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THE EFFECT OF SOCIO-SCIENTIFIC ISSUES (SSI) IN TEACHING SCIENCE: A META-ANALYSIS STUDY

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Abstract

This study aims to summarize the research findings on using socio-scientific issues (SSI) in teaching Science. In recent years, teaching based on socio-scientific issues (SSI) is utilized in science education to promote scientific literacy. A meta-analysis is conducted by calculating the effect size of the 12 studies associated with the SSI implementation in teaching Science published in different regions. The overall effect size was large (1.08), and found that SSI affects teaching science. The effect sizes determined by the categorical variables such as scientific literacy aspects showed that SSI had a large effect on content learning (1.15), competence (0.89), decision-making (1.14), and reasoning (0.81); and year level showed that SSI had a large effect on junior high school (1.43) and senior high school (0.96) while medium effect on college (0.55). Lastly, a significant effect was shown on the moderating effect, such as the class size (p = 0.035), while no significant effect was shown on the duration of implementation (p = 0.487). Considering the effect of SSI in teaching Science, this study could help teachers and educational researchers in science and technology education.

Keywords **–** Socio-Scientific Issues, Content learning, Competence, Decision-making, Reasoning, Meta-analysis.

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1. Introduction

In today's fast-paced and advanced development in society, science education is tasked to take several actions in helping learners develop the knowledge and practices needed to become scientifically and technologically literate individuals (Zeidler, Sadler, Simmons & Howes, 2005). One of the goals of science education is to produce scientifically literate students who are characterized not only by the mastery of the content but also by generating a well-versed decision regarding an issue (Tal & Kedmi, 2006). The capability of an individual to know and apply knowledge in solving problems in connection with Science and technology in everyday life is referred to as scientific literacy (Rubini, Ardianto, Setyaningsih & Sariningrum, 2019). It is also associated with how individuals understand different societal problems, such as in environmental, health, economic sectors, which are brought about the advances in Science and Technology (Yenni, Hernani & Widodo, 2017).

In recent years, teaching based on socio-scientific issues (SSI) is utilized in science education to promote scientific literacy. According to Roberts and Bybee (2007), scientific literacy has two visions: (1) understanding of ideas within a scientific context, (2) understanding of ideas with other contexts – "real-life" situations that are scientific but are influenced by social, political, and ethical issues. The 21st-century learning processes usually involve learning science content containing multidisciplinary socio-scientific issues (Morris, 2014). The use of these multidisciplinary socio-scientific issues can encourage students to make solutions and decisions supported by evidence-based arguments (Owen, Zeidler & Sadler, 2017).

Socio-scientific Issues are open-ended social problems with conceptual and procedural links to Science (Sadler, 2004). They are related to Science and technology in modern societies and usually entail controversy due to the ethical, social, and environmental implications of scientific and technological advances (Zeidler & Nichols, 2009). The primary purpose of using SSI-based education is to provide a framework for understanding scientific information through the help of socio-scientific issues that are meaningful and engaging on the part of the students (Cayci, 2020).

Different studies have shown how SSI affects teaching and learning processes in science education, thereby improving scientific literacy among students. According to Lee and Witz (2009), SSI includes consciousness toward science-technology-society relationships that leads students to participate in the decision-making procedure, thus meeting the societal necessities of improving scientific literacy in science education. SSI in classrooms enhanced students' awareness of the relationship between science and society and enabled them to identify their reasoning's strengths and weaknesses (Ratcliffe & Grace, 2003). According to Gutierez (2015), the use of socio-scientific issues in education is essential in enhancing scientific literacy. It makes Science learning more relevant to students' lives and provides a venue for evaluating students' appreciation of the nature of science and their learning outcomes.

Different studies have shown a significant effect of using SSI-based education in science teaching in improving students' scientific literacy. These studies measured changes in students' scientific literacy from the scientific literacy aspects such as science content learning (Yenni et al., 2017), competence in Science (Tsai, 2018), decision-making (Gutierez, 2015), and reasoning (Thurrodliyah, Prihatin & Novenda, 2020). With this, a meta-analysis is conducted to summarize the results of research studies that showed the effect of using SSI in teaching Science in improving students' scientific literacy.

