



FOSTERING ENTREPRENEURSHIP-STEM CREATIVE THINKING AMONG SECONDARY SCHOOL STUDENTS

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Abstract

Fostering creative thinking in facilitating teaching and learning (TL) of entrepreneurship and STEM at the secondary schools is sparsely documented in the literature and warrants further Inquiry. Thus, this research aimed to assess secondary school students' entrepreneurial STEM creative thinking (E-STEM^{CT}). A comprehensive entrepreneurship-STEM module integrating socio-scientific issues (SSIs) and design thinking (DT) approach was meticulously designed to facilitate TL. A quasi-experimental quantitative study was conducted on 267 Form Four students aged 17 years old enrolled in rural secondary schools. Three intact groups were randomly divided into a) SSIs-DT approach, n=89, b) Design Thinking Approach (DT-A, n=90), and c) Conventional approach (CA, n=88). The E-STEM^{CT} test instrument was developed and applied to measure students' pre- and post-levels of E-STEM^{CT}. Rigorous statistical analysis employing MANCOVA, ANCOVA, and Effect Size techniques was conducted. MANCOVA results revealed statistically significant effects across all TL groups, indicating the effects of the interventions in fostering E-STEM^{CT}. Furthermore, ANCOVA analysis results indicated that the SSIs-DT integration approach significantly increased E-STEM^{CT} and its constructs: Inquiry, New Ideas, Design, Creation, and Commercialization compared to the DT-A and CA approaches. These results support the view that the SSIs-DT integration approach has a positive impact on fostering E-STEM^{CT} among secondary school students.

Keywords: *creative thinking, entrepreneurial-STEM, design thinking, socio-scientific issues, form four students*

Introduction

The implementation of creative thinking in entrepreneurship (E-CT) focuses on cultivating future entrepreneurs who are adept at overcoming the challenges involved in creating and launching new ventures. Bacigalupo et al. (2016) recommended integrating E-CT into educational settings, arguing that it equips students with an entrepreneurial mindset, enabling them to identify market opportunities and devise effective strategies to exploit them. Additionally, students skilled in E-CT tend to exhibit innovative problem-solving abilities. Therefore, incorporating E-CT into Science, Technology, Engineering, and Mathematics (STEM) education enables individuals to feel competent in generating new ideas by exploiting existing opportunities.

Embedding E-CT within STEM education is crucial for preparing secondary school students for careers in STEM fields (Dabney et al., 2012). This integration not only encourages students to tackle complex, real-world problems but also enhances their cognitive reasoning skills. Moreover, E-CT empowers students to adopt a comprehensive approach to exploring innovative solutions within STEM contexts. By fostering E-CT, students can engage with STEM subjects in authentic contexts, nurturing the STEM literacy essential for thriving in today's knowledge-based economy.

The concept of entrepreneurship-STEM (E-STEM) involves addressing local community challenges that require interdisciplinary collaboration across various STEM domains, including digital technology. Through E-STEM initiatives, students acquire the skills to transform ideas arising from the convergence of STEM disciplines into viable commercial ventures. Eltanahy et al. (2020) advocated for collaboration between business educators and STEM educators to infuse E-CT into STEM education, leveraging the entrepreneurial expertise of business educators. Consequently, this study aimed to develop students' entrepreneurial-STEM creative thinking (E-STEM^{CT}) via a practical E-STEM module to guide educators in effectively integrating E-CT into STEM teaching and learning. E-STEM^{CT} merges three key concepts: creative thinking (CT), entrepreneurship (E) and STEM. The E-STEM module combines problem-solving techniques for addressing societal issues through the Socio-scientific Issues (SSIs) approach with creative ideation processes supported by Design Thinking (DT).

Problem Statement

The implementation of entrepreneurial thinking within the Malaysian curriculum is not a novel initiative. Efforts to integrate entrepreneurial thinking have been underway since the introduction of the Integrated Secondary School Curriculum, particularly through subjects such as Finance and Basic Finance. The Curriculum Development Division of the Malaysian Ministry of Education has developed a comprehensive series of STEM resource materials encompassing 17 core and elective subjects at the preschool, primary, and secondary levels. However, the extent to which these STEM resources foster entrepreneurial thinking both within and beyond the classroom remains unclear. A study by the Malaysian Ministry of Education (2013) revealed that students have not adequately internalized entrepreneurial elements and skills in their daily lives. Consequently, it raises the question of the effectiveness of implementing entrepreneurial elements in STEM education by secondary school teachers.

