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Learning chemistry through designing and its effectiveness towards inventive thinking

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Abstract

Learning through designing is the latest innovation in science, technology, engineering, and mathematics teaching and learning in the 21st century. This study aims to identify the effectiveness of EkSTEMiT module in fostering inventive thinking in the subject of electrochemistry. EkSTEMiT module was tested through a quasi-experimental design method of nonequivalent pre- and post-tests. A total of 63 students from four rural schools were involved in this study. Two schools were included in the treatment group (n=32), and two schools were included in the control group (n=31). The instrument used in this study was Inventive Thinking Questionnaire, which consists of adaptability and complexity management, self-regulation, curiosity, creativity, risk-taking, and higher-order thinking and reasoning subdomains. Analysis of MANOVA repeated measures showed no significant effect for group and time and no significant interaction effect between group and time on the level of students' inventive thinking. Although EkSTEMiT module does not have a significant impact on the level of inventive thinking, it can have a particular impact on the teaching of innovative instructors and can subsequently increase interest in the subject of chemistry among students.

Keywords: learning through designing, inventive thinking, electrochemistry

INTRODUCTION

Sustainable development goal 4 calls for quality education and lifelong learning opportunities for all, including formal, nonformal, and informal education at all levels. To produce a future workforce that is competent, creative, and viable, students need to be equipped not only with knowledge but also with necessary skills. Learning through designing is the latest and most effective teaching and learning approach for cultivating the 21st century skills, such as creativity, effective communication, collaboration, and critical thinking. Learning through designing supports the theory of constructionism, which states that the construction of new ideas occurs effectively when students are involved in the production of artifacts in a real life environment (Papert, 1971). The concept of learning through designing is used in teaching and learning so that students have the opportunity to generate ideas and produce a design artifact, such as a digital game (Hwang & Kim, 2016; Kafai & Resnick, 2011; Osman & Lay, 2020; Ronen-Fuhrmann et al., 2008; Weitze, 2014), simulation (Bruckman, 1998; Kaloti-Hallak et al., 2019; Samad & Osman, 2017), model (Pearl & Bless, 2021), prototype (Hill-Cunningham et al., 2018; Lin et al., 2021; Mesutoglu & Baran, 2020; Verner & Korchnoy, 2006; Wilson-Lopez et al., 2016), and robot (Kaloti-Hallak et al., 2019; Long et al., 2020; Winarno et al., 2020). Therefore, this study aims to identify the effectiveness of learning through designing in inventive thinking among rural students with regard to electrochemistry. This effort is organized to cultivate creativity and innovation and focus on students as learning designers.

This aspiration can be fueled by the cultural integration of science, technology, engineering, and mathematics (STEM). STEM integration is seen as capable of elevating the nation as a contributing country

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Contribution to the literature

- This study contributes to the field of electrochemistry through design-based learning.
- This study emphasizes the utilization of inventive thinking in the setting of teaching and learning.
- This study contributes to the constructivism and constructionism theory application in STEM integration.

and not just a user of science and technology. STEM integration can provide workforce in the future to pioneer the k-economy in global market competition. The need for manpower in STEM field is extremely urgent all over the world. According to Prinsley and Baranyai (2015), the skills required as a STEM workforce are design thinking, critical thinking, creative problem solving, time management, active learning in a career context, and lifelong learning. Employers believe that individuals with STEM qualifications are valuable and important to their business even if the qualification is not necessary. Furthermore, employers believe that STEM workforce has an innovative and flexible attitude and can adapt to changes in work or business. The workforce in STEM field receives more lucrative wages than the workforce in a non-STEM field (Light & Rama, 2019; Lytle & Shin, 2020). The unemployment rate recorded by STEM graduates is lower than that of non-STEM graduates (Smith & White, 2019; Wright & Ellis, 2019). This information shows that the workforce in STEM field is extremely necessary and has better future prospects.

Apart from academic achievement, the 21st century skills enable students to face challenges at the global level. These skills consist of digital era literacy, inventive thinking, effective communication, high productivity, and pure values (Osman & Marimuthu, 2010). Inventive thinking is an important 21st century skill that should be nurtured in students because it equips students with cognitive processes that encourage creative and critical thinking in innovative problem solving (Lemke, 2002). Inventive thinking can shape students to be marketable in STEM field. It can solve problems in real situations in line with the vision and paradigm for learning in the 21st century and is needed by every student (Ngaewkoodrua & Yuenyong, 2018). According to Tee et al. (2020), inventive thinking skills can guide learning in students through designing and help in solving problems. The approach of learning through designing provides opportunities for students to explore information according to their interests, learn actively, engage in social interactions by sharing design results, and take responsibility for their own learning (Lay & Osman, 2015; Osman, 2015).

