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Enhancing Critical Thinking Ability and Learning Achievement through a Science, Technology, and Society (STS) Approach for Grade-10 Biology on the Topic of the Chemistry Basis of Life

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Abstract. This study aimed to 1) compare the critical thinking ability of students before and after applying the Science, Technology, and Society (STS) learning approach, and 2) compare students' academic achievement on the topic "Chemistry Basis of Life" with the 70% criterion. The sample group consisted of 40 Grade-10 students from Phadungnaree School in the first semester of the 2024 academic year, selected using cluster sampling. Research instruments included: 1) six STS-based lesson plans over 18 hours, evaluated as highly appropriate (mean scores = 4.31–4.33, S = 0.54–0.58); 2) a Critical Thinking Test comprising 12 situational scenarios with 30 multiple-choice items (difficulty = 0.40–0.73, discrimination = 0.20–0.47, reliability = 0.82); and 3) an Academic Achievement Test with 40 multiple-choice items (difficulty = 0.43–0.73, discrimination = 0.23–0.43, reliability = 0.76). Data were analyzed using mean, standard deviation, percentage, One-Sample t-test, and Normalized Gain (<g>). The results revealed that: 1) students' critical thinking ability significantly improved after STS learning, with an overall normalized gain (<g>) score of 0.58, which is considered a moderate level. When analyzing the improvement in each subskill of critical thinking, it was found that all aspects showed a moderate level of gain. The <g> descending order were as follows: comprehension (<g> = 0.66), identifying assumptions (<g> = 0.63), deductive reasoning (<g> = 0.62), evaluating arguments (<g> = 0.52), and drawing inferences (<g> = 0.49). And 2) students' academic achievement was significantly higher than the 70% criterion at the .05 significance level. The findings suggest that STS-based learning enhances both critical thinking and academic performance. It is recommended that future studies explore its integration with problem-solving, creativity, and teamwork development to support diverse learners and promote real-world application of scientific knowledge.

Keywords: Critical thinking ability; science, technology and society (STS) ; academic achievement; Chemistry as the Basis of Life

INTRODUCTION

In the context of rapid global changes, education systems must adapt to develop students with essential 21st-century skills. Thailand's 20-Year National Strategy prioritizes foundational citizenship values and the development of core competencies, including the 3Rs (Reading, Writing, and Arithmetic) and 8Cs: Critical Thinking and Problem Solving, Creativity and Innovation, Crosscultural Understanding, Collaboration and Teamwork, Communication and Media Literacy, Computing and ICT Literacy, Career and Learning Skills, and Compassion (Office of the Education Council Secretariat, Ministry of Education, 2014). Aligned with the 2024 workforce development policy, which aims to enhance adaptability and reduce unemployment, these competencies support the country's goal of improving educational quality and student potential. Science education is essential in this mission, promoting students' ability to integrate knowledge, apply learning to real-world situations, and act responsibly toward society and the environment (Lomsombut, 2017).

Critical thinking is a vital 21st-century skill, particularly amidst rapid societal and technological change. It enables students to analyze information logically, distinguish facts from opinions, assess information validity, evaluate source reliability, and make informed decisions based on data analysis. The process typically involves gathering information, asking critical questions, and evaluating potential solutions (Herrity, 2023). According to Watson and Glaser (1964), critical thinking encompasses five key aspects: Inference (judging and classifying the probability of conclusions), Recognition of Assumptions (identifying underlying assumptions), Deduction (drawing logical conclusions), Interpretation (weighing evidence to assess conclusions), and Evaluation of Arguments (distinguishing valid reasoning). These skills promote systematic analysis and support the application of thoughtful reasoning in everyday life (Facione, 2015). Moreover, critical thinking helps students synthesize information from diverse sources, leading to deeper understanding and effective application in both academic and real-world contexts (Paul and Elder, 2008).

Making connections between various elements and scientific issues and engaging in reasoned scientific argumentation requires critical thinking. According to the latest PISA (Program for International Student Assessment) results in 2022, conducted by the Organization for Economic Co-operation and Development (OECD), Thailand's average scores were 394 in mathematics, 379 in reading and 409 in science. Compared to PISA 2018, Thailand's average scores decreased in all three areas, with mathematics dropping by 25 points, and science and reading declining by 17 and 14 points, respectively. This reflects problems in Thai students' analytical thinking, critical thinking, and rational data evaluation ability. This aligns with Thailand's educational quality issues as reflected in Ordinary National Educational Test (O-NET) results. According to the National Institute of Educational Testing Service (2023), the average O-NET scores for Grade 12 students nationwide in the 2021 academic year were below 50 points in all subjects: Thai Language (44.90), Social Studies (33.00), English (23.44), Mathematics (21.61) and Science (28.08). Considering the National Institute of Educational Testing Service's assessment criteria, which sets 50-64 points satisfactory and 65 points and above as good, these results indicate that the 2021 O-NET scores for Grade 12 still require improvement and continued educational quality development.

