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A Meta-Analytic Review of the Effectiveness of the Science Writing Heuristic Approach on Academic Achievement in Turkey

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The Science Writing Heuristic (SWH) approach is described as an immersive argument-based science inquiry focusing particularly on learning through epistemic practices. In the literature, several previous studies indicate how academic achievement is positively influenced by the SWH. In addition to these previous studies, several meta-syntheses of qualitative data have been conducted on this particular topic. With these literatures in mind, a quantitative meta-analysis was conducted with ten studies (N = 724) to examine the effectiveness of the SWH on student achievement in Turkey. To present a thoroughly detailed report, this study also examined the following moderators: grade level, subject area, school location, intervention length, and report source. Overall, this study found that in Turkey, the SWH classrooms performed better in academic achievement tests than traditional lecture-based classrooms. Additionally, the SWH is more likely to be effective regardless of grade levels, subject areas, and school locations.

Keywords: the SWH approach, epistemic practices, meta-analysis, academic achievement.
MESC Classification: 97D99
MSC2010 Classification: 62P99

I. INTRODUCTION

With the growing interest in reforming science learning environments from a traditional, lecture-based to a generative practice-based classroom, Turkey pays attention to effective learning approaches (Ministry of National Education [MoNE], 2018; Organisation for Economic Co-operation and Development, 2017). While investigating common features of effective learning environments, science educators and researchers formed the idea that epistemic practices play significant roles in developing knowledge and skills as well as

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growing science concepts (Bransford, Brown, & Cocking, 2000; Buehl & Fives, 2016; Jiménez-Aleixandre & Crujeiras, 2017; National Research Council, 2012). In other words, promoting students' complex problem-solving skills is tightly related to learning through epistemic practices (Kelly, 2011).

Epistemic practices refer to an understanding of knowledge and the process of knowledge generation (Bae, Fulmer, & Hand, 2021; Feucht, 2010; Manz, 2015; Muis & Duffy, 2013). In the classroom emphasizing epistemic practices, students elaborate their knowledge by explaining ideas and asking questions about their conceptual understanding (Hand, Norton-Meier, Gunel, & Akkus, 2016). During knowledge elaboration, students begin to recognize that knowledge is developed by themselves through these social interactions mediated by language (e.g., explanation and asking questions) (Ardasheva, Norton-Meier, & Hand, 2015). That is to say that learning science through epistemic practices allows students to build scientific knowledge through the culture of science which views language as "an epistemic tool" (Fulmer et al., 2021, p. 1).

Epistemic practices have been described by multiple forms: argumentation (Asterhan & Schwarz, 2016; Hand, 2007), small group/peer discussion (Engin, 2017), whole class discussion (Chen, 2011), and writing to multiple audiences (Glynn & Muth, 1994; McDermott & Hand, 2010). Students can build both knowledge and an understanding of knowledge generation because they learn science through various forms of epistemic practices rather than one fixed form. For example, students develop conceptual ideas by designing scientific experiments through small group collaboration or whole class discussions and interpreting results with peers through scientific argumentation.

The Science Writing Heuristic (SWH; Hand & Keys, 1999) approach provides detailed examples about how to create learning environments in which students engage with multiple forms of epistemic practices. The SWH approach is an argument-based intervention that focuses on students' immersion in the development of intellectual resources (e.g., critical thinking skills and scientific knowledge) using language as an epistemic tool. In detail, students in the SWH classrooms develop academic and argumentative language while using writing and argumentation as learning tools (Hand, 2017; Norris & Phillips, 2003). This has been seen in the study of Hand, Chen, and Suh (2020) that "students are encouraged to negotiate from their prior knowledge, through to questions to explore phenomena, to generating claims and evidence in response to these questions, and to the generation of the final summary writing piece" (p. 5). Hence, language-based epistemic practices are critical elements of the SWH approach that creates effective and generative science learning environments.

The SWH approach has been effective in students' academic achievement and critical thinking skills (Hand et al., 2016; Hand, Shelley, Laugerman, Fostvedt, & Therrien, 2018; Lamb, Hand, & Kavner, 2020). Hand (2017) distinguished the SWH approach from other structured argument-based interventions that "our over-riding framework is to see that we need to immerse all learners in using language as an epistemic tool" (p. 21). Furthermore, several studies have shown that the SWH approach is an optimal approach for multicultural classrooms because it embraces diverse learners' engagement through epistemic practices. Ardasheva et al. (2015) described that the SWH approach creates "non-threatening learning environments" (p. 222) for linguistically diverse learners by welcoming every student's different voices. Additionally, investigating the impact of the SWH approach in Turkey would be beneficial due to the increasing number of the implication of the SWH approach in Turkish science classrooms (e.g., Kingir, 2011; Ulu & Bayram, 2015; Yaman, 2018). Therefore, this study focuses on investigating the effectiveness of the SWH approach in Turkey through the lens of a meta-analytic approach.

