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Computational Thinking Through the Engineering Design Process in Chemistry Education

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Abstract: This study investigated the influence of CThink4CS² Module on computational thinking (CT) skills of form four chemistry students. The CThink4CS² Module integrated CT with the Engineering Design Process (EDP) in chemistry class. This study utilized quantitative research methods and quasi-experimental design. Quantitative data were collected using the Computational Thinking Skill Test (CTST) which consisted of algorithmic reasoning, abstraction, decomposition, and pattern recognition constructs. A total of 73 students were in the treatment group (n=39) and control group (n=34). Experimental data were described by means of descriptive analysis and inferential analysis employing two-way MANOVA analysis. The results of the analysis indicated significant differences in CT skills between groups; students in the treatment group demonstrated better results compared to those in the control group. The paper provides insight into the integration of CT and EDP as effective pedagogical strategies for inculcating CT skills.

Keywords: *Computational thinking, engineering design process, chemistry.*

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Introduction

Future workforces are undergoing significant transformation as technological advances swiftly alter the boundaries between work tasks performed by humans and those performed by machines and algorithms. Careers in the digital age necessitate a variety of skills, including the ability to think critically and analytically, solve complex problems, and analyze and evaluate systems (World Economic Forum, 2020). To produce a competent, skilled, and creative workforce in the future, students must be equipped with knowledge and skills.

Today's Science, Technology, Engineering, and Mathematics (STEM) students need 21st-century skills, such as computational thinking (CT), to succeed in chemistry. However, the degree of CT competency is currently regarded moderate (Araujo et al., 2017; Durak et al., 2019; Helsa et al., 2023) due to students' limitations, such as the need for constant internet access in suburban institutions, which reduces their desire to learn CT (Threekunprapa & Yasri, 2020). Furthermore, text-based programming languages are fundamentally passive, emphasizing CT particularly abstract reasoning that is difficult for students (Lee et al., 2023; Threekunprapa & Yasri, 2020). Moreover, the knowledge and experience of teachers may influence students' comprehension of CT concepts (Kong & Lai, 2023). According to Ling et al. (2018), there is a significant shortage of competent and experienced computer science (CS) teachers.

Based on gender comparison, previous research has determined that the level of CT skills between male and female students varied. According to Korkmaz and Bai (2019), in terms of critical thinking abilities, male students have a higher level of CT than female students. Moreover, Israel-Fishelson et al. (2021) discovered that female students have a higher level of computational creativity than male students. In the LEGO robotics program, male students focused more on the operational aspects of robot assembly and coding, whereas female students emphasized group dynamics (Ardito et al., 2020). Nonetheless, other studies indicated that gender did not influence the CT skills of male and female students (Chongo et al., 2020; Sirakaya, 2020; Sung et al., 2023). To identify disparities between male and female students, it is necessary to perform comparisons between genders that are inconsistent in CT.

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CT concepts have been implemented in a variety of disciplines, and the ability to reason computationally is essential in all fields. According to Chongo et al. (2020), its integration with pure science fields, such as chemistry, for systematic problem-solving should also be disclosed. The greatest obstacle to students' success in chemistry is the difficulty in comprehending the underlying concepts and principles that propel discipline (Dewi et al., 2021; Prokša et al., 2018). Abstract chemistry concepts are one of the reasons that cause difficulties in learning chemistry (Çavdar et al., 2017; Irwanto et al., 2018; Malkoc, 2017; Prokša et al., 2019; Ratamun & Osman, 2018).

Meanwhile, engineering has traditionally not been part of the K-12 core curriculum, where students focus predominantly on design projects with little discussion of the science that supports the design and implementation (Zhang et al., 2019). A study conducted by Bartholomew and Pehrson (2022) highlighted the presence of constraints in the execution of CT and engineering design activities. Notably, the engineering design component exhibited a higher degree of success compared to the CT segment, which encountered more challenges. Furthermore, only a small number of studies have examined the CT skills of students in the context of engineering design (Sen et al., 2021). Recent research suggests that engineering thinking and CT may complement one another and provide students with a suitable context for the development of CT (Ehsan et al., 2021). A learning approach to improve current instructional methods in chemistry education by merging CT with the engineering design process (EDP) is needed. EDP enables students to be self-reliant and reflective problem solvers who can integrate diverse concepts (Douglas et al., 2018; Jackson et al., 2021).

Computational Thinking (CT)

CT is defined broadly by Wing (2006) as a fundamental skill required by all individuals and should be included as one of the abilities for all children alongside reading, writing, and arithmetic. CT always refers to the means of thinking used to find solutions to issues (Ardito et al., 2020; Korkmaz & Bai, 2019; Kukul & Çakır, 2020).

