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Research Article

Fostering creative thinking skills through digital storytelling

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Mastering creative thinking skills (CTS) is crucial for enhancing students' science conceptual understanding. However, conventional teaching prioritizes linear thinking over the three sub-CTS essential to science learning: associative, visual, and divergent thinking. Weaknesses in these three sub-CTS cause students to have misconceptions, difficulty in creating mental images, and an inability to generate ideas on abstract scientific concepts. The aim of this study is to evaluate the effectiveness of the Digital Storytelling Science Creative (DSSC) module in enhancing these three sub-CTS, based on the topic of acids and bases. The ASSURE instructional design model guided the DSSC module design and development process. This quasi-experimental design study involved 63 eighth-grade students. Analysis of two-way MANCOVA using the data collected through the administered Creative Thinking Skills Test revealed that the DSSC module group performed significantly better than the control group in divergent thinking. However, the DSSC module did not significantly affect students' associative and visual thinking or gender.

Keywords: Acids and bases; Creative thinking skills; Digital storytelling; Science education

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1. Introduction

The need to cultivate creative thinking skills among school students has become increasingly pressing due to the reliance on innovative scientific ideas (OECD, 2022). Furthermore, psychologists and educators concur that creative thinking skills correlate with enhanced problem-solving abilities and academic achievement (Akpur, 2020; OECD, 2022). Creative thinking skills (CTS) are specific mental abilities that enable the generation of unique and valuable ideas to solve problems through imagination (He, 2017; Ramalingam et al., 2020). Research suggests that training can enhance CTS development (Daud et al., 2012; Larraz-Rábanos, 2021; Ritter et al., 2020). However, conventional teaching methods such as direct instruction focus solely on the principles of linear thinking (Ertmer & Newby, 2013; He, 2017). This approach emphasizes responding to questions and relying on memorization of facts rather than fostering imaginative and generative thought (Igbojinwaekwu, 2016).

In science learning, Suyundikova et al. (2021) identified three essential sub-CTS that support a scientific conceptual understanding: 1) associative; 2) visual; and 3) divergent thinking. According

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to Beaty et al. (2021), associative thinking is the cognitive ability to naturally link concepts together, resulting in the formation of new ideas. Engaging students in interventions promoting close association, such as activities linking new scientific information with their existing experiences, can deepen their understanding of scientific principles (Zhan et al., 2023). Conversely, a lack of stimulation in associative thinking activities has been associated with misconceptions regarding acids and bases (Mubarak & Yahdi, 2020). This misconception arises from a failure to grasp the practical significance of scientific concepts in real-world contexts (Ivanoska & Stojanovska, 2021).

Visual thinking is a crucial cognitive skill in learning science, enabling learners to visualize abstract scientific concepts that may be difficult to grasp through text alone (Trevisan et al., 2019). This process involves creating detailed mental images of any desired objects, scenes, or experiences (Kosslyn, 2005). Engaging students with macroscopic images, such as models, has been shown to assist them in mentally conceptualizing the structure of an atom, thereby rendering these concepts more concrete and comprehensible (Ping et al., 2022). Nonetheless, deficiencies in visual thinking-based activities have hindered students' ability to create mental images related to abstract scientific concepts such as acids and bases (Sesen & Tarhan, 2011). Consequently, students struggle to visualize the concept (Koopman, 2017).

Divergent thinking is a cognitive process utilized to generate creative ideas by considering multiple possible solutions. It often occurs spontaneously and without constraints, resulting in the generation of numerous ideas (Guilford, 1956). Divergent thinking activities such as brainstorming allow students to freely generate ideas related to scientific concepts (Sun et al., 2022). This process helps students build connections between different ideas, deepen their understanding of scientific principles, and explore interdisciplinary connections (Reche & Perfectti, 2020). The lack of emphasis on activities in fostering divergent thinking has caused students to find it difficult to generate ideas related to the acids and bases topic that has been studied (Sesen & Tarhan, 2011). This arises from the students lacking not only the capability to make meaningful connections with initial ideas but also the ideas themselves (Acar & Runco, 2014; Beaty et al., 2021; Benedek et al., 2012; Forthmann et al., 2016).

In summary, weaknesses in these three sub-CTS contribute to students' perception that learning science is difficult. Regarding demographics, Yang and Zhao (2021) reported different CTS levels depending on gender, with female students performing 66% better than males, at 34% (de Cássia Nakano et al., 2021). Gender-based differences are apparent, particularly at higher levels of divergent and associative thinking among female students (Dikici et al., 2020; Hirnstein et al., 2023). Thus, the issues with these three sub-CTS and the gender-based disparities in CTS levels indicate that educators require specialized instruction, such as modular instruction, to enhance the three sub-CTS among students in the topic of acids and bases.