To quantify the effectiveness of the SWH approach, we limited possible literature to quasi-experimental designs that include at least one experimental and one control group. While analyzing the overall effect of the SWH approach on students' science achievement, this study also analyzed how different moderators affect the relationships between the SWH approach and academic achievement. In order to render a more detailed report, the present study examines the effects of five moderators: (a) grade level (e.g., secondary-level or college-level), (b) subject area (e.g., biology, chemistry, or physics), (c) school location (e.g., rural or urban), (d) intervention length (e.g., less than or equal to eight weeks or greater than eight weeks), and (e) report source (e.g., dissertations, journal articles, or master theses). With these objectives in mind, our research questions are:

(1) Does the SWH significantly impact students' academic achievement in Turkey?

(2) How do the moderators affect the relationship between the SWH and academic achievement?

II. LITERATURE REVIEW

1. EPISTEMIC PRACTICES AND THE SWH APPROACH

The Science Writing Heuristic (SWH) is a science learning approach created by Hand and Keys in 1999. The SWH approach is considered an immersive argument-based inquiry because students are encouraged to use argument as a tool to develop knowledge rather than view it as an insipid form that only exists in laboratory reports. Such perspectives that view argument as an epistemic tool distinguish the SWH approach from the traditional, knowledge-replicative approach. Specifically, students in the SWH classrooms have "access to deeper understanding of scientific activity" (Manz, 2015, p. 554) while supporting and elaborating claims by providing evidence. Cavagnetto (2010) also emphasizes that the SWH approach promotes students to learn science through the culture of science (e.g., developing knowledge through academic talks and argument). This means that the SWH approach is oriented for rich knowledge generative environments in which students learn science through epistemic practices. (Bae, Hand, Fulmer, & Hansen, 2018; Feucht, 2010; Kelly, 2011).

As an argument in the SWH classrooms naturally appears within the multiple forms of epistemic practices, Chen, Hand, and Park (2016) provide examples of epistemic practices for teachers and students to facilitate implementation of the SWH approach (see Table 1).

Table 1. SWH examples—Teacher and student

Teacher
1. Exploration of pre-instruction understanding through individual or group concept mapping
2. Pre-laboratory activities, including informal writing, making observations, brainstorming, and posing questions
3. Participation in a laboratory activity
4. Negotiation Phase I—writing data interpretations for laboratory activity in small groups (for example, making a group chart, argument)
5. Negotiation Phase II—sharing group arguments with peers (for example, discussing group arguments in a whole class setting)
6. Negotiation Phase III—comparing science ideas to textbooks or other printed resources (for example, writing group notes in response to focus questions)
7. Negotiation Phase IV—individual reflection and writing (for example, writing a report or textbook explanation)
8. Exploration of post-instruction understanding through concept mapping
Student
1. Beginning Ideas—What are my questions?
2. Test—What did I do?
3. Observation—What did I see?
4. Claim—What can I claim?
5. Evidence—How do I know? Why am I making these claims?
6. Reading—How do my ideas compare with other ideas?
7. Reflection—How have my ideas changed?

In the study of Chen et al. (2016), class begins with students' questioning about big ideas then moves to discuss ideas to reach a consensus on the initial questions, then continues to negotiate ideas about the experiment design. That is to say that participation in negotiating ideas through language practices (e.g., questioning, responding to others' questions, and reflective writing) is key for science learning in the SWH classrooms. When language practice is essential to learning, the learning environment is enriched with students' voices (Ardasheva et al., 2015). As students' voices are valued, students are more likely to grow authorship of ideas as knowledge generators, which results in the development of life-long learning practices (Bendixen & Feucht, 2010; Burr & Hofer, 2002).