1.1. Research Questions

This meta-analysis aims to investigate the effectiveness of using Socio-scientific Issues (SSI) in teaching Science on students' scientific literacy. Specifically, it focused on answering the following research questions:

1. What is the overall effect size of using SSI in teaching Science on students' scientific literacy?
2. What is the effect size according to categorical variables (scientific literacy aspects and year level)?
3. What is the effect size according to continuous variables (class size and duration of implementation)?
4. Is there a significant effect on using SSI in teaching Science according to:
    a) Class Size
    b) Duration of Implementation

1.1.1. Research Hypotheses

In this study, the research hypotheses were proposed:

1. The use of SSI in teaching Science has no significant effect on students' scientific literacy

2. There is no significant effect on using SSI in teaching Science according to class size and duration of implementation.

2. Methodology

2.1. Research Design

This study used Meta-analysis research design which is a quantitative technique that integrates the results of several primary studies to analyze and synthesize them into a coherent product and suggests new emphasis for future researches by exploring deficiencies in existing analyses (Schroeder, Scott, Tolson, Huang & Lee, 2007).

2.2. Data Source and Search Strategies

This meta-analysis uses Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) (Hak, Van Rhee & Suurmond, 2016) guidelines to identify eligible research studies. In searching of research studies for this meta-analysis, Harzing's Publish or Perish software with three (3) databases, namely Google Scholar, Scopus, and CrossRef, was used. In addition, De La Salle University (DLSU) Library database such as the ProQuest online was used as a meta-search engine.

Appropriate keywords were typed in the four databases to identify eligible research studies. Keywords such as "socio-scientific issues", "SSI", "science", "achievement", "scientific literacy", and "quasi-experimental" were used to trim down the number of research studies search in the four databases. Furthermore, this study had pre-set eligibility criteria to choose the most eligible research studies specifically.

2.3. Inclusion Criteria

The criteria used for inclusion into meta-analysis study are given below in detail:

1. The research should use SSI in teaching Science and examine the effect of SSI on students' scientific literacy.
2. Involves quasi-experimental or experimental design that compares SSI-based teaching with traditional-based teaching.
3. Participants should be students in junior high school, senior high school, and college.
4. It must consider science content learning, competency, decision-making, and reasoning as dependent variables in the study.
5. Assessment tools used in studies must have adequate levels of validity and reliability.
6. Reports quantitative data for experimental and control group which includes sample size, post-test mean, standard deviation (SD), and duration of implementation
7. There are no geographical restrictions, but articles should be written in English and must be published in peer-reviewed journals from 2015-2020
8. Articles with incomplete data based on the inclusion criteria are excluded.

After identifying research studies using the keywords such as "socio-scientific issues", "SSI", "science", "achievement", "scientific literacy", and "quasi-experimental", the total number of research studies searched using the four databases was 1248. Figure 1 showed the comprehensive procedure in identifying eligible research studies for meta-analysis following the PRISMA guidelines.

In this study, dissertation and academic journal articles on the use of SSI in teaching Science published from 2015 to 2020 in any country written in English were used as subjects for meta-analysis on the effect size of SSI. The data were collected from the four databases, namely, Google Scholar, Scopus, CrossRef, and Pro-Quest online. A total of 1248 results were found by searching "socio-scientific issues" and "SSI" in the four databases ($n = 998$ in Google Scholar, $n = 17$ in Scopus, $n=200$ in CrossRef, and $n=33$ in ProQuest online), which comprised of 1218 journal articles and 30 dissertations. Upon screening the title and abstracts, 1215 studies were deleted because of the following reasons: (1)

studies not written using English language (n = 7), does not contain the keywords: Socio-scientific issues, SSI, Scientific literacy, Science, and quasi-experimental (1158), Quasi-experimental with one group only (n = 30), effects of SSI do not focus in the field of Science (n = 27), leaving 33 studies to be analyzed in full-text for eligibility. Upon examining the 33 studies in full-text for eligibility, 21 studies were deleted because of incomplete or missing data. Finally, 12 research studies comprised of 2 dissertations and ten journal articles were selected for meta-analysis. Studies that proposed multiple results were analyzed to separate results. For the dissertation published in academic journals, this study chose only the journal article versions.

