FOSTERING CRITICAL THINKING SKILLS OF SCIENCE STUDENTS: AN IMPERATIVE TASK FOR THE TEACHER

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Abstract

Research efforts have identified the significant need to develop critical thinking in science learners. This enables them to use concepts and principles to analyze, interpret, create, assess and improve thinking. However, there are limited studies relating annotated diagrams to the critical thinking skills of science students (biology, chemistry, physics and computer studies). The study employed a quasi-experimental design of two intact classes. With a sample of Nigerian science students (n= 116), (Male =51, Female = 65), aged 14 – 16 years, the study determined the potency of the annotated diagram to enhance students' critical thinking skills. Researchers developed the Critical Thinking Skills Test (CTST) with a reliability coefficient of 0.73. The data generated were analyzed using mean, standard deviation and analysis of covariance. Findings revealed that students' critical thinking skills were significantly enhanced, without a gender gap. The results suggested the need for science teachers to be self-guided in the choice of instructional strategies to employ during teaching teaching-learning process. It concluded that if science instructions are tailored to develop in learners the critical thinking skills needed for sustainable growth and development in nations' economy, then teachers should pay more attention to issues of pedagogy and the needs of the learners and society at large.

Keywords: annotated diagram, critical thinking skills, critical thinking skills test, gender

Introduction

The achievement trends of science students in West African Secondary School Certificate examinations reveal unsatisfactory expectations from stakeholders in education (WAEC, Chief examiners reports, 2021 &2022). Appropriate instructional strategies are crucial for desired learning outcomes, particularly in developing critical thinking skills. Science education scholars have developed strategies to ensure effective teaching and learning of science concepts (Okebukola, 2020; Oludipe et al., 2023; Lameed et.al., 2023, Danmole et al., 2014; Olayanju et al., 2023; Adam, et al., 2023; (Omar & Awang, 2022; Hayati et al., 2023). The traditional method of teaching science concepts to students often leads to memorization and rote learning, hindering the development of critical thinking skills. This passive approach hinders interaction with learning experiences and problem analysis. This study advocates for constructivist instructional strategies to help students construct meaning and develop critical thinking (Okebukola, 2020; Oludipe et al., 2023; Danmole et al., 2014).

Literature reports successful instructional strategies for promoting learning in science classrooms (Olayanju et al., 2023; Adam et al., 2023; Lameed et al., 2023; Akintoye et al., 2023), such as problem-solving and higher-order thinking skills (Nurkaeti, 2018). However, traditional methods are still used by science teachers, resulting in unexcited student performance in school and public exams (Okebukola, 2020). Critical thinking skills are crucial in today's world, especially in addressing issues like food security, health, power supply, and disasters. Science subjects, such as chemistry, biology, physics, and computer studies, require hands-on learning. However, students often perform poorly in science due to conventional teaching methods, limiting their development of critical thinking skills (Okebukola, 2020).

Critical thinking, according to Doyle (2022) involves analyzing, synthesizing, evaluating, and transforming information to solve problems. According to Paul and Elder (2007), it is essential in science education to produce holistic, sound-minded individuals who contribute to economic, scientific, and technological growth. Teachers should adopt instructional strategies to promote critical thinking in students. Wikipedia (2023) states that critical thinkers analyze facts, evidence, observations, and arguments, employing rational, skeptical, and unbiased analysis. They can infer reasonable conclusions and discriminate to provide solutions. Critical thinking skills are indispensable competencies for survival in the 21st century around the world (Odu & Bassey, 2018).

Literature indicates questioning skills, analytical skills, evaluation skills and synthetic skills as critical thinking skills that instructions should ensure to develop in learners. To align science education with the demands of the 21st-century workforce calls for a paradigm shift from a traditional teacher-centre approach to a student-centre approach that fosters active learning, problem-solving, and creativity (Zaharin et al., 2018; Asyari et al., 2016; Lameed et al., 2023; Facione, 2015). Critical thinking is crucial for global society development, involving purposeful, concise, and problem-solving thinking (Facione, 2015). Core cognitive skills include interpretation, analysis, evaluation, inference, explanation, and self-regulation. These skills help develop learners' mental abilities and critical thinking abilities. Higher-order thinking skills, such as analysis, synthesis, and valuation, are essential for solving higher-order tasks (Facione, 2015; Silitonga, Penjaitan and Supriyati, 2020; Lameed, Adam, Benjamin and Muraina, 2023).