In the context of developing new educational products in science, the Socio-scientific Issues (SSIs) approach, a pedagogical method utilizing socio-scientific issues as a learning context, has been frequently employed in classroom settings (Siew & Ahmad, 2023). In Malaysia, SSIs was incorporated into the Form Four science curriculum beginning in 2019. Via the SSIs approach, students are called to make wise decisions on socio-scientific issues that involve ethical implications (Sadler, 2004; Zeidler et al., 2006). This methodology enables students to explore and connect scientific concepts with daily life and community issues (Driver & Sadler, 2004). Hence, the application of SSIs not only enhances students' scientific knowledge but also encourages them to engage in discourse about the aftermaths of scientific issues on the morality of society.

In the realm of entrepreneurship education, the Design Thinking (DT) approach has been advocated as a strategic teaching methodology and has gained considerable popularity in recent decades (Daniel, 2016). DT involves a process-oriented learning method that fosters collaborative thinking among students to create various STEM prototypes (Erdogan & Stuessy, 2015). This approach has been widely applied to address open-ended, human-centered, and real-world problems (Sarooghi et al., 2019).

However, the implementation of SSIs and DT in fostering E-CT within STEM teaching and facilitation (TF) at the secondary school level is sparsely documented in the literature and warrants further Inquiry. Moreover, both SSIs and DT possess unique strengths that are complementary in cultivating E-CT. Therefore, it is imperative to analyze the integration of SSIs and DT approach to evaluate its effects in promoting E-STEM^{CT} among secondary school students. The E-STEM^{CT} assessed in this study comprises five stages: Inquiry, New Ideas, Design, Invention, and Commercialization. These five stages are adapted from the Science Entrepreneurial Thinking learning model (SET) by Buang et al. (2009). The proposed SET

consists of five steps: observation, new ideas, innovation, creativity, and value, developed based on the integration of science and entrepreneurship disciplines. Nevertheless, the SET learning outcomes culminate with students collecting community feedback on product ideas through surveys. The students are not guided through the step to introduce their product ideas to the market. According to Della Corte and Del Gaudio (2017), new ideas or products may have potential, but their real value is defined by how well they are received in the market. By introducing the stage of Commercialization in the five stages of E-STEM^{CT}, it is anticipated that students are capable of innovating, creating, and embodying entrepreneurial principles, thereby fulfilling the anticipated human capital requirements by 2030.

Theoretical Background

Socio-scientific Issues

The socio-scientific issues (SSIs) are those matters debated within society that are intricately linked to scientific ideas and principles (Zeidler, 2014). Researchers in the field of science education argue that SSIs can serve as active contexts that enable students to connect their learning experiences within the school to broader societal contexts (Topçu et al., 2018). Topçu et al. further contend that SSIs have the capacity to provide a new contextual dimension to learning experiences, thereby transforming their nature and significance.

Sadler (2004) highlighted that students are encouraged to address socio-scientific issues with moral implications in a scientific context when using SSIs to enhance science teaching and learning. This enables students to investigate science and make connections between it and society and daily living in their local area (Driver et al., 2000). Accordingly, using SSIs not only helps students learn more about science but also stimulates their discussion on how science affects morals in society (Sadler & Zeidler, 2005). In this sense, through discussion and debate, SSIs give students the chance to think about current issues, assess statements, examine the facts, and evaluate diverse ethical perspectives. Students who receive support through SSIs will also develop greater analytical and careful problem-solving skills. Students' perceptions of entrepreneurship are improved as a result of the scientific information they get from discussing socio-scientific problems and how to better produce ideas for societal solutions (Sadler & Donnelly, 2006).

Design Thinking Model

A method for developing students' Higher Order Thinking Skills (HOTS) through reasoning-based design is called Design Thinking (DT). Another definition of DT is an open procedure for solving problems (Dorst, 2011). Additionally, DT is a type of thinking process for problem-solving that begins with goals and objectives in order to solve specific difficulties (Razzouk & Shute, 2012). A five-stage DT learning model was presented by Plattner (2019) of Stanford University's Institute of Design as a foundation for resolving real-life issues through creative ideation stages. This five-stage involves developing empathy, establishing the scope, ideation, prototyping, and testing.

In the initial stage of the DT model, which involves developing empathy, students attempt to comprehend the demands of users. At this point, students set aside their preconceptions and hear directly from consumers what they need to know (Chaudhari, 2021). Students gather a variety of user concerns from the empathy stage in order to define the scope in the second stage. After that, students synthesize and analyze issues to identify the main issues that need to be resolved. Students at this level also create precise, well-defined issue statements. Then, using a variety of ideation strategies, including Brainstorming, Brainwriting, and SCAMPER,

students focus on generating original ideas that could address the specified problem statements during the ideation stage of the DT model (Chaudhari, 2021). The prototyping stage follows, during which students construct prototypes and turn their ideas into finished products. During the prototyping stage, students often encounter difficulties and setbacks. Therefore, they should create quick, inexpensive, low-fidelity prototypes to share with peers and teachers for feedback (Moitra, 2017). During the final stage, user testing, students evaluate their prototypes and gather feedback from users. Through this testing process, students can make modifications, assess the prototype's effectiveness, and determine if it meets the problem-solving goals. If necessary, they can continue refining the design.