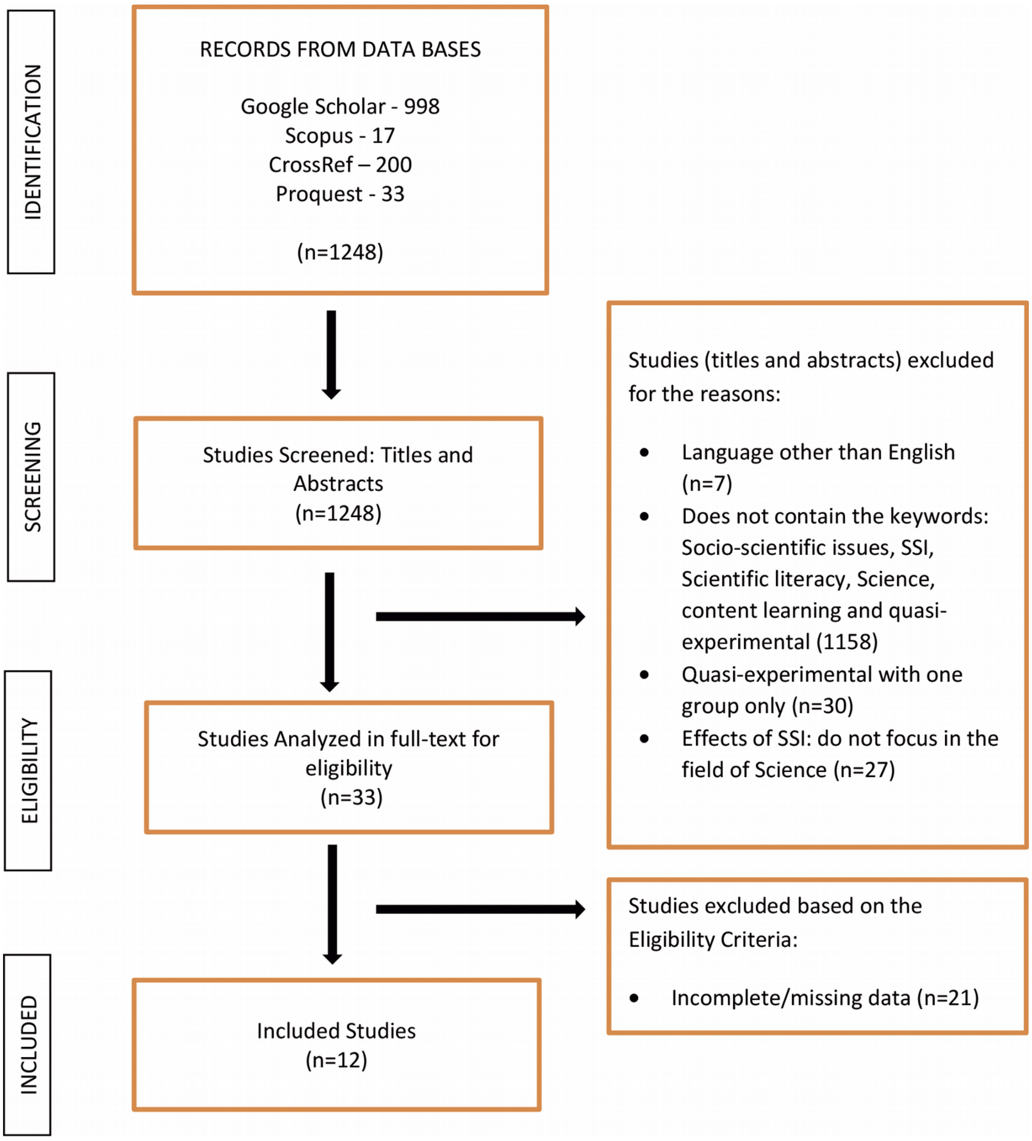

Figure 1. Research Studies Selection using PRISMA (Hak et al., 2016)

2.4. Data Analysis

Meta-essentials version 1.5 (Hak et al., 2016) was used to analyze the data extracted from the 12 studies included in this meta-analysis. Meaningful categories for coding were identified for the 12 papers being reviewed. Gender is excluded as it was mixed in all the studies. This study finalized vital categories such as study source characteristics and quantitative data. For the study source characteristics, data extracted from the research studies were the author/s, year of publication, region, and SSI topics. The quantitative data, mean, SD, and sample size for the experimental and control group were extracted. The standardized mean difference was used the measure the effect size from the mean of the post-test scores of students in the two groups. This study used the interpretation criteria proposed by Hedge and Olkin (1985) to interpret the effect size found in the results of this meta-analysis, which is shown in Table 1.