1.1. Impact of Digital Storytelling on Three Sub-Creative Thinking Skills and Gender

Previous research suggests that digital storytelling (DST) contributes to the enhancement of students' creative thinking skills (CTS) and comprehension of complex concepts (Anderson et al., 2018; Coventry, 2008). In developing associative thinking, tasks such as writing a story related to a mission to occupy the planet Mars have stimulated students to relate scientific knowledge to support for story ideas (Smyrnaiou et al., 2020). For instance, students tend to associate their storytelling with scientific ideas related to planet size, light brightness, and gravity.

Regarding the development of visual thinking, Yilmaz and Goktas (2017) stated that the more descriptions are used in a story, the more imaginative processes are involved in the production of creative ideas. In academic settings, students engage in the imagination process when considering problem-solving strategies and the consequences of each solution (Duveskog et al., 2012). Moreover, imagination is involved in representing ideas through visual representations, such as pictures, in DST video creation (Rosly et al., 2016).

From another stand point, Crăciun et al. (2016) stated that DST helps enhance students' divergent thinking in terms of idea flexibility (different categories of ideas) and elaboration by giving them the opportunity to express their ideas in various ways. For instance, the production of stories improved when students tried to describe in detail each scene in the script, making their story idea engaging and simple to understand (Crăciun et al., 2016; Sheafer, 2017).

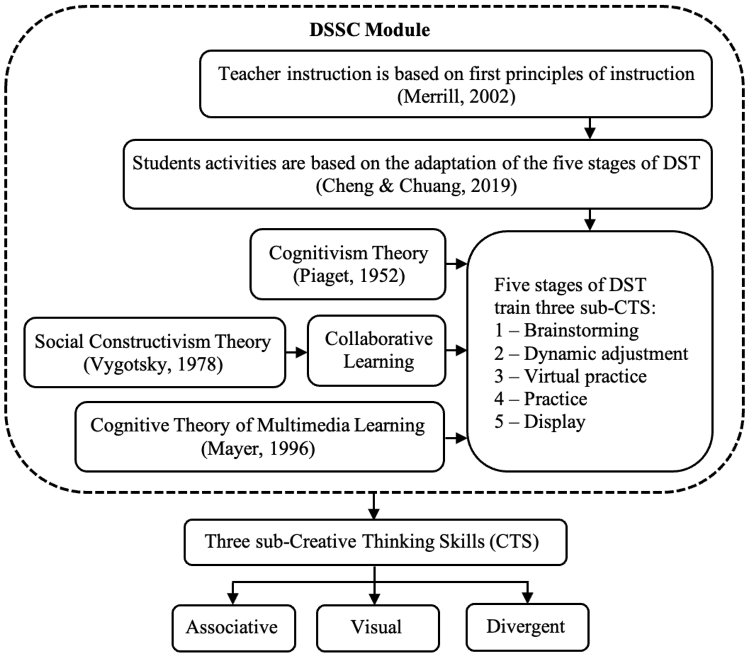
With respect to gender, verbal activity in DST provides balanced opportunities for male and female students to express ideas and helps the students get better grades in their studies (Hwang et al., 2014). For instance, the dominance of male students, who are free to express themselves verbally, has helped them to achieve higher test scores (Susanti & Ramdani, 2022). Likewise, for female students, situations where opportunities to express ideas are discussed in a story led to meaningful improvement in emotional intelligence, which aided their learning (Zarifsanaiey et al., 2022). Additionally, engagement in multimedia instruction also increases male and female students' academic achievement through supported visual learning needs (Ercan, 2014).

Hence, through a combination of digital media and storytelling activities in DST, it is hypothesized that DST can enhance three sub-CTS - namely associative, visual, and divergent thinking - and help bridge the achievement disparity between students of different genders.

1.2. Conceptual Framework of the DSSC Module

To establish the scholarly foundation of the research and to ensure the studied phenomena are understood, learning theories were used to support the study. Figure 1 depicts the conceptual framework of the Digital Storytelling Science Creative (DSSC) module.

Figure 1
Conceptual framework of the DSSC module (Source: Authors)



In Figure 1, Merrill's first principles of instruction guided the teacher's lesson planning to deliver the learning objectives in the DSSC module (Merrill, 2002). This instructional model aids students, especially those new to a concept, in understanding through demonstrations before they tackle the assigned tasks (Kirschner et al., 2006).