A number of measures and transformations have been implemented to equip STEM human resources with the 21st century skills. However, some obstacles and constraints must be overcome. The level of inventive thinking in students is less encouraging. According to Saleh et al. (2020), the level of inventive thinking skills in students is concerning. Critical thinking skills and creativity in mainstream education are still insufficient to meet the standards set to produce knowledgeable and highly skilled workers in the 21st century. Furthermore, one of the subconstructs of inventive thinking, creativity, is at a moderate level (Kumar, 2020; Turiman et al., 2020), and instructors lacks creative teaching methods, and thus less emphasis has been placed on the 21st century skill elements, such as inventive thinking, in teaching and learning (Adnan & Ismail, 2018). Instructors think that cultivating inventive thinking skills can be implemented successfully if they are provided with modules, including teaching aids (Kiong et al., 2018). However, the modules on the market only focus on drills and revisions and are exam-oriented only (Hassan & Osman, 2016). Some studies have shown no significant difference in inventive thinking between treatment and control groups (Chifamba & Wijaya, 2020; Lay & Osman, 2020). Compared with traditional learning, the process of designing artifacts or products in a project takes a longer time (Osman & Lay, 2020; Penuel, 2019; Weitze, 2021).

The Ministry of Education has outlined a shift in system transformation in the education development plan 2013-2025. One of the transformational shifts is providing equal access to international quality education in all schools, including rural schools. However, the achievement of rural schools is lower than that of urban schools (Echazarra & Radinger, 2019; Hernández-Torrano, 2018). Apart from the aspect of achievement, the level of the 21st century skills, especially inventive thinking, is at a less encouraging level (Kan'an, 2018; Wan Husin et al., 2016). According to Zhang (2020), special consideration must be given to the development of rural instructors in the process of rural education development.

Therefore, EkSTEMiT module, which is based on learning through designing, has been developed, and its effectiveness in enhancing inventive thinking in rural students for the fourth form electrochemistry topic has been evaluated.

Research Question

This study aimed to address the following research question (RQ): What are the effects of learning through designing approach on students' inventive thinking?

THEORETICAL FRAMEWORK

The constructivism and constructionism theory served as the conceptual basis for this study.

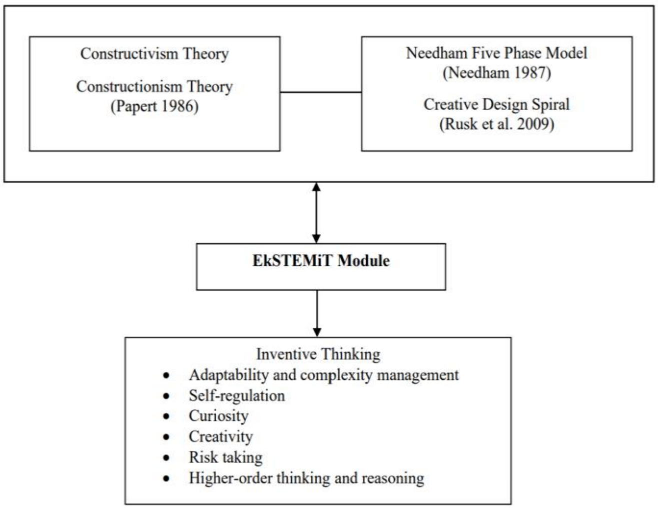

Figure 1. Conceptual framework

Constructivism theory focuses pupils' development of their own knowledge. The constructionism theory emphasizes that learning through designing has produced an understanding of how an idea is shaped and transformed when delivered through various media and realized contextually (Ackerman, 2000). This part explains the concepts of learning through designing and inventive thinking to elucidate the concepts underpinning EkSTEMiT module. **Figure 1** shows the conceptual framework of this study.

Learning Through Designing

STEM integration provides a definition different from interpretation. The definition is based on acronyms and science and math subjects. According to the National Research Center of the United States, STEM integration builds relationships between and within subjects related to STEM (National Research Council, 2014). Based on STEM integration approach, real-world problem solving cannot be taught separately from STEM disciplines in schools (Burrows et al., 2021; Fulton et al., 2010; Han et al., 2020; Roehrig et al., 2021).

Through conventional approaches STEM subjects have been taught in silos to students in schools (Burrows et al., 2021; Fulton et al., 2010; Han et al., 2020; Roehrig et al., 2021). Various STEM integration models have been introduced (Deniz et al., 2020; Gardner, 2017; Han et al., 2020; Ortiz-Revilla et al., 2020; Reynante et al., 2020), which emphasize the development of the 21st century skills. Kafai and Resnick (1996) found a difference between learning through designing and professional design, where learning through designing focuses on producing artifacts rather than final products. The professional design focuses on the final product as an important decision. Therefore, even if the expected final product is not designed by a student, learning still occurs through the student's engagement in a certain period. To develop design thinking similar to of an engineer, engineering design can be applied to teaching and learning. Engineering design together with engineering thinking enable students to be independent and reflective who can integrate various ideas to solve problems (Douglas et al., 2018; Jackson et al., 2021; Moore et al., 2014). In addition, student motivation and engagement and enjoyment of learning science increase when teaching is integrated with the engineering design (Kaloti-Hallak et al., 2019; Long et al., 2020; Macalalag et al., 2009; Winarno et al., 2020). Students benefit from firsthand experience with how engineers think and work (Douglas et al., 2018; Kaloti-Hallak et al., 2019; Long et al., 2020; Yu et al., 2020).

Many researchers have researched learning through designing by applying design models, such as the creative design spiral (Osman & Lay, 2020; Samad & Osman, 2017), the engineering design process (Douglas et al., 2018; Kaloti-Hallak et al., 2019; Long et al., 2020; Yu et al., 2020), and the TMI model (Park, 2018; Scaradozzi et al., 2019). The design learning model provides step-by-step guidance, tools, and cyclical information to enable students to manage ideas and to complete meaningfully products (Martinez & Stager, 2013). According to Rusk et al. (2009), students build their own ideas and then try and test those ideas with various alternatives, get input and suggestions from instructors and friends, and generate new ideas based on the experience they go through throughout the design process.

