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Effectiveness of 6E Inquiry-Based Learning in Developing Critical Thinking Skills in Biology Among Secondary School Students in Kebbi State, Nigeria

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Abstract
The ability to think critically is one of the fundamental abilities needed in the workplace. The development of critical thinking skills (CTS) among Nigerian secondary school students is having little effect as current practice of teaching is 'conventional' that do not promote the development of skills. In order to replace rote learning, a new approach to teaching and learning is needed that places more emphasis on learning, comprehending and measuring skills. It was believed by many educators that 6E Inquiry-Based Learning (6EIBL) is capable of promoting critical thinking skills among learners. Numerous studies have documented the benefits of critical thinking in raising student achievement, in addition to the urgent need to address poor critical thinking among Nigerian secondary school students. Educators in Nigeria are required to use instructional strategies that motivate and help students build a strong sense of critical thinking to appreciate and value the sciences. Contrary to expectations in earlier researches, the effect of 6EIBL on increasing students' levels of critical thinking in science subjects especially biology at the secondary school level in Nigeria has not been demonstrated. This study compares the effect of 6EIBL with conventional teaching methods on students' critical thinking in learning biology among 80 fourth-grade students A non-equivalent control group design was adopted. Purposive sampling was used in two schools to compose experimental and control groups. Each intact class contains 40 participants. The data was obtained using the Photosynthesis Critical Thinking Questionnaire PCTQ). Descriptive statistics and the sample t-test were used to examine the variables. The findings showed that 6EIBL increases students' critical thinking abilities to solve photosynthesis problems. Additionally, students in the experimental group performed better in conducting experiments and other activities and retained the skills more than students in the control group.

Keywords: Critical Thinking, 6E Inquiry-Based Learning, Conventional Teaching Methods, Biology.

Introduction

In the twenty-first century, one of the skills that students should possess is critical thinking. According to the American Association of Colleges of Teacher Education, critical thinking, problem-solving, communication, teamwork, creativity, and innovation are the abilities that students need to develop in order to succeed (Kivunja, 2014) [20]. Additionally, the questions posed by the Trends in International Mathematics and Science Study highlight the significance of critical thinking abilities (TIMSS) (Cáceres, Nussbaum, & Ortiz, 2020) [8]. As a result, when teaching biology to students, their critical biological thinking abilities must be taken into account. However, the students' capacity for biological critical thought is still insufficient.

In Nigeria, secondary schools were established specifically to teach students to master knowledge and skills for everyday application (Kennedy, 2011) [19] and to satisfy the requirement for middle- and low-skilled labor in the nation. However, it should be highlighted that inadequate efforts to prepare students for the 21st century skills like critical thinking have resulted in low performance among secondary school students, a high graduate jobless rate, and a shortage of human resources

(Sada, Mohd, Adnan, & Yusri, 2016) [22]. The world is changing quickly, and there is a huge demand for highly qualified individuals as well as an increase in the number of diverse vocations. Accordingly, students need to gain crucial abilities like CTS to get ready for future employment as technicians, engineers, and leaders (Masek, & Yamin, 2012). Critical thinking skills are essential component of contemporary education and cannot be isolated from one another (Zhou, Huang, and Tian, 2013) [23]. These skills are essential tool in today's society since they help students overcome the problems by building new ideas, making wise decisions, and comprehending their surroundings (Rahman, 2019). He further argued that critical thinking is learned skills and a product of education, training, and practice that must be created, practiced, and regularly included into the curriculum. As such, educators should try to employ teaching techniques that foster the growth of these skills.

Employers nowadays, are focusing on how to find better candidates that not only have technical skills but also have the ability to think critically, solve problems, make wise decisions, and more (Audu, Kamin, Musta'amal, Saud, & Hamid, 2014). It was proposed that critical thinking skills be incorporated into the students' training to serve as a catalyst toward the analysis of unfamiliar situations, where-by their methods of questioning, problem-solving, and decision-making capabilities will center on a framework of rational thinking (Sada, et al., 2016) [22]. The most effective way to learn and teach crucial skills like critical thinking skills in schools is through active teaching techniques (Dekker, 2020; Hernández-de-Menéndez, Vallejo Guevara, Tudón Martínez, Hernández Alcántara, & Morales-Menendez, 2019) [10, 15].