Small Effect Size	Medium Effect Size	Large Effect Size
$\lvert g \rvert \leq 0.20$	$\lvert g \rvert = 0.20 – 0.80$	$\lvert g \rvert >.80$

Table 1. Interpretation of Effect Size

There are two commonly used statistical models in a meta-analysis, and these are the fixed-effects and the random-effects. Random effects are used if there is no heterogeneity in the data extracted from the articles being reviewed. Data extracted from the 12 studies are said to be heterogeneous if the p-value of Cochran's Q statistic is significant ($p < 0.05$).

This study conducted a publication bias test to secure the internal validity of the meta-analysis results, which can be analyzed using the degree of left-right symmetry found in the distribution of effect sizes based on the funnel plot. Lastly, moderator variables like sample size and duration of implementation were analyzed to examine their significant effect on using SSI in teaching Science on students' content learning.

3. Results and Discussion

3.1. Characteristics of Included Studies

This study included 12 papers published using the English Language from 2015 to 2020 without any geographical restriction. This study finalized vital categories such as study source characteristics and quantitative data. For the study source characteristics, data extracted from the research studies were the author/s name, year of publication, region, and SSI topics. Table 2 presented the characteristics of studies included according to source characteristics.

Article No.	Author/s	Year of Publication	Region	SSI Topics
1	Yenni et al.	2017	Asia	Soil, Air, Water Pollution
2	Yenni et al.	2017	Asia	Soil, Air, Water Pollution
3	Nurtamara, Suranto and Prasetyanti	2019	Asia	Biotechnology
4	Rubini et al.	2019	Asia	Global Warming
5	Penn and Ramnarain	2018	Africa	Genetically Modified Organisms
6	Eggert, Ostermeyer, Hasselhorn and Bögeholz	2013	Europe	Climate change
7	Eggert et al.	2013	Europe	Climate change
8	Gutierez	2015	Asia	Biotechnology, environmental degradation, and cancer research
9	Tsai	2018	Asia	Hazard, natural resources, environment, frontiers of science and technology
10	Thurrodliyah et al.	2020	Asia	Environmental issues
11	Cayci	2020	Asia/Europe	Nuclear power
12	Shoulders and Wyatt	2018	North America	Solar energy

Table 2. Source Characteristics

Table 3 showed the frequency and percentage of the 12 research studies according to scientific literacy aspects being measured and year level.

Meanwhile, Table 4 presented the quantitative data category such as sample size, pretest, and post-test means and SDs for the two groups extracted from the 12 research studies.

	Frequency (n=12)	Percentage (%)
Scientific Literacy Aspects		
Content	4	33
Competence	3	25
Decision-making	3	25
Reasoning	2	17
Year Level		
Junior High School	5	42
Senior High School	5	42
College	2	17

Table 3. Number of Articles according to science literacy aspects, year level, and use of SSI

Article No.	Sample Size (n)		Pretest Mean and SD				Posttest Mean and SD			
	SSI	Traditional	SSI	SD	Traditional	SD	SSI	SD	Traditional	SD
1	32	33	46.72	8.45	44.42	8.21	86.59	7.89	76.26	8.34
2	32	33	53.12	7.89	47.48	9.22	84.76	8.34	74.62	8.23
3	21	23	32.45	13.64	33.33	13.3	82.8	10.96	62.32	16.41
4	34	30	15.2	3.45	14.5	2.91	20.03	2.01	16.23	2.43
5	48	56	3.98	1.48	3.35	1.30	4.58	0.98	2.83	1.28
6	129	119	2.80	1.82	2.60	1.70	4.88	1.64	3.53	1.66
7	129	119	8.72	2.91	8.59	2.82	10.69	3.46	9.05	3.34
8	34	38	11.03	2.51	10.39	1.65	22.39	1.78	18.29	1.49
9	77	50	7.29	1.48	7.24	1.42	8.14	1.14	7.10	1.52
10	20	16	27.63	8.90	28.05	12.88	79.56	8.65	73.33	15.11
11	53	52	38.08	11.26	41.56	9.74	52.51	12.52	40.62	12.27
12	82	59	16.59	3.46	15.34	3.39	20.12	2.83	19.63	2.82

Table 4. Quantitative Data

3.2. Overall Effect Size from Forest Plot

Complete quantitative data from the 12 research studies, as shown in Table 5, were analyzed using the Meta-essentials Version 1.5 (Hak et al., 2016). The overall effect size from the forest plot is being interpreted to answer the first research question, which determines the effectiveness of using SSI in teaching Science on students' content learning. Table 5 showed the overall effect size obtained from the forest plot.