Based on an investigation into the root causes of this issue at the school level, they stem from an education system that emphasizes memorization over analytical thinking. Students are unfamiliar with questioning, analyzing data, and reaching conclusions independently. Additionally, educational, and social environmental factors affect students' critical thinking problems. Families and communities prioritize rote learning over encouraging students to think analytically about various media. In today's environment, where genuine and false information intermingle, students lack skills in filtering information and evaluating its reliability (Office of the Basic Education Commission, 2006). Teaching methods that promote students' critical thinking abilities will make instruction more effective, enabling students to think analytically, seek knowledge, and develop their own problem-solving approaches (Soodsane, 2018). Based on the researcher’s survey, it was found that the academic achievement of Grade-10 students at Phadungnaree School in the 2023 academic year declined to 68%, which was below the expected criterion of 72% (Phadungnaree School, 2023) This decline reflects a lack of critical and analytical thinking skills, which can be attributed to several factors. These include a teaching system that emphasizes rote memorization over analysis and synthesis, as well as limited opportunities for students to practice questioning and engage in evidence-based reasoning. Consequently, students face difficulties distinguishing facts from opinions. Furthermore, the current information landscape is saturated with diverse content, including both factual and misleading information. The lack of skills in evaluating sources leads students to believe in unsupported or inaccurate information more readily. Therefore, to enhance students' critical thinking skills and address the issue of declining academic performance, it is essential to adapt teaching methods to better align with student contexts and emphasize instructional approaches that promote analytical thinking. One such approach is the Science, Technology, and Society (STS) model, which fosters learning through the integration of real-world issues with scientific and technological knowledge. In evaluating academic achievement, the researcher set the 70% threshold as the standard criterion. This decision is based on the guidelines of the Basic Education Core Curriculum B.E. 2551 (2008) and the criteria established by the National Institute of Educational Testing Service (NIETS, 2023), which classify scores in the range of 70–74% as indicative of a "good" level of learning performance. Therefore, using this criterion provides a meaningful reference to determine whether students have attained the desired learning outcomes at a satisfactory level.

The Science, Technology, and Society (STS) approach connects social issues with science and technology, promoting effective learning through real-life situations. This study follows Carin's (1997) five-stage model: 1) Search, 2) Solve, 3) Create, 4) Share, and 5) Action, which engages students by linking technology, social issues, and context, fostering deeper understanding (Yuenyong et al., 2007). STS supports Constructivist theory by helping students relate new knowledge to prior experiences, while promoting critical thinking and addressing scientific, technological, social, environmental, and ethical dimensions (Pimchan & Samranwanich, 2014; Kowtrakul, 2016). It encourages creative problem-solving, argumentation, and reflective evaluation, improving academic achievement (Mulyanti et al., 2021; Yager, 1993). Despite its widespread use to improve attitudes and performance, research on STS's impact on scientific reasoning and problem-solving at the secondary level is limited (Boesdorfer & Lorsbach, 2014). In Thailand, most STS studies focus on theory (Wattanakasiwich & Ananta, 2010). One key topic in secondary science is "The Basic Chemistry of Life," which is part of the "Substances and Their Properties" section in the Basic Education Core Curriculum B.E. 2551 (Office of the Basic Education Commission, 2008). This content, which forms the basis for understanding biological components and biochemical processes, is often difficult for students due to abstract concepts and memorization-based instruction (Yager & Akcay, 2010). Integrating STS into this topic can help students connect knowledge to real-life situations, understand social and environmental impacts, and develop critical thinking, aligning with curriculum goals and fostering 21st-century skills. This study aims to develop and assess STS-based learning activities to enhance scientific reasoning and problem-solving among Grade-10 students.

In this research, the researcher has chosen the STS (Science, Technology, and Society) Approach model based on Carin (1997) concept, aiming to study critical thinking abilities and academic achievement in Biology, specifically regarding Chemistry as the Basis of Life, among Grade-10 students. In this teaching approach, the instructor serves as a learning process facilitator and allows students' opportunities to develop critical thinking abilities, research skills, and teamwork through activities emphasizing problem-solving and developing understanding of basic Chemistry of living things found in daily life and its practical applications. This is intended to make the teaching-learning process beneficial and aligned with current and future educational needs, with potential for future educational development.