When student learning activities are being undertaken, the DSSC module employs the training mechanism of the three sub-creative thinking skills simultaneously across the five stages of digital storytelling. These stages involve individual cognitive interaction, stimulating cognition through the receipt of new knowledge, and recalling information (Akpan & Kennedy, 2020; Piaget, 1952). To facilitate the incorporation of new knowledge into pre-existing cognitive structures (schemes), the module emphasizes activities involving write-ups of a complete story by comprising two plots related to, in this case, firstly, the theoretical concepts in the acids and bases topic and, secondly, daily situations with which students would be familiar.

Additionally, the DSSC module incorporates social interaction among students through collaborative learning. This approach aims to foster idea proliferation through the formation of heterogeneous groups of students with diverse achievements, which creates scaffolding in the different levels of prior knowledge and addresses weaknesses in associative thinking (Cheng & Chuang, 2019; Hsu et al., 2014; Liang & Chang, 2014; Vygotsky, 1978). From a gender-social perspective, each group includes both females and males to ensure balanced discussion dialogues (Robertson, 2012).

The activities in the DSSC module involve text and video images, stimulating both auditory and visual senses in each of the five DST activity levels. Therefore, this utilizes the two-channel concept in the Cognitive Theory of Multimedia Learning developed by Moreno and Mayer (1999). Mayer suggested that to reduce cognitive load and improve learning, multimedia presentations should add relevant and engaging words, pictures, and sound while eliminating unnecessary words or redundant points.

Based on the conceptual framework presented in Figure 1, this study developed the following research questions: 1) Do the levels of mastery of the three sub-CTS differ between the students in the DSSC module group and those in the control group? 2) Do the levels of mastery of the three sub-CTS differ between the students in the DSSC module group and those in the control group based on gender? Accordingly, the following null hypotheses were formulated:

H_{01}: There is no significant main effect of the DSSC module group and the control group on the mean post-test scores for mastery of three sub-CTS.

H_{02}: There is no significant main effect of gender on the post-test scores for mastery of the three sub-CTS.

2. Methodology

2.1. Research Design

This research implemented a non-equivalent control group pre-test and post-test quasi-experimental design. The term "non-equivalent" means that the experimental and control groups are not equivalent because the distribution of individual samples is not done randomly (Campbell & Stanley, 1963). However, the random assignment was conducted by allocating intact classes of students to the experimental and control groups, while individual equivalence was achieved through pre-test matching (Cohen et al., 2018). This was necessary because the school students were pre-assigned by the school administration to existing classes based on their skills and abilities, and these assignments could not be changed. A pre-test was conducted to ensure homogeneity between the two groups in terms of existing knowledge on the topic of acids and bases. The results of the two-way analysis of variance (ANOVA) of the pre-test scores indicated no significant difference in prior knowledge between either group ($F(1,59) = 2.32$, $p = .13$) or between the genders ($F(1,59) = .60$, $p = .80$), with $p > .05$. The obtained results show that the initial achievement levels of students before treatment are homogeneous across the group and genders.

2.2. Research Sample

Two public high schools in Hulu Selangor, Malaysia were selected randomly to be involved in this study based on their pre-test achievement. A total of 63 eighth-grade students participated, all of whom were 14 years old. The treatment group underwent the DSSC module and contained 31 participants, comprising 11 males (35%) and 20 females (65%). Meanwhile, the control group received conventional teaching methods and consisted of 32 participants, 10 males (31%) and 22 females (69%).

2.3. Instrument

The creative thinking skills test (CTST) was used in this study to measure the three sub-creative thinking skills of the students: associative, visual, and divergent thinking. The CTST tests students' comprehension of the properties of acids and bases as well as neutralization. It comprises three subsections that contain 18 subjective questions worth a total of 50 marks. The first subsection measures associative thinking and consists of 8 questions related to the task of giving answers to three stimulus words based on the adaptation of the Remote Associates Test by Mednick (1962). The second subsection consists of 2 questions for the drawing task, aimed at measuring visual thinking based on three indicators: vividness, originality, and transformative qualities, adapted from the Test of Creative Imagery Abilities by Jankowska and Karwowski (2015). The third subsection consists of 8 structured open-ended questions based on four indicators: fluency, flexibility, originality, and elaboration, adapted from Torrance Tests of Creative Thinking (Torrance, 1979). Both pre-post CTST had similar questions regarding Bloom's taxonomy level and the concepts tested.