Inventive Thinking

According to the World Economic Forum (2018), analytical thinking and innovation, as well as active learning and learning strategies, will continue to increase in significance until 2022. The substantial rise in value of skills such as technology design and programming illustrate the rising demand for diverse forms of technology competence. However, critical thinking, persuasion, negotiation, attention to detail, resilience, flexibility, and the ability to solve complex problems are all examples of 'human' qualities that will continue to be in demand. **Figure 2** shows the top ten skills demand in 2022.

Figure 2. Top-10 skills demand in 2022 (World Economic Forum, 2018)

The majority of the identified skills are inventive thinking skills that will be essential in the future workforce. According to enGauge 21st century skills (Lemke, 2002), inventive thinking is one of the skills addressed as the 21st century skills apart from digital era literacy, effective communication, and high productivity.

Inventive thinking is defined as a cognitive process that employs creative and critical thinking during problem solving to generate innovative or specially designed solutions (Lemke, 2002). It is a key element to succeed and thrive in the 21st century and an important "life skill" (Ngaewkoodrua & Yuenyong, 2018; Turiman et al., 2020). Inventive thinking skills consist of six subdomains, namely, adaptability and complexity management, self-regulation, curiosity, creativity, risk taking and higher order thinking, which should be nurtured in students, so they can face unpredictable and demanding situations in the profession and in life in this globalized digital age (Turiman et al., 2020).

Adaptability and complexity management or flexibility refers to students' ability to change their way of thinking, attitudes, and actions when addressing a task with limited time and resources while learning. Students will be able to identify and comprehend changes and use positive thinking to modify thoughts, attitudes, and behaviors to cope with new environments (Lemke, 2002). Adaptability and flexibility skills are emphasized in engineering students in a design project to solve problems (Kraśniewski & Woźnicki, 1998; Sirotiak & Sharma, 2019). Several techniques increase students' flexibility and complexity management skills, including information and communication technologies, where students conduct online self-evaluation and attend virtual classrooms (Penman & Thalluri, 2014). In the era of the COVID-19 epidemic, when online learning was implemented owing to school closure, the role of adaptability and flexibility in students is crucial (Besser et al., 2022; Tseng et al., 2020). The second subdomain is self-regulation, which allows students to set goals, plan how to achieve those goals, manage time, and assess the quality of their learning on their own (Lemke, 2002). According to Nelson et al. (2014), self-regulation is a self-learning process in which students actively participate in their own learning by using skills and support from instructors. Self-regulation is one of the most important predictors of academic success and an essential learning skill (De Corte, 2019; Gorgoz & Tican, 2020; Yavuzalp & Bahcivan, 2021). According to Pintrich (2012), students with self-regulation abilities are more motivated for academic performance, learn better than other students, and are more effective in achieving their goals.

The third subdomain is curiosity, which refers to students' interest in learning something new and their inquiries while doing so; it is an essential component of life-long learning (Lemke, 2002). Curiosity motivates students to explore their environment and acquire new knowledge (Burda et al., 2019; Cankaya et al., 2018; Dean et al., 2020; Lindholm, 2018). Students are more likely to be curious when they are asked questions (Burda et al., 2019; Wade & Kidd, 2019). Answers that generate new questions must come from beyond the box and from the novel and perplexing world (Lindholm, 2018). The fourth subdomain is creativity, which allows students to generate new ideas and genuine products, to make powerful, generative, imaginative, and environmentally sensitive judgments on ideas put forward, and to freely assess themselves (Lemke, 2002). Students' creative thinking is exemplified by their openness to consider problems or difficulties, share their ideas with others, and accept feedback (Supena et al., 2021). The development of one's creative thinking abilities can be included in the study of scientific topics (Allina, 2018; Cremin et al., 2015; Lian et al., 2018; Supena et al., 2021; Thuneberg et al., 2018). According to Elald and Batd (2015), creativity-based learning enhances the academic achievement of students.

The fifth subdomain of risk refers to students' willingness to make mistakes and their willingness to accept challenging assignments, share information, and receive feedback from peers (Lemke, 2002). Assessments, examinations, worry, and apprehension throughout the learning process are among the risks in education (Leiman et al., 2015). According to a study by Cerezo (2004), problem-based learning enhances group dynamics and its effect on at-risk students. Students must understand how to reduce risks associated with cognitive and emotional workouts by employing logical arguments, examining difficulties, and making sensible decisions. Higher-order thinking and reasoning is the last subdomain of inventive thinking. Higher-order thinking and reasoning refer to cognitive processes, such as analyzing, comparing, evaluating, and synthesizing learning problems and current information. Students can compare analyses, make inferences and interpretations, evaluate and solve assignment problems, and use these skills in real life (Lemke, 2002). Yee et al. (2015) stated that higher-order thinking is created when new information is acquired or maintained, collated, and linked to existing knowledge. Using higher-order thinking as a teaching tool potentially develops higher cognitive levels in pupils (Alrawili et al., 2020; Hadi et al., 2018; Kim et al., 2020). Moreover, increasing mobile learning technologies in school can facilitate the development of higher-order thinking skills in pupils (Kim et al., 2020; Prahani et al., 2020).