RESEARCH OBJECTIVES

1. To study critical thinking abilities before and after implementing instruction based on the Science, Technology, and Society (STS) approach.
2. To compare the learning achievement on the topic of " Chemistry as the Basis of Life" of Grade-10 students against the 70% criterion.

METHODOLOGY

The methodology section of the document describes the research design and procedures used to study the effectiveness of teaching in enhancing critical thinking abilities including the analysis of students' academic achievement compared to the 70% criteria.

Population and Sample

The study population comprised 200 Grade-10 students from five mixed-ability classrooms at Phadungnaree School, Mahasarakham, Thailand, during the first semester of the 2024 academic year. A cluster random sampling technique was employed to select a sample of 40 students, with the classroom serving as the unit of random assignment.

Research Tools

The research tools used in this study can be categorized into three types.

1. Learning Management Plan

This study was conducted in accordance with the revised Basic Education Core Curriculum B.E. 2551 (A.D. 2008), updated in 2017 (B.E. 2560), focusing on the subject Additional Science – Biology 1, specifically under the strand The Chemical Basis of Life for Grade-10 students. This content aligns with Learning Standard 1 of the Science Learning Area, which emphasizes understanding the nature of living things and life processes.

The learning management plan follows the Science, Technology, and Society (STS) approach, designed to enhance teaching and learning (Table 1). In this case study, it was developed for a biology course on "Chemistry as the Basis of Life" for Grade-10 students. The six lesson plans were implemented with a total duration of 18 hours. The learning management plan was indicated as highly appropriate with an average rating ranging ("$\bar{x}$") from 4.31 to 4.33 and standard deviation (S) between 0.54 to 0.58.

Table 1. Learning Management Plan

Plan	Content STS	hours
The Chemical Basis of Life	Understanding atoms, elements, compounds, and water is fundamental to recognizing the composition of matter and making informed choices in daily life—such as selecting safe products, consuming food, and medicine wisely, and choosing clean water. It also raises awareness of the environmental and health impacts of chemical use in agriculture, promoting responsible decision-making.	3
Carbohydrates	Carbohydrates are the body’s primary energy source, essential for supporting daily activities. Choosing slow-digesting carbohydrates and consuming them in appropriate amounts helps maintain a healthy weight and reduces the risk of chronic diseases.	3
Proteins	Protein plays a vital role in growth, cell repair, muscle development, and immune function. Consuming an adequate amount of protein promotes good health, while excessive intake may negatively affect body function.	3
Lipids	Fat plays a vital role in providing energy for the body; however, excessive intake can lead to health problems. Understanding how fat functions and accumulates in the body supports better health management, including choosing healthy fats and moderating consumption.	3
Nucleic Acids	Nucleic acids, such as DNA, play a vital role in the inheritance of genetic traits and are essential for personal health management, particularly in the prevention of genetic diseases. Understanding DNA contributes to both everyday health awareness and advancements in medical science.	3
Chemical Reactions in Living Cells and Enzymes	The study of biological processes, such as digestion and enzyme function, is crucial for understanding the factors that influence the body's efficiency. Making informed choices regarding healthy food and careful use of chemicals directly impacts personal health and helps mitigate long-term environmental effects. Awareness of these factors is essential for the well-being of individuals and society.	3

The content of this research was based on the Grade-10 Biology curriculum, under the topic "The Chemical Basis of Life," with a total of 18 instructional hours, comprising the following subtopics.

The learning management plan was based on the Science, Technology, and Society (STS) approach, following the instructional model proposed by Carin (1997: 27–28), which comprises five key steps. A series of biology lesson plans were developed under the topic "Chemistry as the Basis of Life" as follows:

- Search – Students explore their prior knowledge and express their curiosity by identifying what they want to learn. Their ideas, questions, and problems of interest are categorized to guide the learning process.
- Solve – Each group of students selects a specific question or problem they wish to investigate. They then formulate an action plan to conduct research and seek answers related to subtopics within the unit.
- Create – Students synthesize information gathered from various sources to draw conclusions and summarize the answers to their initial questions or problems. They also design methods to present their findings effectively.
- Share – Each group presents their research findings and solutions to the class. This stage involves discussion and exchange of ideas, promoting collaborative learning and reflection.
- Act – Students apply the knowledge they have acquired through practical activities both inside and outside the classroom, reinforcing learning through real-world application.