Number of Studies	Z-value	p-value	Effect Size	CI Limit	Standard Error
12	6.01	0.000	1.08	0.68-1.48	0.18

Table 5. Overall Effect Size

Table 5 showed the meta-analysis results on the 12 research studies on the effects of SSI in teaching Science on students' scientific literacy. The overall effect size was 1.08, and the 95% confidence interval had lower and upper limits, which was from 0.68 to 1.48. According to the effect size interpretation criteria proposed by Hedge and Olkin (1985), the overall effect size was large. It can also be noted that the z-value and p-value showed in the forest plot were significant, suggesting that the null hypothesis must be rejected. Thus, the use of SSI in teaching Science has a significant effect on students' scientific literacy aspects being measured. The significant p-value also suggests that the random-effects model is more appropriate to use. Furthermore, Figure 2 showed the pictorial representation of the forest plot, and Table 6 showed the effect size, Hedge's g, for each of the 12 research studies.

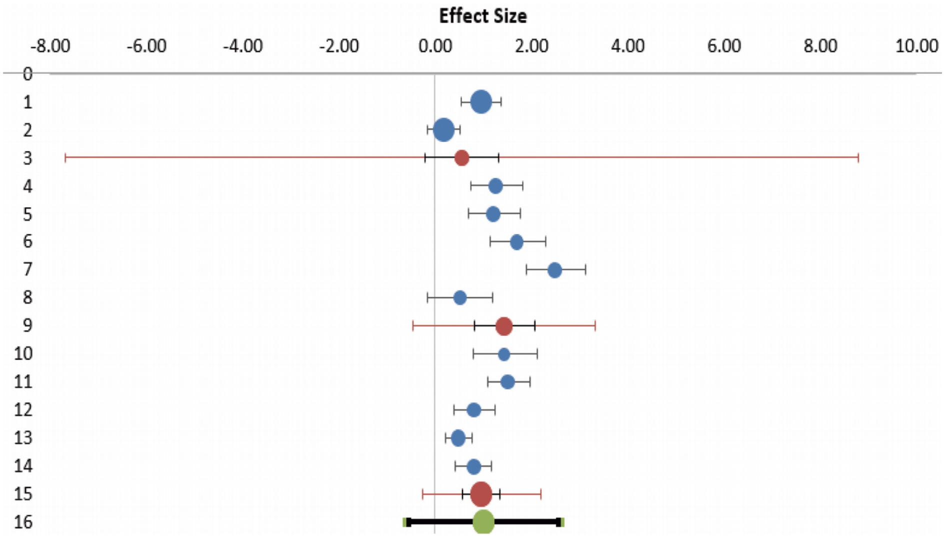

Figure 2. Forest Plot

Article No.	Study name	Hedges' g	CI Lower limit	CI Upper limit	Weight
1	Yenni et al.	1.26	0.73	1.81	8.09%
2	Yenni et al.	1.21	0.69	1.76	8.11%
3	Nurtamara et al.	1.43	0.78	2.13	7.31%
4	Rubini et al.	1.69	1.14	2.29	7.84%
5	Penn and Ramnarain	1.51	1.08	1.96	8.63%
6	Eggert et al.	0.81	0.39	1.25	8.69%
7	Eggert et al.	0.48	0.21	0.76	9.45%
8	Gutierez	2.48	1.89	3.13	7.57%
9	Tsai	0.79	0.43	1.17	9.00%
10	Thurrodliyah et al.	0.51	-0.16	1.20	7.31%
11	Cayci	0.95	0.55	1.36	8.82%
12	Shoulders and Wyatt	0.17	-0.16	0.51	9.17%

Table 6. Effect Size of 12 Research Studies

3.3. Test of Heterogeneity

Random effects are used if there is heterogeneity in the data extracted from the articles being reviewed. Data extracted from the 12 studies are said to be heterogeneous if the p-value of Cochran's Q statistic is significant ($p < 0.05$). Table 7 showed the results of the test of heterogeneity on the 12 research studies being reviewed.