Inventive thinking is a 21st century skill that must be developed to produce innovative thinkers who can contribute to national prosperity. Inventive thinking instils in students the creativity, innovation, and exploration required to think outside the box and solve real-world problems.

METHODS

This section contains thorough information about the study's participants, methodology, data collection instruments, and data analysis.

Participants

The researcher has sought information regarding the school's achievement background by consulting the District Education Office. The selected respondents were form four students in the science stream who were studying chemistry from four secondary schools. Each school offers only one science stream class on chemistry. Owing to administrative constraints, the random assignment of students to groups was not possible. Two schools were selected as the treatment group and two other schools were included in the control group due to the low enrollment in science classes in rural areas. This categorization was used to meet the minimum number of respondents required in the experimental study, which was 30 people for each group, and to allow generalizations to be made (Wong & Kamisah, 2016). A total of 63 students (19 males and 44 females) were selected as respondents; 32 of the students were included in the treatment group, and 31 students were included in the control group. The four schools had similar achievement backgrounds, and the school locations were not extremely far from one another.

Students were given pretests to address preexisting group differences, and information on the students' characteristics was gathered. Participating students were 15-16 years old. Male and female instructors with 13 and 15 years of experience were assigned to the treatment group, whereas female instructors with 10 and 11 years of experience were assigned to the comparison group. Before the study, all four instructors shared similar perspectives on teaching and learning, and the instructional style employed in chemistry classes. Even though these instructors were accustomed to traditional instructor-centered education, they were required to execute the national standard scientific curriculum, which emphasized learning through designing. To fulfil the science curriculum's requirements, students were encouraged to engage in this research study.

Procedure

A quasi-experimental two-group pre-/post-test design with nonequivalent treatment and comparison groups was used in examining the effect of EkSTEMiT module on inventive thinking skills. The researcher first arranged a session to inform the instructors about the study. Instructors were given materials and explanations of the module's concept and structure. The researcher then explained how to utilize EkSTEMiT module during T&L. For the treatment group, the researcher held a briefing about the activities in EkSTEMiT module. The students in the treatment group were introduced to the researcher, the purpose of her presence in the classroom, and the curriculum that would be taught.

The Inventive Thinking Questionnaire (ITQ) was administered twice to the treatment and control groups. The findings of the inventive thinking pretest were used in determining the homogeneity of inventive thinking between the treatment and control groups. Five weeks had been set aside for EkSTEMiT module intervention. The post-test was given to both groups again after the intervention. The pre- and post-tests for ITQ were given to the treatment and control groups at the same time.

Data Collection Tools

This research was conducted using a quantitative research design. ITQ served as the instrument for quantitative data collection.

Inventive Thinking Questionnaire

The researcher adapted ITQ with a five-point Likert scale to measure the impact of EkSTEMiT module use on students' inventive thinking (Arsad et al., 2011). Beginning with 42 items, the subdomain of inventive thinking was divided into six items for adaptability and complexity management, nine for self-regulated, seven for curiosity, seven for creativity, six for taking risks, and six for high-order thinking and reasoning. However, after the pilot study was conducted, some items were unsuitable and needed to be removed. After the researcher removed the items, Cronbach's alpha value was 0.839 for a total of 37 items, indicating that ITQ had high reliability. **Table 1** shows Cronbach's alpha value for each subdomain of inventive thinking.

Developing Activities of EkSTEMiT Module

The topic of electrochemistry was selected by the researcher according to studies that found electrochemistry to be one of the most difficult topics for students to learn and instructors to teach (Karamustafaoglu & Mamlok-Naaman, 2015; Lay & Kamisah, 2015; Lee & Kamisah, 2010). Molten electrolysis and electrolysis of an aqueous solution are the subtopics addressed by EkSTEMiT module's activities. Four learning-through-design activities were created: building a computer simulation for the electrolysis simulation activity, an e-poster for the poster-in-pocket activity, education board games for the DIY board game activity, and pop-up cards for the paper engineer activity. In addition, the researcher devised a timeline for each activity in the module. Systematically, each activity was executed according to the creative design spiral steps (Rusk et al., 2009).

Teaching Intervention

The duration of implementation for the experimental and control groups was five weeks. In the control groups, lessons were based on a conventional method.

Table 1. Reliability index of ITQ

Sub-domain	Number of items	Cronbach's alpha value	Total Cronbach's alpha value
Adaptability & complexity management	5	0.793	0.839
Self-regulation	9	0.821	
Curiosity	7	0.860	
Creativity	6	0.888	
Risk taking	5	0.852	
Higher order thinking & reasoning	5	0.818	

In the experimental groups, lessons were based on learning through designing according to EkSTEMiT module. All subtopics were delivered in the same weeks and in the same order to both groups. Also, pre- and post-tests were administered on the same day and week.