2. Critical Thinking Test (CTT)

The Critical Thinking Test (CTT) is a multiple-choice assessment tool developed to measure students' critical thinking skills based on the theoretical framework of Watson and Glaser (1964). The test consists of 30 items, equally distributed across five core dimensions of critical thinking: (1) Inference, (2) Recognition of Assumptions, (3) Deduction, (4) Interpretation, and (5) Evaluation of Arguments. Each item was constructed based on real-life situational scenarios relevant to science learning, aiming to assess students' ability to apply critical thinking in authentic contexts.

The development process began with the drafting of 40 items, each targeting three of the five specific dimensions of critical thinking. These items were then reviewed for content validity by three experts in science education and educational measurement. Revisions were made in response to expert feedback to improve clarity, appropriateness, and alignment with the test objectives. All items were assessed using the Item-Objective Congruence (IOC) method, and each received an IOC score of 1.00, indicating unanimous agreement on their relevance to the intended constructs.

Following content validation, the test was pilot tested with 30 Grade-10 students possessing similar characteristics to the target population. Item analysis was conducted to ensure psychometric quality. The difficulty index (P) ranged from 0.40 to 0.73, and the discrimination index (D) ranged from 0.20 to 0.47, both within acceptable ranges. The internal consistency reliability, calculated using the Kuder-Richardson Formula 20 (KR-20), was 0.82, indicating a high level of reliability.

3. Academic Achievement Test (AAT)

The Academic Achievement Test (AAT) is a 40-item multiple-choice assessment, with four options per item, developed to evaluate students' understanding of the biology topic "Chemistry as the Basis of Life" following the implementation of the instructional intervention. The test was constructed based on behavioral learning objectives and guided by Bloom's Taxonomy, ensuring coverage of cognitive levels ranging from knowledge to evaluation.

The test items were developed in alignment with the core curriculum content and the specified learning outcomes. Initially, a 50-item test was constructed and subjected to content validity evaluation by three experts to determine the alignment between the test items and the behavioral objectives. The Item-Objective Congruence (IOC) index ranged from 0.33 to 1.00. Items with IOC values below 0.50 were considered for elimination, resulting in the last version comprising 40 items.

Subsequently, the revised test was piloted with 30 students who possessed characteristics similar to those of the target population. The item analysis indicated that the test demonstrated acceptable quality, with difficulty indices ranging from 0.43 to 0.73 and discrimination indices ranging from

0.23 to 0.43. The reliability of the test, calculated using the Lovett Formula, was found to be 0.76, indicating a high level of internal consistency.

Data Collection

Research Design

This study employed pre-test and post-test experimental research design to measure critical thinking abilities and assess academic achievement.

Data Collection Procedures

1. Permission and Data collection: A formal request was submitted to the administration of Phadungnaree School during the first semester of the 2024 academic year to seek approval for conducting the experiment and collecting data.

2. Student Orientation: Students were informed about the instructional approach based on the STS (Science, Technology and Society) concept for the biology unit, " Chemistry as the Basis of Life."

3. A pre-test was conducted to assess the critical thinking abilities of the students.

4. The experiment was conducted using lesson plans based on the Science, Technology and Society (STS) approach in a biology course on " Chemistry as the Basis of Life ". A total of six lesson plans were implemented over 18 hours.

5. Post-tests: Upon completion of the learning units, students were administered post-tests to measure both academic achievement and critical thinking abilities.

6. Data Analysis: All collected data were analyzed using statistical methods to draw conclusions and summarize the experimental results.

Data Analysis

The researcher analyzed the data using statistical software. The following procedures were conducted.

1. Critical Thinking Abilities: Mean and standard deviation were calculated to compare the pre- and post-test scores. A normalized gain (<g>) test was employed to assess the actual increase in students' learning. The normalized gain is calculated as the ratio of the actual gain in percentage points from the pre-test to the post-test to the maximum possible gain. The normalized gain was categorized into three levels:

High gain: <g> ≥ 0.7

Moderate gain: 0.7 > <g> ≥ 0.3

Low gain: 0.0 ≤ <g> < 0.3

2. Academic Achievement: Mean, standard deviation, and percentage were calculated to describe the post-test scores in biology. A one-sample t-test was used to compare the mean post-test score to a criterion of 70%. The academic achievement scores were interpreted according to the assessment criteria shown in Table 2.

