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The Effectiveness of Scientific Argumentation Strategy towards the Various Learning Outcomes and Educational Levels Five Over the Years in Science Education: A Systematic Review and Meta-analysis Using R Application

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ABSTRACT

This study aimed to investigate the effectiveness of scientific argumentation strategy towards various learning outcomes and educational levels five over the years in science education. This study was used systematic review and meta-analysis using R application. Selected ten articles from Web of Science database during 2016-2020 were used in this study. The results showed that scientific reasoning is more effective for improving through scientific argumentation in the higher education level than other learning outcomes and other educational levels with effect size 1.39 and standard error (0.2478. So, we can conclude that there is evidence to suggest using a scientific argumentation strategy in improving scientific reasoning in higher education level both in the teaching process and the research.

Keywords: Scientific argumentation, Meta-analysis, Science education

INTRODUCTION

Scientific argumentation plays a role important in science that tries to validate a claim on the basic reasons in a manner that reflect the values in the community of science (Norris et al., 2007). Scientific argumentation is a logical and rational discourse aimed at finding the relationship between ideas and evidence (Duschl et al., 2007). Sampson & Schleigh (2013) state that there are three scientific argumentation components, including the claim, the evidence, and justification of the evidence. The claim is about explaining to answer the research question, the evidence is activity to interpret the results of observing, measuring, or looking for other studies, a justification of the evidence is about explaining the relevant or rational evidence and linking it to a specific concept (Sampson & Schleigh, 2013). Scientific argumentation in science education has many advantages, such as stimulating students' motivation, promoting

conceptual understanding, enhancing the performance of students, and developing critical thinking (Faize et al., 2007).

Today, scientific argumentation is a pedagogical practice and core competency in school science in many countries (Giri & Pailiy, 2020). Programme for International Student Assessment (PISA) encourages the ability to use scientific evidence to support the claims as one of the important in scientific argumentation components (OECD, 2013). The National Research Council (NRC 2012) identified engaging in argument from evidence as one of the eight essential scientific practices that students should experience in K-12 science education. The European Union officially recommended incorporating scientific argumentation as a set of key competencies for lifelong learning (European Union, 2006). Tsai (2018) found that the socio-scientific issue scientific argumentation strategy involves diverse responses, explanations, and challenging opposite views with countering ideas.

A previous study by Engelmann et al. (2016) showed that scientific argumentation is one of the successful strategies to enhance scientific reasoning. However, this previous study has conducted a meta-analysis on scientific reasoning to investigate the suitable strategy which successfully implemented in improving scientific reasoning at the school level. So, we need to investigate the effectiveness of scientific argumentation strategy towards various learning outcomes in science education in various education levels.

Based on the previous studies, this study aimed to investigate the effectiveness of scientific argumentation strategy towards the various learning outcomes and educational levels in science education using systematic review and meta-analysis. This study would provide educational researchers with a deeper understanding of the learning outcomes that can be improved effectively through scientific argumentation at various educational levels.

METHOD

This study was used systematic review and meta-analysis. This study's steps were adapted to the systematic review steps by Dixon-Wood et al. (2006) and Meta-analysis by Lipsey and Wilson (2001). First, we reviewed and decided the research questions “what is the most effective learning outcome to be improved through scientific argumentation strategy and what is the most effective educational level to improve that learning outcome during five over the years in science education?”. Second, we conducted systematic literature to find articles five over the years from 2016 until 2020 in the Web of Science database through the term "scientific argumentation" and found 631 papers. Third, we used the following criteria to select the articles included in the meta-analysis: (a) The paper was an empirical publication in a scientific journal; (b) English language of publication; (c) The paper was included a report of intervention and at

least one between-group comparison in a post-test measuring scientific argumentation; (d) The interventions were conducted in junior high school, high school, and undergraduate level. From the third step, we got ten selected articles that consist of 16 various learning outcomes which be developed through scientific argumentation strategy. Then, we conducted the meta-analysis using the R application.

RESULTS AND DISCUSSION

We have analyzed the comparison of the level group, learning outcome, and the teaching method on scientific argumentation strategy (Table 1).

