OmniaScience

Journal of Technology and Science Education
JOTSE, 2023 – 13(3): 718-739 – Online ISSN: 2013-6374 – Print ISSN: 2014-5349
https://doi.org/10.3926/jotse.2151

EFFECTIVENESS OF SCIENCE-TECHNOLOGY-SOCIETY (STS) APPROACH ON STUDENTS' LEARNING OUTCOMES IN SCIENCE EDUCATION: EVIDENCE FROM A META-ANALYSIS

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Received March 2023
Accepted June 2023

Abstract

Scientific literacy development significantly impacts real-world outcomes, leading to scrutiny of instructional approaches for global reform in science education. This study aimed to determine the efficacy of the Science-Technology-Society (STS) approach in improving students' scientific learning outcomes. A quantitative research design, using meta-analysis guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol, was used to determine the effect sizes of previous studies on the STS approach's effectiveness in science learning and teaching. The study analyzed 16 effect sizes from 14 empirical studies from January 2017 to September 2022 using Harzing's Publish or Perish application and Comprehensive Meta-Analysis (CMA) software. Results showed that the STS approach significantly and positively impacts students' learning outcomes ($g = 1.882$), particularly psychomotor skills, affective domain, and cognitive skills. Moderator analysis showed that STS is an effective teaching strategy that yields similar positive results regardless of the assessed learning outcomes. The findings demonstrated that the STS approach facilitates students' development of scientific knowledge, skills, and mindset to innovate for real-world problems. These findings provided empirical information that are essential for learning analytics applications in predicting learners' performance and diagnosing instructional practices. Implications for future research and practice, as well as addressing publication bias, are highlighted in order to maximize the benefits of the STS approach in science education.

Keywords – Science-Technology-Society approach, Meta-analysis, Learning outcomes, Learning analytics, Science education.

To cite this article:

Acut, D., & Antonio, R. (2023). Effectiveness of Science-Technology-Society (STS) approach on students' learning outcomes in science education: Evidence from a meta-analysis. *Journal of Technology and Science Education,* 13(3), 718-739. https://doi.org/10.3926/jotse.2151

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1. Introduction

The advancement of science literacy has the potential to have a significant impact on real-world outcomes (Croce & Watson-Vandiber, 2020). According to the Programme for International Student Assessment (PISA), scientific literacy is defined by three competencies: explaining phenomena scientifically, evaluating and designing scientific inquiry, and scientifically interpreting data and evidence (OECD, 2018). Individuals who are scientifically literate can then synthesize ideas, formulate arguments, defend ideas, and reframe concepts to accommodate new information and valuable learning (Croce & Firestone, 2020). Hence, education has always aimed to prepare students for the future, especially in the volatile, uncertain, complex, and ambiguous (VUCA) world of today. Making it necessary to define fundamental components of educational practice at any age requires a critical understanding of emerging societal problems (Johansen & Euchner, 2013; Panthalookaran, 2022).

Among the current and emerging issues facing the world are the unequivocal proof that Earth is warming at an unprecedented rate (Competente, 2019), the outbreak of infectious and unknown diseases (Salihu & Azuine, 2019), and the spread of false information on social media platforms (Talwar, Dhir, Singh, Virk & Salo, 2020). Hence, recent efforts to reform science education have centered on teaching students science that deepens their understanding of the nature of science, equips them with the skills to critically evaluate scientific information as well as to apply it in real-world contexts, and sets them on a path of lifelong learning in science (Dass, 2005; Acut & Latonio, 2021). Specifically, Acut (2022) implemented science investigatory projects, capstone projects, and robotics projects which provided numerous opportunities for students to achieve high-level learning outcomes, collaborate, and innovate modern technologies that could potentially help emerging environmental problems such as climate change and pollution. Alarde, Bartolabac, Acut, Cane and Magsayo (2022), in particular, created an arduino-based photobioreactor that efficiently removed carbon dioxide levels in the atmosphere while also progressing, resulting in a counterintuitive approach to climate change and global warming. Furthermore, Antonio and Prudente (2021) improved students' conceptual understanding of antimicrobial resistance and argumentation skills through metacognition and argument-driven inquiry approaches. Students gained an understanding of the emergence and spread of antimicrobial resistance among pathogenic bacteria, which has become a growing public health concern in recent decades. Madaiton, Tomaquin, Visitacion, Villaver, Malingin, Nacua et al. (2022) employed conceptual change strategies to address students' misconceptions. The intervention assisted students in identifying false information and superstitious beliefs, as well as correctly grasping scientific concepts.

Similar to this, the Science-Technology-Society (STS) approach aimed to solve problems and thinking processes involving concept transfer by applying the concepts learned in school to the real situation in society (Primastuti & Atun, 2018). With its primary focus on explaining and analyzing science and technology as intricate social constructs with corresponding social influences, STS is regarded as an interdisciplinary field of academic teaching and research (Sismondo, 2010). Students' interests are therefore stimulated and they are better able to understand how science, technology, and society are interconnected when they are exposed to interesting topics, such as circumstances that are relevant to their daily lives (Chantaranima & Yuenyong, 2013). Teaching instructions, such as STS, therefore can effectively accomplish the vision of science education reform toward sustainable science literacy and educational quality (Zoller, 2013).

1.1. STS Through the Years

Midway through the 1960s, academicians and scholars alike began to cast doubt on the benefits of science and technology, which had up until that point largely gone unquestioned. This led to the emergence of STS as a distinct academic field of study for teaching and research in the United States (Cutcliffe, 2019). The STS approach is defined by the National Science Teachers Association as the key to involve learners in experiences and issues that are directly related to their lives. STS teaches students skills that will enable them to become active, responsible citizens by responding to issues that affect their lives. Science education, through STS strategies, will produce scientifically literate citizens for the twenty-first century (NSTA, 1991). STS instructional approach, therefore, has been increasingly recognized as an approach to science teaching and learning that can effectively accomplish the vision of science education reform around the world (Dass, 2005). Because science and technology are historically, politically, and culturally embedded, STS concludes that they can only be understood in context, a corollary to the idea of constructivism (Cutcliffe, 2019).