There is a need for a change from teacher-centered approaches to more learner-centered methods that are designed to improve learners' engagement and learning involvement. This was because, the needs of the learners' lifelong needs and growth of critical thinking skills cannot be satisfied by traditional methods of teaching. In the modern evolution of the pedagogical approach, one novel technique that has been asserted to foster students' capacity for critical thinking is the usage of 6E learning cycle (Libata, Ali, & Ismail, 2023; Mecit, 2006) [21]. Moving to 6E inquiry-based learning (6EIBL) as a new learning and teaching strategy is therefore considered as a potential remedy for this issue.

According to the literature 6EIBL is beneficial in specific learning domains, including as information acquisition, critical-thinking skills, and motivation Libata, et al., 2023) [21]. Numerous academics have emphasized that 6EIBL can encourage deep learning rather than surface learning thereby increasing institution-wide advantages; enhancing active learning; increases students' critical thinking skills; enhance self-directed learning; collaboration and communication skills; fosters the growth of responsibility; and increase the educational value ((Libata, et al., 2023; Dakker, 2020; Buaphat, Sonsupap, & Sitti, 2019) [21, 10, 7].

Additionally, 6EIBL helps students cultivate and improve higher-order thinking abilities, problem-solving abilities, leadership abilities, creative and critical thinking, as well as self-regulated learning habits, all of which are essential for successful performance in the modern business environment (Lu, Yang, Shi, & Wang, 2021). Students who used the 6EIBL method gained the skills that employers of today require (Baird, & Parayitam, 2019) [5]. The 6EIBL approach's main objective is to promote CTS development through activity-based and problem-solving procedures.

Based on the literature reviewed in this research, the effects of a 6E Inquiry-based Learning for secondary school students in Kebbi State, Nigeria, are not yet clear (Usman, Mohd, & Ahmad, 2023; Ameen et al., 2022). Many of the studies found focused on university level (Osuyi, 2021). References related to secondary school students are few in the STEM subjects and the 6EIBL process in Kebbi State, Nigeria (Ameen, et al., 2022). The publications analyzed by the researchers were unable to address the present study's research variables, which are 6EIBL, critical thinking, and the concept of photosynthesis.

The present research was integrated with the 6Es (elicit, engage, explore, explain, elaborate, and evaluate) as the stages for learning photosynthesis concept. Senior secondary school four (SS I) students in Kebbi state Nigeria served as the population of the study in which sixty (80) participants were selected as sample from two schools in Argungu Education Zone of Kebbi state Nigeria. The selected students were given some unstructured real-world problems to solve. They were encouraged to perform some experiments, demonstrations, illustrations, and other activities that required deep thinking to be solve. The aim is to examine the effects 6EIBL on the level of student's level of critical thinking in solving biological problems. For this reason, research question and hypotheses were stated as follows:

Research Questions

1. Is there any mean difference in the scores of the Photosynthesis Critical Thinking Skill Questionnaire (PCTKQ) between students exposed to 6EIBL and CTM?

Hypothesis

1. There is no significant mean difference in the PCTSQ scores between students exposed to STEM-7EIBL and CTM.
2. There is no significant difference in the mean scores of post-questionnaire scores and delayed post-questionnaire scores on the Critical Thinking of students exposed to 6EIBL.

Review of Related Literatures

Concept of 6E Inquiry-Based Learning Approach

The 6E Learning cycle model was born as a development of 5E which is included in the learning cycle model. The development of the 5E learning cycle into the 6E learning cycle occurs at certain stages, namely the Elicit, Engage, Explore, Explain, Elaborate and Evaluate stages. In the elicit stage, as the first stage of the 6EIBL learning cycle, the teacher tries to raise or bring in student's initial knowledge by giving fundamental questions relating to the material to be studied. 6E Learning Cycle, which is part of constructivist learning, prioritizes prior knowledge or understanding which will later become the foundation for new knowledge (Libata, et al., 2023). Engage stage: This activity aims to get students' attention, encourage their thinking skills, and help them access the initial knowledge they already have. The third stage is "Exploration". In this stage students are given the opportunity to work both independently and in groups without direct instruction or direction from the teacher. Students manipulate an object, conduct experiments, investigate, observe, and collect data, to make preliminary conclusions from experiments conducted.