Teaching Control Groups

The instructors taught the control groups with 2012 chemistry curriculum (Ministry of Education, 2012). The teaching philosophy used in these lessons was that knowledge resides with the instructor and it is the instructor's obligation to communicate that knowledge as facts to pupils. The learning approach employed in the control group adheres to a conventional approach, characterized by a teacher-centered approach to teaching and learning. Following the specified textbook, the instructors explained the knowledge structures. At the conclusion of each class, the instructors posed straightforward questions on key subjects. The instructors would dictate notes, and the students would copy them. Unit-related experiments were conducted, and homework assignments were distributed. The absence of any engagement in the process of designing objects hinders the expansion of knowledge in relation to new or different circumstances. **Figure 3** shows the comparison between conventional method and learning through designing.

Teaching Treatment Groups

The treatment groups utilized Needham's Five Phases instructional paradigm to facilitate teaching and learning in the classroom, employing the same curriculum as the control group. In this model, five phases of instruction: orientation, eliciting ideas, restructuring ideas, applying ideas, and reflection, which review the concepts taught (Needham, 1987). During the phase of applying ideas, students are required to design artefacts that have been resulted from the ideas and concepts that have been acquired. During this phase, students apply the acquired knowledge to novel settings, thereby further developing their understanding. Phase-by-phase activity descriptions using learning through designing were discussed in depth. The activities prepared in relation to the topic "molten electrolysis" were presented to serve as examples, as similar procedures were performed during the same phase of the lesson for each subtopic.

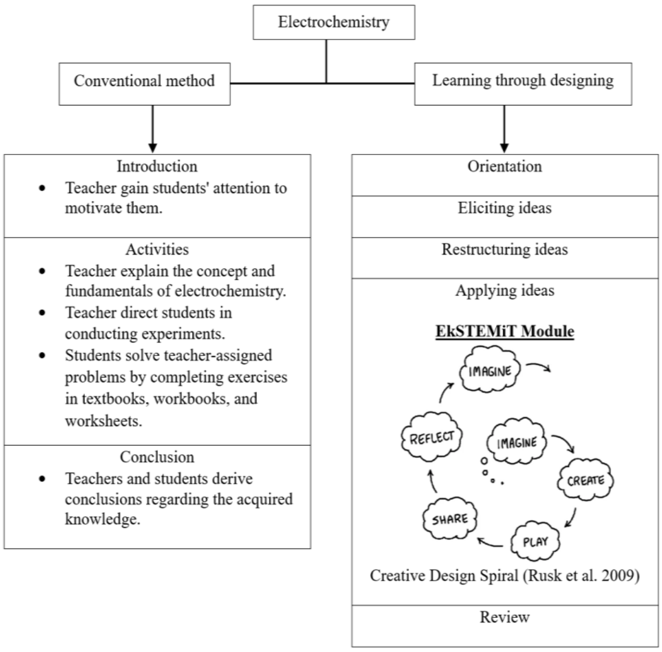

Figure 3. Comparison between conventional method & learning through designing (Samad & Osman, 2017)

Phase 1: Orientation

The objective of the orientation phase is to capture the attention and interest of students and encourage them to define learning objectives. The methods that can be used in this phase are practical activities, real problem solving, instructor demonstrations, video viewing, or searching information from newspapers. Using a few straightforward activities, the instructor uncovers the pupils' prior understanding of the topic. In this phase, instructors introduce electrolysis to illustrate the connection buzzer that emits a sound when a circuit is complete. The students are asked about their thoughts on how the buzzer is able to create sound.

Phase 2: Eliciting ideas

During the phase of eliciting ideas, the students and instructors have the opportunity to detect common misunderstandings. Discussion in small groups and presentation of results are suggested as possible methods. Students receive few materials and are instructed to classify the materials as electrolyte or a non-electrolyte. Then, the students explained why each substance is categorized as an electrolyte or non-electrolyte.

Table 2. Steps in creative design spiral

Steps	Explanation	Inventive thinking
Imagine	Planning design -Students are needed to design computer simulations for electrolysis of molten lead (II) bromide, $PbBr_2$ using Microsoft Power Point software. -Students have to come up with a plan & sketch it out.	Risk & Self-regulation
Create	Stages for developing a computer simulation of molten $PbBr_2$ electrolysis are, as follows: -Anions move toward anode. At anode, anions release electrons to create an atom or molecule. Anode releases anions. -External circuit wires carry electrons from anode to cathode. -The cathode attracts cations (positive ions). At the cathode surface, cations receive electrons to create atoms or molecules. Cations discharge at the cathode. -The external circuit and anode and cathode chemical changes are displayed.	Creativity & Self-regulation
Play	Simulation experiment -Students test computer simulation of molten $PbBr_2$ electrolysis (which has been designed). -Students continuously test the simulation to determine the efficacy of their designs. -Modifying effect option, animation painter, animation, & trigger panes allows for improvisation.	Adaptability & complexity management & Curiosity
Share	Sharing & presentation -The outcomes of the simulation design are presented to the instructors and peers. -Peers' and instructors' comments and recommendations will be considered. -Students improvise based on the sharing session with peers and instructors.	Adaptability & management complexity & Higher order thinking
Reflect	Reflection & evaluation -Students evaluate the experience received from participating in this activity. -Students independently assess the level to which their understanding, skills, & competencies have changed.	Self-regulation & Higher order thinking
Imagine	A new cycle in which repetition underlies innovation. Imagine-create-experiment-share-reflect generates new ideas & launches a creative cycle.	