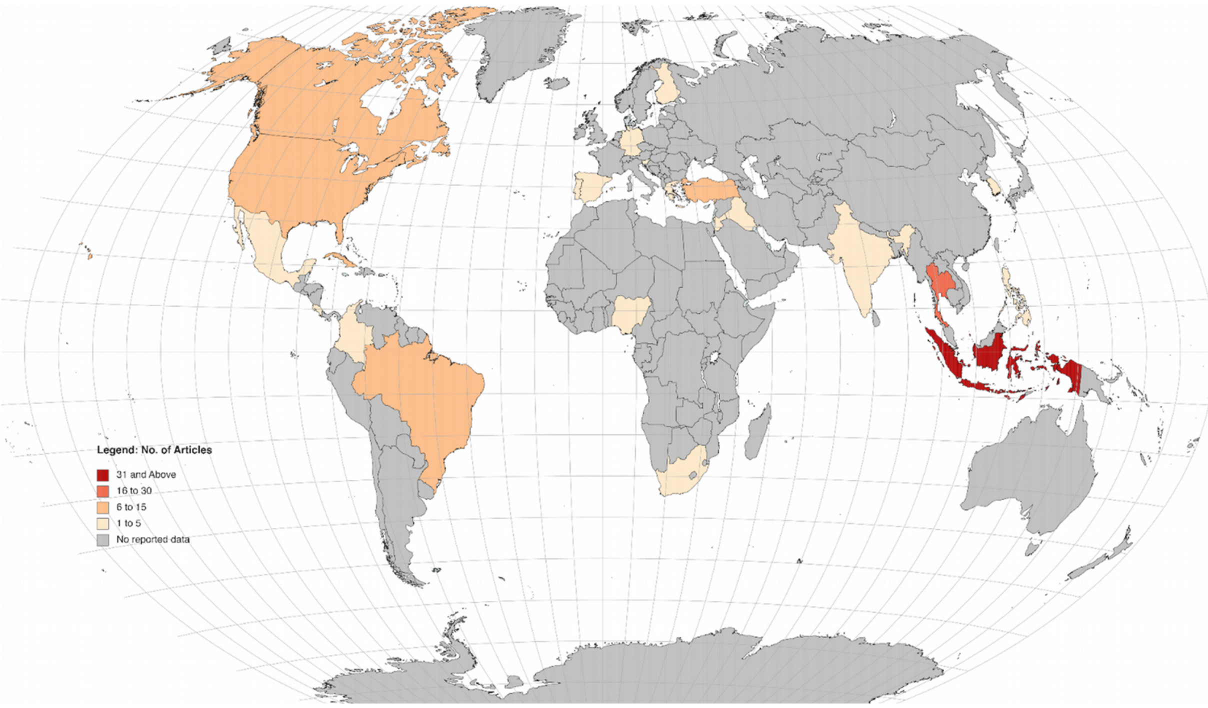
Due to technological solutions to a problem that must be understood in the context of the specific socio-political-economic system, it gave rise to the different STS approach variations. This evolution includes (1) Science, Environment, Technology and Society (SETS) approach; (2) Science, Technology, Society, Environment (STSE) approach; and (3) Society, Technology, Science (STM) approach. Learning with the SETS approach is an integrated method that aims to teach students how to integrate knowledge from four different areas: science, the environment, technology, and society. The SETS approach can motivate students to study science in its entirety, utilize it in technological applications, understand its effects on the environment and societal advancement (Usmeldi, Amini & Trisna, 2017). Similarly, STSE is an all-encompassing term that supports a wide range of different kinds of theorizing about the relationships between science, technology, society, and the environment and firmly embeds science in social, technological, cultural, ethical, and political contexts (Gallagher, 1971). In addition, the STM model provides students with direct experience in raising issues or problems that are happening in the community (Syamsuddin, Irfandi & Bundu, 2019). SETS, STSE, and STM all trace their origins back to the STS approach (Pedretti & Nazir, 2015; Usmeldi et al., 2017; Irfandi, Bundu & Syamsuddin, 2019). The STS approach has resulted in specific outcomes of student achievement in science that have been extensively documented. Figure 1 depicts the implementation of the STS approach in the last five years (2017-2022) based on a systematic search, a prerequisite for every meta-analysis study. With 354 research studies, there is no doubt that the STS approach has been used in academic institutions up until the present.

1.2. Impact of STS Instruction and the Need for a Systematic Review

Numerous studies have been conducted to identify the precise outcomes of students' scientific achievements after using the STS approach (Gallagher, 1971; Dass, 2005; Chantaranima & Yuenyong, 2013; Zoller, 2013; Kapici, Akcay & Yager, 2017; Primastuti & Atun, 2018; Irfandi et al., 2019; Poluakan, Kapubau, Suryani, Sumampouw & Rungkat, 2020; Putra, 2021). Collectively, these STS-related published reports show measurable gains in student performance in terms of understanding and application of fundamental scientific principles, mastery of scientific ideas and procedures, and the ability to apply scientific ideas and procedures in novel contexts, particularly those found in real-world settings. Additionally, they show a significant improvement in students' attitudes toward science and careers in the scientific field as well as a significant increase in students' scientifically relevant creative abilities.

Systematic reviews have been conducted to assess the efficacy of the STS approach in the science teaching-learning process (Bennett, Hogarth & Lubben, 2003; Lubben, Bennett, Hogarth & Robinson, 2005; Jung, Yoon & Kwon, 2008; Irmita, Fahriyah, Zahara, Delina & Ekaputra, 2016). As the name suggests, systematic reviews typically involve a thorough and detailed plan and search strategy with the aim of reducing bias by locating, evaluating, and synthesizing all pertinent studies on a specific topic (Jamal, Ibrahim & Surif, 2019). A meta-analysis component is frequently present in systematic reviews, and it entails the use of statistical methods to combine the data from various studies into a single quantitative estimate or summary effect size (Petticrew & Roberts, 2006).

Systematic reviews of the effects of context-based and STS approaches in the teaching of secondary science were conducted by Bennett et al. (2003) and Lubben et al. (2005). Results demonstrated that while the methods employed did not negatively impact students' understanding of scientific concepts, they motivated students and promoted more positive attitudes. In a review of 56 articles from 1991 to 2006, Jung et al. (2008) found that STS instruction had a greater positive effect than conventional instruction on raising students' attitudes toward science, learning outcomes in the subject, capacity for inquiry, attitudes toward the environment, and environmental knowledge. Similarly, Irmita et al. (2016), conducted a meta-analysis of 5 studies from 2007 to 2014 regarding the effect of STS approach to the learning outcomes of students. Results indicated that the STS approach has a major influence on science learning, aspects of the science process skills, and if applied in teaching approximately nine weeks. However, the literature cited above only reviewed the usefulness of STS approach on students' learning outcomes, such as learning achievement, attitudes toward science, and ability to apply concepts. Aside from the results not written in English (Jung et al., 2008) and only few studies were included (Irmita et al., 2016), there is insufficient data to demonstrate the impact of this approach when other variables are taken into account, such as the study's location, educational levels, implementation duration, and the discipline being studied. Hence, this necessitates an updated and quantitative in-depth review, which includes the analysis of effect sizes of learning outcomes and the variables that might affect the implementation of the STS approach.



Note. Map not drawn to scale; Research articles data is based from Harzing's Publish or Perish (Adams, 2022) meta-search engine results with year inclusion 2017-2022.

Figure 1. Geographic representation of STS approach implementation across the globe

1.3. Purpose of the Study and Research Questions

The STS instructional approach has positively influenced curricular reforms in K-12 science classrooms. Thus, this meta-analysis is geared to investigate curricular science reform through STS instruction as described by empirical studies conducted by educational researchers all over the world. Through this systematic literature review, the extent to which the STS approach is effective is determined by analyzing research studies that have been conducted in various scientific disciplines, such as biology (Astuti, Manurung & Juriani, 2019; Pratama, Abdurrahman & Jalmo, 2018; Putra, 2021), chemistry (Igboanugo, 2021; Poluakan et al., 2020; Priyambodo, Primastuti, Fitriyana & Pandhanugraha, 2021), science (Kapici et al., 2017; Prasasti & Listiani, 2019; Syamsuddin et al., 2019), and natural science (Budi, Sunarno & Sugiyarto, 2018; Irfandi et al., 2019; Widiastuti & Purnawijaya, 2021). The core of this research, which includes a myriad of scientific data, is to analyze the relative effect sizes of the different characteristics and moderators of the STS approach. Specifically, this study aimed to address the following questions:

1. How effective is the STS instructional approach in improving students' learning outcomes in terms of:

   1.1. cognitive outcome;

   1.2. affective outcome; and

   1.3. psychomotor outcome?

2. How does the effectiveness of the STS instructional approach differ according to the:
    2.1. locale of the study;
    2.2. educational level;
    2.3. scientific discipline;
    2.4. learning outcome;
    2.5. STS approach variations; and
    2.6. duration of implementation?
3. What were the STS instructional approaches that have been employed by the included studies to improve students' learning outcomes in science education?