Research on critical thinking and thinking skills has been conducted globally (Asyari et al., 2016; Lameed et al., 2023; Hayati et al., 2023). Studies show that problem-based learning and group investigation enhance students' critical thinking skills. Lameed et al. (2023) found that problem-solving instruction can elevate students' thinking from lower-order to higher-order thinking. Omar and Awang (2023) suggest that the learning environment and student cooperation predict higher-order thinking skills. Science teaching should instill critical thinking in students to prepare them for societal challenges.

Annotated drawing is a visual representation of an idea, object, or concept that can improve students' learning outcomes in science subjects (Australian Academy of Science [AAS], 2009). Studies suggest that annotation can enhance reading skills, increase reading scores, and improve content understanding (Gomez & Gomez, 2007; Danmole & Lameed, 2014). It is recommended for subjects like Mathematics, Social Studies, Literature, and Science, as it promotes hands-on, inquiry-based learning. Annotated drawing develops students' knowledge, skills, and understanding of science, fostering meaningful linkages between diagrams and labelled parts (Zywica & Gomez, 2008; Danmole & Lameed 2014). The literature lacks empirical studies on annotated drawing as an instructional strategy for fostering critical thinking in students (Abualrob, 2019; Olawuyi et al., 2011; Atwa et al., 2022). Previous studies have shown that students struggle with problem-solving in science subjects (Araz & Sungur, 2018). Annotated drawing is considered a metacognitive strategy, engaging students in real science activities and developing critical thinking skills (Danmole & Lameed, 2014). This study aims to determine the potential of annotated drawings to predict critical thinking skills in secondary science students.

Gender issues in science education stem from learning societal roles and norms, which are passed down to future generations. The relationship between gender and learning outcomes in science education is a significant topic, as gender roles and norms are formed within society, affecting learners' skills, behaviour patterns, and values, which are passed down to future generations (Hoominfar, 2020). According to Tekkaya, Ozcan and Sungur (2001), studies on gender, learning outcomes, and participation in science education reveal mixed feelings and inclusivity. Some studies show gender differences in perception of difficult concepts, while others show no significant differences in achievement, critical thinking ability, or participation (Ozan, Ozgur, Kat and Elgun, 2013). For example, Lameed et al. (2023a) as well as Oludipe et al. (2023) found no significant difference in the critical thinking ability of students exposed to problem-solving instruction in biology.

Studies show persistent gender gaps in STEM fields, with low engagement of women and 84% of men having qualifications in STEM fields (Ferguson and Ng (n.d). This can be attributed to perceived self-efficacy, willingness to operate outside traditional roles, access to role models, perceived irrelevance of STEM to girls, views that engagement requires greater intelligence, and girls feeling less capable than boys (van Aalderen-Smeets & van der Molen, 2018; Holmes et al., 2018). The study by Chauke (2022). Additionally, male students differ in autonomy, and independence, and reject stereotypical feminine identities, which can discourage female involvement and achievement in STEM fields (Folberg and Kaboli-Nejad, 2020). This study therefore determines the ability of annotated drawing to foster critical thinking of students in science. Specifically, the study sought to test the following hypotheses:

Research Hypotheses

The following hypotheses were formulated to guide the study and tested at 0.05 level of significance:

Ho_1: There is no statistically significant difference in critical thinking mean scores of science students taught with annotated diagram strategy and lecture method

Ho_2: There is no statistically significant difference in the critical mean score of male and female science students taught with annotated diagram strategy

Methodology

The study adopted a quasi-experimental non-randomized pre-test and post-test, non-equivalent research design. It explored the potency of annotated diagrams in fostering critical thinking in science students. 116 SSS3 science students offering biology, chemistry, physics and computer studies in two intact classes participated in the study. The science students were purposively involved because drawing occupies a prime position in the summative evaluation of their attainment in the science curricula. Data were collated with the use of a self-developed critical thinking skill test (CTST) with a split-half reliability coefficient of 0.73. The CTST was administered as pretest and posttest before and after treatment. The treatment began with permission being sought from the school authorities to obtain consent from the teachers and the students. The teachers were briefed on the objectives of the study and a timeframe was established to carry out the study. After obtaining approval for the study, the researchers administered a pretest to both the experimental and control groups. Following this, the students in the experimental group were engaged with annotated diagram instructions, while the students in the control group were taught using the traditional lecture method. This continued for three weeks. In the annotated diagram instruction, learning objectives were presented, followed by the introduction of the topic for interaction. The researchers then proceeded to draw diagrams, label them, and explain the functions/descriptions of the parts. Students were asked to carefully and critically observe the illustrated annotated diagrams, relate the diagrams to their functions, and use the annotated diagrams to answer analytical, evaluative, and creative questions that tested their abilities. The students' ability to answer questions on analysis, synthesis, and evaluation (CTST) indicated their critical thinking ability. Data collected were analyzed using mean, standard deviation and analysis of covariance.