The CTST was content-validated by five experts and piloted for reliability with 34 high school students. The content validity of the CTST was assessed using the content validity index (CVI), ensuring that the measurement instrument truly represents the content domain it intends to measure (Polit & Beck, 2006). The CVI was calculated as .83, exceeding the minimum value of .80 for accepted items (Davis, 1992). This scale-level CVI indicates the percentage of items deemed content-valid for subsections by experts.

Reliability was measured using the Intraclass Correlation Coefficient (ICC), whereby three science teachers were appointed as evaluators of all the subjective CTST questions answered by the 34 students. The obtained ICC value is .99, indicates excellent interrater reliability (Koo & Li, 2015), with the score being $F(33,66) = 1263.83$, $p <.05$. This value was determined using a two-way mixed model.

2.4. DSSC Module Activities and Students' Work

To facilitate the design and development of the DSSC module, the authors utilized the ASSURE model as a guiding framework. This model consists of six steps for effectively integrating media and technology into instructional planning and implementation procedures (Heinich et al., 2002). The DSSC module underwent content validity assessment through the judgment of three experts using a questionnaire. The content validity index (CVI) value for the DSSC module was .97, exceeding the minimum CVI value of accepted items, .80 (Davis, 1992). All the activities designed in the DSSC module were deemed appropriate and recorded a high degree of expert agreement, 90%.

The five stages of activities in the DSSC module were intended to intervene in and address the problem that students have difficulty in learning the concept of acids and bases. Therefore, the focus was on the skill process of associating this concept with everyday phenomena, using visual stimuli such as pictures and storytelling to trigger idea generation among the students. Each group taking the DSSC module completed the production of digital storytelling using the worksheets shown in Figure 2.

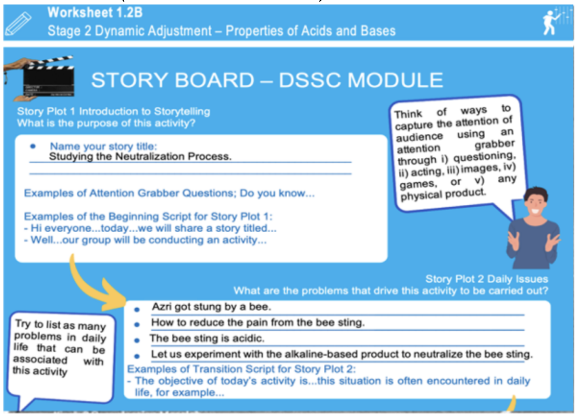
2.4.1. Stage one: Brainstorming

Figure 2a shows an example of the brainstorming activity that trains students in preliminary DST skills, specifically by having them write a science story by combining the plots of two stories into a single complete storyline. Integrating these story plots emphasizes the relationship between scientific concepts and everyday situations. Students first examined pictures representing everyday situations or materials, after which they produced a story linking these situations to the concept of acids and bases by completing the DSSC module worksheet.

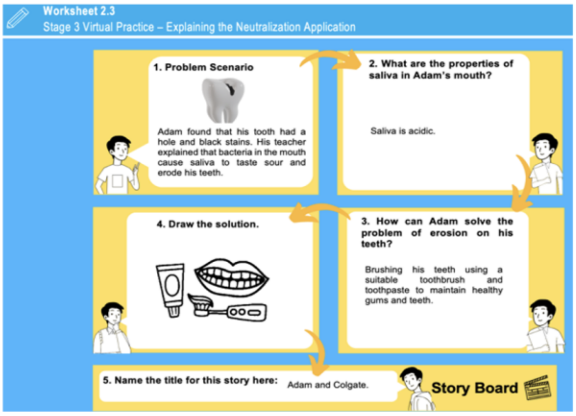
Figure 2

Examples of DSSC module worksheets completed by students (Source: Authors)

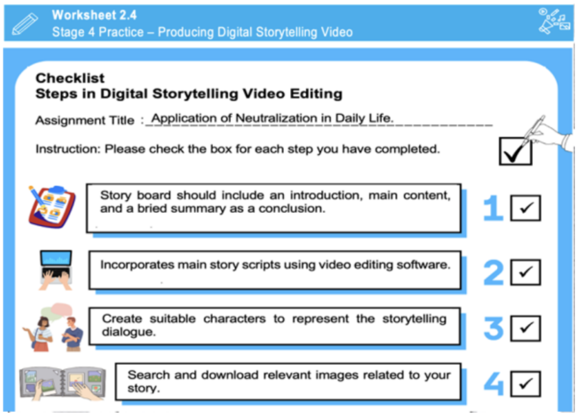
a) Stage 1 Brainstorming



b) Stage 2 Dynamic adjustment



c) Stage 3 Virtual practice



d) Stage 4 Practice

2.4.3. Stage three: Virtual practice

Figure 2c depicts the virtual practice stage activity, in which students solve daily life problems by explaining the solution in story format. During this activity, the students expressed their views on and demonstrated their understanding of acids and bases by compiling stories to apply their scientific knowledge to problem-solving. In addition to arranging the story, the students also created concrete mental images of the acids and bases concept through visual representation sketches or drawings of suggested solutions, thus completing the storyboard.