2. Methods

2.1. Research Design

The effectiveness of STS approach in enhancing students' scientific learning outcomes was examined using meta-analysis, which is a purely quantitative type of systematic review (Antonio, 2022; Picardal & Sanchez, 2022) and a comprehensive statistical analysis of previous studies' findings (Antonio & Prudente, 2022; Funa & Prudente, 2021; Glass, 1976; Santos & Prudente, 2022; Schroeder, Scott, Tolson, Huang & Lee, 2007). By examining the gaps in present research, meta-analysis seeks to draw generalizations about the status of the literature and recommends a new focus for future research (Cohen, Manion & Morrison, 2007; Cresswell, 2013). The researchers gathered empirically supported published studies, categorized the studies' characteristics, and computed the effect sizes using a standard scale following the detailed instructions provided by Tawfik, Dila, Mohamed, Tam, Kien, Ahmed et al. (2019).

2.2. Literature Search Procedures

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses, or PRISMA (Moher, Liberati, Tetzlaff & Altman, 2009), were used to guide the selection of relevant studies (see Figure 2). The diagram depicts the flow of data through the various stages of a systematic review. It depicts the number of records identified, those included and those excluded, as well as the reasons for exclusions. Research articles were identified from five (5) meta-search engines and databases using Harzing's Publish or Perish application for macOS (Adams, 2022), namely Crossref, Google Scholar, OpenAlex, PubMed, and Scopus. A systematic search was conducted for published research that evaluated the effectiveness of the STS approach on student learning. Several keywords, with some variations to account for specific retrieval sources (Bernard, Borokhovski, Schmid, Tamim & Abrami, 2014), were strategically entered in meta-search engines: 'science achievement', 'science attitude', 'science interest', 'science motivation', 'critical thinking ability', 'scientific literacy', 'scientific concepts', and 'learning outcomes'. These words were entered into meta-search engines at random and interchangeably, with the constant use of the words 'STS approach' or 'Science-Technology-Society Approach' until all studies were exhausted.

All authors independently conducted the literature search based on the inclusion and exclusion criteria. The authors then compared the results and refined the literature search until the consensus was reached. With a zero-percent search error, there were 1,761 research articles returned by different data-bases as relevant at initial literature search. Using the Google Sheets data clean-up tools, 112 duplicates were removed. However, manual duplicate checking was also carried out because the online tool was unable to detect other duplicates (n = 38) due to other differences (i.e., word and number formatting). Since the specific mention of an STS approach was not evident in all 1,257 papers, they were eliminated; hence, only 354 papers remained to be assessed using the inclusion and exclusion criteria after the title and abstract were manually reviewed.

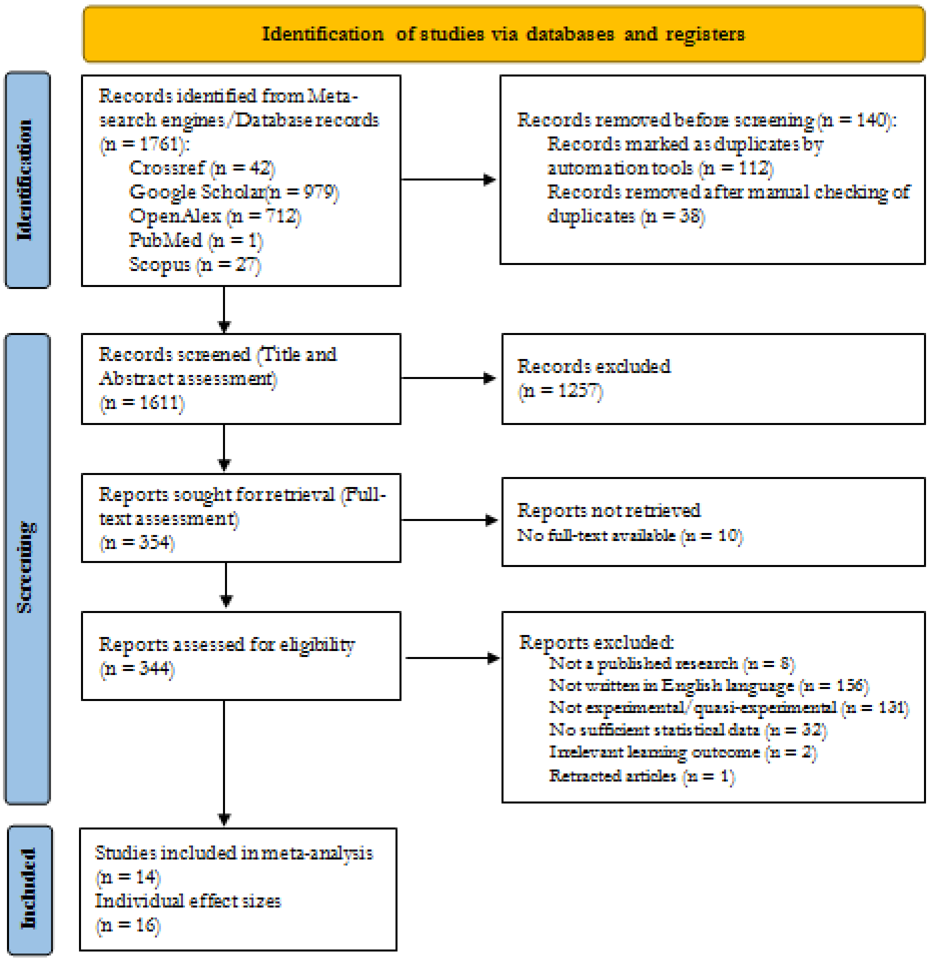


Figure 2. Flow diagram of the literature search using PRISMA protocol

2.3. Inclusion and Exclusion Criteria

Only research articles pertinent to the scope of this study were investigated and analyzed purposively. The researchers established an inclusion criteria in determining journal articles, specifically: a) full text copy of the article must be available online; b) the manuscript must be written using the English language; c) must be an empirical study; d) date of publication must be from 01 Jan 2017 up to 30 Sep 2022; e) inclusion of explicit reference to an STS approach must be evident in the article's title or abstract; f) must utilized experimental and/or quasi-experimental research design with pretest and posttest control groups, thenceforward the non-STS approach or traditional teaching or conventional approach was used in the control group and the STS approach in the experimental group, respectively; g) sufficient statistical or qualitative (i.e., means, standard deviations) must be provided; h) must use any of the following learning outcomes - scientific attitudes and learning achievement as the dependent (outcome) variables; i) was conducted in a K to 12 or higher education setting, and; j) must focus on any scientific disciplines. Literature suggests that research in the sciences, including education, require more cutting-edge research, as these fields change quickly with the acquisition of new knowledge and the need to share it rapidly with practitioners in those fields. Studies published in the past 5 years are a good benchmark since these sources are more current and reflect newest findings (Price, Jhangiani & Chiang, 2015). Hence, in the present meta-analysis, the search for published articles from 2017 to 2022 was prioritized.

The meta-analysis excluded 340 studies from the 354 research articles. Several studies (n=156) were excluded because they were not written in English. These studies were published in Indonesian, Spanish, Portuguese, Arabic, Thai, Korean, and Turkish. Furthermore, there are 131 studies that did not use pure experimental or quasi-experimental research designs. Some studies, for example, used pre-experimental and research and development (R&D) research designs. Other studies were excluded because they did not provide enough statistical information (n = 32), did not have an available full-text manuscript (n = 10), were not published research (n = 8), had an irrelevant learning outcome (n = 2), and one (1) article was retracted. An article retraction is the removal of an already published article from a journal (Grieneisen & Zhang, 2012).

Following the exclusion of the 430 research articles, a manual search was conducted to exhaust and verify the literature, yielding 14 research articles qualified for inclusion in the meta-analysis. To quantify the magnitude of the effect of the STS approach on students' learning outcomes, fourteen (14) research studies with sixteen (16) effect sizes were included. In the reference list, these studies are denoted by an asterisk. Effect size is a statistical concept that quantifies the magnitude or strength of the effectiveness of a particular intervention. For example, an investigator studying numerous trials evaluating a new teaching approach may calculate the average standardized difference between treatment and control groups across all investigations to obtain a mean effect size. There are 16 effect sizes in this meta-analysis since two of the fourteen articles had multiple outcomes (Astuti et al., 2019; Prasasti & Listiani, 2019), which are indicated with an asterisk in Table 1.