Results

Ho$_1$: There is no statistically significant difference in critical thinking mean scores of science students taught with annotated diagram strategy and lecture method

Table 1: *Summary ANCOVA of students' critical thinking in groups*

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	895.911[a]	2	447.956	125.192	.000	.689
Intercept	571.323	1	571.323	159.670	.000	.586
Pretest Critical thinking	78.310	1	78.310	21.886	.000	.162
Group	889.687	1	889.687	248.645	.000	.688
Error	404.330	113	3.578			
Total	8252.000	116				
Corrected Total	1300.241	115				

a. R Squared = .689 (Adjusted R Squared = .684)

Table 2: *Mean and standard deviation of critical thinking in experimental and control groups*

Group	N	Mean	Std. Deviation
Experimental	61	10.2623	2.43517
Control	55	4.9455	1.53259
Total	116	7.7414	3.36251

The result in Table 1 reveals there is a significant difference in the critical thinking mean scores of students exposed to annotated diagrams and lecture method ($F_{(1, 113)}$ = 248.65; p > 0.05, η^2= .688). The treatment effect size of .688 indicates that the use of an annotated diagram accounts for 68.8% contribution of the variance in the critical thinking attainment. Also, table 2 shows that science students in the annotated diagram pulled a higher mean score ($\bar{x}$ = 10.26) than students in the lecture method ($\bar{x}$ = 4.95). It implies that the use of an annotated diagram strategy significantly fostered critical thinking in science students. Thus hypothesis 1 is rejected.

Ho2: There is no statistically significant difference in critical thinking mean scores of male and female science students taught with annotated diagram strategy

Table 3: *Summary ANCOVA of gender critical thinking in the annotated diagram*

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	29.489[a]	2	14.744	1.311	.274	.023
Intercept	1322.678	1	1322.678	117.617	.000	.510
Pretest Critical thinking	4.336	1	4.336	.386	.536	.003
Gender	23.265	1	23.265	2.069	.153	.018
Error	1270.753	113	11.246			
Total	8252.000	116				
Corrected Total	1300.241	115				

a. R Squared = .023 (Adjusted R Squared = .005)

Table 4: *Mean and standard deviation of gender critical thinking*

Gender	N	Mean	Std. Deviation
Male	51	7.2157	3.37825
Female	65	8.1538	3.31771
Total	116	7.7414	3.36251

Table 3 reveals there is no significant difference in the critical thinking mean scores of male and female students taught with annotated diagram strategy ($F_{(1, 113)}$ = 2.069; p > 0.05, η^2= .018). The treatment effect size is 1.8% which is an indication that there is a small effect of gender on critical thinking attainment. Further, table 4 shows that female participants have higher mean scores ($\bar{x}$ = 8.15) than males ($\bar{x}$ = 7.22), however, this does not account for a significant difference in critical thinking based on gender. Thus hypothesis 2 is accepted.

Discussion

The study seeks to improve science students' critical thinking through annotated diagrams. Results show a significant difference in the critical thinking attainment of students exposed to annotated diagrams and lecture method. This aligns with previous studies on student-centred pedagogy (Danmole & Lameed, 2014; Asyari et al., 2016; Amoah et al., 2021; Lameed et al., 2023). Annotated diagrams help students make meaning of learning and move from lower-order thinking to higher-order thinking levels. They assist students in observing, reading, interpreting, analyzing, judging, and creating new information, developing skills for problem-solving. Traditional students struggled to attain critical thinking due to a lack of interaction with diagrams. The study suggests that traditional teaching methods promote rote learning and memorization, leading to misconceptions and negative attitudes towards learning.