Although CT is the underlying logic of computer science, it can also be applied to other science and engineering fields with real-world applications (Peel et al., 2021). The integration of CT with STEM subjects can enhance the learning of STEM and CT subjects (Zhang et al., 2019). According to Harel and Papert (1990), computer learning in conjunction with other subjects is more effective than learning it separately. Zhang et al. (2019) demonstrated that the integration of CT and STEM subjects can enhance the learning of STEM and CT subjects. Numerous researchers, for example Aslan et al. (2020), Chongo et al. (2021), Holme (2019), Lia et al. (2020), Lodi (2019), Musaeus and Musaeus (2019) and Zhang et al. (2019), investigated the integration of CT skills with chemistry and science teaching and learning.

Important CT skills include algorithmic reasoning, abstraction, decomposition, and pattern recognition. Table 1 describes CT skills. CT promotes the development of problem-solving skills and techniques, whether or not a computer is utilized. Mensan et al. (2020) stated that the application of CT skills in the classroom can be accomplished through unplugged and plugged-in activities encompassing a wide range of subject areas. Plugged-in activities utilize computer software and instructional programming or learning programs that are either freely available online or for purchase, whereas unplugged activities do not involve the use of digital instruments or computer programming.

The best method for students to apply CT skills is through plugged-in activities (Brackmann et al., 2017; Weintrop & Wilensky, 2017). On the other hand, unplugged activities are also an effective way to integrate CT into teaching and learning (Caeli & Yadav, 2020; Delal & Oner, 2020; del Olmo-Muñoz et al., 2020; Kuo & Hsu, 2020; Rich et al., 2020; Saxena et al., 2020; Threekunprapa & Yasri, 2020). del Olmo-Muñoz et al., (2020) discovered that students who were exposed to entirely plugged-in activities had lower level of CT than those exposed to unplugged activities first and then plugged-in activities later. This could due to the relationship between sensory motor factors and high-level cognitive processes, which reveals the effect of an unplugged approach on the mastery of CT skills (Città et al., 2019). However, unplugged and plugged-in activities have a variety of advantages for fostering CT abilities in students.

Table 1. Description of Each CT Skill

Computational Thinking Skills	Description
Decomposition	Break down a task or problem into smaller, more specific portions (Selby & Woollard, 2014).
Pattern recognition	Identifying patterns for a task or problem's characteristic, process, or relationship to coordinate knowledge and solve similar tasks or problems using the same strategy (Kasan et al., 2016).
Abstraction	To gain a deeper understanding of a task or problem, it is important to focus on the specifics that are essential and eliminate those that are superfluous (Wing, 2011).
Algorithmic reasoning	The solution to a task or problem is presented as a series of step-by-step instructions (Selby & Woollard, 2014).

Engineering Design Process (EDP)

The most recent and effective teaching and learning strategy for developing 21st-century skills, such as creativity, effective communication, collaboration, and critical thinking, is learning by design. In the classroom, the concept of learning through design is implemented so that students can generate ideas and create design artifacts, such as digital games (Osman & Lay, 2022; Weitze, 2014), simulations (Chongo et al., 2021; Samad & Osman, 2017), and robotics (Winarno et al., 2020). EDP is practiced in the classroom to assist students design artifacts in a systematic manner.

EDP is a series of steps taken to solve a problem. This model is iterative and is composed of five stages: ask, imagine, plan, create, and improve (Hill-Cunningham et al., 2018). At the ask stage, students identify and define the types of engineering problems by asking questions. Then, students engage in brainstorming throughout the second stage. At the plan stage, students organize their projects by selecting the most promising ideas and compiling a list of required components, resources, and instruments. At the create stage, students build a prototype, test it, and identify any issues with it. Figure 1 shows the EDP diagram.

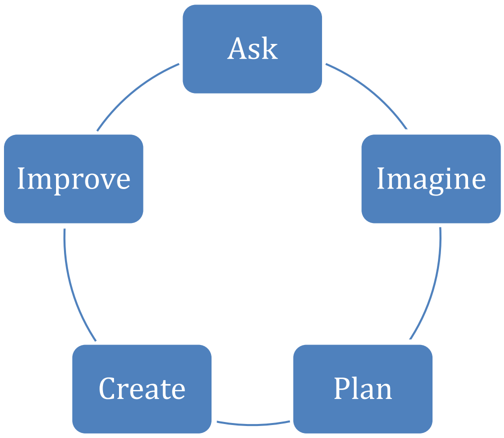

Figure 1. EDP Diagram (Source: Hill-Cunningham et al., 2018)

EDP assists students master concepts and skills, such as problem solving, critical thinking, and collaboration, in accordance with the evolution of education in the 21st-century. Students develop their capacity for critical thinking as they progress through EDP learning (Jeng et al., 2020; Putra et al., 2021). Students who possess deduction, explanation, and evaluation skills can employ scientific knowledge during the design process (Jeng et al., 2020). Moreover, EDP helps students enhance their ability to solve problems they have experienced previously (Jackson et al., 2021; Kaloti-Hallak et al., 2019; Winarno et al., 2020). EDP-based learning innovations are anticipated to be a viable alternative solution to a variety of problems (Winarno et al., 2020), whereas collaboration is an integral component of EDP (National Research Council, 2009). Students can engage in sharing their ideas and comprehension and work within constraints (Murthi et al., 2023; Pearl & Bless, 2021).