Explanation is the 4th stage of 6E where teachers encourage

students to explain the concepts and definitions they understand in their own words and show examples related to the concept to complete the explanation. Elaboration as the 5th stage is where students apply symbols, definitions, concepts, and skills to problems related to the examples of lessons learned. Evaluation which is the 6th stage is where the students will judge and evaluates the learning outcomes which has been done. At this stage a variety of assessment strategies can be used both formally and informally.

Concept of Critical Thinking

Critical thinking is the intellectually disciplined process of actively and skillfully conceptualizing, applying, analyzing, synthesizing and evaluating information gathered from, or generated by observation, experience, reflection, reasoning, or communication, as guide to belief and action (Zhou et al., 2013) [23]. They further maintained that these are parts of the deliberate, self-regulating judgement process known as critical thinking, along with an explanation of the supporting evidence, concepts, methods, criteria, and context. Similar to this, critical thinking is defined as the act of analyzing the evidence supporting various assertions, judging if drawn conclusions are logically supported by the evidence, and taking into account alternative explanations (Fani, 2011) [12]. It is believed that together with decision-making, problem-solving, and creative thinking, critical thinking is one of the higher cognitive capacities (Colucciello, 1999) [9]. Critical thinking therefore, will encourage students to think "sideways" and experiment with many perspectives, ideas, and points of entry.

The ultimate goal of education has always been to learn and teach higher-order cognitive skills like critical thinking particularly in science education. According to Hickson (2016), the scientific method and critical thinking are both methodical and technical ways to analyze and teach the process of thinking. Students must learn the process of critical thinking just as they learn the scientific approach. Building critical thinking among secondary school students has become essential with the current growth of globalization, if we want to have qualified engineers, medical doctors, technicians etc. for the future. Teaching critical thinking is thought to be as important as educating a person (Masek & Yamin, 2012).

The Necessity of Developing Critical Thinking Skills in Secondary School Students

Researches has demonstrated the necessity of fostering critical thinking skills among students all around the world. This is due to the fact that many of them, even at the university level, lack advanced problem-solving techniques (Halpern, 1999; Marin & Halpern, 2011) [14]. Everyone agrees that critical thinking skill is evolving into a crucial instrument and the secret to success in contemporary cultures. The world is also evolving quickly in terms of IT sophistication, and interdependencies. There is a need for more critical thinkers to make decisions that are consistent with evaluative and critical thinking rather than accepting tradition and authority (Marin & Halpern, 2011) [14]. Instead of understanding their place in modern society, students are supposed to take charge of their lives and better them (Ten Dam & Volman, 2004).

Nigerian students are completely absent from international tests like the "Trends in International Mathematics and Science Study," which is a worrying scenario (Atsumbe, 2019) [4]. This further demonstrates that Nigerian learners are not receiving the kind of education necessary to equip them for success in a globalized, competitive environment that values creativity, innovation, and critical thinking. Additionally, the majority of employers in different countries have stated their displeasure with the students' vital abilities and accomplishments, citing the quality of school graduates as a major source of concern (Ismail, Yussof, & Sieng, 2011) [18]. Additionally, it has been observed in Nigeria that the majority of secondary school students were unable to complete tasks that call for the use of critical thinking (Isah Usman et al., 2013) [17].

The tendency in secondary school biology teaching methods in Nigeria is still "traditional," and these are the kinds of methods that frequently prevent students from developing critical thinking skills that enable them to be independent and self-reliant (Garba, 2010; Kennedy, 2011) [13, 19]. This explains why young people's unemployment in Nigeria seems to be rising quickly—many of them lack critical thinking and other employable skills. Because of the poverty rate in the nation, students should start developing their critical thinking abilities in secondary schools if they want to become self-employed (Garba, 2010; Onu, 2013) [13].

The majority of observers concur that employers today require more skilled personnel than they did in the past (Bowell & Kingsbury, 2013; Twiname & Gibb, 2012) [6]. Therefore, it is crucial to develop CTS among Nigerian secondary school students. In order to develop and improve students' ability to work productively with others, develop management skills, leadership skills, a commitment to accurate work, the capacity to adhere to instructions, plans, and directions, the capacity to organize and use time efficiently, a commitment to personal achievement, and the ability to perform skillfully, it is important to foster critical thinking in them (Angelo, 1995; Duron, Limbach, & Waugh, 2006) [3, 11]. Since the industries in this new knowledge era contain more complex and sophisticated high-tech equipment and computerized systems, which create more complex problems that are more dependent on cognitive abilities to solve, critical thinking skills should therefore be integrated into secondary school training.