Table 2. Assessment Criteria

Score Range (%)	Indicates
80–100%	Excellent
70–79%	Good
65–69%	Fairly Good
60–64%	Satisfactory
55–59%	Moderate
50–54%	Minimum Acceptable
50–54%	Below Minimum Standard

Note. Adapted from *Guidelines for Learning Assessment and Evaluation* (pp. 22–23), by Office of the Basic Education Commission, n.d., retrieved May 10, 2025, from https://sgs.bopp-obec.info/menu/data/ระเบียบงานวัดผล.pdf.

RESULTS

The comparison of critical thinking abilities before and after learning through the Science, Technology, and Society (STS) approach of the target group both before and after the STS-based learning approach implementation were done. A 30-item multiple-choices critical thinking test evaluated five aspects: 1) The ability to summarize and infer, 2) The ability to identify preliminary agreements, 3) The ability to deduce, 4) The ability to interpret, and 5) The ability to evaluate arguments. The test average score was calculated and converted into percentages. The results indicated that all 30 students demonstrated an improvement in critical thinking abilities after participating in STS-based learning. The data were analyzed using the Normalized Gain statistic (<g>), focusing on both individual progress and the average N-gain of critical thinking abilities scores before and after the STS approach among Grade-10 students. The findings are presented in Table 3 and Table 4

Table 3. Percentage, average scores, and average N-Gain (<g>) of critical thinking abilities assessment before and after learning through the STS approach for individual grade-10 students

No.	Scores (%)		<g>	Level	No.	Scores (%)		<g>	Level
	Pretest	Posttest				Pretest	Posttest		
1	45.0	67.5	0.42	Moderate	21	47.5	65.0	0.55	Moderate
2	50.0	70.0	0.40	Moderate	22	45.0	70.0	0.83	High
3	50.0	75.0	0.75	High	23	47.5	75.0	0.55	Moderate
4	52.5	70.0	0.44	Moderate	24	42.5	60.0	0.54	Moderate
5	47.5	75.0	0.46	Moderate	25	47.5	70.0	0.82	High
6	32.5	57.5	0.51	Moderate	26	37.5	82.5	0.60	Moderate
7	50.0	72.5	0.60	Moderate	27	52.5	70.0	0.78	High
8	50.0	72.5	0.64	Moderate	28	30.0	75.0	0.66	Moderate
9	60.0	92.5	0.66	Moderate	29	35.0	70.0	0.75	High
10	50.0	85.0	0.30	Moderate	30	40.0	45.0	0.29	Low
11	50.0	85.0	0.64	Moderate	31	45.0	57.5	0.25	Low
12	47.5	75.0	0.63	Moderate	32	55.0	90.0	0.78	High
13	50.0	85.0	0.50	Moderate	33	47.5	75.0	0.55	Moderate
14	57.5	82.5	0.43	Moderate	34	37.5	55.0	0.27	Low
15	45.0	80.0	0.46	Moderate	35	32.5	80.0	0.82	High
16	52.5	80.0	0.56	Moderate	36	27.5	72.5	0.53	Moderate
17	45.0	87.5	0.73	High	37	32.5	70.0	0.65	Moderate
18	37.5	77.5	0.53	Moderate	38	35.0	80.0	0.56	Moderate
19	52.5	77.5	0.33	Moderate	39	40.0	85.0	0.78	High
20	57.5	77.5	0.63	Moderate	40	30.0	82.5	0.78	High
average Pre-test = 57.75					average Post-test = 82.50				
average n-gain			0.59		Moderate				
Number of students: 10			> 0.7		High				
Number of students: 27			≥ 0.3 ≤ 0.7		Moderate				
Number of students: 3			< 0.3		Low				

From Table 3, the analysis of pre-learning scores revealed that the students' average critical thinking ability was 57.75%. After learning through the STS approach, the average increased to 82.50%. Furthermore, the analysis of progress in critical thinking abilities using the Normalized-gain (n-gain) method showed that 10 students (25%) achieved high progress (n-gain > 0.70) with an average n-gain of 0.80, 27 students (67.5%) demonstrated moderate progress (n-gain between 0.30–0.70) with an average of 0.53, and 3 students (7.5%) showed low progress (n-gain < 0.30) with an average of 0.27.

The overall average n-gain for all Grade-10 students was 0.59, categorized as Moderate. This suggests that the STS-based learning approach facilitated notable progress in critical thinking abilities for most students, though some require additional support to further enhance their learning outcomes.