Phase 3: Restructuring ideas

Restructuring ideas raise awareness of a scientific perspective to change, link, and convert it to a more scientific perspective. This phase can be conducted through clarification and exchange, exposure to conflict situations, development of new concepts, and evaluation. In this phase, students undertake experiments to investigate the electrolysis of molten lead (II) bromide. Students document observations, judgments, and debates in accordance with the practical textbook's requirements. Instructors oversee the practical method, observing the students' science process and manipulative skills, assisting students as needed, and checking experiment safety. Students must define electrolysis, conductors, electrolyte, non-electrolyte, anode and cathode, anions, and cations.

Phase 4: Applying ideas

The phase of idea application is utilized to identify newly renovated or constructed concepts from the phase of restructuring ideas, and the reflection step assesses and evaluates student comprehension of previously modified concepts. During the application phase, EkSTEMiT module will be put into practice. In this phase, students use Microsoft Power Point software to create a computer simulation that demonstrates the state of the ion in the compounds of molten lead (II) bromide, $PbBr_2$, the flow of ions to the electrode, and the ion discharge that occurs during the electrolysis of molten $PbBr_2$. When designing the simulation, students employ the creative design spiral steps, as shown in **Table 2**.

Phase 5: Review

The review phase provides a platform for students to exchange ideas and create reflection on the contradiction of ideas. In this phase, students receive four chemical compounds and are instructed to write half equations and the products generated at the cathode and anode on the prescribed worksheet.

Analysis of Data

Analysis of data obtained from inventive thinking questionnaire

Quantitative data obtained from ITQ was analyzed using inferential and descriptive statistics. The data obtained from the instrument was collected in the form of a table to facilitate analysis and data presentation. Descriptive analysis was performed on the inventive thinking pre-test to generate mean (M) and standard deviation (SD). The homogeneity of inventive thinking was determined for treatment and control groups involved. Inferential statistics 2×2×6 MANOVA

Table 3. Descriptive statistics of mean inventive thinking pre-test scores by group

Group	M	SD	n
Treatment	3.7701	0.3011	32
Control	3.6989	0.2904	31

Table 4. Descriptive statistics of mean sub-domains of inventive thinking

Sub-domain	Group	M	SD	n
Adaptability & complexity management	Treatment	3.29	0.35	32
	Control	3.28	0.34	31
Self-regulation	Treatment	4.05	0.36	32
	Control	4.03	0.41	31
Curiosity	Treatment	3.85	0.47	32
	Control	3.79	0.46	31
Creativity	Treatment	3.89	0.45	32
	Control	3.94	0.47	31
Risk taking	Treatment	3.73	0.53	32
	Control	3.64	0.52	31
Higher-order thinking & reasoning	Treatment	3.80	0.40	32
	Control	3.52	0.48	31

repeated measures analysis was used in determining effectiveness of EkSTEMiT module on inventive thinking in students. MANOVA repeated-measures analysis involved two groups (treatment and control), was performed twice (pre- and post-test), and included the six subdomains of inventive thinking: adaptability and complexity management, self-regulation, curiosity, creativity, risk-taking, and higher-order thinking and reasoning.

RESULTS

Homogeneity of Inventive Thinking

Comparative analysis of the mean scores for inventive thinking shows no significant difference between the treatment and control groups, although the mean score of the treatment group (M=3.7701 & SD=0.3011) surpasses that of the control group (M=3.6989 & SD=0.2904). **Table 3** shows a comparison of the mean scores of the inventive thinking pre-test.

Table 4 shows the descriptive statistics for the mean inventive thinking pre-test scores based on subdomains by group. As shown in **Table 4**, students from the treatment group (M=3.2900 & SD=0.3500) are able to adapt and manage higher complexity than students in the control group (M=3.2800 & SD=0.3400). However, the difference is small, indicating that the ability to adapt and manage the complexity of both treatment and control groups are almost identical. In the self-regulation subdomain, the students in the treatment group (M=4.0500 & SD=0.3600) have higher self-regulation pre-test scores than the students in the control group (M=4.0300 & SD=0.4100); however, the mean value is nearly identical. In the curiosity subdomain, students in the treatment group (M=3.85 & SD=0.4700) exhibit higher curiosity than students in the control group (M=3.7900 & SD=0.4600), but this difference is not statistically significant, and the mean values are nearly identical. However, in the creativity subdomain, students in the treatment group (M=3.8900 & SD=0.4500) have lower creativity than the students in the control group (M=3.9400 & SD=0.4700), but the difference in these values is small. In the subdomain to take risks, students in the treatment group (M=3.7300 & SD=0.5300) show higher risk-taking behavior than the control group (M=3.6400 & SD=0.5200), but the difference is small. In the subdomain of higher-order thinking and reasoning, students from the treatment group (M=3.8000 & SD=0.4000) have higher levels of thinking and reasoning skills than students in the control group (M=3.5200 & SD=0.4800), but the mean values are almost the same and equivalent.

Table 5. Multivariate test

Effect	PTV	F	df1	df2	p	PES
Group	0.160	1.778	6	56	0.120	0.160
Time	0.078	0.786	6	56	0.585	0.078
Group*time	0.147	1.607	6	56	0.162	0.147

Note. PTV: Pillai's trace value; PES: Partial eta squared; & Significance level=0.05

Given that the mean values are almost the same and equivalent, the treatment and control groups are homogeneous in terms of the level of inventive thinking before the study begins. The homogeneity between the groups allows a comparison and evaluation of the effectiveness of EkSTEMiT module.