6E Inquiry-Based Learning and the Building of Critical Thinking Skills

In a wider educational context, the number of studies that reported 6E learning as being less effective are very few compared to the number of studies reporting its effectiveness in improving performance and building critical thinking skills (Abdullahi, Asniza, & Muzirah, 2021) [1]. When compared to Bloom's taxonomy of the cognitive domain, 6E appears to be effective in promoting learning at a higher cognitive level for application and evaluation. The 6E learning cycle encourages higher order thinking skill components Libata, et al., 2023) [21]. Several studies that are related to 6E and critical thinking skills have showed positive outcomes and asserted that 6E could be a suitable option for acquiring the skills needed by the industries (Alsaleh, 2020; Uğur, Duygu, ŞEN, & Kirindi, 2020) [2].

Some of the advantages of 6E learning cycle are: (1) can stimulate students to recall previous material, (2) can improve student learning towards better because this model prioritizes student experience but it also can form active, critical and creative students. (3) Motivate students to be more active and increase curiosity, (4) train students to learn concepts through experimental activities (Abdullahi, et al., 2021) [1]. Based on

the existing problems and considering the advantages of the inquiry learning approaches, the researchers are interested in conducting research by applying this 6E Inquiry-Based Learning in order to stimulate and develop in the students critical thinking skills.

Methodology

Along with a review of the literatures, the ASSURE model was adapted in this study to create the present study approach. This is in line with the suggestions made by Milano, & Ullius, (1998), that the development of the learning style can be modified to fit the needs of the research using other current modules or models. ASSURE model was selected because it is more effective and is most frequently used for designing teaching and learning approaches (Ali, Ibrahim, Abdullah, Surif, Abdul Talib, &Saim, 2015, Ibrahim et al 2022).

The Fuzzy Delphi Method (FDM) was employed in the determination of the experts who validated the current approach. It is a method of ascertaining opinions and consensus among experts on anything (Anderson, 1975). The application of FDM, in this study is to avoid some of the drawbacks of the conventional Delphi technique, like data loss due to some procedures which takes a long time (Mohd Jamil, Siraj, Hussin, Mat Noh, &Sapar, 2014). Additionally, FDM requires fewer experts as validators (Anderson, 1975). This is further supported by Adler and Ziglio (1996), who asserted that 10 to 15 experts are sufficient if there is a high degree of agreement and consistency among the experts. As a result, fifteen (n=15) experienced Biology teachers participated in the validation of the present technique.

Teaching experiences and qualifications of the teachers, are the basis for the selection criteria for the sample. At least ten years of professional experience and a minimum of a B. Sc. in Education are requirements for becoming an expert for validation purpose. The fifteen (15) experts selected were given a 20-item questionnaire to complete in order to assess the suitability of the developed approach in terms of its Content, Objectives, Language, and Evaluation techniques. Their comments were examined using the scale content validation index (S-CVI). Four-Likert scores (1=Not relevant, 2=Less relevant, 3=Quite relevant, and 4=Highly relevant) were used as proposed by Davis (1992).

To determine the suitability and effectiveness of the developed approach, a mixed-method approach was employed. This method is common among educational researchers (Plano & Clark, 2011). The design entails first obtaining quantitative data and then gathering qualitative data to supplement the quantitative findings (Creswell, 2014). The quantitative information was obtained to address the research questions, and the qualitative data was utilized to complement the creation of the 6E Inquiry-based Learning Approach.

A document analysis was first be carried out prior to the creation of the present approach This served as the basis on which the current approach was built. This is due to the fact that document analysis gives the researcher all the information they need to decide what should be in the development of new innovative approach. Analysis of learners, concept of photosynthesis, SS1 Biology textbooks, teacher's scheme of works and lesson plans were among the materials that were analyzed.

Following the intervention, interviews with teachers and students were performed to gather more feedback on the effectiveness, suitability, and shortcomings of the developed approach. The researcher conducted interviews with five students and five teachers from among the available participants to ascertain whether the approach improves student's critical thinking in photosynthesis. The interview was specifically designed to determine the impact, acceptance, and usefulness of the 6EIBL in promoting student's critical thinking in learning the concept of photosynthesis.