Table 7 showed that the p-value of Cochran's Q Statistics is significant. The high measure of heterogeneity suggests that individual findings used in this meta-analysis cannot be considered to be studies of the same population. This result also implied that subgroup analysis could be performed.

Q-value	pQ	I^2
75.70	0.000	85.47%

Table 7. Test of Heterogeneity

3.4. Subgroup Analysis

Subgroup analysis was performed to determine the effect size according to the categorical variables such as scientific literacy aspects (content, competency, decision-making, and reasoning) and year level (junior high school, senior high school, and college). Tables 8 and 9 showed the effect size according to the subgroups that were made in this study.

Table 8 showed the effect sizes according to the dependent variables. The effect size for content (1.15) was the largest, followed by decision-making (1.14), competence (0.89), and reasoning (0.81). According to the effect size interpretation criteria proposed by Hedge and Olkin (1985), SSI had a large effect size on all the dependent variables, as well as the combined size effect of 0.91. Meanwhile, a high level of heterogeneity can be seen in all scientific literacy aspects being measured. The results of this study are similar to the study of Yenni et al. (2017) that showed significant improvement in students' science content learning using SSI in teaching environmental pollution. In a study conducted by Tsai (2018), students' competence in Science was also enhanced upon embedding online argumentation of socio-scientific issues in their science class. Students' reasoning towards a particular issue was also studied by Thurrodliyah et al. (2020), which improved after using SSI in problem-based learning. On a local note, Gutierez (2015) conducted a study on integrating socio-scientific issues in teaching biotechnology to high school students, which significantly affected students' bioethical decision-making skills.

Table 9 showed the effect sizes according to year level. The effect size for college (0.55) was the smallest. The effect size for senior high school was 0.96, and the largest effect size was 1.13 for junior high school. According to the effect size interpretation criteria, the effect size for college was medium, while the effect size for junior and senior high school was large. This result agrees with the study conducted by Yenni et al. (2017) that using SSI in teaching environmental pollution topics had more impact on junior high school students than on college students based on the assessment tools and learning logs that they used. It can also be noted that the p-values for each year level were all significant. Thus, moderator analysis can be performed. Meanwhile, a high measure of heterogeneity can also be seen in each year level.

Subgroup name	Hedges' g	CI Lower and Upper limit	Q	pQ	I^2
Content	1.15	0.46-1.82	35.10	0.000	91.45%
Competence	0.89	0.66-1.13	34.51	0.001	90.23%
Decision-making	1.14	0.30-2.59	37.31	0.000	94.64%
Reasoning	0.81	0.40-1.22	28.67	0.005	89.45%
Combined Effect Size	0.91	0.36-2.18	75.70	0.000	85.47%

Table 8. Effect Size by Dependent Variables

Subgroup name	Hedges' g	CI Lower and Upper limit	Q	pQ	I^2
Year Level					
College	0.55	0.21-1.32	8.59	0.003	88.35%
Junior High School	1.43	0.80-2.06	20.94	0.000	80.90%
Senior High School	0.96	0.57-1.35	18.93	0.001	78.87%
Combined Effect Size	1.01	0.55-2.57	75.70	0.000	85.47%

Table 9. Effect Size according to Year Level

3.5. Moderator Analysis

In this study, the effect of using SSI in teaching science is determined according to the set moderator variables, which were the class size and duration of implementation. Moderator analysis was performed to determine if these moderator variables significantly affect the intervention being studied. Table 10 showed the results of the moderator analysis according to class size and duration of implementation.

Category	Covariate	B	SE	β	Z-value	p-value
Class size	Intercept	1.70967	0.34		5.07	0.000
	Moderator	-0.01294	0.01	-0.52	-2.11	0.035
Duration of implementation	Intercept	0.49	0.49		2.87	0.004
	Moderator	0.18	0.18	-0.21	-0.69	0.487

Table 10. Results of moderator analysis according to class size and duration of implementation

Table 10 showed the gradient according to class size, which was -0.01294 ($p < 0.05$), while the gradient according to the duration of implementation was 0.18 ($p > 0.05$). This study showed the use of SSI in teaching science had a significant effect on students' content learning according to class size and had no significant impact according to the duration of implementation.