The study found no significant difference in critical thinking attainment between male and female students in annotated diagram instruction. Both genders performed equally well in higher-order thinking tasks in biology, according to Lameed et al. (2023). Other studies found no significant gender differences in pre-service integrated science teachers' gender performance, perception of difficult concepts in biology, and gender differences in chemistry when appropriate pedagogy is employed (Oludipe et al, 2023); Etoboro et al, 2017 & Saibu et al, 2022). However, this finding negates Mau et al. (2020) who found a greater gender difference in STEM learning experience, parental involvement, and STEM self-efficacy of students in a study to determine gender differences in STEM career aspiration and social cognitive factors in collectivist and individualist cultures. Also, at variance with this finding, Folberg and Kaboli-Nejad (2020), submitted that men perceived STEM careers as useful than women, and women are a numerical minority. This is an indication that the use of an annotated diagram strategy in science instruction is gender friendly because it appeals to the sense of sight, engages them in drawing, and labelling, and gives students the privilege to develop critical thinking and apply critical thinking skills to given problems. It therefore means that when science teachers employ appropriate instructional strategies, students' learning outcomes improve and gender gaps are bridged in science classrooms. The disparity between the findings of this study and others may be attributed to the instructional strategy (annotated diagram), study population and concepts of interest.

Conclusion

The study found that science students' critical thinking skills improved significantly when they were taught using annotated diagrams compared to traditional teaching methods. This suggests that students can enhance their thinking skills through constructivist strategies. The strategy used in the study helped develop their critical thinking skills, enabling them to effectively solve problems. Therefore, the study suggests that science teachers should consider using annotated diagram strategies in their instruction.

Reference

Abualrob, M. M. A. (2019). Determinants of building 21st-century skills in Palestinian elementary schools. *Higher Education Studies, 9*(2), 108 – 116.

Adam, U. A, Lameed, S. N, Tonade, O., Onowugbeda, F. U., Benjamin, A., Ige, A. M. & Muraina, I. O (2023). A new piece of the puzzle: Deploying technologically enhanced Jigsaw method to solve the puzzle of meaningful learning in Biology. *Aseana Journal of Science and Education*, *3* (1), 8 – 17.

Anderson, L. W., Krathwohl, D. R., & Bloom, B. S. (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's Taxonomy of educational objective* (Complete ed.). Longman

Akintoye, H., Adam, U.A., Lameed, S. N., Bankole, I. S., & Benjamin, A. (2023). A Case for culture-techno-contextual approach for enhanced academic achievement in STEM Education, *Journal of Educational Sciences*, *7*(4), 530 – 544.

Amoah, J. E. M., Eminah, J. K., Ngman-Warac, E. I. D. & Azure, J.A. (2021). Improving first-year Integrated science students' biological drawing at Mfantsipim School, *International Journal of Sciences: Basic and Applied Research (IJSBAR)*, online, 294-310.

Araz, G., & Sungur, S. (2018). Effectiveness of problem-based learning on academic performance in genetics. *Science and Education, 3* (1), 8 – 17.

Asyari, M., Almuhdhar, M. H. I., Susilo, H., & Ibrohim. (2016). Improving critical thinking skills through the integration of problem-based learning and group investigation. *International Journal for Lesson and Learning Studies, 5*(1), 36 – 44.

Atwa, Z., Sulayeh, Y., Abdelhadi, A., Jazar, H. A., & Eriqat, S. (2022). Flipped classroom effects on grade 9 students' critical thinking skills, psychological stress and academic achievement. I*nternational Journal of Instruction, 15*(2), 737 – 750.

Australian Academy of Science (2009). *Literacy focuses across curriculum connections units, primary connection project stage 3* from www.qualityteaching(2006-2008)dee wi.gov.al

Chauke, T. A. (2022). Gender differences in determinants of students' interest in STEM education. *Social Sciences, 11*(534).

Danmole, B. T., & Lameed, S. N. (2014). Exploring annotated drawings for improving Nigerian secondary school students' achievement in genetics. *International Journal of Biology Education, 3*(1), 1 – 11.

Doyle, A. (2022). Critical thinking definition, skills, and examples. *ThoughtCo. thoughtco.com/critical-thinking-definition-with-examples-2063745.*

Etoboro, A. B. & Fabinu, O. E. (2017). Students' perceptions of difficult concepts in biology in senior secondary schools in Lagos state. *Global Journal of Educational Research*, *16*, 139 -147.

Facione, P. A (2015). Critical thinking: What it is and why it counts. Measured reason LLC, Insight Assessment

Folberg, A. M., & Kaboli-Nejad, S. (2020). A mixed method examination of gender differences in perceptions of STEM among Iranian Americans. Journal of Social Issues, 76(3), 543–576. https://doi.org/10.1111/josi.12393

Gomez, L., & Gomez, K. (2007). Reading for learning: Literacy supports for 21st century work. *Phi Delta KKappan, 89*(3), 224-228.

Hayati, E. M., Purwanto, A & Hidayat, D. H. (2023). Analysis of the cooperative learning effectiveness on students' critical thinking skills in science learning for primary students. *Al-Ishlah: Journal Pendidikan, 15* (1), 1145-1153.