These 14 research papers had undergone peer-review process. Peer review has been the foundation of the scholarly publication system since it effectively submitted an author's work to the scrutiny of other experts in the field. As a result, it encourages authors to aim for high-quality research that advances the subject, ensuring that only high-quality research publications are distributed to the scientific community (Kelly, Sadeghieh & Adeli, 2014).

2.4. Coding Procedures

Using Google Sheets, relevant information from research articles were analyzed and coded. The following features were carefully noted by the researchers: a) authors and year of publication; b) locale; c) learning domain; d) educational level; e) scientific discipline; f) STS approach variations; g) implementation duration; h) research design; and i) group comparison with statistical results such as means, standard deviations, and sample size.

The authors of this meta-analysis purposely classified the various learning outcome variables contained in the 14 articles into three groups based on the learning domains: cognitive, emotional, and psychomotor (Kraiger, Ford & Sals, 1993). Learning outcomes are declarations of the information, abilities, and attitudes that every student should have and be able to exhibit after successfully completing a learning experience or series of learning experiences.

Due to the limited number of articles included (n = 14), the first author conducted the coding procedures with direct supervision from the second author. The latter then validated the coded data for its accuracy and truthfulness. Both authors reached a consensus for the finality of the coded data. Discrepancies such as misclassified data, duplicated data, omitted data, and typographical errors were found while reviewing the coded data. To remedy the data input problems, both authors corrected the data by encoding it in the appropriate category, ensuring that it is encoded only once in the document, filling in missing data, and suitably correcting extraneous characters. For the missing data, 10 articles did not disclose the implementation duration. Due to time constraints, the authors were not able to contact the authors of the studies that were included in this meta-analysis. Hence, the data gathered were solely based on the available full manuscript, as per inclusion and exclusion criteria. In this context, the missing data in the manuscript is coded as "Not Reported".

2.5 Data Analysis

For the analysis, the random-effects statistical model was used. The studies included in the analysis are assumed to be a random sample of potential studies. The effect sizes, Hedges' g, of the 16 studies were calculated to determine the effectiveness of the STS approach in improving students' learning outcomes. Hedges' g is the standardized mean difference, which equals the difference in mean values between the experimental and control groups divided by the standard deviation (Hedges & Olkin, 1985). Hedges' g was preferred over Cohen's d because it is more effective at correcting for the bias associated with small sample sizes (Borenstein, Hedges, Higgins & Rothstein, 2010 as cited by Picardal & Sanchez, 2022). Effect sizes, therefore, can be regarded as standardized measures of where the experimental data fall in the control data distribution. Using Cohen's (1988) criteria, the magnitude of the effect sizes was classified as large (g = 0.80 and above), medium (g = 0.50 to 0.79), small (g = 0.20 to 0.49), and no effect (g is less than 0.19). A positive and larger effect size indicates that the group exposed to the STS approach achieved a better learning outcome than the control group who received traditional instruction.

The statistical analyses were carried out using Comprehensive Meta-Analysis Version 4 (Borenstein, Hedges, Higgins & Rothstein, 2022). Moderator and subgroup analyses (Borrenstein, Hedges, Higgins & Rothstein, 2009) were also performed using the mixed effects analysis to determine whether the effectiveness of STS approach on students' learning outcomes varied when grouped according to specific locale, educational level, scientific discipline, learning domain, STS approach variation, and duration of implementation. All tests were computed with a 95% confidence interval, and p-values less than 0.05 were deemed statistically significant. Using the Begg-Mazumdar test, Egger's regression method, classical and Orwin's fail-safe N tests, publication bias was quantitatively described and visualized (Begg & Mazumdar, 1994; Egger, Smith, Schneider & Minder, 1997). Manifestations of publication bias are evident if the ϱ-value is less than 0.05.

3. Results

3.1. General Study Characteristics

A total of 1,629 students were exposed to STS and conventional approaches in the studies included in this meta-analysis. Table 1 shows the descriptive features of these studies, including the author, year of publication, locale, learning domain, educational level, scientific discipline, STS approach variation, duration of implementation, research design, and statistical data from the experimental and control groups.

The meta-analysis used fourteen research articles with sixteen effect sizes. One of these studies was published in 2017, two more in 2018, four more in 2019, one more in 2020, and six more in 2021. Twelve of these investigations were conducted in Asia, one in Africa, and one in North America. The effectiveness of the STS approach in enhancing students' cognitive abilities has been studied in nine studies, in six studies for students' affective domain, and in one study for students' psychomotor capabilities. Furthermore, the teaching interventions were carried out at all levels of basic education: four in grade school, five in junior high school, four in senior high school, and one with a mix of grade school and junior high school students. It can also be seen that the STS approach is widely used in various scientific disciplines such as biology (21%), chemistry (37%), natural science (21%), and science in general (21%). Poluakan et al. (2020), for instance, used the STS approach to teach twenty-five students about additives and addictive substances. Prasasti and Listiani (2019) conducted the approach for twelve weeks, Kapici et al. (2017) for nine weeks, Igboanugo (2021) for five weeks, and Putra (2021) for three weeks, while the other studies do not mention the implementation's duration. The majority of the research designs in the articles were quasi-experimental (86%), with only 7% using mixed method or pure experimental research designs. Finally, statistical data from the experimental and control groups show that the STS approach produced better results than the traditional approach.

3.2. Effect Sizes of STS Approach in Teaching Science Concepts

The heterogeneity analysis was significant ($\varrho < 0.05$), and the Q-Value was determined to be 194.25 with 15 degrees of freedom, as shown in Table 2. Because the value of I^2 is 92.285, it also indicates a high degree of heterogeneity among STS instruction studies. The calculated effect sizes for the random-effects model range between 1.452 (lower limit) and 2.311 (upper limit) at a 95% confidence interval. The overall weighted effect size of 1.882 indicates that the STS approach has a significant large and positive effect on students' learning outcomes (Cohen, 1988). Therefore, the STS approach is effective and has a positive impact on students' cognitive, affective, and psychomotor outcomes.

The researchers also calculated the Hedges' g effect sizes of the studies within a 95% confidence interval. The forest plot distribution, as shown in Table 3, revealed that the majority of the studies favored the STS approach group over the non-STS group. These studies, however, have varying effect sizes and degrees of effectiveness. For instance, the study by Syamsuddin et al. (2019) has the largest effect size (g = 4.937), showing that the STS approach had a significant impact on students' scientific attitudes in comparison to students who followed science learning using the non-STS approach. While using a collaborative learning-based STS approach, the study by Priyambodo, Fitriyana, Primastuti and Artistic (2021) has the smallest effect size (g = 0.435), but students' motivation in the experimental class improved more than that of the control class.