Table 1. Comparison of the educational level, learning outcome, and the teaching method on scientific argumentation strategy

Reference	Educational Level	Learning outcome	Teaching method on scientific argumentation strategy
Acar & Patton (2016)	Higher education	Knowledge achievement	Argumentation-Based Inquiry
Acar & Patton (2016)	Higher education	Scientific reasoning	Argumentation-Based Inquiry
Tsai (2018)	Senior high school	Scientific competencies	Socio-scientific issues Online-Argumentation Pattern (SOAP)
Tsai (2018)	Senior high school	Sustainability attitudes	Socio-scientific issues Online-Argumentation Pattern (SOAP)
Larrain et al. (2018)	Elementary school	Disciplinary content knowledge	Peer-Group Argumentative Dialogue
Larrain et al. (2018)	Elementary school	Individual argumentation skills	Peer-Group Argumentative Dialogue
Pekel (2019)	Junior high school	Students' understanding	Argumentation-based concept cartoons
Ping et al (2019)	Senior high sc	et al.Science Process Skills	Modified Argument-Driven Inquiry (MADI) Strategy
Ping et al (2019)	Senior high sc	et al.Practical Skills	Modified Argument-Driven Inquiry (MADI) Strategy
Ping et al (2019)	Senior high sc	et al.Experimental Planning	Modified Argument-Driven Inquiry (MADI) Strategy
Larrain et al (2019)	Junior high sc	et al.Science content knowledge	Peer argumentation
Fan et al (2020)	Higher education	students' argumentation ability	Online argumentation model
Fan et al. (2020)	Higher education	Knowledge achievement	Online argumentation model
Faize & Akhtar (2020)	Higher education	Environmental knowledge	Scientific argumentation strategy
Faize & Akhtar (2020)	Higher education	Environmental attitude	Scientific argumentation strategy
Giri & Paily (2020)	Senior high school	Critical thinking	Toulmin's argument pattern (TAP) within Think-Read-Group-Share-Reflect (TRGSR) scientific argumentation strategy

Table 1 shows that there are two learning outcomes in elementary school level that can be improved through scientific argumentation strategy (Larrain et al., 2018), two learning outcomes in junior high school level that can be improved through scientific argumentation strategy (Pekel, 2019; Larrain et al., 2019), six learning outcomes in senior high school level that can be improved through scientific argumentation strategy (Tsai, 2018; Ping et al., 2019; Giri & Paily, 2020), and six learning outcomes in higher education level that can be improved through scientific argumentation strategy (Acar & Patton, 2016; Fan et al., 2020; Faize & Akhtar, 2020). Based on the systematic review, higher education and senior high school levels are the most educational level studied on various learning outcomes through the scientific argumentation strategy. The example in the previous study in higher education by Fan et al., (2020) was developed online argumentation model for undergraduate students to get proficient in critiquing arguments, defending claims in reasoned discussions with peers, presenting high-quality argumentation, and linking science education and daily experiences in the instructional argumentation process for improved learning. The example in the previous study in senior high school by Tsai (2018) was integrated the socio-scientific issue in the scientific argumentation strategy in senior high school. Sadler and Zeidler (2005a;b) state that students need to support their arguments using scientific evidence. So, it can be the reason why scientific argumentation can be implemented in senior high school.

We divided learning outcomes into three types through scientific argumentation strategy, including knowledge, skills, and attitude (Gagne, 1984). Gagne (1984) and Bloom (1956) state that knowledge, skill, and attitude are the learning outcomes that have been distinguished and appear to be widely accepted. Table 1 shows that there are 11 learning outcomes in knowledge domain that can be improved through scientific argumentation strategy (Acar & Patton, 2016; Tsai, 2018; Pekel, 2019; Larrain et al., 2018; Fan et al., 2020; Faize & Akhtar, 2020; Larrain et al., 2019; Giri & Paily, 2020), three learning outcomes in skill domain that can be improved through scientific argumentation strategy (Larrain et al., 2018; Ping et al., 2019), and two learning outcomes in attitude domain that can be improved through scientific argumentation strategy (Tsai, 2018; Faize & Akhtar, 2020). Based on the systematic review, the learning outcome in the knowledge domain is the most learning outcome which be developed through scientific argumentation. All educational levels in these previous studies assess the learning outcome in the knowledge domain. Tsai (2018) assessed students' scientific competencies as one of the scientific knowledge to identify questions and to draw evidence-based conclusions using online argumentation of socio-scientific issues. Additionally, Pekel (2019) examined the effectiveness of argumentation-based concept cartoons on students'

understanding of global warming, ozone layer depletion, and acid rain, compared to a traditional teaching Strategy. Dawson and Venville (2013) stated that one of the aims of international science education is to develop a deeper understanding of students on the world around them and they could use the understanding of science to contribute to public debate and make informed and balanced decisions about scientific issues that impact their lives. Jimenez-Aleixandre & Erduran (2008) state that scientific argumentation strategy as scientific learning is to develop a scientific way of thinking that is characterized by question-driven processes of inquiry about social and natural phenomena, in which evidence is gathered and alternative interpretations evaluated through a rational process that unfolds in the discourse, leading to knowledge construction and conceptual understanding

