn are also outcomes from both VCLE and gamification implications.. Students who study with the VCLE STEAM-ification format are more creative and creative innovation is higher than the students who study according to the normal teaching plan.

7 Limitations and future recommendations

The first limitation for the study's conceptual model development is how creative thinking or creativity is defined, their criteria, and concepts, as there is no single definition for neither. Second, many technological factors are necessary for a VCLE or gamified environment to work effectively and smoothly. In countries like Thailand, especially in rural areas, implementation and success might be difficult, if not impossible, to achieve. As was noted throughout the paper, there has been an evolution from STEM to STEAM, with the addition of 'art' being somewhat hard to define and what context in which it used. Also, throughout the study's research, the issue of 'gender' was often discussed and evaluated within the context of STEAM and gamification. However, these results are mixed and somewhat unclear. It is suggested that similar studies address the issue of gender's role in a successful STEAM and gamification implication. Also, future studies might conduct a deeper analysis of which players perceive digital devices as most useful and why this is so.

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Data availability The data and materials that support the findings of this study are available from the corresponding author upon reasonable request.

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Declarations

Consent to participate Informed consent was obtained from the two panels of experts (19 individuals total) involved with this study.

Consent for publication The experts have consented to the submission of their input to the journal.

Conflicts of interest The authors declare there is no conflict of interest.

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