Holmes, N. (2018). Engaging with assessment: Increasing student engagement through continuous assessment. *Active Learning in Higher Education*, *19*(1), 23-34. https://doi.org/10.1177/146978741772323

Hoominfar, E (2020). Gender socialization. *Doi: 10.10071978-3-319-70060 – 113.1*

Lameed, S.N, Adam, U. A, Benjamin B. A. & Muraina, I.O (2023a). Beyond the confines of achievement in secondary school biology: Higher-order thinking in focus. *Journal of Educational Sciences*, *7*(1), 11 – 26.

Mau, W., Chen, S., Li, J., & Johnson, E. (2020). Gender difference in STEM career aspiration and social-cognitive factors in collectivist and individualist cultures. *Administrative Issues Journal: Connecting, Education, Practice, and Research*, *1*(1), 30 – 46.

Ng, W & Ferguson, J. (n.d). Engaging high school girls in interdisciplinary STEM. *Science Education International, 31*(3), 283 – 294. https://doi.0rg/10.33828/sei.v31.i3.7

Nurkaeti, N. (2018). Polya's strategy: An analysis of mathematical problem-solving difficulty in 5th grade elementary school. *EduHumaniora: Journal Pendidikan Dasar, 10*(2), 140 -147

Okebukola, P. A. (2020). *Breaking Barriers to Learning: The culture-techno-contextual Approach*. Sterling Publisher

Olawuyi, B. O., Olasehinde-Williams, O., Durosaro, I. A., & Yahaya, L. A. (2011). Critical thinking and higher education in Nigeria. In D.O. Durosaro, A. A. Adegoke (Eds.), Higher *education and globalization* (pp. 105-112). Sterling-Holden Publisher Ltd

Olayanju, M. O., Oludipe, O. S., Akindoju, O. G., & Lameed, S. N (2023). Can cognitive apprenticeship tweak the attitude and entrepreneurial skill development of pre-service Integrated science teachers of different ability divides? TIJER - *International Research Journal*, *10* (9), 28 – 40.

Oludipe, O. S., Olayanju, M. O., Akindoju, O. G. & Lameed, S. N. (2023). Is cognitive apprenticeship a gender non-chauvinistic instructional strategy for improving pre-service integrated science teachers' cognitive achievement towards a knowledge economy? *International Journal of Innovative Research and Advanced Studies (IJIRAS), (10), 1 – 8.*

Omar, M. S. & Awang, M. I. (2023). The learning environment as a predictor of higher-order thinking skills. *International Journal of Evaluation and Research, 12*(1), 395 – 402.

Ozcan, T., Ozgur, S., Kat, A., & Elgun, S. (2013). Identifying and comparing the degree of difficulty in biology subject by adjusting its reasons for elementary and secondary education. *Procedia-Social and Behavioural Sciences, 116,* 113 -122.

Paul, R., & Elder, L. (2007). *A guide for educators to critical thinking competency standards.* Dillon Beach, CA; Foundation for Critical Thinking.

Tekkaya, C., Ozcan, O & Sungur, S (2001). Biology concepts perceived as difficult by Turkish high school students. *Journal of Education*, *21*,145 -150.

Saibu, O. S., Oludipe, O.S. & Owolabi, T. (2022). Bridging gender disparities in senior secondary chemistry: What magic can Entrepreneurial-Motivated-Approach perform? *World Journal of Advanced Research and Reviews*, *16*(03), 1032–1043. https://wjarr.com

Silitonga, H. T. M., Panjaitan, M., & Supriyati, Y. (2020). Problem-solving-based physics learning strategy to enhance students' higher-order thinking skills. *Journal of Physics: Conference Series,* doi:10.1088/1742-6596/1567/41042104

van Aalderen-Smeets, S. I., Walma van der Molen, J. H. (2018). Modelling the relation between students' implicit beliefs about their abilities and their educational STEM choices. *International Journal of Technology and Design Education 28*, 1–27. https://doi.org/10.1007/s10798-016-9387-7

Zaharin, N. L., Sharif, S., & Mariappan, M. (2018). Computational thinking: A strategy for developing problem-solving skills and higher order thinking skills (HOTS). *International Journal of Academic Research in Business and Social Sciences, 8*(10), 1265 – 1278.

Zywica, J., & Gomez, K. (2008). Annotating to support learning in the content areas: Teaching and learning sense. *Journal of Adolescent and Adult Literacy*, *52*(2)