Effect of EkSTEMiT Module on Inventive Thinking

The effectiveness of EkSTEMiT module on students' inventive thinking was assessed through MANOVA repeated measure 2×2×6 analysis. The findings show that no significant group main effect (F[6, 56]=1.778, p>0.05) with an effect size of 0.160. The main effect of test time was not significant (F[6, 56]=0.786, p>0.05) with an effect size of 0.078. The interaction effect between group and test time is not significant (F[6, 56]=1.607, p>0.05) with an effect size of 0.147. The results are shown in **Table 5** and **Table 6**.

Although the results of the above multivariate and univariate tests are not significant, the researcher performs descriptive analysis to obtain a detailed picture of each subdomain inventive thinking. **Figure 4** shows a graph of the mean difference of the pre-and post-test scores for the six subdomains of inventive thinking. The results of the descriptive analysis indicate an increase in the average inventive thinking scores across all subdomains of inventive thinking, determined by the pre- and post-test scores.

Table 6. Univariate test

Effect	Dependent variable	ST	df	MS	F	p	PES
Time	Adaptability & complexity management	0.390	1.00	0.039	0.296	0.588	0.005
	Self-regulation	0.131	1.00	0.131	0.707	0.404	0.011
	Curiosity	0.009	1.00	0.009	0.058	0.811	0.001
	Creativity	0.298	1.00	0.298	1.882	0.175	0.03
	Risk taking	0.001	1.00	0.001	0.002	0.966	0.000
	Higher-order thinking & reasoning	0.500	1.00	0.500	0.500	2.234	0.035
Time*group	Adaptability & complexity management	0.091	1.00	0.091	0.699	0.406	0.011
	Self-regulation	0.226	1.00	0.226	1.218	0.274	0.020
	Curiosity	0.210	1.00	0.210	1.421	0.238	0.023
	Creativity	0.429	1.00	0.429	2.705	0.105	0.042
	Risk taking	0.495	1.00	0.495	1.515	0.223	0.024
	Higher-order thinking & reasoning	0.348	1.00	0.348	1.557	0.217	0.025

Note. ST: Squared total; MS: Mean squared; & PES: Partial eta squared

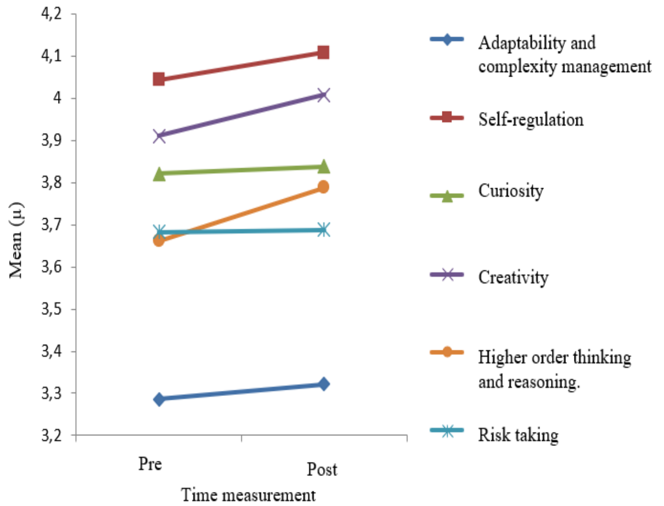

Figure 4. Comparison of mean score inventive thinking sub-domains according to time

DISCUSSION & IMPLICATIONS

Inventive thinking is an important skill for students to master in the 21st century. The workforce required in the 21st century is not only concerned with knowledge but also demands the mastery of skills, such as collaboration, effective communication, critical thinking, and creativity. Thus, the teaching and learning process of students in the classroom should be changed to attract interest in the 21st century skills and knowledge (Lay & Kamisah, 2018; Penuel, 2019; Wu et al., 2021). Learning through designing is the latest innovation in education that can foster inventive thinking in students.

Based on the analysis of the data, it was determined that there was no statistically significant disparity observed in inventive thinking between the treatment and control groups. In contrast, prior research conducted by Chan (2017), Jeong and Kim (2015), Melhem (2020), and Turiman et al. (2020) has demonstrated a notable augmentation in the capacity for inventive thinking. Based on the time measurement, it was determined that there was no statistically significant disparity observed across all subdomains of inventive thinking when comparing the pre- and post-test results. The statistical analysis revealed that the interaction effect between measurement time and group was not determined to be statistically significant. While the observed changes may not be statistically significant, the descriptive statistics indicate a rise in the level of inventive thinking across all subdomains of inventive thinking as measured over time. This implies that the marginal improvement in inventive thinking is not attributable to the time aspect, but rather to the impact of EkSTEMiT module intervention.