Author	**Year**	**Locale**	**Learning domain**	**Educational level**	**Scientific discipline**	**STS Approach variation**	**Duration**	**Research design**	**STS Group Statistical Data**			**Non-STS Group Statistical Data**		
									Mean	**SD**	**n**	**Mean**	**SD**	**n**
Astuti et al.*	2019	Asia	Cognitive	JHS	Biology	SETS Approach	NR	Quasi	82.40	13.10	32	49.00	15.02	32
Astuti et al.*	2019	Asia	Affective	JHS	Biology	SETS Approach	NR	Quasi	74.60	7.500	32	41.50	9.400	32
Budi et al.	2018	Asia	Cognitive	JHS	Natural Science	SETS Approach	NR	Mixed	84.11	7.360	32	77.86	9.190	32
Igboanugo	2021	Africa	Affective	SHS	Chemistry	STS Approach	5 weeks	Quasi	86.66	21.19	157	71.66	14.81	153
Irfandi et al.	2019	Asia	Affective	GS	Natural Science	STM Approach	NR	Pure	78.38	3.151	26	69.15	2.569	26
Kapici et al.	2017	North America	Cognitive	GS, JHS	Science	STS Approach	9 weeks	Quasi	5.768	2.450	301	2.453	1.200	308
Poluakan et al.	2020	Asia	Cognitive	JHS	Chemistry	STS Approach	NR	Quasi	88.52	6.219	25	68.88	10.28	25
Prasasti & Listiani*	2019	Asia	Cognitive	GS	Science	SETS Approach	12 weeks	Quasi	73.98	6.130	25	61.66	7.040	25
Prasasti & Listiani*	2019	Asia	Psychomotor	GS	Science	SETS Approach	12 weeks	Quasi	82.71	5.625	25	68.24	5.990	25
Pratama et al.	2018	Asia	Cognitive	JHS	Biology	STS Approach	NR	Quasi	77.30	7.280	32	67.60	6.620	32
Priyambodo, Primastuti et al.	2021	Asia	Cognitive	SHS	Chemistry	STSE Approach	NR	Quasi	68.92	11.38	35	62.28	9.620	34
Priyambodo, Sukirno et al.	2021	Asia	Affective	SHS	Chemistry	STSE Approach	NR	Quasi	135.6	11.82	34	120.7	20.05	34
Priyambodo, Fitriyana et al.	2021	Asia	Affective	SHS	Chemistry	STSE Approach	NR	Quasi	71.25	4.810	30	68.87	5.910	32
Putra	2021	Asia	Cognitive	JHS	Biology	SETS Approach	3 weeks	Quasi	86.63	6.246	27	69.56	8.405	27
Syamsuddin et al.	2019	Asia	Affective	GS	Science	STM Approach	NR	Quasi	123.0	3.833	26	108.7	1.232	26
Widiastuti & Purnawijaya	2021	Asia	Cognitive	GS	Natural Science	SETS Approach	NR	Quasi	76.47	11.26	29	52.64	14.73	32

Note. *GS* = Grade School; *JHS* = Junior High School; *SHS* = Senior High School; *SETS* = Science, Environment, Technology and Society; *STS* = Science, Technology, Society; *STSE* = Science, Technology, Society, Environment; *STM* = Society, Technology, Science; *NR* = Not Reported; *Quasi* = Quasi Experimental Design; *Mixed* = Mixed Methods Design; *Pure* = Pure Experimental Design; *SD* = Standard Deviation; *n* = Sample size

*Articles with two (2) effect sizes

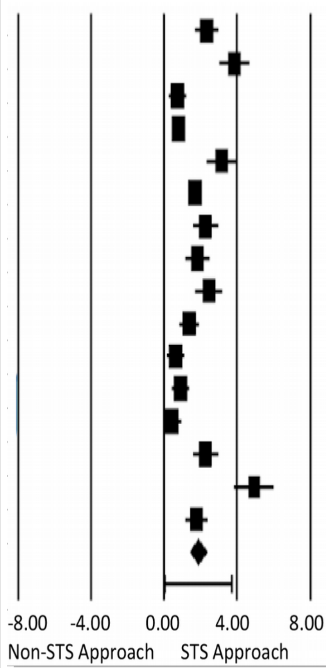
Table 1. Descriptive features of the included studies that investigated the effectiveness of STS approach

Model	Effect size and 95% confidence interval						Test of null (2-Tail)		Heterogeneity statistics			
	No. of Studies	Hedges' *g*	Std error	Variance	Lower limit	Upper limit	Z-value	ϱ-Value	Q-Value	df (Q)	ϱ-Value	I^2
Fixed	16	1.468	0.055	0.003	1.359	1.576	26.563	0.000*	194.425	15	0.000*	92.285
Random	16	1.882	0.219	0.048	1.452	2.311	8.588	0.000*				

Note. Std=Standard error; *Significant at ϱ < 0.05

Table 2. Overall effect size and heterogeneity analysis

Authors	Statistics for each study							Forest Plot
	Hedges' *g*	Std error	Variance	Lower limit	Upper limit	Z-Value	ϱ-Value	Hedges' g and 95% CI
Astuti et al. (2019)	2.341	0.322	0.104	1.710	2.973	7.266	0.000*	
Astuti et al. (2019)	3.845	0.420	0.177	3.022	4.669	9.153	0.000*	
Budi et al. (2018)	0.702	0.256	0.065	0.241	1.242	2.902	0.004*	
Igboanugo (2021)	0.817	0.118	0.014	0.585	1.048	6.923	0.000*	
Irfandi et al. (2019)	3.162	0.413	0.171	2.352	3.972	7.652	0.000*	
Kapici et al. (2017)	1.722	0.095	0.009	1.537	1.908	18.168	0.000*	
Poluakan et al. (2020)	2.275	0.360	0.129	1.571	2.980	6.328	0.000*	
Prasasti & Listiani (2019)	1.836	0.334	0.111	1.183	2.490	5.506	0.000*	
Prasasti & Listiani (2019)	2.450	0.371	0.138	1.724	3.177	6.607	0.000*	
Pratama et al. (2018)	1.377	0.275	0.076	0.838	1.917	5.002	0.000*	
Priyambodo, Primastuti et al. (2021)	0.623	0.244	0.059	0.145	1.101	2.553	0.011*	
Priyambodo, Sukirno et al. (2021)	0.899	0.252	0.063	0.406	1.393	3.570	0.000*	
Priyambodo, Fitriyana et al. (2021)	0.435	0.254	0.064	-0.063	0.932	1.712	0.087	
Putra (2021)	2.272	0.346	0.120	1.594	2.950	6.566	0.000*	
Syamsuddin et al. (2019)	4.937	0.556	0.309	3.847	5.026	8.879	0.000*	
Widiastuti & Purnawijaya (2021)	1.783	0.300	0.090	1.194	2.374	5.938	0.000*	
Pooled Effect	1.882	0.219	0.048	1.452	2.311	8.588	0.000	



Note. Std=Standard error; *Significant at ϱ < .05

Table 3. Effect sizes distribution and forest plot of studies that used STS approach

3.3. Moderator Analysis of Studies Using STS Instruction

The following variables were subjected to moderator analysis: study locale, students' educational level, scientific discipline studies, learning domain outcome, STS approach variations, and implementation time, as shown in Table 4. The largest effect size on students' learning outcomes was found in studies conducted in Asia (g = 2.010), followed by those in North America (g = 1.722) and Africa (g = 0.817). When grouped by research location, the heterogeneity suggests that there are significant differences in the effect sizes of the included studies (Qb = 40.402; ϱ < .05). In terms of educational level, the STS approach has a larger effect size on students in grade school (g = 2.760) than on students in junior high school (g = 2.109), combined grade school and junior high school (g = 1.722), and senior high school (g = 0.751). The effect sizes of the included studies differed significantly (Qb = 69.049; ϱ < .05). Moreover, the STS approach had the greatest impact on the teaching and learning of Science in general (g = 2.620), followed by Biology (g = 2.425), Natural Science (g = 1.862), and Chemistry (g = 0.948). When the effect sizes of the included studies were grouped according to the scientific discipline studied, significant differences were discovered (Qb = 14.734; ϱ < .05). Also observed were large effect sizes when the included studies were categorized into learning domains. Psychomotor skills (g = 2.450), affective skills (g = 2.267), and cognitive skills (g = 1.630) were the student outcomes that were most impacted by the STS approach. The three learning domains, however, did not differ significantly from one another (Qb = 4.4520; ϱ > .05). When STS approach variations were clustered, STM (g = 4.011), SETS (g = 2.150), and STS (g = 1.506) had large effect sizes, while STSE (g = 0.653) had a medium effect size. A significant difference was also discovered among the STS variation subgroups (Qb = 30.816; ϱ < .05). Finally, when the included studies were grouped by implementation duration, large effect sizes were observed among the subgroups: 3 weeks (g = 2.272), 12 weeks (g = 2.122), 9 weeks (g = 1.722), and 5 weeks (g = 0.817). Eleven studies, with a g = 1.972 effect size, were unable to report the duration of their implementation. Nonetheless, a significant difference (Qb = 49.689); ϱ < .05) was seen among studies when clustered into different implementation durations.