Table 4. Percentages, average scores, and average N-Gain (<g>) by component of critical thinking abilities assessment before and after learning through the STS approach

Critical Thinking Objectives by Aspect	Number of Students Who Answered Correctly (%)		Average Score ($\bar{x}$)		Average N-gain Score (<g>)	Meaning
	Pretest	Posttest	Pretest	Posttest		
The ability to 1. summarize and infer	54.58	76.67	3.28	4.60	0.49	Moderate
2. identify preliminary agreements	55.00	83.33	3.30	5.00	0.63	Moderate
3. deduce	55.42	82.92	3.33	4.96	0.62	Moderate
4. interpret	57.92	85.83	3.48	5.15	0.66	Moderate
5. evaluate arguments	65.83	83.75	3.95	5.02	0.52	Moderate
Overall	58.87	81.83	3.19	4.90	0.59	Moderate

Based on Table 4, when analyzing the scores from the critical thinking abilities assessment before and after learning, broken down by the components of critical thinking, it was found that the average scores of students improved across all components after the STS-based learning approach. The details are as follows: Component 1: Ability to Summarize and Infer. The average percentage increased from 54.58% to 76.67%, with an average n-gain score of 0.49. Component 2: Ability to Identify Preliminary Agreements. The average percentage increased from 55.00% to 83.33%, with an average n-gain score of 0.63. Component 3: Ability to Deduce. The average percentage increased from 55.42% to 85.83%, with an average n-gain score of 0.62. Component 4: Ability to Interpret The average percentage increased from 57.92% to 85.83%, with an average n-gain score of 0.66. And component 5: Ability to Evaluate Arguments The average percentage increased from 65.83% to 83.75%, with an average n-gain score of 0.52.

Comparison of Academic Achievement in Biology on the Topic of “Chemistry as the Basis of Life” using the Science, Technology, and Society (STS) approach against the 70% criterion were assessed using a 40-item multiple-choices test covering five domains: knowledge recall, understanding, application, analysis, and evaluation. The scores were analyzed using a one-sample t-test to compare the results against the 70% criterion, as shown in Table 5.

The results from Table 5, analyzed by using the one-sample t-test, revealed that the academic achievement of Grade-10 students after learning through the STS approach on the topic of "Chemistry as the Basis of Life" was significantly higher than the 70% criterion at the .05 significance level.

Table 5. Comparison of Academic Achievement After Learning Through Science, Technology, and Society (STS) Approach on the Topic of " Chemistry as the Basis of Life " Among Grade-10 Students

Assessment	**Number of Students (n)**	**Full Score**	**Average Score ($\bar{x}$)**	**Standard Deviation (S.D.)**	**70% criterion**	**df**	**t-value**	**Sig 1-tailed**
Post-test	40	40	28.9	3.26	28	39	1.74*	.04

(*significant at the .05 level)

DISCUSSION

1. The Impact of STS-based Learning on Critical Thinking Abilities

The research findings indicate that Science, Technology, and Society (STS)-based learning plays a significant role in enhancing students' critical thinking abilities. The average n-gain score was found to be at a Moderate level (0.58), with specific components such as interpretation and preliminary agreement identification achieving higher n-gain scores of 0.66 and 0.63. According to the instructional approach that emphasizes students' connection to real-world problems, analytical questioning, and active participation, learning activities were designed based on the Science, Technology, and Society (STS) framework, consisting of the following five phases: 1) Search – This phase enhances students' ability to identify initial assumptions, as they must distinguish between relevant and irrelevant information and determine what is essential for problem-solving. It also supports the development of interpretation skills, as students are required to assess and evaluate the credibility of information from various sources. 2) Solve – This phase promotes deductive reasoning, as students must logically connect the gathered data to formulate rational answers within given scenarios, using principles of logical reasoning in their decision-making. 3) Create – This stage contributes to the ability to draw inferences, as students synthesize their research findings and connect different facts to develop coherent and reasonable conclusions that relate directly to the studied issue. 4) Share – Presenting information in this phase fosters students' ability to evaluate arguments. They must listen to differing opinions and counterarguments and assess their validity and soundness. 5) Act – The final phase strengthens both inferencing and argument evaluation skills, as students apply their acquired knowledge to real-life situations, aiming to solve problems or drive change based on logical reasoning and outcome-based evaluations. These results congruent with the study of Yager and Akcay (2010) that the STS (Science, Technology, and Society) enhances analytical and argumentative skills as students must integrate information from various sources to evaluate facts. The findings of this study confirm that students show significant development in summarization, referencing, and deductive reasoning. Furthermore, STS learning reduces the limitations of traditional memory-focused approaches by stimulating interest and fostering a broader contextual understanding. This enables students to effectively connect knowledge to real-life social and technological issues. These findings align with Bybee's (1990) research, which shows that learning that integrates science, technology, and society encourages deeper thinking as students analyze diverse situations and pose meaningful questions to address everyday problems. This reflects the importance of designing learning activities that focus on fostering deep understanding and enabling students to apply their thoughts in multifaceted ways.