The current study specifically used the nonequivalent control experimental group, pre-test and post-test designs in determining the impact of independent variables on dependent variables. The design was employed to assess the effect of the 6EIBL and CTM on secondary school (SSI) student's critical learning abilities in the concept of photosynthesis. The participating students were specifically pre-tested to determine groups' equivalents in critical thinking skill in the concept of photosynthesis. To assess the effects of the two compared methods (6EIBL and CTM) post-test was administered immediately following the intervention.

As shown in table 1 below, the study's design and methodology were schematically represented as O1 as the pre-test X1 as the intervention to the experimental group, and X2 as the intervention for the control group; O2 and O3 as the post-test and delayed posttest respectively.

Table 1: Research Design

Group	Pre-test	Intervention	Post-test
EG	O1,	X1,	O2,
CG	O1,	X2,	O2,

Two public secondary schools were selected randomly in which purposive sampling was employed to assign participants into intact classes of experimental and control group. Permanent biology teachers of the two sampled schools were used to deliver the intervention after given them a five-day training on the principles of 6EIBL. To control the risk of selection and instrumentation, the researcher ensured the conditions under which intervention was delivered were identical. Photosynthesis Critical Thinking Skill Questionnaire were developed by the researcher to measure student's critical thinking abilities. Experienced biology teachers and experts in science education were used to validate the two instruments. The reliability these instruments were calculated using the KR-21 methodology.

The 80 samples of SSI students were divided into two groups. The first experimental group received instruction using the 6EIBL, whereas the second group—the control group—received support using a CTM. The researcher ensured that the research assistants in both the experimental and control groups had comparable backgrounds in terms of experience and training in order to prevent bias between the two groups. The researcher also ensures that both of the research assistants were B.Sc. Ed educators at the same institution and had at least 10 years of teaching experience.

For data analysis, IBM SPSS version 24 was used. Descriptive statistical techniques were employed to find the mean and standard deviation for the pre-tests, and post-tests of the PCTSQ. Independent samples t-test was used to test the hypotheses as required. All the hypotheses were tested at the = 0.05 (P 0.05) level of significance.

Results

Table 2: Mean Scores of Pre-questionnaires and Post-questionnaire on Critical Thinking of Students Exposed to 6EIBL and CTM

Group	N	Pre-score		Post-score		Mean difference
		Mean	Std. Dev.	Mean	Std. Dev.	
Control	40	40.00	21.341	65.40	28.791	25.40
Experimental	40	40.93	21.397	81.68	19.958	40.75
Mean difference		0.93		16.28		

As showed in table 2, the two groups have no difference in their critical thinking at the pre-test level. After the treatment, the control group's critical thinking means improved and rise to 65.40 with a standard deviation of 28.791 and a mean difference of 25.40 compared to the experimental group that was exposed to the use of 6EIBL, whose mean score rose from 40.93 to 81.68 with a mean difference of 40.75. After the intervention (post-test), the mean difference gained between the two groups rose to 16.28. These observations showed a major positive effect of 6EIBL on the critical thinking of students exposed to it.

Table 3: Mean Scores of Post-questionnaire and Delayed Post-questionnaire on Critical Thinking of Students Exposed to 6EIBL and CTM

Group	N	Post-score means		Delayed Means		Mean difference
		Mean	Std. Dev.	Mean	Std. Dev.	
Control	40	65.40	28.791	60.92	29.246	-4.48
Experimental	40	81.68	19.958	84.60	15.988	2.93
Mean difference		16.28		23.68		

Students in the experimental group had a higher mean (81.68) in their critical thinking abilities as indicated in Table 3, when compared with the control group's mean (65.40). The mean difference was 16.18. The students in the control group did not have the advantage of improved retention, as shown in the delayed mean score, which decreased with a mean difference of -4.48 compared with their counterparts in the experimental group, whose retention improved from 81.68 to 84.60 with a mean difference of 2.93. This is a clear picture that the utilization of the 6EIBL had a major effect on the critical thinking of students in the experimental group.

Hypothesis Testing

Table 4: Two samples t-test on post-questionnaire and delayed post-questionnaire on Critical Thinking of Students Exposed to the 6EIPBL.