Few studies have been conducted or published on the extent to which CT and EDP are integrated. Therefore, the CThink4CS^2 Module, which integrated CT and EDP, was developed in this study, and its effectiveness in enhancing CT skills of form four chemistry students was evaluated.

Research Question

The purpose of this study is to determine the effect of CThink4CS^2 Module on CT skills of form four chemistry students. This study also determined the effectiveness of the CThink4CS^2 Module based on the comparison between male and female students. To accomplish these purposes, the following research questions are outlined.

1. Is there a significant difference in the mean score of post CT skills test of form four chemistry students between the treatment group and control group?
2. Is there a significant difference in the mean score of post CT skills test of form four chemistry students based on gender?

CThink4SC^2 Module Conceptual Framework

The CThink4CS^2 Module was designed and developed according to the instructional design of İŞMAN Model adopted from İşman (2011). The central idea of this model is that students construct their own knowledge using educational technology resources. Constructivism and constructionism are the two primary learning theories utilized in the development of the CThink4CS^2 Module.

Moreover, the teaching and learning approaches involved are inquiry-based science education (IBSE) and learning through design. The CThink4CS^2 Module includes unplugged and plugged-in CT activities.

Constructivist learning theory emphasizes that students construct their own knowledge based on their own learning experiences. According to Piaget (1961), assimilation and adaptation occur when students explore new information. Assimilation occurs when a student compares newly acquired information with his existing knowledge. In contrast to adaptation, which occurs if existing information is inconsistent with new information, this mechanism adapts its thought processes to the new information. Piaget (1961) also emphasized that exploration is the foundation of learning. Students should investigate relationships and concepts through engaging activities. Consequently, the learning activities of the CThink4CS^2 Module employ the BSCS 5E Instructional Model (Bybee et al., 2006), which is in line with the concept of inquiry exploration. Moreover, Vygotsky (1978) believed that the social environment influences learning and emphasized the function of social interaction in cognitive development and learning. Based on this theory, a collaborative approach strategy, in which students collaborate in small groups for each activity, is proposed in this module.

Constructionism theory is derived from the concept of constructivism theory. According to constructionism theory, students effectively construct new ideas when they participate in the production of artifacts in a real-world setting (Papert, 1972). According to Ackermann (2001), constructionism theory approach that emphasizes learning through design has provided an understanding of how an idea is formed and transformed when presented in various mediums contextually. Learning through design emphasizes the learning experienced by students rather than concentrating solely on the final product (Kafai & Resnick, 1996). In designing a product or artifact, such as a robot, model, simulation, comic, narrative, or poem, students share their designs with their peers to receive feedback (Martinez & Stager, 2013). The CThink4CS^2 Module applied EDP for the development of design thinking to assist students in designing problem-solving.

Inquiry denotes seeking knowledge or data by posing questions (Crawford, 2014; Harlen, 2012). According to Kennedy (2014), IBSE is the art of creating challenging learning situations, in which students observe and question a phenomenon, explain observations, design and conduct experiments to collect data to support theories or vice versa, analyze data, draw conclusions based on experimental data, and design and construct models. The IBSE concept engages students directly in student-centered activities in the classroom (Fitzgerald et al., 2021; Herranen & Aksela, 2019; Treagust et al., 2020). Moreover, IBSE classroom activities can implement 21st-century skills by encouraging students to collaborate with peers and teachers to solve learning problems (Fitzgerald et al., 2021; Harlen, 2012; Juntunen & Aksela, 2013; King, 2012; Saavedra et al., 2019; Sotiriou et al., 2017; Van Heuvelen et al., 2020). The CThink4CS^2 Module utilizes the BSCS 5E Instructional Model to support IBSE principles. The BSCS 5E Instructional Model includes five phases, namely engagement, exploration, explanation, elaboration, and evaluation (Bybee et al., 2006). Each phase has a specific function and leads to coherence in teacher instruction (Cetin-Dindar & Geban, 2017; Lye & Koh, 2014; Senan, 2013). These phases are used to design inquiry learning sequences in the CThink4CS^2 Module for chemistry class.