It is clear that Design Thinking (DT) offers significant strengths in the context of student learning. Dotson et al. (2020) explained that Project-Based Learning (PjBL) is student-centered learning that requires students to collaborate with peers to understand the needs of the local community regarding real-life issues. They then apply their knowledge to generate ideas, seek solutions, and gather feedback throughout the process. Given the emphasis of the PjBL teaching model on socio-scientific issues, the PjBL model is highly suitable for integration with the DT model to foster students' E-STEM^{CT}.

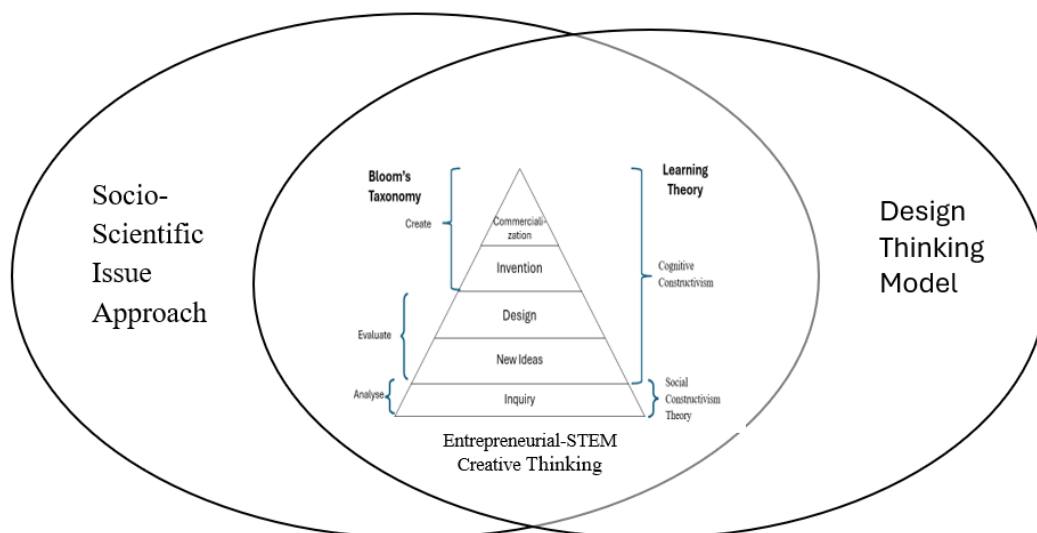
Entrepreneurial-STEM Creative Thinking (E-STEM^{CT})

The term 'Entrepreneurial-STEM creative thinking (E-STEM^{CT})' integrates three essential elements: creative thinking (CT), entrepreneurship (E), and STEM. CT denotes a cognitive process employed to develop unique, useful, and valuable ideas for more distant exploration (Aggarwal & Woolley, 2019). It represents a mode of thinking capable of generating novel and valuable ideas (Sternberg, 2003). Entrepreneurship, on the other hand, is defined as a practice leading to the invention of new ventures, products, and profits (Watts & Wray, 2012). Entrepreneurship encompasses the search for opportunity sources, the process of discovery, the utilization of chance, and their accomplishment (Bacigalupo et al., 2016). In other words, entrepreneurship is the individual's ability to turn their ideas into reality by leveraging existing opportunities. In this study, Entrepreneurial-STEM (E-STEM) incorporates the principles of entrepreneurship with STEM disciplines. Evidently both the context of entrepreneurship and STEM share some common goals because both aim to develop students' creative thinking. These competencies are not only required by STEM practitioners, but they are fundamental for entrepreneurs. Infusing E into STEM will encourage students to produce quality designs, functional products, or start a new business using the knowledge of STEM. Thus, entrepreneurial-STEM creative thinking (E-STEM^{CT}) can be viewed as one's capacity to produce unique, useful, and valuable products or services, processes, or practices that enhance market value.

Theoretical Framework

In this study, E-STEM^{CT} is defined as generating outstanding or unique STEM-related ideas that can create market value. The E-STEM^{CT} comprises five steps starting from Inquiry, New Ideas, Design, Invention, and Commercialization. These five steps are adapted from the SET model by Buang et al. (2009) and are based on the integration of the socio-scientific issue approach and the DT model, as illustrated in Figure 1.