2.4.4. Stage four: Practice

Figure 2d illustrates the activity in the practice stage, in which students produce a digital storytelling video based on the topic provided in the DSSC module. This activity involves creating a video using pictorial representations and editing software. The DST video-editing process is guided by a checklist provided in the DSSC module, which was designed based on elements of digital storytelling (Robin, 2016). In this stage, students select and collect materials to convey the story clearly, combining graphics, text, background sound recordings, animation, and music to generate storytelling ideas.

2.4.5. Stage five: Display

The last stage of activities in the DSSC module is display, in which the students' DST videos are showcased to classmates and teachers. Subsequently, classmates use a scoring rubric to assess the content of the DST videos produced by each group. The objective of this evaluation was to ascertain the degree to which the students' comprehension corresponds with the acquired knowledge of acids and bases concepts. An example of the student's final product, a DST comic dialogue, is shown in Figure 3.

Figure 3
Stage five display (Source: Authors)

a) Students watching their DST work b) The example of DST video displayed

2.5. Research Procedure

The research was conducted during scheduled Science classes within the regular school timetable, in accordance with the curriculum outlined for the academic year. The students underwent the module for 60 minutes three times a week for six consecutive weeks. While the treatment group engaged with the DSSC module to learn about acids and bases, the control group received conventional direct instruction. Following approval from the ethics committee, the researcher organized a session to brief class instructors on the study involving both groups. Specifically for the treatment group, a briefing on DSSC module activities and implementation was provided. Two experienced science teachers, one male and one female, each with 16 and 12 years of teaching experience, respectively, were chosen to facilitate the research process. The creative thinking skills test (CTST) was administered twice: once before the instructional intervention (pre-test) and again after the completion of the six-week teaching and learning sessions (post-test) for both the treatment and control groups.

2.6. Data Analysis

Before running the data analysis, CTST instruments were scored by three assigned science teachers using the provided scoring schemes. Subsequently, total correct scores were converted to percentages. Data analysis involved descriptive and inferential analysis using the Statistical Package for Social Science (SPSS) version 29 software. Notably, no missing data were identified. The effectiveness of the DSSC module on students' creative thinking skills was assessed through a two-way multivariate analysis of covariance (MANCOVA). The assumptions specific to MANCOVA were evaluated and met: multivariate normality was assumed, outliers were absent, variances were homogeneous, linear relationships between variables were established, no singularity (indicating multicollinearity) was detected, and homogeneity of variance-covariance was non-significant. To test hypotheses, Wilk's Lambda and p-values were utilized (Elliott & Woodward, 2015).

3. Results

3.1. Descriptive Analysis

The data analysis in this study begins with the presentation of descriptive statistics, including mean (M) and standard deviation (SD) values, as illustrated in Table 1.

Table 1
Descriptive statistics for three sub-CTS based on group and gender

Groups	*N*	*Post-test of three sub-CTS*					
		Associative		*Visual*		*Divergent*	
		M	*SD*	*M*	*SD*	*M*	*SD*
DSSC Module (Treatment)							
Male	11	75.18	13.08	77.91	9.64	70.45	7.16
Female	20	66.15	18.55	80.80	10.86	67.05	21.05
Total	31	69.35	17.15	79.77	10.38	68.26	17.34
Conventional Teaching (Control)							
Male	10	68.80	11.78	80.60	7.20	44.10	16.33
Female	22	68.68	11.44	84.41	9.40	55.18	16.56
Total	32	68.72	11.36	83.22	8.84	51.72	17.04

Note. N = Number of samples.