Learning through design supports the constructionism theory of Papert (1972), which stated that students effectively construct new ideas when they are involved in the production of artifacts in a real-world setting. According to Kafai and Resnick (1996), there is a distinction between learning through design and professional design, in which learning through design focuses on the current process of producing artifacts and disregards the ultimate product. Therefore, even if the ultimate product designed by students does not meet expectations, learning still occurs as a result of student participation over a specific time period. However, teachers and students encounter obstacles when implementing learning through design in schools. Compared to conventional learning, designing artifacts or products in a project requires a considerable amount of time (Barnett, 2005; Bhattacharya & Bhattacharya, 2006; Lay & Osman, 2018; Osman & Lay, 2022). In addition, the design process implemented in schools is rigid due to the linear, indirect nature of its stages (Martinez & Stager, 2013). Therefore, the CThink4CS^2 Module employs EDP when designing unplugged or plugged-in CT artifacts. Figure 2 summarizes the conceptual framework of this study.

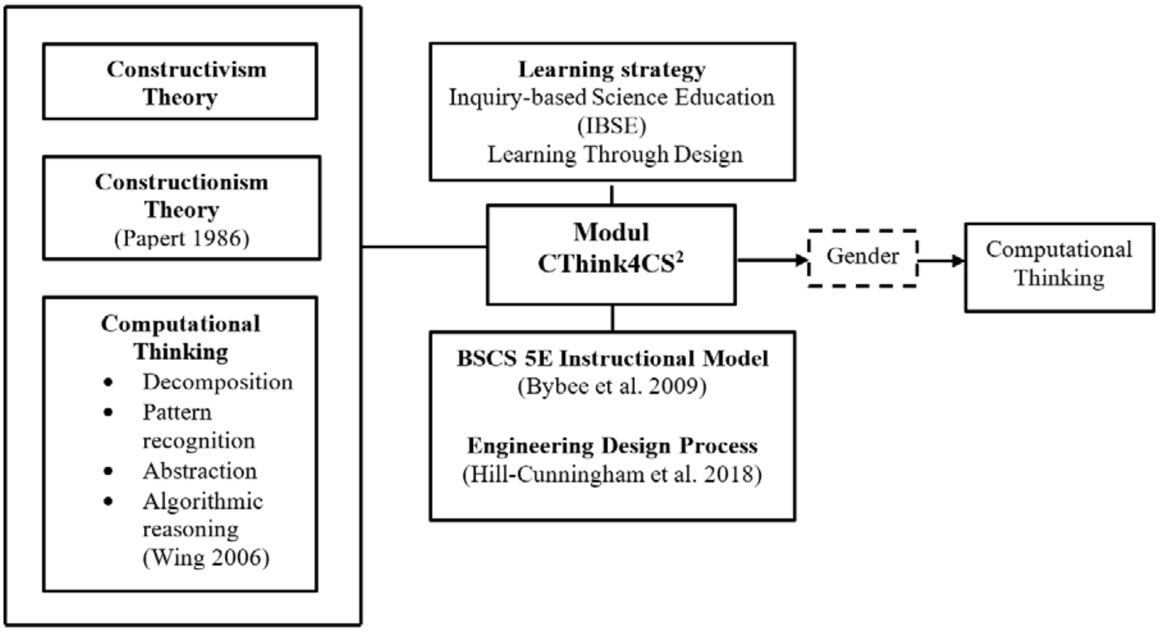

Figure 2. Conceptual Framework

Methodology

Research Sample

The selected respondents were form four students from two secondary schools in Negeri Sembilan, Malaysia who studied the chemistry subject in the science stream. One school was designated as the treatment group, while the other was assigned as the control group. This categorization is intended to meet the minimum number of respondents required for the experimental study, which is 30 for each group, and to permit generalization (Chen & Osman, 2016). A total of 73 students (40 males and 33 females) were selected as respondents; 39 students were assigned to the treatment group, and 34 students were assigned to the control group. The achievement histories of the two schools were comparable, and the institutions were not distant from each other geographically.

Table 2. Number of Participants by Group and Gender

Group	Gender		Total
	Male	Female	
Treatment	21	18	39
Control	19	15	34
Total	40	33	73

Randomly assigning students to groups was not possible due to administrative constraints. Students between the ages of 15 and 16 participated in pre-tests to account for pre-existing group differences, and information regarding their characteristics was collected. The treatment group had a chemistry teacher with 18 years of experience, whereas the control group had a chemistry teacher with 16 years of experience. Prior to the study, both teachers had similar views on teaching and learning as well as the instructional approach they employed. These teachers were acclimated to teacher-centered instruction, but they were required to implement the national standard scientific curriculum. To meet the science curriculum requirements, students were encouraged to engage in this study.