1) The Effectiveness of the SWH Approach in Multiple Learning Conditions

With the critical role of the SWH approach in the creation of rich learning environments in epistemic practices, one question rises "are they [the learning approaches] effective for all students?" (Brod, 2020). In the study of Lamb et al. (2020), the SWH positively influences to upper elementary classrooms (grade 4 and 5) in rural areas with a high percentage of students from low socio-economic status. Lamb et al. investigated critical thinking patterns and inferential skills of students who experienced the SWH approach for one year. By employing computational experimental modeling, Lamb et al. found that the SWH approach positively affects students' development of cognitive attributes such as reasoning and analytic thinking. A similar finding also appears in a longitudinal study of Chanlen (2013). Students in both, high and low achieving groups, experienced the SWH since 3rd grade for ten years, then have significantly improved statewide-standardized test scores. Further, Chanlen found a larger effect of the SWH on low achieving groups compared to the effect on high achieving groups. This does not mean that the SWH is only favorable to the low achieving groups, but the SWH can play a critical role in resolving the achievement gap issues that exist in the traditional science teaching method. In sum, Chanlen highlights the SWH approach helps students (both high and low achieving groups) significantly grow achievement scores by reducing a gap.

Furthermore, the effectiveness of the SWH approach was also examined regarding intervention length. Yaman (2018) examined writing scores of college-level students who experienced the SWH approach for 16 weeks in chemistry methods courses. She found that the students significantly gained high performance in argumentative writing tasks. In detail, the students improved their abilities of justification (e.g., tight causal connection between question, claim, and evidence) and proper use of multiple representations to enhance their argument. Adding to this finding, high school students who experienced non-traditional, generative writing intervention for eight weeks (e.g., writing letters to multiple audiences to share what they learned in science classrooms) showed significant growth in academic achievement (Hand, Hohenshell, & Prain, 2004). The non-traditional writing intervention was part of the SWH activities used as one of the summative assessments at the end of the unit.

Such essential roles of the SWH in promoting students 'academic achievement are also found in qualitative systematic reviews. Villanueva, Taylor, Therrien, and Hand (2012) highlight the impact of the SWH approach on the learning outcomes of students with special needs. Their qualitative review study illuminates the essential role of the SWH in improving the scientific literacy of students with special needs. Additionally, Hand et al. (2020) found that the effectiveness of the SWH on students' science learning, regardless of grade levels and cultural backgrounds. Through a comprehensive qualitative review, Hand et al. identified three conditions for successful implementation of the SWH: (1) long-term intervention, (2) teachers' theoretical understandings of the SWH, and (3) immersive use of language practices (e.g., academic talk, writing, and reading).

2) The SWH in Turkey

The SWH has gained attention in Turkey around a decade ago as Turkish science educators attempt to make science classrooms more immersive, knowledge generative (Gunel, Kingir, & Geban, 2012; MoNE, 2013). Gunel et al. (2012) argue that the SWH approach helps promoting students' scientific literacy through epistemic practices (e.g., engaging in discussions, constructing arguments and providing evidence to support claims). Erol (2010) argue that the SWH approach supported middle school students' development of conceptual understandings of acid and bases. Similarly, Guler (2016) also found college-level students significantly improved academic achievement after eight weeks interventions of the SWH approach. This positive impact of the SWH implies that public school teachers and college-level instructors in Turkey developed their understanding of the SWH and successfully implemented it to their classrooms (Hand et al., 2020). As the number of classrooms that implement the SWH increased in Turkey, many studies highlighted the impact of the SWH on students' learning outcomes: content knowledge (Unal, 2016), critical thinking (Kucuk Demir, 2014), and writing competence (Yaman, 2018). In addition, studies examined the effectiveness of the SWH in different grade levels such as middle schools (Ulu & Bayram, 2015), high schools (Kingir, Geban, & Gunel, 2013), and college levels (Erkol, Kisoglu, & Buyukkasap, 2010) and different subject areas such as biology (Ceylan, 2010), chemistry (Kingir et al., 2013), and physics (Guler, 2016).

2. THE NECESSITY OF A META-ANALYTIC REVIEW

To provide a comprehensive understanding of the critical role of the SWH approach in Turkey, employing a systematic approach is essential (Bergstrom & Taylor, 2006; Crombie & Davies, 2009). We have found several qualitative systematic review studies that highlighted the impact of the SWH approach on students' conceptual understanding. For example, a recent qualitative systematic review on writing in science (Huerta & Garza,

2019) provides extensive interpretations on the positive impact of the SWH approach through the comprehensive review matrix. Another qualitative review study highlighting a write-to-learn approach across 25 years (Hand, 2017) broadens the role of the SWH approach in students' language development. These qualitative systematic review studies well established the impact of the SWH approach based on the patterns and trends from the findings of single studies.