3.1.1. Comparison of mean scores for three sub-CTS based on group

Table 1 shows a comparison of the mean scores for associative thinking based on the groups. The descriptive analysis of these scores reveals that the mean score of the treatment group (M = 69.35, SD = 17.15) surpassed that of the control group (M = 68.72, SD = 11.36). In this associative thinking task, students in the DSSC module demonstrate a better ability to connect their learning of acids and bases properties by accurately naming materials closely related to the three stimulus words in the test question. Furthermore, the treatment group also obtained a higher mean score for the divergent thinking (M = 68.26, SD = 17.34) than the control group (M = 51.72, SD = 17.04). This indicates that students who underwent the DSSC module performed better in generating the correct number neutralization equations (fluency), listing the uses of neutralization in daily life across different categories (flexibility), suggesting unique applications of acids and bases (originality), and providing detailed explanations about the properties and applications of acids and bases (elaboration).

However, the mean score for visual thinking was lower for the treatment group (M = 79.77, SD = 10.38) compared to the control group (M = 83.22, SD = 8.84). In this visual thinking task, although there was an improvement in post-test scores for students in the DSSC module, they performed less effectively compared to the control group in drawing two experiment diagrams: one illustrating neutralization and the other illustrating the determination of acidity or alkalinity of a substance.

3.1.2. Comparison of mean scores for three sub-CTS based on gender

Comparing the differences in mean scores based on gender within each group, males in the treatment group scored higher in associative thinking (M = 75.18, SD = 13.08) and divergent thinking (M = 70.45, SD = 7.16), while females scored higher in visual thinking (M = 80.80, SD = 10.86). In the control group, females scored higher in all three sub-CTS, although the differences are not substantial.

Comparing the differences in mean scores based on gender across different groups, male students in the treatment group obtained a higher mean score for associative thinking (M = 75.18, SD = 13.08) than male students in the control group (M = 68.80, SD = 11.78). Similarly, the mean score for divergent thinking of male students in the treatment group (M = 70.45, SD = 7.16) was higher than that of male students in the control group (M = 44.10, SD = 16.33). However, the mean score for visual thinking of male students in the treatment group (M = 77.91, SD = 9.64) was lower than that of male students in the control group (M = 80.60, SD = 7.20). Meanwhile, a comparison of the different groups indicates that the mean score for divergent thinking for female students in the treatment group (M = 67.05, SD = 21.05) was higher than that of females in the control group (M = 55.18, SD = 16.56).

3.2. Inferential Analysis

To determine whether null hypotheses were rejected or accepted, inferential analysis was carried out. The inferential statistics are presented based on the two-way MANCOVA results, as shown in Table 2.

Table 2
Analysis of two-way MANCOVA on three sub-CTS

Effect	*Dependent Variables*	*Sum Squared*	*df*	*Mean Squared*	*F*	*p*	*Partial Eta Squared* (η^2)
Group	Associative	190.18	1	190.18	1.23	.27	.02
	Visual	104.99	1	104.99	1.18	.28	.02
	Divergent	5299.89	1	5299.89	25.46	.00*	.31
Gender	Associative	66.06	1	66.06	0.43	.52	.01
	Visual	159.27	1	159.27	1.785	.19	.03
	Divergent	588.72	1	588.72	2.828	.09	.05
Group*Gender	Associative	1.66	1	1.66	0.01	.92	.00
	Visual	10.63	1	10.63	0.12	.73	.00
	Divergent	56.63	1	56.63	0.27	.60	.01

Note. *Significance level, $p < .05$

3.2.1. The effect on three sub-CTS based on group

Referring to the first null hypothesis of this study, H_{01}: there is no significant main effect of the DSSC module group and the control group on the mean post-test scores for mastery of three sub-CTS. The MANCOVA results indicate that the division into groups had a significant main effect on the difference in the divergent thinking levels, obtaining a value of $p < .05$, which is $F(1,62) = 25.46$, $p = .00$, partial $\eta^2 = .31$ (Table 2). This corresponds to a large effect size of .31 according to Cohen's (1988) guidelines. However, the main effect of the group was not significant in terms of the difference in the levels of associative thinking, obtaining a value of $p > .05$, which is $F(1,62) = 1.23$, $p = .27$ and a partial $\eta^2 = .02$ effect size value that was small (Cohen, 1988). Similarly, the main effect of the group was not significant in terms of the difference in the levels of visual thinking, obtaining a value of $p > .05$, which is $F(1,62) = 1.18$, $p = .28$ and a partial $\eta^2 = .02$ effect size value that was small (Cohen, 1988).

Further investigation was undertaken on whether the main effect of the group was significant in terms of the difference in the degree of divergent thinking. Therefore, the analysis continued by evaluating the post-hoc comparison for three sub-CTS between the treatment group and the control to determine which group was more effective. Adjustment was made for multiple comparisons using analysis of the Bonferroni confidence intervals at a significance level of .05, as shown in Table 3.