The activities within EkSTEMiT module place a strong emphasis on engaging students in hands-on artefact design. Subsequently, students are encouraged to share the artefacts they have created with both their peers and teachers (Hill-Cunningham et al., 2018). This sharing process allows for valuable input and comments to be received, which in turn facilitates the opportunity for students to adjust based on the feedback received. This finding is consistent with the research conducted by Wan Husin et al. (2016), which prioritized the cultivation of inventive thinking through the implementation of project-oriented problem-based learning. Furthermore, EkSTEMiT module places a strong emphasis on activating existing information during the initial stages of learning. This deliberate focus on prior knowledge serves as a catalyst for stimulating curiosity among students (Wade & Kidd, 2019), ultimately fostering a sense of self-regulation. The study conducted by Wade and Kidd (2019) employs trivia questions as a means to inspire curiosity within student participants.

Furthermore, EkSTEMiT module places significant emphasis on the aspect of collaboration, whether it be during the process of designing artefacts or conducting experiments. Collaboration within small groups entails the active engagement of students in constructive dialogue, wherein they engage in critical discourse supported by empirical data, exchange views, and collectively arrive at informed judgements. During the experimental procedure, students engage in collaborative efforts to make systematic observations, analyze collected data, and subsequently derive logical conclusions. In the creative design spiral, the share stage is where students engage in the exchange of design ideas with their peers and teachers during the design process. The comments and input provided by peers and teachers are thoroughly evaluated and supported with justification. The collaborative design approach has been found to foster critical thinking (Murthi & Patten, 2023; Pearl & Bless, 2021; Putra et al., 2023), hence enhancing students' inventive thinking abilities and promoting higher-order thinking skills. This study is found to be in line with prior research conducted by Kaloti-Hallak et al. (2019) and Kamisah and Lay (2020).

However, within the context of obtaining insignificant results in this study, there are a few potential explanations. Firstly, it appears that the utilization of design as a learning approach does not yield significant improvements in students' capacity for inventive thinking. Several factors influence the findings of this study, including students' lack of design experience in the classroom. This finding is consistent with the data gathered from this study and from the research conducted by Lock et al. (2020) and Weitze (2021). The teaching and learning atmosphere that has been highlighted has changed the learning routine experienced by students, which is previously exam oriented, and instructor centered and only sourced from textbooks. This finding is in line with the findings of a study by Donnelly and Hernandez (2018), who found that changes to the active student-centered learning approach led to negative perceptions in students. This new learning environment has given instructors and students a bit of a surprise in implementing teaching and learning in the classroom. In addition, students in rural areas are less exposed to classroom activities that focus on the 21st century skills, such as inventive thinking. This statement has been supported by Hernández-Torrano (2018), who found that rural students have a low level of interest, challenge, and satisfaction toward classroom activities. A study by Echazarra and Radinger (2019) has shown that the subject content, pedagogy, and classroom practices of rural school instructors are at lower levels than those of urban schools.

In addition, the implementation of teaching and learning with EkSTEMiT module in a short period of time and a limited number of activities is one of the factors that lead to insignificant research findings. EkSTEMiT module intervention includes the four subtopics of electrochemistry and is carried out in just five weeks. This statement is supported by the study of O'Connor et al. (2021), who suggested adding one month to the development of garden safety design in peer learning. Lozano-Jiménez et al. (2021) stated that the addition of self-determination theory intervention time is needed to increase the motivation of instructors and students.

The implementation of EkSTEMiT module provides instructors with multidisciplinary skills, such as the use of Canva application, which is widely used by researchers in their studies (Christiana & Anwar, 2021; Ilham et al., 2022; Miluniec & Miciuła, 2020). Canva application not only allows the creation of e-posters, but it also includes templates for creating certificates, cards, flyers, brochures, and other contemporary documents. These acquired skills can be used not only in teaching and learning but also in a variety of formal and informal school tasks. Thus, the development of EkSTEMiT module implies that instructors can foster creativity and acquire multidisciplinary skills that can improve their competencies and talents.

Learning through designing is a student-centered active learning concept. Students are provided with systematic step-by-step guidance to guide students in designing a desired artifact. Students are required to explore relevant information and resources in producing designs. Therefore, the implication of the study that can be seen for students is that they are more independent in the acquisition of information and knowledge. Students no longer depend on the instructor 100% in obtaining knowledge.

CONCLUSIONS

Cultivating STEM in the national education system can prepare students for a career in STEM field. Malaysia needs to increase the number of experts in STEM field to encourage innovation and ensure the country is competitive in the global economy. A competent future workforce not only should master knowledge in STEM field but should also have the skills, abilities, interest, and value of work toward the career they pursue.

Learning through designing is the latest classroom approach and can support the integration of STEM. Nevertheless, the design process implemented in schools is rigid, where the steps used are linear and indirect. This situation results in ambiguous learning objectives. Instead, students should be given cyclical step-by-step guidance, tools, and information, which they can use in managing their ideas and effectively prepare the products they create. Learning through designing emphasizes the process that students go through while building the product rather than the final product. Students employ the 21st century skills, such as creativity, effective communication, collaboration, and critical thinking throughout the design process. Although the results of this study show that EkSTEMiT module, which is based on learning through designing, has no effect on inventive thinking. It can have a positive impact on the teaching of innovative instructors and as a result, increases student interest in chemistry subjects.

Suggestions. In this study, EkSTEMiT module was found to have no effective impact on inventive thinking among students despite the increase in each subdomain of inventive thinking. A longer period of time should be given to students when completing a design assignment. In addition, the effect of this EkSTEMiT module can be studied on student achievement in the electrochemistry topic and based on gender and socioeconomic level.

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