Figure 1
Theoretical Framework



The E-STEM^{CT} model aligns with two learning theories and higher levels of Bloom's taxonomy. The first step of E-STEM^{CT} is conducting an inquiry into socio-scientific issues while considering user demands. This step corresponds with social constructivism theory and analyzing level of Bloom's taxonomy, where students in groups conduct inquiries to identify problems or opportunities and gather information on what has been done and what remains to be done in solving these issues, utilizing STEM knowledge (Rigolizzo & Amabile, 2015). The second step in E-STEM^{CT} is generating new ideas through reasoning that can meet customer needs. Generating numerous new ideas and combining them with existing STEM concepts enhances the likelihood of finding an effective solution (Allen et al., 2018). The next step, Design, is a critical evaluation of ideas in the creative process, enabling students to formulate new ideas through sketches and subsequently assess their feasibility. Both the New Ideas and Design steps align with the Evaluating level of Bloom's Taxonomy. The fourth step in E-STEM^{CT}, Invention, involves the implementation of new ideas. The aim of this step is to execute the idea or produce a new product on a small scale initially, allowing for testing of its functionality and effectiveness. The final step of E-STEM^{CT} is commercializing ideas through digital technology. Commercialization at this stage involves creating marketing campaigns, branding, and even new business models to support the commercialization process. The Invention and Commercialization steps align with the Creating level of Bloom's Taxonomy. Whereas, the steps of New Ideas, Design, Invention, and Commercialization are linked to cognitive constructivism, emphasizing the development of critical and creative thinking skills. This theoretical framework supports the students' ability to cultivate E-STEM^{CT}.

Research Aims and Questions

Overall, this research aimed to evaluate to what extent the integration of the Socio-scientific Issues and Design Thinking Approach (SSIs-DT) helps in fostering E-STEM^{CT} among Form Four students, compared to the Design Thinking approach (DT-A) and Conventional approach (CA). The study employed three TL approaches: SSIs-DT, DT, and CA. Specifically, the objectives were to compare the effects of the SSIs-DT approach with the DT-A and CA approaches on E-STEM^{CT} and the dimensions of Inquiry, New Ideas, Design, Invention, and Commercialization.

The research question guiding this study was: Are students taught through the SSIs-DT approach achieve significantly higher mean scores in E-STEM^{CT} and the dimensions of a) Inquiry, b) New Ideas, c) Design, d) Invention, and e) Commercialization, compared to those taught through DT-A and CA?

Research Methodology

Design

This study employed a quantitative approach with a quasi-experimental pre-test and post-test control group design to assess the effects of three different teaching and facilitation (TF) approaches on the E-STEM^{CT} of Form Four students. The researcher employed a simple random sampling method in determining groups of students, either in the SSIs-DT, DT-A, or CA groups. The independent variable comprised three TF approaches: SSIs-DT (experimental group I), DT-A (experimental group II), and CA (control group). The dependent variables focused on students' performance in E-STEM^{CT}, specifically measuring the dimensions of Inquiry, New Ideas, Design, Invention and Commercialization. The research was conducted over a three-month period from April to June 2023.

Sample

From a total population of 912 Form Four students in rural areas (Tawau District Education Office, 2022), this study involved 267 students from three selected schools based on identical pre-test mean scores achieved in the E-STEM^{CT} test. A total of 90 students were selected from school A, 93 from school B, and 93 from school C, all situated in Tawau, Sabah, Malaysia, with the consent of the school principal and Tawau District Education Office. Within each school, a total of three classes were randomly assigned to one of the TF approaches as intact class: SSIs-DT, DT-A, and CA. The participants included 129 male students (48.3%) and 138 female students (51.7%), all aged 17 years old. Of these, 89 students (33.30%) participated in the SSIs-DT approach, 90 students (33.70%) in the DT-A approach, and 88 students (33.33%) in the CA approach.

Teaching and Facilitation (TF) Approaches

The teaching and facilitation approaches were divided into three types: the Socio-scientific Issues and Design Thinking Approach (SSIs-DT), Design Thinking approach (DT-A), and Conventional approach (CA). The SSIs-DT group received full treatment of the E-STEM module, where students engage in Project-Based Learning (PjBL) activities resulting from the integration of socio-scientific issues with the entire design thinking process. Students in the SSIs-DT intervention group were introduced to socio-scientific issues and required to produce products that meet user needs based on the five steps of E-STEM^{CT}. Meanwhile, the DT-A group was exposed to a design thinking process-based approach only. Students in the DT-A group engaged in PjBL activities to produce products using the five steps in the design thinking process suggested by Plattner (2019) without exposure to socio-scientific issues. The CA group, on the other hand, received the conventional TF method, conducted in a student-centered manner but without the aid of the E-STEM module. In this CA group, students are asked to produce products based on a common PjBL model. At the end of the research, all groups were required to produce six different types of invention models.