A prior meta-analysis reported no clear correlation between the effect size and the duration of implementation (Bellini, Peters, Benner & Hopf, 2007; Kwon, Lee & Lee, 2016). In addition, Gül Ture, Yalcin and Yalcin (2020) stated that selecting socio-scientific issues in teaching science is more important than the duration of implementation. However, the use of SSI in teaching science should be implemented with the smallest number of participants to ensure content learning and encourage students to make solutions and decisions supported by evidence-based arguments and reasoning (Owen et al., 2017).

3.6. Publication Bias

This study conducted a publication bias test to secure the internal validity of the meta-analysis results, which can be analyzed using the degree of left-right symmetry found when this study examined the distribution of effect sizes based on the funnel plot. The result of this test is presented in Figure 3.

As presented In Figure 3, the funnel plot is constructed symmetrically, which denotes that this study could not find a publication bias in 12 research studies chosen to be the subjects of this study. This result is also supported by the high measure of heterogeneity using the test of heterogeneity.

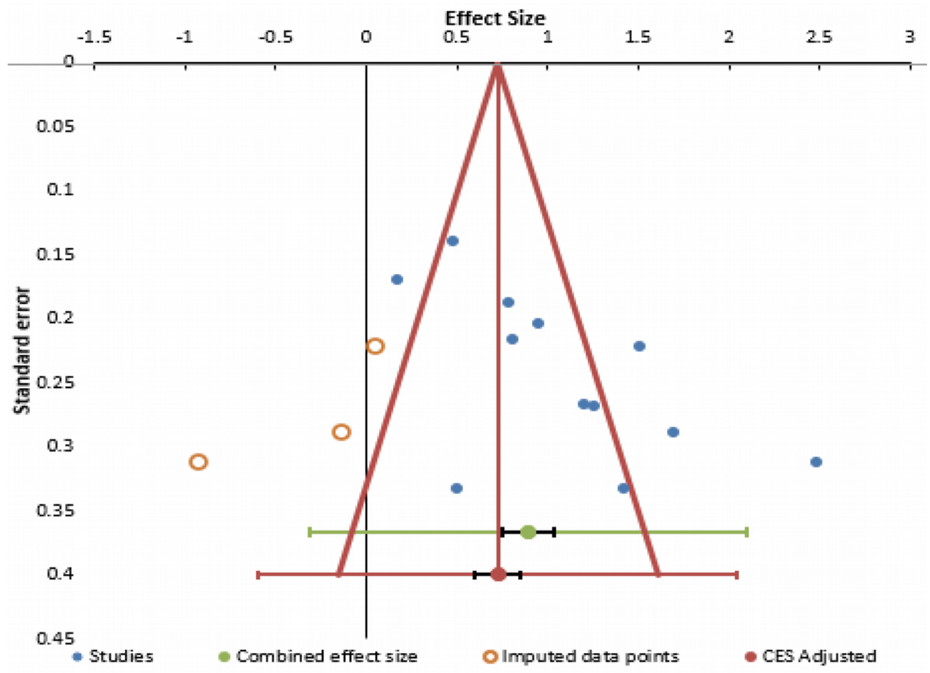

Figure 3. Funnel Plot

4. Conclusion

This study confirmed the effects of using socio-scientific issues (SSI) in teaching Science on students' scientific literacy. In particular, the use of SSI was found to have a large effect on students' content learning (Yenni et al., 2017), competence (Tsai, 2018), decision-making (Gutierez, 2015), and reasoning (Thurrodliyah et al., 2020). Meanwhile, using SSI in teaching science is found to have a large impact on junior and senior high school students while a medium impact on college students. This result agrees with the study conducted by Yenni et al. (2017) that using SSI in teaching environmental pollution topics had more impact on junior high school students than on college students based on the assessment tools and learning logs that they used. Lastly, the use of SSI in teaching science significantly affected students' scientific literacy according to class size and had no significant effect according to implementation duration. These results support the study of Bellini et al. (2007) and Kwon et al. (2016) that the course of implementation is not correlated with the effect size.

A range of desirable goals has been achieved in the literature when SSI is integrated into classroom practice. In addressing SSI in the classroom requires teachers to incorporate student-centered classroom practices that promote the students' development of knowledge and higher-order skills. The teacher's best function is a facilitator who designs learning activities that provide students with opportunities to actively participate in learning experiences such as processes of inquiry, debate, and exploring evidence-based arguments and reasoning. It also requires teachers to be skilled in structuring appropriate socio-scientific issues that could lead to science content learning and in leading interactive discussions.

Declaration of Conflicting Interests

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

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