Stage	N	Mean	Std. Dev.	Std. Error	T	Df	p-value
Post-test	40	81.68	19.958	3.156	0.723	78	0.472
Delayed-test	40	84.60	15.988	2.528			

(t-critical =2.00, $p < 0.05$)

The result in Table 4, did not reveal a significant difference in critical thinking of students taught photosynthesis concept in their post-questionnaire and delayed post-questionnaire scores. The mean scores of delayed post-questionnaires of critical thinking slightly increased, but the difference was not significant. The t-value obtained was 0.723, with a p-value of 0.472 ($p > 0.05$) obtained at 78 degrees of freedom (df). These observations did not provide sufficient evidence to reject the null hypothesis. The null hypothesis that there is no significant difference in the mean scores of post-questionnaire scores and delayed post-questionnaire scores on the critical thinking of students exposed to 6EIBL is therefore retained.

Discussion

The current study revealed that students in the experimental group who were exposed to the 6EIBL in learning concept of photosynthesis had a higher mean score that was significantly different from the mean score of students in the control group. This was because they actively participated to think critically in performing activities assigned to them to solve the given problems. The study confirmed the findings of Sada, et al., (2016) [22]; Dekker, (2020) [10]; Hernández-de-Menéndez, et. Al, (2019) [15], who stated that high critical thinking development can be assured when students are involved in the learning process. This result is also in line with Angelo, T. A. (1995) [3] findings that high greater critical thinking is linked to suitable and innovative strategies that are able to improve and develop student critical thinking, interest, and performance. The results are also consistent with Buaphat, et. al.'s, (2019) [7], report that students who have participated in 6EIBL classes have their critical thinking improved and are less likely to drop out of school. The finding reflected the report of Burwell-Woo et al. (2015), and Shaheen and Kayani (2017), who stated that a person's critical thinking can be boast through constructivist, innovative approaches like the 6EIBL approach.

The study demonstrated that the critical thinking of the students at the post-questionnaire and the retention levels of the experimental group did not differ significantly. The study discovered that the scores obtained after using the 6EIBL did not decrease or increase significantly at the delayed post-questionnaire level. The finding here is consistent with Hickson (2016) [16], and Nugent's (2015) reports, which reported that students are able to develop high critical thinking ability and retain information learned under 6EIBL longer compared to conventional teaching methods.

Positive effects on students' learning are seen when STEM education approaches are used, leading to increased student critical thinking and interest (Abdullahi, et al. 2021) [1]; Mustafa et al., 2016). This supported the results of this study, which increased students' critical thinking, interest, and

success in biology instruction. The present study confirmed those of other related investigations (Alsaleh, 2020; Uğur, Duygu, ŞEN, & Kirindi, 2020) [2]. For study participants and biology teachers to solve difficulties in the real world, 6EIBL can be highly helpful. 6EIBL in secondary education boosts students' critical thinking in their ability to complete the educational requirements for potential future employment. The learning sequence employed in 6EIBL greatly influenced the development of critical thinking in the students. The approach is found to be a learner-centered, practical, activity-focused learning style in which the teacher serves as a facilitator. Classroom observations show students conduct group activities, discuss findings, and deduce from their findings.

Conclusion

The findings of the current study have shown that teachers' choice of teaching and learning styles has a great impact on learner's critical thinking abilities and supported the utilization of 6EIBL in increasing student's critical thinking in their ability to solve photosynthesis problems. In which case, the findings of the present study lend support to those of other investigations. For biology teachers and high school students to tackle real-world problems, the 6EIBL approach can be very helpful. Students' confidence in their ability to achieve higher levels of achievement can be improved if they were able to think critically in solving problems, which is a prerequisite for future employment prospects. Their confidence and critical thinking can increase when they participate in 6EIBL environment. Teachers can maximize student involvement in the learning process by integrating science concepts with 6EIBL. The process is a student-centered learning strategy that provides students more freedom to learn independently. The 6EIBL emphasizes the conduct of many hands-on activities through different stages and processes which requires students to thinking critically in solving real-world scenarios. It is necessary for future research to extend the current study's constrained parameters. The current study was limited to biology students in public senior secondary one (SS1) and to the concept photosynthesis. Future research is therefore, required to test the effect 6EIBL on critical thinking in other secondary school levels, private schools and other disciplines.

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