			Test for Effect				Test for Heterogeneity		
Moderator	**Subgroups**	**k**	**Hedges' *g***	**Std error**	**Variance**	**95% CI**	**Q-Value**	**Df (Q)**	**ϱ-Value**
Locale	Asia	14	2.010	0.291	0.085	1.440, 2.580	40.402	2	0.000*
	North America	1	1.722	0.095	0.009	1.537, 1.908			
	Africa	1	0.817	0.118	0.014	0.585, 1.048			
Educational level	Grade School	5	2.760	0.475	0.226	1.829, 3.691	69.049	3	0.000*
	Junior High School	6	2.109	0.413	0.170	1.300, 2.918			
	Grade School & Junior High School	1	1.722	0.095	0.009	1.537, 1.908			
	Senior High School	4	0.751	0.091	0.008	0.572, 0.930			
Scientific discipline	Science	4	2.620	0.513	0.263	1.614, 3.626	14.734	3	0.002*
	Biology	4	2.425	0.479	0.230	1.486, 3.364			
	Natural Science	3	1.862	0.656	0.430	0.576, 3.148			
	Chemistry	5	0.948	0.224	0.050	0.509, 1.388			
Learning domain	Psychomotor	1	2.450	0.371	0.138	1.724, 3.177	4.4520	2	0.108
	Affective	6	2.267	0.564	0.318	1.162, 3.372			
	Cognitive	9	1.630	0.194	0.038	1.249, 2.011			
STS approach variations	STM	2	4.011	0.886	0.786	2.273, 5.748	30.816	3	0.000*
	SETS	7	2.150	0.349	0.122	1.466, 2.834			
	STS	4	1.506	0.310	0.096	0.898, 2.113			
	STSE	3	0.653	0.144	0.021	0.370, 0.935			
Duration of implementation	3 weeks	1	2.272	0.346	0.120	1.594, 2.950	49.689	4	0.000*
	12 weeks	2	2.122	0.306	0.094	1.522, 2.722			
	Not reported	11	1.972	0.352	0.124	1.283, 2.661			
	9 weeks	1	1.722	0.095	0.009	1.537, 1.908			
	5 weeks	1	0.817	0.118	0.014	0.585, 1.048			

Note. k = Frequency of effect sizes; Std = Standard error; CI = Confidence Interval; Df = Degrees of freedom
*Significant at ϱ < .05

Table 4. Moderator and subgroup analyses of studies that investigated the effectiveness of STS approach

3.4. Publication Bias

The likelihood of publication bias is indicated by taking into account the funnel plot. The visual representation of the funnel plot analysis revealed an asymmetrical funnel due to an uneven distribution around average effect sizes (Figure 3). Begg-Mazumdar rank correlation, Egger's regression method, classical and Orwin's fail-safe N tests were performed to confirm this finding. Kendall's tau, calculated using the Begg-Mazumdar rank correlation, was 0.66 (ϱ = 0.000). Egger's regression test revealed that the intercept is 3.160 (ϱ = 0.08). The results of the classical fail-safe N tests indicated that, in order to nullify the overall effect size and make the ϱ-value non-significant (ϱ > .05), 2,840 additional STS approach studies must be included in this meta-analysis. According to Orwin's fail-safe N test, 386 missing null studies are required to raise the current overall average size to a certain level. Although the Egger's regression test and the fail-safe N tests results are satisfactory, visual inspection and Kendall's tau reveal signs of publication bias.

3.5. STS Approach Variations and Additional Strategies Used

The studies included in this meta-analysis utilized different STS approaches in the teaching and learning science from various educational levels as shown in Table 5. From the 14 studies included, SETS has been the most widely used (36%), followed by STS (29%), STSE (21%), and STM (14%). Visual-media was used by Astuti et al. (2019) to support the SETS approach. Budi et al. (2018) used the SETS approach in conjunction with modular instruction. Prasasti and Listiani (2019) implemented SETS-based guided experiment books. Pratama et al. (2018) and Poluakan et al. (2020), on the other hand, used the STS approach in combination with worksheet-based activities and Facebook-assisted learning, respectively. When Priyambodo, Primastuti et al. (2021a), Priyambodo, Sukirno, Primastuti, Fitriyana & Pandhanugraha (2021b) and Priyambodo, Fitriyana et al. (2021c) implemented the STSE approach, it was blended with a collaborative learning approach. Irfandi et al. (2019) and Syamsuddin et al. (2019) used the STM approach solely, without combining it with other approaches.

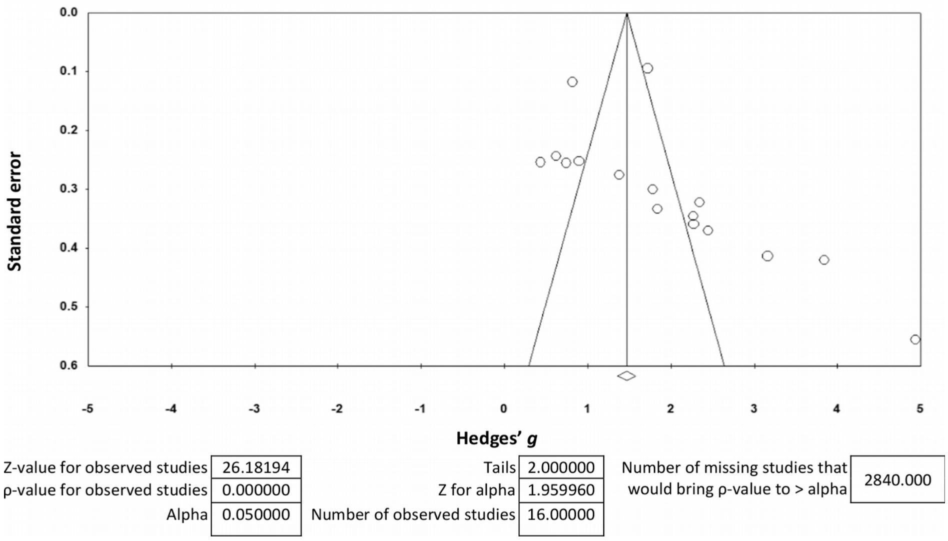


Figure 3. Standard error funnel plot of publication bias

STS approach variation	k	Hedges' *g* (effect size)	Additional Instructional Strategies Used	Study Exemplar
STM	2	4.011 (Large)	Not reported	When teaching science in the classroom, Syamsuddin et al. (2019) applied the STM approach, which is meant to foster students' development of a scientific mindset.
SETS	7	2.150 (Large)	Visual-media assisted approach, IPA module approach, Guided experiments book approach	Budi et al. (2018) created a natural science module design that invited students to consider the use of the concept of science in the form of related technology. Prasasti and Listiani (2019) aimed to empower scientific literacy through SETS-based guided experiment books for the students to unite science, environment, and society. Astuti et al., (2019) used the help of visual media to facilitate students understanding the material and linking science, environment, and society through technology.