However, few studies highlight the effect of the SWH approach by using a meta-analysis. We chose a meta-analysis because it provides a statistical measure to complement the missing aspects of qualitative research (Bergstrom & Taylor, 2006). Many studies also indicate that a meta-analysis plays a significant role in examining the effectiveness of interventions by complementing the limitations of qualitative systematic reviews (Bayraktar, 2001; Bergstrom & Taylor, 2006; Crombie & Davies, 2009).

The power of meta-analytic reviews not only provides comprehensive quantitative views but also contributes to the gap in the current studies and future directions (Bergstrom & Taylor, 2006; Crombie & Davies, 2009). Unlike a qualitative systematic review, a meta-analysis review study has its advantage in that it provides an overall effect by combining multiple effect sizes of the studies on a particular topic. Crombie and Davies (2009, p. 2) state that "meta-analysis offers a rational and helpful way of dealing with a number of practical difficulties that beset anyone trying to make sense of effectiveness research." Based on their argument, a meta-analysis allows researchers to conduct a "study of studies" (Bergstrom & Taylor, 2006, p. 351) by incorporating evidence from the findings of other studies.

With this regard, using a meta-analysis is suitable for the current study which attempts to investigate the effectiveness of learning interventions with a precise estimation (Castro-Alonso, Wong, Adesope, & Paas, 2021). The purpose of this study is to determine the overall effectiveness of the SWH approach on Turkish students' academic achievement when compared to traditional instruction. Several studies highlighted the effectiveness of the SWH in Turkish science classrooms (Gunel et al., 2012; Kingir et al., 2013; Sahin, 2016), but few studies provide a quantitative systematic view on the effectiveness of the SWH approach in Turkish learning environments. Therefore, this study fills the gap in research related to the effectiveness of the SWH approach through a quantitative meta-analysis.

III. RESEARCH METHODOLOGY

By adopting the approach of Borenstein, Hedges, Higgins, and Rothstein (2011), this study was designed by the three methodological steps: (a) a presentation of inclusion and exclusion criteria with rationale, (b) a description of the procedures for locating and coding study characteristics, and (c) a discussion of the effect size calculations.

1. INCLUSION AND EXCLUSION CRITERIA

For the present study, a study in a database was deemed eligible for inclusion if it:

(1) included at least one academic achievement outcome. Here, academic achievement means results from content knowledge-based exams such as summative assessment. This can take the form of either standardized tests or exams created by a teacher/instructor.

(2) was conducted at an educational institution. We defined the scope of educational institutions as K-20 education. The intervention recipients must be students, as we would like to see the effectiveness of the SWH on student academic achievement.

(3) was conducted in Turkey. That is to say, the primary studies must collect their data in Turkey. The study location was restricted to Turkey because the SWH is a commonly used argument-based science inquiry in other counties as well, and we intend to focus on the effectiveness of the SWH in this particular region.

(4) focused on a general population of students. As general population data were desired, no studies were included if they have an explicit focus on gifted students or students with learning disabilities.

(5) was published in English or Turkish. This requirement is due to the researchers' limited translation abilities.

(6) was published between 1999-2018. We selected 1999 as the start of the collection of studies because the SWH approach was created in 1999.

(7) included minimal standards of quasi-experimental designs; this is done to ensure that a sufficient amount of quantitative data is available for calculating effect sizes.

(8) included at least one pre-test and one post-test; this is done to ensure that a sufficient amount of quantitative data is available for calculating effect sizes.

(9) included at least two groups (treatment-control). We excluded treatment-only designs due to the smaller effect sizes compared to treatment-control designs.

2. LITERATURE SEARCH AND SELECTION OF THE STUDIES

The major restriction of the selection of studies was whether the studies were conducted in Turkey. This restriction was applied in order to restrain the scope of the review to the effectiveness of the SWH approach in Turkey. Literature searching was performed through databases as well as reference sections of the relevant studies. Three databases were searched: Web of Science (WoS), APA PsychNET (APA), and Databases of National Thesis Center of the Council of Higher Education in Turkey (YOKSIS). These electronic databases were searched in February 2019 for a publication year between 1999 and 2018. Hence the initial screening included three database searches: First, WoS was searched for topics in terms of the descriptors "(argument*based* OR argument*inquiry* OR science writing heuristic*) AND (science OR physics OR physical OR chemistry OR earth science)." Second, APA was searched for any field using the same descriptors. Finally, YOKSIS were screened for any field with the descriptors "argument*based* OR argument*inquiry* OR science writing heuristic*" to reach a comprehensive data collection of unpublished doctoral dissertations and unpublished master's theses on the SWH approach.