Experimental Design

The effectiveness of the CThink4CS^2 Module was tested on CT skills using a quasi-experimental two-group pre-test–post-test approach with non-equivalent treatment and comparison groups. The use of a quasi-experimental design was necessitated by the fact that random sampling techniques cannot be used exclusively in sample selection. The treatment and control groups were randomly chosen but not their samples. This was due to the fact that the intervention of this study was administered in the current school year, with the sample consisting of students from the existing class.

The Computational Thinking Skill Test (CTST) was administered twice to the treatment and control groups. The results of the CTST pre-test were used to determine whether the CT levels of the treatment and control groups were comparable. The intervention was scheduled to take place within seven weeks. After the intervention, the post-test was administered again to both groups. The pre- and post-tests of CTST were administered simultaneously to the treatment and control groups.

Research Tool

This study employed quantitative research methods. CTST was an instrument used to acquire quantitative data and evaluate the effectiveness of the CThink4CS^2 Module. The CTST utilized in this study was adopted from the Bebras International Challenge on Informatics and Computational Thinking (Blokhuis et al., 2015, 2016, 2017). CTST is highly valid and reliable. CTST was validated by three experts in CT, while reliability was measured using the Kuder Richardson formula with internal consistency, r = 0.88. The CTST consisted of 16 objective multiple-choice questions. Each CT skill assessed in this study, namely algorithmic reasoning, abstraction, decomposition, and pattern recognition, consisted of four CTST questions. Additionally, CTST items were designed according to three levels of difficulty, namely easy, medium, and difficult. Table 3 shows the details of CTST according to CT skills and difficulty levels.

Table 3. CTST Items According to CT Skills and Difficulty Levels

Item	CT Skill	Level of Difficulty	Percentage
1.	Algorithmic reasoning	Easy	
2.	Abstraction	Easy	
3.	Algorithmic reasoning	Easy	
4.	Decomposition	Easy	43.75%
5.	Abstraction	Easy	
6.	Pattern recognition	Easy	
7.	Decomposition	Easy	
8.	Algorithmic reasoning	Medium	
9.	Abstraction	Medium	
10.	Pattern recognition	Medium	31.25%
11.	Decomposition	Medium	
12.	Pattern recognition	Medium	
13.	Abstraction	Difficult	
14.	Decomposition	Difficult	25.00%
15.	Algorithmic reasoning	Difficult	
16.	Pattern recognition	Difficult	

Procedure

The implementation period for the experimental and control groups was seven weeks. Lessons in the experimental groups were based on the CThink4CS^2 Module, which integrated CT and EDP. In the control group, instruction was given based on conventional practices. Both groups were exposed to each subtopic in the same weeks and in the same order.

The teacher instructed the control group through the 2018 Chemistry Curriculum textbook (Ministry of Education, 2018). The pedagogical approach utilized in these classes was that knowledge resided in the teacher and was transferred to students as facts. The teacher guided students through various knowledge structures while following the prescribed textbook. The teacher posed simple questions on important topics at the end of each class. Students copied the instructor-dictated notes. Experiments related to the unit were conducted, and homework was assigned.

The treatment group utilized the CThink4CS^2 Module based on the BSCS 5E Instructional Model for classroom teaching and learning. This model consists of five instruction phases: engagement, exploration, explanation, elaboration, and evaluation (Bybee et al., 2006). The CThink4CS^2 Module included unplugged and plugged-in CT activities for the topic of Salt. Unplugged activities encompassed Units 1 to 5, whereas plugged-in activities encompassed Units 6 to 11. According to del Olmo-Muñoz et al., (2020), unplugged activities are more suitable to be implemented in the classroom before plugged-in activities as an introduction to CT.

In the first week of this study, respondents from both groups were administered the CTST pre-test to determine the homogeneity of the studied group. Then, the treatment group was briefed on this study and attended a three-hour introductory Scratch workshop. The teachers were oriented on the concepts of CT and Scratch 3.0 software. To introduce the concept of CT, respondents from the treatment group were exposed to the CT unplugged activities in the Salt topic in the second week. In the third week, respondents continued to engage in the unplugged activities of CThink4CS^2 Module, and they were introduced to the EDP for the first time. In the fourth week, respondents engaged in unplugged CT activities by integrating CT and EDP through the design of pseudocode and flowcharts for experimental algorithms. They were first introduced to plugged-in CT activities using Scratch in the fifth week. At this stage, they designed stationary objects in Scratch. In the sixth week of this study, respondents were tasked with designing moving objects in Scratch. In the seventh week, a digital educational game incorporating chemistry concepts was designed by the respondents using Scratch. In addition, they presented and disseminated educational games to their peers and teachers. Finally, both treatment and control group respondents took the CTST to determine the effectiveness of the CThink4CS² Module on CT.