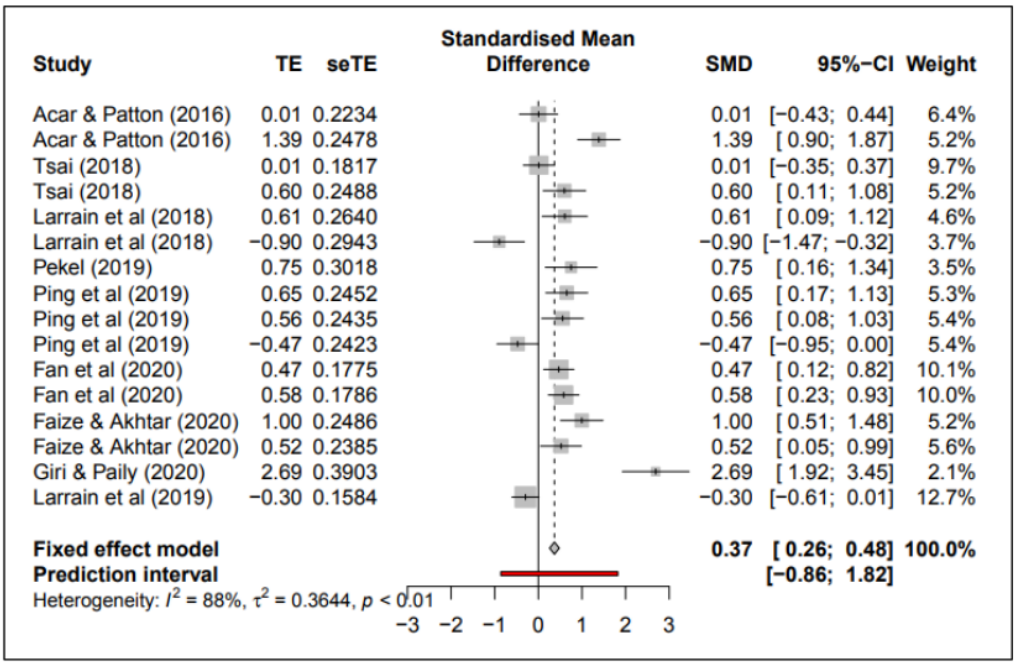

Figure 1. Meta-analysis result of scientific argumentation strategy on various learning outcomes and educational levels

Figure 1. shows that the pooled effect size of 16 learning outcomes which improved through scientific argumentation strategy in various education levels is medium level (i = 0.88, SMD = 0.37, p < .01, k = 16) (Cohen, 1988). It means that all learning outcomes include knowledge, skills, and attitude that can be improved through scientific argumentation. Figure 1. Shows that the study from Giri and Paily (2020) has the highest pooled effect size (SMD = 2.69) in this meta-analysis study that assessed students' critical thinking in senior high school using Toulmin's argument pattern (TAP) within Think-Read-Group-Share-Reflect (TRGSR)

scientific argumentation strategy. However, the study has the highest error (seTE = 0.3903) in this meta-analysis study. That is because the mean of the experimental group has a high gap with the control group's mean if we compare it with the studies in this meta-analysis. According to Hunter dan Schmidt (1990), there are two limitations in a meta-analysis study to collect the data are sampling error and error of measurement. So, the most effective learning outcome to be improved through scientific argumentation strategy is scientific reasoning in higher education level by Acar & Patton (2016) with effect size 1.39 and standard error 0.2478. Engelmann et al. (2016) state that scientific reasoning and scientific argumentation use evidence and communicates and scrutinizes the results of a scientific discovery process, and Lawson (2010) states that argumentation and scientific reasoning have a relationship with each other. Additionally, D'Souza (2018) states that the argumentation strategy is the practice in a science activity that can enhance the epistemic foundation to evaluate good evidence and develop the reason and determine the theories. So, it can be the reason why scientific reasoning is the more effective learning outcome which be developed through scientific argumentation. Additionally, Acar & Patton (2016) studied in the higher education level. So, we can conclude that scientific reasoning is more effective to be improved through scientific argumentation strategy in the higher education level than other learning outcomes and other educational levels.

CONCLUSION

The scientific reasoning is more effective for improving through scientific argumentation in higher education than other learning outcomes and other educational levels with effect size 1.39 and standard error (0.2478. So, we can conclude that there is evidence to suggest using a scientific argumentation strategy in improving scientific reasoning in higher education level both in the teaching process and the research.

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