Instrument

Two equivalent and parallel E-STEM^{CT} Tests developed by Arifin and Siew (2023) were used as pre-tests and post-tests, respectively, to assess students' E-STEM^{CT}. The E-STEM^{CT} test was found to have high item reliability, respondent reliability and inter-rater reliability (Arifin & Siew, 2023). The test consists of 10 structured and open-ended items that require students to answer questions in statements and sketch ideas. The items are grouped into five dimensions of E-STEM^{CT}: a) Inquiry (2 items), b) New Ideas (2 items), c) Design (2 items), d) Invention (2 items), and e) Commercialization (2 items). The main question in the E-STEM^{CT} test requires students to produce a combination of face masks and shields that can address the socio-scientific issues presented. The context of using face masks and shields was chosen because it aligns with the themes of the National Curriculum Standard Document used in the E-STEM module, namely Safety and Health. The grading system for the E-STEM^{CT} test dimensions was adapted from Ho et al. (2013). Each item carries a minimum score of 0 and a maximum score of 3.

Data Analysis

Information gathered through the E-STEM^{CT} Test instrument underwent both descriptive and inferential analysis via SPSS version 29 software. Descriptive analysis involved categorizing mean values for individual dimensions and the overall E-STEM^{CT} using De Vaus's (2002) suggested scale. This scale facilitates classification into low, moderate, and high levels by allocating the full score of each dimension into three levels. Table 1 outlines the levels for the mean scores of E-STEM^{CT} and its dimensions.

Table 1*Mean Analysis Level for E-STEM^{CT} and its Dimension*

Level	E-STEM ^{CT} Dimension	E-STEM
Low	0.00 – 2.00	0.00 – 10.00
Moderate	2.01 – 4.00	10.01 – 20.00
High	4.01 – 6.00	20.01 – 30.00

Source: Adapted from De Vaus (2002)

Inferential analysis, on the other hand, involves the use of Multivariate analysis of variance (MANOVA) and multivariate analysis of covariance (MANCOVA) to assess the effects of the SSIs-DT, DT-A, and CA on E-STEM^{CT} and all dimensions of E-STEM^{CT} while controlling for covariates. The six controlled covariates were pre-STEM^{CT}, pre-Inquiry, pre-New Ideas, pre-Design, pre-Invention, and pre-Commercialization.

Research Results

Table 2 presents the pre-test and post-test levels of E-STEM^{CT}, as well as the five constituent dimensions within E-STEM^{CT}: Inquiry (Iq), New Ideas (NI), Design (D), Invention (IN), and Commercialization (Cm). According to Table 2, there is a shift in mean score levels from moderate to high for E-STEM^{CT} and all dimensions following exposure to the SSIs-DT. Conversely, for the DT-A and CA groups, the mean score level remains moderate.

Table 2
Levels of E-STEM^{CT} and its Dimensions in the Pre-test and Post-test

Dimension	TF approaches	N	Pre-test			Post-test		
			M	SD	Level	M	SD	Level
E-STEM ^{CT}	SSIs-DT	89	11.58	2.795	Moderate	24.75	3.874	High
	DT-A	90	11.71	2.666	Moderate	17.88	3.932	Moderate
	CA	88	12.47	3.377	Moderate	12.49	3.705	Moderate
Iq	SSIs-DT	89	2.43	0.824	Moderate	4.98	1.500	High
	DT-A	90	2.37	0.867	Moderate	3.46	1.545	Moderate
	CA	88	2.47	0.934	Moderate	2.61	1.527	Moderate
NI	SSIs-DT	89	2.12	0.963	Moderate	4.96	1.437	High
	DT-A	90	1.97	1.011	Moderate	3.38	1.612	Moderate
	CA	88	2.18	1.199	Moderate	2.95	1.330	Moderate
D	SSIs-DT	89	1.87	0.907	Moderate	5.04	1.287	High
	DT-A	90	1.94	1.021	Moderate	3.89	1.777	Moderate
	CA	88	2.23	1.132	Moderate	2.44	1.660	Moderate
IN	SSIs-DT	89	2.35	1.012	Moderate	5.02	1.522	High
	DT-A	90	2.49	0.939	Moderate	3.71	1.973	Moderate
	CA	88	2.60	0.941	Moderate	2.33	1.811	Moderate
Cm	SSIs-DT	89	2.51	0.785	Moderate	5.07	1.214	High
	DT-A	90	2.89	0.917	Moderate	3.74	1.503	Moderate
	CA	88	2.99	1.023	Moderate	2.50	1.682	Moderate