Table 3
Post-hoc comparison for three sub-CTS between groups

Three sub-CTS	*Comparison of groups*	*Mean Difference*	*p*	*95% Confidence Interval*	
				Lower bound	*Upper bound*
Associative	Treatment - Control	4.29	.27	−3.46	12.05
Visual	Treatment - Control	−3.19	.28	−9.09	2.70
Divergent	Treatment - Control	22.69	.00*	13.68	31.69

Note. *Significance level, $p < .05$

Table 3 reveals a significant difference in the mean scores for divergent thinking between the treatment and the control groups ($p < .05$, $p = .00$). The substantial difference in means was 22.69, with a 95% confidence interval ranging from 13.68 to 31.69. The difference between the mean values illustrates that the treatment group had a significantly higher mean score than the control group in terms of the increase in the divergent thinking post-test mean scores.

3.2.2. The effect on three sub-CTS based on gender

For the second null hypothesis of this study, H_{02}: there is no significant main effect of gender on the post-test scores for mastery of the three sub-CTS. Table 2 indicates that the effect of the DSSC module on all three sub-CTS was not significantly different based on gender, with all the p-values obtained being p >.05. However, there was a relatively small effect size, with partial η^2 ranging from .01 to .05 (Cohen, 1988). Additionally, it is worth noting that no significant interaction effects between group and gender were observed across any of the sub-CTS. This implies that the results obtained were not influenced by the specific test group.

4. Discussion

4.1. The Effect of the DSSC Module on Three Sub-CTS Based on Group

Our results demonstrate a significant improvement in divergent thinking among students who underwent the DSSC module compared to those who experienced conventional teaching. This improvement was evident in the post-test through four indicators 1) fluency - total number of ideas, 2) flexibility - different categories of ideas, 3) originality - ideas that differ from the majority of ideas, and 4) elaboration - details of an idea. Students' enhancement in divergent thinking is a result of the opportunity given to them to generate ideas related to the acids and bases topic in various ways through digital stories (Coventry, 2008). This arose from the students' abilities to make meaningful connections with ideas, in which they had been trained using the worksheet provided in the DSSC module. On the other hand, the differences between the associative thinking achievements were not statistically significant; nevertheless, students following the DSSC module achieved greater improvements, with their mean score surpassing the conventional teaching group (Table 1). This slight improvement in associative thinking was influenced by recommendations from previous research advocating for a team-based collaborative approach to address weaknesses in associative thinking (Cheng & Chuang, 2019).

The primary objective of our study is to extend prior research by focusing on improving three sub-components of creative thinking skills (CTS): associative, visual, and divergent, utilizing digital storytelling as a pedagogical tool (Coppi, 2016). However, contrary to expectations, the participation of students in the DSSC module did not significantly improve outcomes in visual thinking compared to conventional teaching methods, despite incremental improvement in post-test scores from pre-test assessments. This suggests shortcomings in implementing the DSSC module, notably insufficient attention from students during stage four practice activities. In this stage, students' self-regulation plays a crucial role in helping them focus on translating planned story plots with related visual representation into video content. These aspects have been stressed by previous literature suggesting that attention significantly impacts visual processes and the accurate assessment of visual comprehension (Hetley et al., 2014).

Therefore, it is crucial to emphasize students' attention by reminding them of learning objectives and assessment criteria to minimize the formation of unrelated mental images (Schmoelz, 2018; Silseth, 2013). To address these challenges, Nunvarova et al. (2023) propose clear explanations by teachers about the assessment criteria for acids and bases learning outcomes, emphasizing the initial stages of digital story production to facilitate comprehension of abstract concepts.

4.2. The Effect of the DSSC Module on Three Sub-CTS Based on Gender

As can be seen from the Table 2, no significant difference was found in the post-test results for all three sub-CTS based on gender when comparing the students following the DSSC module with those experiencing a conventional teaching method. This result shows the existence of differences in gender mastery in creativity based on three sub-CTS despite the usage of digital storytelling in the form of specialized modular instruction. There is consistent evidence from past research showing the gender inequality in creativity mastery, favoring female superiority (Baer & Kaufman, 2008; Kim & Michael, 1995; Piaw, 2014; Ulger & Morsunbul, 2016). Bart et al. (2015) further elaborate that female high school students perform better in verbal tests assessing divergent thinking, while males perform better in visual tests. However, based on the descriptive statistics shown in Table 1, improvements in the mean scores for performance based on gender were evident in the DSSC module group, with males scoring higher in divergent and associative thinking while females scoring higher in visual thinking. This contrasts with the groups following conventional teaching, in which females scored higher in all three sub-CTS.