STS approach variation	k	Hedges' *g* (effect size)	Additional Instructional Strategies Used	Study Exemplar
STS	4	1.506 (Large)	Facebook-assisted learning, Worksheet-based activity	In order to learn science, Poluakan et al. (2020) enhanced the use of e-learning and blended learning while utilizing the STS learning paradigm with the aid of Facebook social media. The impact of STS approach-based worksheets on raising students' levels of scientific literacy regarding the concepts of environmental pollution was measured by Pratama et al. (2018).
STSE	3	0.653 (Medium)	Collaborative learning	Priyambodo, Primastuti et al. (2021), Priyambodo, Sukirno et al. (2021) and Priyambodo, Fitriyana et al. (2021) used STSE as collaborative learning in chemistry teaching, allowing students to carry out learning activities in situations where two or more people are attempting to learn a chemistry concept together.

Note. k = number of effect sizes; Using Cohen's (1988) criteria, the magnitude of the effect sizes was classified as large (g = 0.80 and above), medium (g = 0.50 to 0.79), small (g = 0.20 to 0.49), and no effect (g is less than 0.19).

Table 5. STS Approach variations and additional strategies used in science instruction

4. Discussion

Science-Technology-Society (STS) is highly regarded as a constructivist and contextualized approach in science education. Previous research has shown that using the STS approach is an effective approach for improving students' learning outcomes, specifically in the cognitive, psychomotor, and affective domains (Budi et al., 2018; Pimvichai, Yuenyong & Buaraphan, 2019; Prasasti & Listiani, 2019; Syamsuddin et al., 2019). Despite the fact that the STS approach is increasingly being recognized as a method for science teaching and learning, there is a need to update and analyze studies pertaining to its effectiveness. To the best of the researchers' knowledge, there has been no systematic reviews, in the form of a meta-analysis, published in the last 20 years that thoroughly reviewed the effect sizes as well as indicators such as the location of the studies included, educational levels, scientific disciplines, learning domains, STS approach variations, and implementation duration. Consequently, the researchers carried out the present meta-analysis in order to fill research gaps and identify future research directions.

This meta-analysis includes fourteen (14) empirical studies with sixteen (16) effect sizes conducted in African, Asian, and North American regions between 2017 and 2022. The total effect size of the included studies was g = 1.882, indicating a large and positive effect on 1,629 students from elementary to senior high school science classes. This result implies that using the STS approach is generally and significantly effective in improving students' learning outcomes in science, supporting previous meta-analysis studies that found the STS approach to be more effective than the traditional method (Jung et al., 2008; Irmita et al., 2016). Due to the wide range of learning outcome variables, the researchers divided them into three categories based on the learning domains: cognitive, affective, and psychomotor (Kraiger et al., 1993). Cognitive domain includes learning outcomes, mainly scientific literacy, and the capacity for critical thought. The elements of the affective domain are motivation, interest, and attitudes toward science. The psychomotor domain includes scientific abilities.

When each study was analyzed, STS approach had been to have a large and positive impact on students' critical thinking ability (Astuti et al., 2019;), scientific attitudes (Astuti et al., 2019; Irfandi et al., 2019; Syamsuddin et al., 2019), interest in learning (Igboanugo, 2021;), ability to apply scientific concepts (Kapici et al., 2017), scientific learning (Poluakan et al., 2020), scientific literacy (Pratama et al., 2018; Prasasti & Listiani, 2019), scientific skills (Prasasti & Listiani, 2019), motivation (Priyambodo, Sukirno et al., 2021), and learning outcomes (Putra, 2021; Widiastuti & Purnawijaya, 2021). Medium effect sizes were observed in the studies of Budi et al. (2018) and Priyambodo, Primastuti et al. (2021) on students' critical thinking skills. In the study by Priyambodo, Fitriyana et al. (2021) on students' motivation for learning science, a small effect size (g = 0.435) was observed. The results are consistent with previous findings that the STS approach improves students' critical thinking and problem-solving skills (Wongsila & Yuenyong, 2019) and their understanding of the nature of science and attitudes toward science (Akcay & Ackay, 2015) significantly more than do students who receive traditional instruction. Implication could be drawn that the STS approach is a suitable and effective teaching strategy that improves students' learning outcomes across all domains of learning.

The large heterogeneity statistic ($I^2 = 92.285$) prompted the use of a moderator analysis. As previously mentioned, the STS approach has been applied contextually at different grade levels in a variety of science subjects for varying lengths of time. As a result, different concepts were adapted, tasks were at different difficulty levels, different learning strategies were employed, and different learning sessions were held, all of which had an impact on the learning outcomes. This suggests that despite the fact that positive effect sizes were found, it is extremely important to take these variables into account. The effect size is significantly influenced by the research location ($\varrho < 0.05$), as the students involved come from various geographical locations. Students may experience different learning outcomes depending on their learning environments (Closs, Mahat & Imms, 2022; Yuenyong, Jones & Yutakom, 2008). The findings of this meta-analysis revealed that Asian studies, followed by American and Nigerian studies, have the largest effect sizes. The ongoing curricular reforms, especially in those Asian nations that did poorly in recent international assessments, are credited with having the largest and most positive effect size among the three subgroups (Irmita et al., 2016). This disparity appears to be due to instructional materials and the depth of the science topic (Pratama et al., 2018). In order to develop students' ability to think critically, a large-scale pedagogical shift toward student-centered learning was implemented (Astuti et al., 2019), which included the STS approach. Up to this day, the STS approach remains as a worldwide science education reform (Pedretti & Nazir, 2015) that gives students the opportunity to compare science, technology and society with each other and to appreciate how science and technology contribute to the latest knowledge/information construction (Pratama et al., 2018).

Besides this, given that the STS approach has been used in elementary through senior high school levels and across scientific disciplines, the educational level and science domain were found to have a substantial impact on the effect size ($\varrho < 0.05$). Grade school, junior high school, as well as a combination of grade school and junior high school subgroups all had large and positive effect sizes in this meta-analysis, compared to the senior high school subgroup, which only had a medium effect size. Over the chemistry subgroup, the science, biology, and natural sciences subgroups have significant and favorable effect sizes. The outcome is attributed to the complexity of the concepts (Igboanugo, 2021; Priyambodo, Fitriyana et al., 2021). The students who participated in the intervention considered the subjects electrolysis and acid-base chemistry to be challenging. Subject matter difficulty rises as education level rises, affecting students' learning outcomes (Kaur & Kaur, 2015; Yu, 2021). Furthermore, the duration of the implementation has a significant impact on the effect sizes ($\varrho < 0.05$) of the studies included in this meta-analysis. Findings showed that 3 weeks of implementation produced the largest effect size, which is in contrast to the meta-analysis findings of Irmita et al., 2016 that the STS approach has a substantial influence on the learning outcomes if imposed within 9 weeks versus 4 weeks and further asserted that spacing out study sessions over a longer period of time enhance long-term memory. This may be attributed to the novelty effect, which produces favorable results when a novel approach, the STS, is implemented. When a new approach is used, there is a tendency for the outcome to initially get better, but this is more due to increased interest in the approach than any actual improvement in learning or achievement. Therefore, as novelty lessens, the beneficial effect also does (Clark, 1983; Rodrigues, Pereira, Toda, Palomino, Pessoa, Carvalho et al., 2022). Student's engagement needs to be sustained through meaningful instructional approaches to overcome the novelty effect (Tsay, Kofinas, Trivedi & Yang, 2019).