The multivariate test Pillai's Trace, as shown in Table 3, indicates an overall significant effect of the TF approaches, [$F(12, 508) = 23.340, p < .05$] on E-STEM^{CT} and post-Iq, post-NI, post-D, post-Iq, and post-Cm dimensions. Nevertheless, there was no significant effect of control variables or covariates (pre- E-STEM^{CT}, pre-Iq, pre-NI, pre-D, pre-In, and pre-Cm) on the E-STEM^{CT} [$F(6, 253) = .997, p > .05$], post-Iq [$F(6, 253) = .580, p > .05$], post-NI [$F(6, 253) = .909, p > .05$], post-D [$F(6, 253) = .962, p > .05$], post-In [$F(6, 253) = .383, p > .05$], and post-Cm [$F(6, 253) = 1.012, p > .05$] respectively. This indicates that the TF approach is a contributing factor to mastery in E-STEM^{CT} and its dimensions of Inquiry, New Ideas, Design, Invention, and Commercialization., by controlling for covariate variables.

The result of ANCOVA test unveiled a notable effect of the TF approaches on E-STEM^{CT} [$F(2, 263) = 209.487, p < .05, \eta^2 = .614$], as well as on Iq [$F(2, 263) = 27.598, p < .05, \eta^2 = .173$], NI [$F(2, 263) = 45.955, p < .05, \eta^2 = .259$], D [$F(2, 263) = 64.372, p < .05, \eta^2 = .329$], In [$F(2, 263) = 34.815, p < .05, \eta^2 = .209$], and Cm [$F(2, 263) = 66.297, p < .05, \eta^2 = .335$]. Strong correlations were observed between the TF approaches and the dependent variable, indicating that 61.4% (E-STEM^{CT}), 17.3% (Iq), 25.9% (NI), 32.9% (D), 20.9% (In), and 33.5% (Cm) of the obtained variance were explained by the implementation of the SSIs-DT.

Table 3*MANCOVA and ANCOVA Test Results for the Effect of TF approaches and E-STEM^{CT} Covariates*

Effect	MANCOVA			ANCOVA			
	Pillai's Trace F	df	p	F	df	p	η^2
TF Approach	23.340	12, 508	< .05	209.487	2, 263	< .05	.614
Pre-E-STEM ^{CT}	.997	6, 253	.428	.886	1, 263	.347	.003
TF Approach	23.340	12, 508	< .05	27.598	2, 263	< .05	.173
Pre-Inquiry	.580	6, 253	.746	1.771	1, 263	.184	.007
TF Approach	23.340	12, 508	< .05	45.955	2, 263	< .05	.259
Pre-New Ideas	.909	6, 253	.489	.998	1, 263	.319	.004
TF Approach	23.340	12, 508	< .05	64.372	2, 263	< .05	.329
Pre-Design	.962	6, 253	.451	2.707	1, 263	.101	.010
TF Approach	23.340	12, 508	< .05	34.815	2, 263	< .05	.209
Pre-Invention	.383	6, 253	.889	2.214	1, 263	.138	.008
TF Approach	23.340	12, 508	< .05	66.297	2, 263	< .05	.335
Pre-Commercialization	1.012	6, 253	.418	.301	1, 263	.584	.001

Post-Hoc analysis was also conducted to determine the effect of the independent variables on the dependent variables. Table 4 presents the pairwise comparison results of mean and effect size for the effect of TF approaches on E-STEM^{CT} and its dimensions: Iq, NI, D, In, and Cm. Pairwise comparison of means indicated that the SSIs-DT approach was significantly higher than the DT-A for overall E-STEM^{CT} and all dimensions within E-STEM^{CT} ($p < .05$). Similarly, pairwise comparison of means also showed that the SSIs-DT approach was significantly higher than the CA for overall E-STEM^{CT} and all dimensions ($p < .05$). The same findings were observed in the pairwise comparison of means between the DT-A and CA, where the DT-A was significantly higher than the CA for overall E-STEM^{CT} and all dimensions within E-STEM^{CT} ($p < .05$).

Overall, students exposed to the SSIs-DT showed a large effect size ($d = 1.76$) in comparison to DT-A in terms of E-STEM^{CT}. Additionally, a large effect size was also observed in the comparison between the SSIs-DT and CA ($d = 3.23$) and between DT-A and CA ($d = 1.41$). The comparison between SSIs-DT and DT-A also showed a large effect size for the dimensions of Iq ($d = 0.99$), NI ($d = 1.03$), and Cm ($d = 0.973$), and indicated a moderate effect size for the dimensions of D ($d = 0.741$) and In ($d = 0.743$). In the comparison between SSIs-DT and CA, a large effect size was demonstrated in all dimensions.