Additionally, this is consistent with the study by Mulyanti, et al. (2021), which found that the STS approach can effectively stimulate critical thinking and data analysis skills among students. This reflects the effectiveness of connecting scientific knowledge to societal and technological issues, consistent with the findings of this study, which show that STS-based learning design is a powerful tool for developing critical thinking and applying knowledge in complex situations effectively. Thus, STS learning not only stimulates critical thinking and analytical skills but also enhances context-based understanding of societal and technological connections to daily life. Moreover, the average n-gain score was 0.58, which is categorized as a moderate level. Among the students, 27 (67.5% of the sample) had n-gain scores at the moderate level, with an average n-gain of 0.53 for this group. This reflects a satisfactory improvement in critical thinking abilities following the implementation of STS-based learning. However, the research also indicates that some students remain at a moderate to low level in critical thinking, potentially due to factors such as varying levels of foundational understanding or a lack of activities that stimulate deeper thinking. This finding aligns with Cavas's (2011) study, which explored the use of STS in developing analytical skills among secondary school students in Türkiye. While critical thinking abilities improved, tailoring activities to meet the needs of different student groups remained crucial for enhancing the effectiveness of STS learning. This discussion suggests that researchers should consider increasing support and designing more challenging activities to stimulate deeper thinking for students with lower achievement levels.

In addition to the development of critical thinking skills reflected by the average n-gain score, the STS (Science, Technology, and Society) instructional approach also demonstrates a strong connection to key theoretical frameworks in education, particularly the concept of Constructivism. This theory posits that learners construct new knowledge through interaction with their environment, direct experiences, and reflective thinking (Vygotsky, 1978). The STS model effectively supports this by engaging students in a variety of learning activities such as inquiry-based questioning, group discussions, experimental design, and the evaluation of real-world social and technological issues. Learning through authentic, real-life contexts enables students not only to acquire content knowledge but also to develop critical thinking skills. These skills are fostered through processes of analysis, comparison, logical reasoning, and evidence-based decision-making. This is reflected in the observed improvements in students' abilities to draw inferences and apply deductive reasoning. Saputri, Harahap, and Rosita (2021) found that the STS approach significantly enhances students' critical thinking abilities, as learners are required to connect information from diverse sources and critically evaluate facts within real-world situations. Moreover, the STS approach aligns well with the principles of Active Learning, which emphasize genuine student engagement. Interaction among peers and with the instructor through hands-on activities—such as discussion, experimentation, and small-scale projects—serves as a key factor in promoting deep understanding and analytical thinking, which are essential 21st-century skills (Prince, 2004). Considering these findings, it is evident that the STS approach not only enhances students' academic achievement in quantitative terms but also promotes knowledge construction, positive attitudes, and the development of essential cognitive skills for life in the modern world. Designing learning activities that are appropriately challenging, tailored to students' prior knowledge, and connected to relevant social contexts will further strengthen the effectiveness of STS-based instruction.

2. The learning achievements of students after STS-based learning.

The average learning achievement score was 28.9 out of 40 points, equivalent to 72.25%, which is significantly higher than the 70% criterion (Sig = .04). The t-value obtained from the hypothesis testing was 1.744, indicating that this instructional approach effectively improved learning outcomes. The instructional activities aligned well with Bloom's taxonomy in the following aspects: 1) Knowledge and memory: Students reviewed materials such as documents, videos, slides, or manuals and answered simple questions to assess memory, such as "What are the basic chemical components of living organisms?" Activities such as flashcard games or online quizzes reinforced students' recall of fundamental information, such as basic chemical equations or definitions. 2) Application: Students designed simple experiments, such as testing the chemical properties of substances found in daily life, enabling them to connect knowledge to real-world scenarios. 3) Evaluation: Students wrote essays or engaged in discussions on the pros and cons of using certain chemicals in daily life, allowing them to evaluate information and express reasoned opinions. 4) Analysis: Students compared two chemical compounds, analyzed similarities and differences, and engaged in case studies to identify chemical components and their effects, thus developing skills to discern components and relationships and 5) Understanding: Group discussions were organized where students explained concepts in their own words, such as describing the role of Chemistry in living organisms. Tools like diagrams or mind maps helped students summarize content and demonstrate their understanding of key concepts. These findings are consistent with the study by Yager and Akcay (2008), which found that implementing STS-based learning significantly improved students' academic performance in various domains compared to textbook-based instruction. Students in STS classrooms demonstrated a stronger grasp of fundamental concepts, better application skills, enhanced creative thinking, and a greater capacity to pose complex questions. Moreover, they developed more positive attitudes toward science and showed a higher ability to apply scientific knowledge to real-life situations.