This study was conducted at school in accordance with the twice-weekly learning schedule. The time for one slot took 60 minutes, and one slot was conducted for 90 minutes per week. However, the students completed the design task outside of their regular class time. Unplugged activities included the use of ionic cards, such as flash cards containing the chemical formulas of ions and designing flowcharts and pseudocode. During the plugged-in activities, students used Scratch 3.0 to create digital games on the Salt topic. When designing the assigned artifact, students must adhere to the steps outlined in the EDP. Teachers acted as facilitators throughout the intervention, guiding students as they conducted activities, experiments, and designed problem-solving strategies.

Data Analysis

The quantitative data of the CTST pre-test were analyzed using inferential and descriptive statistics. Tables were used to organize instrument data to facilitate data analysis and presentation. Descriptive analysis served to generate the mean and standard deviation. Homogeneity of CT skills in the treatment and control groups was determined. On the other hand, two-way MANOVA analysis was used as inferential statistics to determine the effectiveness of the CThink4CS² Module on the level of CT among students. Based on the pilot test, the Kuder–Richardson Formula 20 or KR20 reliability for the entire test was 0.88, which indicated that the CTST has high degree of reliability.

Table 4. Levene's Test for CT Post-Test Scores by Gender and Group

Box's M	F	df1	df2	Sig.
79.817	2.372	30	11603.369	.000

Before performing the MANOVA analysis, the homogeneity of the variance–covariance matrix must be determined using Levene's test. Homogeneity of variances–covariances determined whether the variances–covariances of the dependent variables were similar across all independent variables, namely group and gender. Non-significant results of Levene's test indicated that the variance–covariance assumption was met. Table 4 presents the result of Levene's test, which was not statistically significant (F = 2.372, p < .001). Consequently, the assumption of homogeneity of variances–covariances for CT skills was upheld, and thus the two-way MANOVA analysis could be proceeded.

Findings/Results

The results of the two-way MANOVA analysis revealed significant differences in CT skills between the treatment and control groups. In the meantime, the results indicate that there is no statistically significant disparity in CT skills between male and female students.

Effect of CThink4CS² Module on Students' Computational Thinking Skills by Gender

The difference in CT skills test results between the two genders was insignificant. In general, the levels of CT skills among male and female were almost equal. Based on descriptive data, the difference between male and female students' CT skills could be determined. Comparisons between students' CT skills post-test stratified by gender and group are summarized in Table 5.

Table 5. Comparison of Mean Scores for CT Skills by Groups and Gender

Group	Gender	M	SD	N
Treatment	Male	11.05	2.247	21
	Female	11.61	2.524	18
	Total	11.31	2.364	39
Control	Male	8.95	3.704	19
	Female	6.47	2.875	15
	Total	7.85	3.543	34
Total	Male	10.05	3.170	40
	Female	9.27	3.710	33
	Total	9.70	3.422	73

Male students in the treatment group scored higher on the CT skills test (M = 11.05, SD = 2.247) compared to the control group (M = 8.95, SD = 3.704). In addition, the mean score of female students in the treatment group for CT skills (M = 11.61, SD = 2.524) exceeded that of the control group (M = 6.47, SD = 2.875). These results indicated that the CT skills of students based on the CThink4CS² Module were superior to those students who used the conventional approach. Overall, male students (M = 10.05, SD = 3.170) have higher CT skills than female students (M = 9.27, SD = 3.710).

Effect of CThink4CS² Module on Students' Computational Thinking Skills

Table 6 demonstrates the results of the two-way MANOVA test. The Wilks' Lambda value was used to identify statistically significant differences between the independent variable and dependent variable. The results indicated that the main effect of group was significant (F (4,66) = 8.111, p < .001), but no significant difference was observed in the main effect of gender (F (4,66) = 1.456, p = .226). In addition, the interaction effect between group and gender was not significantly different (F (4,66) = 0.877, p = .054). The two-way ANOVA results summarized in Table 7 indicated that the inclusion of all four constructs of CT skills was significantly affected by group. A significant main effect of group on each CT construct was observed: algorithmic reasoning (F (1,1.930) = 10.502, p = .002), abstraction (F (1,3.242) = 21.678, p < .001), decomposition (F (1,1.414) = 28.009, p < .001), and pattern recognition (F (1,1.927) = 12.845, p = .001).