Table 4

The Results of Post-Hoc analysis and Effect Size for the TF approaches on E-STEM^{CT} and its Dimensions

Dimension	Post-Hoc analysis	<i>MD</i>	<i>p</i>	<i>d</i>	Interpretation
E-STEM ^{CT}	SSIs-DT vs DT-A	6.863	< .05	1.76	Large
	SSIs-DT vs CA	12.240	< .05	3.23	Large
	DT-A vs CA	5.376	< .05	1.41	Large
Inquiry	SSIs-DT vs DT-A	1.496	< .05	0.99	Large
	SSIDT vs CA	2.371	< .05	1.56	Large
	DT-A vs CA	.875	< .05	0.55	Moderate
New Ideas	SSIs-DT vs DT-A	1.569	< .05	1.03	Large
	SSIs-DT vs CA	2.005	< .05	1.45	Large
	DT-A vs CA	.436	< .05	0.29	Small
Design	SSIs-DT vs DT-A	1.170	< .05	0.741	Moderate
	SSIs-DT vs CA	2.631	< .05	1.750	Large
	DT-A vs CA	1.461	< .05	0.843	Large
Invention	SSIs-DT vs DT-A	1.315	< .05	0.743	Moderate
	SSIs-DT vs CA	2.616	< .05	1.608	Large
	DT-A vs CA	1.302	< .05	0.728	Moderate
Commercialization	SSIs-DT vs DT-A	1.325	< .05	0.973	Large
	SSIs-DT vs CA	2.563	< .05	1.752	Large
	DT-A vs CA	1.238	< .05	0.777	Moderate

Discussion

The research findings indicated that students taught via the SSIs-DT approach performed significantly better compared to their peers taught using the DT-A and CA approaches in mastering E-STEM^{CT}. Through exposure to the E-STEM Module, students can engage in inquiry by unraveling problems and identifying user needs to generate new implementable solutions (Qamariyah et al., 2021). The SSIs-DT integration approach provides opportunities for holistic student learning by connecting aspects of science, society, and creativity. Through inquiry into these issues, students can better understand the complex relationships between science and society (Owens et al., 2017).

In the context of mastering the inquiry dimension, exposure to socio-scientific issues and design thinking plays a crucial role in guiding the inquiry process by providing students with focus and context. Relevant socio-scientific issue exposure facilitates in-depth inquiry and adds meaning to students' learning (Lindahl et al., 2019). The selection of these issues is a critical step that directs product development toward a more purposeful and meaningful

outcome (Stoltz et al., 2013). Through discussions of relevant issues, reasoning and subsequent discussions become more meaningful and applicable to real life (Capkinoglu et al., 2020). This step creates a strong foundation for deep and creative inquiry, enabling students to integrate design thinking and comprehensively understand socio-scientific issues.

In regard to the New Idea dimension, the SSIs-DT integration approach provides a strong foundation to help students explore unique and diverse ideas that meet user needs. Learning about socio-scientific issues opens opportunities to explore various community issues, including social, cultural, and scientific aspects (Qamariyah et al., 2021). This exploration involves a deep understanding of these complexities, allowing students to examine society's realities from multiple perspectives. The knowledge gained through this exploration forms the basis for generating ideas that are both relevant and contextual. By better understanding the issues facing society, students can design solutions to address real-world problems (Lindahl et al., 2019). They can integrate social and cultural understanding with scientific knowledge to create holistic and effective solutions. The E-STEM Module also fosters empathy through design thinking, helping students develop unique ideas that meet user needs. Applying empathy brings students closer to the realities of users' lives, enabling them to deeply understand their challenges and needs.

Furthermore, mastering the Design dimension through the SSIs-DT integration approach has shown a significant increase in mean scores compared to the DT-A and CA approaches. The socio-scientific issue approach provides a strong foundation for problem analysis and innovative opportunity identification (Safwatun Nida et al., 2020). By gaining a deep understanding of the issues affecting society, students can gather and analyze critical information. Design thinking then plays a role in utilizing the results of this analysis and transforming them into prototypes that provide practical solutions (Dam & Teo, 2018; Dotson et al., 2020). This step encourages students to think creatively and adapt their understanding to user needs within the socio-scientific context. The prototyping process becomes a tool that helps students convey their concepts and perspectives in a more concrete and understandable way. Methods like brainstorming and creative thinking techniques through design thinking create opportunities for generating concepts that are not only unique (Kangas et al., 2013) but also relevant to the socio-scientific issues at hand.

The intervention conducted for the SSIs-DT integration approach also has a positive impact on mastering the Invention dimension. Awareness of socio-scientific issues helps align products more holistically with societal values and needs (Fowler et al., 2009). Design thinking enables quick product adaptation based on user feedback and changes in market and social needs. The iterative process in design thinking provides opportunities to test prototypes rapidly and make continuous improvements based on user feedback (Alcaraz-Dominguez & Barajas, 2021). Creating products that meet user needs enhances product dissemination and competitiveness in the market (Tavassoli & Karlsson, 2015). The socio-scientific issue analysis process within SSIs-DT also helps students gain a deeper understanding of a product's social impact. When they comprehend an issue, they become more open to considering societal values in product design (Ahmad & Siew, 2022).