In addition, the implementation of STS-based learning activities reflects the principles of active learning and constructivism, both of which emphasize the role of learners as central agents in the learning process. Students construct their own knowledge through inquiry, questioning, and discussions based on real-world issues (Vygotsky, 1978; Prince, 2004). This approach encourages higher-order thinking skills, as categorized in Bloom's taxonomy (1956), especially analysis, evaluation, and application—skills essential for learners in the 21st century. Furthermore, Yager and Akcay (2008) affirmed that students taught using STS-based instruction demonstrated significantly higher comprehension and application of scientific concepts compared to those taught using traditional methods. This enhancement is attributed to increased opportunities for active engagement, contextual learning, and greater motivation through real-life relevance. However, STS-based instruction also presents certain challenges. These include the complexity of designing activities that appropriately integrate social and technological contexts, and the additional time required compared to conventional methods. This observation aligns with Aikenhead's (2005) assertion that the success of STS instruction depends heavily on the teacher's capacity to meaningfully connect scientific content with students' real-life experiences.

CONCLUSION AND IMPLICATIONS

The research on "Enhancing Critical Thinking Ability and Learning Achievement through a Science, Technology, and Society (STS) Approach for Grade-10 Biology on the Topic of the Chemistry Basis of Life." has summarized the following research findings:

Comparison of students' critical thinking skills before and after learning through the STS approach.

It was found that students' critical thinking skills increased significantly. The average pre-test score was 17.32 out of 30, or 57.75%, while the post-test score increased to 24.75, or 82.50%. The analysis of Normalized Gain (n-gain) revealed an average n-gain of 0.58, which is considered Moderate. Among the students, 25% showed a high level of n-gain (n-gain > 0.70), 67.5% were in the moderate range (n-gain between 0.30-0.70), and 27% had a low n-gain (n-gain < 0.30). When considering specific aspects, the n-gain values were as follows: 1) ability to interpret (n-gain = 0.66), 2) ability to deduce (n-gain = 0.62), 3) ability to identify premises (n-gain = 0.63), which were the highest areas of development. The ability to summarize references (n-gain = 0.49) and assess arguments (n-gain = 0.52) also showed improvement. These results reflect the effectiveness of the STS approach in stimulating critical thinking and connecting content to real-life experiences.

Comparison of students' academic achievement after STS-based instruction on the biology topic "Chemistry as the Basis of Life" against the 70% achievement criterion.

It was found that the average post-test score was 28.90 out of 40, or 72.25%, which is above the set criterion. A statistical test using One-Sample t-test showed a t-value of 1.744 with statistical significance at .05 level (Sig = .04). This indicates that the STS-based learning management significantly contributed to the improvement of academic achievement. The STS approach played a crucial role in designing activities that connect scientific knowledge with technology and societal issues, making the content more meaningful and relevant to the students' daily lives.

Implications for practical

1. Educators should focus on designing activities that promote in-depth thinking and argumentation on real-life issues.

2. The use of technology and online learning resources, such as instructional videos, virtual models, and collaborative learning platforms, should be integrated into the teaching process to enhance student engagement and facilitate effective learning.

Implications for future research

1. Research findings indicate that students demonstrate varying levels of comprehension, with some exhibiting low to moderate critical thinking skills (n-gain < 0.30). To ensure inclusive skill development, future studies should investigate the impact of STS-based learning on teamwork skills, allowing students with stronger comprehension to explain and support the learning of their peers effectively.

2. The study revealed that some students still possess moderate to low critical thinking skills and struggle to connect scientific knowledge with real-world contexts due to differences in comprehension levels and a lack of deep-thinking activities. As a result, future research should explore the integration of STS-based learning with problem-solving and creative thinking skills through activities that blend science, technology, and society. This approach aims to enhance students' creativity and their ability to apply knowledge effectively in real-life problem-solving scenarios.

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