These results indicate that the DSSC module specifically contributes to improving divergent thinking skills in male students, a trend previously noted to be at a lower level by scholars (Dikici et al., 2020; Hirnstein et al., 2023). In this study, male students showed improvements in divergent thinking, with an increased number of correct responses and a better ability to explain various applications related to concepts of acids and bases. Prior research has pointed out positive outcomes in divergent thinking associated with activities such as script writing (Lashari et al., 2022) and the utilization of story mapping (Groshans et al., 2019). On top of that, the enhancement of divergent thinking is facilitated by a collaborative approach to digital storytelling, which has proven effective in fostering the exchange and generation of ideas among students (Smeda et al., 2014).

Meanwhile, comparing the different groups indicates that the mean score for divergent thinking for female students in the DSSC module group was higher than that of females in the conventional teaching group. Additionally, a comparison of the mean scores of male students in the DSSC module and those in the conventional teaching group reveals that the former obtained higher mean scores for associative and divergent thinking. This implies that the significant result obtained for divergent thinking mainly affected both male and female students in the DSSC module group, rather than those in the conventional teaching group.

Previous research on the difference in mastery between genders on three components of sub-CTS remains unclear due to a lack of explanation on the effect of teaching methods on these three skills. Therefore, our research findings contribute to the body of knowledge by emphasizing how verbal activities integrated with multimedia using digital storytelling influence the mastery of divergent thinking, considering gender differences. A neuroimaging study conducted by Boccia et al. (2015) shows that engagement in verbal creativity activity activates the left hemisphere of the brain, which is also responsible for divergent thinking (Palmiero et al., 2012).

The insignificant result obtained in this study regarding gender equality across three sub-CTS could be attributed to mixed-gender groupings with an imbalance of male and female distribution in the collaborative groups. Gender equality in three sub-CTS could be further improved by considering gender-based assignment settings, as proposed by Feng et al. (2023). Firstly, it is noted that male students often have weaker communication skills compared to females in collaborative settings. Hence, it is suggested that all male groups receive extra support from teachers to aid male students. Secondly, when there is an uneven gender distribution in a class, it is advised to prioritize same-gender groups over mixed ones. This can foster better social dynamics and communication. Thirdly, teachers should monitor students who tend to coast without active participation. Lastly, in mixed-gender groups with unequal representation, selecting a leader from the underrepresented gender can encourage inclusivity and fair participation. These measures aim to create an environment where all students can thrive collaboratively.

5. Conclusion and Recommendation

The digital storytelling science creative (DSSC) module was designed to improve students' understanding of acids and bases by fostering three sub-skills of creative thinking. Throughout the module, students participated in a collaborative digital storytelling project encompassing five stages, enabling them to apply their knowledge of acids and bases. Working in groups, students utilized these concepts to create digital storytelling videos.

Our research findings indicate that using the DSSC module outperforms conventional teaching methods in supporting the comprehension of acids and bases. Notably, this approach demonstrates efficacy in fostering divergent thinking, which encompasses fluency, flexibility, originality, and elaboration, fundamental components of creative thinking skills (CTS). Previous research has concluded that divergent thinking influences academic achievement. The results of the structural equation modeling analysis by Mohtar (2019) showed that the most powerful relationship exists between divergent thinking and science subject achievement. Similarly, the indicators of divergent thinking, fluency, flexibility, and originality were used in the scientific creativity test by Hu and Adey (2002) to determine intellectual traits as a key component of science learning ability.

Therefore, considering the highlighted importance of developing divergent thinking in science learning, future researchers could build upon this finding and emphasize the other two crucial sub-components of CTS: associative and visual thinking. This could be achieved through alternative instructional strategies or modifications to the DSSC module to improve its effectiveness on all three sub-CTS components. Additionally, the findings of this study emphasize the importance of considering the composition of male and female students in group assignments in a collaborative approach, as it impacts gender-based sub-CTS achievement.

5.1. Limitations

This research provides insights into the practical application of digital storytelling in the form of modular instruction for enhancing creative thinking skills on the topic acids and bases. The module was a short intervention within the formal school syllabus and the yearly lesson planning, with additional topic time provisions adding other constrictions. The limited time consumption likely hindered the discussion between students, potentially influencing the richness of the story content, despite the opportunities they were given to browse the internet for information using the technological facilities available.

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Data availability: The data supporting the findings of this study are available upon request. Interested researchers may contact the corresponding author for access to the data.

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