Table 6. Two-Way MANOVA Analysis of CT Scores by Group and Gender

Effect	Wilks' Lambda value	F	Dk1	Dk2	p	Partial eta square
Group	.670	8.111	4.000	66.000	**.000**	.330
Gender	.919	1.456	4.000	66.000	.226	.081
Group*gender	.870	2.459	4.000	66.000	.054	.130

The significance level is .05

Table 7. Tests of Between-Subjects Effects

Effect	Construct	Sum of square	dk	Mean square	F	p	Partial eta square
Group	Algorithmic reasoning	7.656	1	7.656	10.502	**.002**	.132
	Abstraction	23.113	1	23.113	21.678	**.000**	.239
	Decomposition	23.143	1	23.143	28.009	**.000**	.289
	Pattern recognition	.041	1	.041	12.845	**.001**	.157

The significance level is .05

Table 8 exhibits the expected mean margin for the CT skill constructs between the treatment and control groups. The results indicated that the algorithmic reasoning construct of the treatment group (M = 2.817) outperformed the control group (M = 2.165), abstraction construct of the treatment group (M = 3.004) outperformed the control group (M = 1.870), decomposition construct of the treatment group (M = 2.980) outperformed the control group (M = 1.846), and the pattern recognition construct of the treatment group (M = 2.655) outperformed the control group (M = 1.826). Overall, the mean post-test scores of the treatment group were higher than those of the control group for all constructs of CT skills.

Table 8. Mean Expected Margin of CT Constructs by Group

Construct	Group	Mean	Standard error	Confidence interval 95%	
				Upper	Lower
Algorithmic reasoning	Treatment	2.817	.137	2.544	3.091
	Control	2.165	.147	1.871	2.459
Abstraction	Treatment	3.004	.166	2.673	3.335
	Control	1.870	.178	1.514	2.226
Decomposition	Treatment	2.980	.146	2.689	3.271
	Control	1.846	.157	1.532	2.159
Pattern recognition	Treatment	2.655	.157	2.341	2.969
	Control	1.826	.169	1.489	2.164

Discussion

The results of data analysis demonstrated that the CThink4CS² Module was effective in enhancing students' CT skill levels. The CThink4CS² module integrated the concept of CT with design-based learning via EDP for the topic of salt in the form four chemistry subject. The IBSE method of teaching and learning was implemented in the classroom.

Through the CThink4CS² Module, the concept of CT was introduced first through unplugged and then through plugged-in activities. Unplugged activities utilized ionic cards and other equipment available in the classroom, whereas plugged-in activities exposed students to Scratch software. This learning approach enabled students to explore their CT skills progressively. The results confirmed that unplugged activities were preferred than plugged-in activities as an introduction to CT in the classroom (del Olmo-Muñoz et al., 2020). This could be due to the relationship between sensory motor factors and high-level cognitive processes, which reveals the effect of unplugged approach on the mastery of CT skills (Città et al., 2019).

Past studies have also shown an increase in CT skills by using cards in the classroom (Delal & Oner, 2020; Kuo & Hsu, 2020). The CThink4CS² Module employs ionic cards to develop ionic equations rather than Scratch cards (Monjelat &

Lantz-Andersson, 2020) and board game cards (Kuo & Hsu, 2020). According to Sung et al. (2023), Bebras cards are intended to help students develop their CT skills while also introducing them to more advanced computing concepts. The unplugged activities of CThink4CS² Module are cost-effective because they utilize cards and other common classroom supplies, such as paper, pencils, and markers (Delal & Oner, 2020; Saxena et al., 2020). Unplugged computing makes computer science more accessible to those who are unable or unwilling to use computers without sacrificing instructional effectiveness.

The activities of CThink4CS² Module also emphasize collaboration in small groups. When students solve a problem, they collaborate to find a solution (Delal & Oner, 2020; Saxena et al., 2020; Kuo & Hsu). Previous research has demonstrated that collaborative unplugged and plugged-in CT activities enhance students' CT skills (Kukul & Çakır, 2020; Resnick et al., 2009; Tonbuloğlu & Tonbuloğlu, 2019; Zakaria & Iksan, 2020). Korkmaz et al., (2017) and Tonbuloğlu and Tonbuloğlu (2019) also agreed that collaboration is a factor that influences CT skills. Collaboration in CT, particularly unplugged activities, enables students to pose questions to their peers, set them in motion, and provide them instructions to achieve objective, and to learn how to make comparable efforts to execute a computer process (Curzon, 2014). Peer collaboration becomes an effective form of scaffolding for enhancing the learning efficacy of individuals.

Scratch is a programming software used in the plugged-in activities offered in the CThink4CS² Module. The use of Scratch in the activity of designing digital games pertaining to the topic of Salt enhanced the students' CT skills. This result is consistent with studies conducted by Gillott et al. (2020), Helsa et al. (2023), Mouza et al. (2020), and Weintrop and Wilensky (2017). When students use Scratch by dragging and dropping blocks in accordance with Scratch algorithm, they can develop algorithmic reasoning (Bučková & Dostál, 2019; Da Cruz Alves et al., 2019; Gillott et al., 2020; Lockwood & Mooney, 2018; Mouza et al., 2020) as the arrangement of the blocks indicates the flow of the program. Furthermore, Scratch is the ideal programming language for teaching students about basic coding and CT skills. According to Grover and Pea (2013), there is an important correlation between computer technology and programming. Enhancing students' CT skills through the use of computer technology can help students adapt to the rapid advancement of information and computer technology in society (Hsu et al., 2018). This approach is perfect for use in classrooms with today's digital native students.