Furthermore, there are significant differences of effect sizes when the included studies were grouped as to the STS approach used. The STM, SETS, and STS subgroups all had large and favorable effect sizes, while the STSE subgroup had a medium effect size. These approach variations can be attributed to contextualization, which Rivet and Krajcik (2007) define as a pedagogical strategy that makes use of students' prior knowledge and everyday experiences to aid in their understanding of scientific ideas and concepts. Recent meta-analysis results revealed that contextualized instruction has contributed to improving science learning (Badeo & Duque, 2022; Picardal & Sanchez, 2022).The STM approach was applied by Irfandi et al. (2019) and Syamsuddin et al. (2019) using science and technology issues that are relevant to everyday life and are present in the environment around students. Students gained a positive scientific outlook following the intervention, which they can use to apply scientific principles to problems pertaining to daily life in the community. Furthermore, several STS approach variations employed additional strategies to improve learning outcomes. The SETS method was used in conjunction with the visual-media assisted method (Astuti et al., 2019), the IPA module method (Budi et al., 2018), and the guided experiments book method (Prasasti & Listiani, 2019). By making abstract concepts concrete and simplifying complex concepts, the use of visual media, modules, and guided-experiments books improved learning outcomes in terms of students' level of thinking. While Putra (2021) and Widiastuti and Purnawijaya (2021) only used the SETS approach without any additional strategies, the results showed that students still value science learning more than those in the non-SETS group. According to Poluakan et al. (2020), in relation to STS approach subgroup, the teaching model stimulated students' interest in science learning, particularly with regard to enhancing scientific literacy, when used in conjunction with the social media platform, Facebook. As a result of the study's findings, teachers and students will interact outside of the classroom when using social media for educational purposes. The results of Pratama et al. (2018) demonstrated how the STS approach and worksheets could work together to enhance the scientific literacy of the grade 7 students' learning outcomes. Compared to the other domains of scientific literacy, the collaborative connections had a significant impact on the students' learning of the science content. When using only the STS approach, Kapici et al. (2017) and Igboanugo (2021) found that students' interest in chemistry and their ability to apply their knowledge of science both increased. Comparatively to students who received textbook-focused instruction, students were better able to meaningfully apply fundamental scientific concepts to novel situations. Furthermore, by effectively integrating chemistry as a science with its applications in technology, social issues, and values, the STS instructional approach reduces the abstractness of chemistry concepts and phenomena, making learning chemistry more meaningful for the learners. Finally, the STSE subgroup employed collaborative strategies that had an impact on students' critical thinking. Learning activities in collaborative learning encouraged students to understand the chemistry concept in a follow-up knowledge, beginning with identifying phenomena, explaining scientifically why these phenomena occur, how these phenomena affect society, and how technology plays a role in solving these problems (Priyambodo, Primastuti et al. (2021), Priyambodo, Sukirno et al. (2021), Priyambodo, Fitriyana et al. (2021).

Data analysis revealed that when the included studies were grouped according to the learning domains, they yielded substantial effect sizes. The result favors the experimental groups signifying that the STS approach is more effective than the conventional approach. Interestingly, of the six moderating variables included in this meta-analysis, only learning outcomes reveal no differences. This finding implies further that, the STS is an effective teaching strategy that yields similar positive results, regardless of the learning outcomes assessed (cognitive, psychomotor, and affective). To generate meaningful and sound implications, the researchers examined the likelihood of a publication bias. As previously mentioned, Kendall's tau and the funnel plot both show publication bias. However, funnel plot visual interpretation is inherently subjective (Harbord, Harris & Sterne, 2009). In order to further determine whether the publication bias is likely or not, rank correlation tests were applied. Begg-Mazumdar test results that show evidence of publication bias have a p-value greater than 0.05. However, Sterne, Gavaghan and Egger (2000), as cited by Eger and Maridal (2015), suggested that the Begg and Mazumdar (1994) method has very low power to detect bias in situations where the number of studies in the meta-analysis is small. The Egger's regression test for publication bias should be preferred over the Begg-Mazumdar test given the number of studies included in this meta-analysis as the latter may produce erroneous positive results. Egger's regression test resulted in a p-value greater than .05, therefore, publication bias is unlikely. Publication bias refers to an author's failure to publish the results based on the direction or significance of the findings. Negative research findings are often not published due to the belief that they have failed.

Studies with negative results are often hampered by small sample sizes, insufficient power, lack of group differences, and higher incidence of complications. This can lead to either the editor not submitting the research for additional review or reviewers rejecting the manuscript. If negative results are submitted and deemed appropriate based on methods, statistical techniques, and discussion, they should be considered for publication (Higgins, Thomas, Chandler, Cumpston, Li, Page et al., 2019; Nair, 2019).

4.1. Implications for Further Research and Practice

Throughout this review, numerous questions and new insights have emerged. First of all, it seems that the STS approach could indeed support students' natural tendency to integrate their personal understandings of their social, technological and natural environments into biology, chemistry, natural science, and general science concepts. However, only a few quantitative studies in earth science and physics have been conducted using the STS approach. In this regard, since earth science and physics are so pervasive in everyday life, it would be interesting to conduct a study to confirm the efficacy and understand the characteristics of this approach. Additionally, it would be valuable for future research to further investigate the efficacy of STS approach in an integrated STEM learning environment. STEM education teaches children the value of technology and innovation. As a result, when students come across new technologies, they will be ready to embrace them rather than be reluctant. As the world becomes more technologically centered, this will give them an advantage in the global landscape.

It is very difficult to establish causal relationships because education is a very complex reality that is influenced by a wide range of agents and factors. The ability to conduct causality analyses and respect the various levels of analysis of the variables would be made possible by longitudinal studies with large and representative samples. The STS approach and its effects on students' learning outcomes would also be thoroughly studied through the use of mixed method and case studies in an effort to better understand the complex educational reality. Additionally, the researchers urged future studies to disclose implementation duration and sufficient statistical data, explicitly lay out the steps involved in putting the STS approach into practice, and publish unfavorable results that will aid in establishing causal links between the underlying variables used in the intervention.

In order to ensure that teachers and curriculum developers are equipped to combine the STS approach with cutting-edge teaching techniques, training programs that are geared toward these groups must be established. Due to their different life experiences, teachers and students approach problems in various ways. The significance of hearing the points of view of teachers and students regarding their training, needs, and concerns must also be taken into account. Listening to teachers and students will enhance the STS approach implementation and increase the coherence between the curriculum's offerings and what teachers and students encounter on a daily basis. In other words, there is a chance to use the theory to improve how teaching and learning are done in practice.

4.2. Limitations of the Current Review

The current meta-analysis aimed to deepen current knowledge and understanding of the effectiveness of the STS approach in fostering students' learning outcomes, particularly the cognitive, affective, and psychomotor learning domains; however, the study had some limitations in terms of its implementation, as with any other study. Very few studies were found and included in the review because there were not many rigorous studies that examined the topic of STS approach that met the inclusion criteria. Most of the recent studies that utilized STS approach were not written in English, did not employ quasi or pure experimental research methods, and did not provide sufficient statistical data. Furthermore, despite the extensive database searches, only studies published between 2017 and 2022 were included; the low number of studies found that addressed the research questions may be due in part to this.

5. Conclusion

The current meta-analysis investigated how the STS approach can be used in the educational process of students to produce high levels of cognitive, affective, and psychomotor outcomes. Fourteen studies (with

16 effect sizes) were analyzed for this purpose using quality and inclusion/exclusion criteria. The STS approach has been shown to significantly and favorably affect students' learning outcomes. There are significant differences of effect sizes when the included studies were grouped as to the study locale, educational level, scientific discipline, STS approach variations, and duration of implementation. Visual media, modular instruction, guided experiments book, social media-assisted learning, worksheet-based activities, and collaborative learning were also used to implement the STS approach in science classes. It should be noted that the majority of the studies included are based solely on pretest-posttest scores differences and data collected with small sample sizes, so long term studies with large sample sizes, mixed methods, and case studies would be beneficial to further investigate the possible mutual relationship between the different variables involved in the STS approach implementation. Implications for future research and practice are discussed in order to broaden the benefits of the STS approach in science education.

Acknowledgement

The authors would like to express their sincerest gratitude to the Sotero B. Cabahug FORUM for Literacy, Bulacan State University, and Department of Science and Technology - National Research Council of the Philippines for the support given in this study.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

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