In the Commercialization dimension, the significant difference for the SSIs-DT group compared to the DT-A and CA groups indicates that understanding the market through socio-scientific issues and design thinking can enhance students' commercialization skills. When students are exposed to socio-scientific issues related to the community, they gain in-depth insights into the problems faced by the public (Stoltz et al., 2013). This understanding provides a strong foundation for comprehending the needs and desires of the target market.

By delving into socio-scientific issues, students can identify opportunities to create relevant and meaningful products or solutions (Chowdhury et al., 2020). This is crucial in marketing, where products aligned with social values and societal needs tend to garner greater

support. In this way, students not only learn how to create products that meet functional needs but also understand the relationship between products and societal demands (Gemmell et al., 2012). Design thinking guides students in leveraging digital platforms such as social media, websites, and digital applications to deliver product messages creatively. They learn to craft effective marketing messages using these platforms, developing writing and content design skills that capture the attention of audiences in the digital space (Siddiq et al., 2016).

The lower mean score for the DT-A compared to the SSIs-DT approach demonstrates that integrating socio-scientific approaches into product invention processes is more structured. The socio-scientific issue approach explicitly addresses relevant issues and encourages students to think more broadly (Khishfe et al., 2017). These highlighted socio-scientific issues provide students with opportunities to investigate user problems, increasing the potential to generate new, implementable solutions (Safwatun Nida et al., 2020). Students gather information and assess creative ideas that can be translated into meaningful products. In this context, students can delve into socio-scientific issues by designing solutions that are not only scientifically effective but also beneficial to society as a whole. This comprehensive experience fosters holistic learning that involves not only academic aspects but also an appreciation of community realities.

Moreover, the CA, which obtained the lowest post-mean scores compared to the SSIs-DT and DT-A approaches, is attributed to its lack of focus on mastering thinking skills in teaching. The absence of emphasis on explicit thinking approaches in teaching results in less satisfactory mastery among students. This has been highlighted by Changwong et al. (2018), who showed that the CA does not encourage students to think actively, lowering their interest in active exploration in the classroom and leading to inconsistent student achievements.

Conclusions and Implications

The study findings demonstrate a significant positive effect of the E-STEM module, which integrates Socioscientific Issues (SSIs) and the Design Thinking (DT) approach, on students' E-STEM^{CT}. This effect is particularly evident in the dimensions of Inquiry, New Ideas, Design, Innovation, and Commercialization. These results underscore the potential of integrating SSIs and the DT approach to enhance the mastery of E-STEM^{CT} among Form Four students, providing a strong rationale for educators worldwide to consider implementing entrepreneurial elements in STEM education.

The integration of socio-scientific issues and design thinking complements each other, fostering comprehensive development in students' E-STEM^{CT} and providing diverse learning experiences. Through this approach, students not only gain a deep understanding of socio-scientific issues but also learn to devise innovative and forward-thinking solutions. Incorporating design thinking into the learning process creates opportunities for students to develop entrepreneurial skills, such as designing quality products, understanding markets, and planning marketing strategies. As a result, this approach has broad implications for holistic student learning, encompassing scientific, social, creative, and entrepreneurial aspects.

The observed shift in mean score levels from moderate to high for the dimension of Commercialization highlights the importance of cultivating a sustained interest in commercialization within STEM education. While the SSIs-DT approach may initially boost the dimensions of Inquiry, New Ideas, Design, and Innovation, elements such as Commercialization play a critical role in influencing students' E-STEM^{CT}. Therefore, a holistic approach to STEM education, such as the SSIs-DT approach, is required - one that connects in-class learning with real-world applications, particularly in commercialization.

At the policy level, this research provides empirical evidence supporting the incorporation of the E-STEM^{CT} model into national educational frameworks. Given its potential impact on

critical and creative thinking skills and problem-solving skills, there is an urgent need for educational reform to meet the demands of the 21st century. The study's findings can guide policymakers in designing more effective STEM curricula that better integrate E-STEM^{CT} elements, thereby enhancing student learning experiences and ultimately shaping the future of education worldwide.

Finally, future research could explore the long-term effects of the SSIs-DT approach on E-STEM^{CT} among lower secondary school students. Such studies could unveil new findings for enhancing students' E-STEM^{CT}. Additionally, this research could be used to compare the SSIs-DT approach with other innovative teaching methods, providing valuable insights into best practices for STEM education in the development of E-STEM^{CT}.

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Declaration of Interest

The authors declare no competing interest.

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