The implementation of learning through design strategy, namely utilizing EDP, demonstrated significant enhancement in the development of CT abilities among students. The process of learning through design included critical and creative thinking skills effectively through involvement in the task of designing various artifacts featured in the CThink4CS² Module. EDP actively engages in the use of critical thinking skills and creativity by providing explanations, establishing associations, questioning information, offering justifications, problem-solving, creating generalizations, and developing persuasive arguments to influence others. This discovery is in line with the research conducted by Sen et al. (2021) on robot and model development, and Tarrés-Puertas et al. (2022) on the Qui-Bot H2O project. Furthermore, EDP instructs students to design artifacts in an orderly, systematic manner to generate meaningful learning (Douglas et al., 2018; Jeng et al., 2020; Kaloti-Hallak et al., 2019; Long et al., 2020; Moore et al., 2014).

The CThink4CS² Module revealed no significant gender-based differences between male and female students. The reason may be because the CThink4CS² Module activities were designed to foster collaboration between male and female students. Similar results were also reported by Ardito et al. (2020) on the correlation between gender disparities in collaborative attitudes towards CT. Thus, it was evidenced that the activities in this module were appropriate for individuals of all genders. Integration of inquiry-based CT and EDP concepts and the combination of unplugged and plugged-in activities succeeded in bridging the gender gap in CT skills. The application of this module can also narrow the competence gap between males and females in CT. In addition, the studies of Chongo et al. (2020) and Sirakaya (2020) found that gender factor did not affect the CT skills of male and female students. These results are in line with Sustainable Development Goal SDG 5 on gender equality in science, technology, and innovation (United Nations Educational Scientific and Cultural Organization [UNESCO], 2020).

Conclusion

The results of the data analysis indicated that there was a substantial main impact of group when conducting a comparison between the treatment group and control group. Descriptively, it can be observed that the treatment group, which involved the CThink4CS² Module intervention, exhibited better results compared to the control group subjected to conventional instruction on the topic of Salt. It was evidenced that the CThink4CS² Module was a better option for incorporating the teaching and learning of chemistry, specifically for the topic of Salt, with the aim of enhancing CT skills. As proposed by Chongo et al. (2020), it is recommended that the integration of CT into the domain of pure science for the purpose of methodical problem-solving should also be acknowledged. The CThink4CS² module integrated the concepts of CT and EDP by utilizing both unplugged and plugged-in activities to facilitate the designing of desired artifacts. The cultivation of an interactive and learner-centric educational setting additionally promotes the development of collaborative, communicative, and both creative and critical thinking proficiencies.

Additionally, this study also discovered that the CThink4CS² Module did not exhibit a significant disparity in the primary impact of gender on CT skills. This demonstrated that the methods of instruction employed in the CThink4CS² Module effectively reduced the disparity in CT abilities between male and female students. Thus, it can be inferred that the CThink4CS[2] Module demonstrated suitability for implementation among both male and female student populations. This study also addresses the key knowledge gap pertaining to the disparity in CT skills among male and female students, examining multiple dimensions based on the studies of Korkmaz and Bai (2019), Israel-Fishelson et al. (2021) and Ardito et al. (2020). Through the CThink4CS[2] Module, male and female students experienced equal learning opportunities and demonstrated competitive performance.

Recommendations

This study suggests assessing the CThink4CS[2] Module based on student performance in chemistry subjects in addition to CT skills. Learning strategy can also be evaluated from an affective standpoint based on students' attitudes towards CT and chemistry. Further investigation is warranted to explore the perspectives of K-12 students and teachers in rural locations with regard to the integration of CT and EDP, taking into consideration the facilities and constraints they encounter. Future research should also investigate K-12 students' perspectives regarding the use of an integrated CT-EDP approach towards CT dispositions.

Limitations

This study has certain limitations. The activities of CThink4CS[2] Module, including the task of designing artifacts, were quite time-consuming. After classroom hours, students were required to spend time in design-related activities. The use of the school's computers and internet was restricted to class time, and the instability of the school's internet connection occasionally distracted students from completing their assignments.

Ethics Statements

The studies involving human participants were reviewed and approved by the Universiti Kebangsaan Malaysia. The participants provided their written informed consent to participate in this study.

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Authorship Contribution Statement

Abdul Samad: Conceptualization, design, data acquisition, data analysis and interpretation, writing. Osman: Editing/reviewing, drafting manuscript supervision, final approval. Nayan: Supervision, critical revision of manuscript.

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