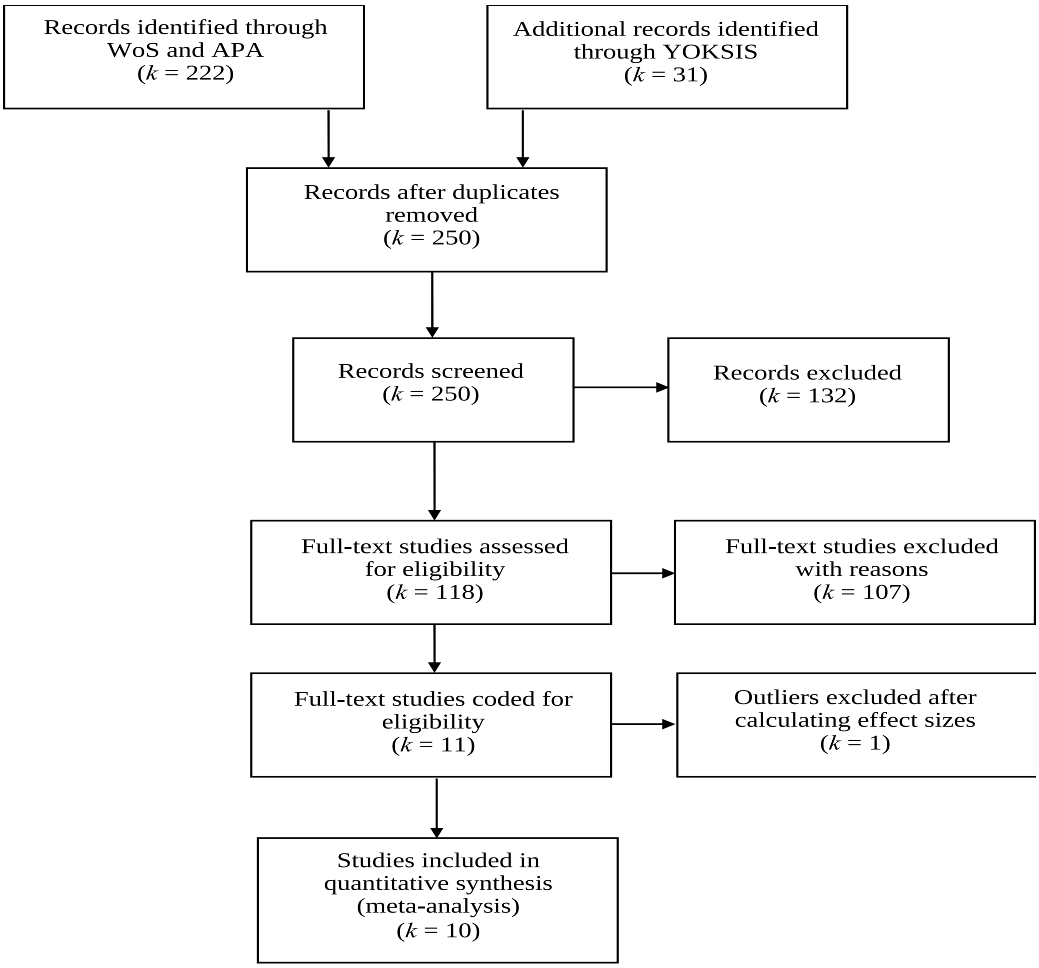

Figure 1. Flowchart for identification and selection of studies

A total of 253 studies were selected through the initial search process (see Figure 1). After removing three duplicates, we moved to review selected 250 studies. Then, one of the authors conducted the next screening phase by reviewing the titles and abstracts of the studies. Through the process, 118 studies were selected then reviewed by both authors for the final selection. The authors applied the nine selection criteria listed above to the full-text copies to finalize eligible studies for the meta-analysis. The inter-rater agreement between the authors was 94%, which indicates that the authors disagreed with seven studies (about 6%). Through the conversations, the authors decided to exclude the seven studies because four studies did not provide means and standard deviations for calculating effect sizes (criteria 8), two studies did not satisfy the criteria of the general population of students (criteria 4), and one study only provided critical thinking test scores, without academic achievement outcomes (criteria 1). Once disagreements were resolved, we subsequently selected 11 studies, which meet the criteria for calculating effect sizes.

3. CODING OF STUDY FEATURES

We coded study features to explain the variations that exist in primary study settings. To this end, a coding form was created to extract relevant information related to study features and effect sizes (see Table 2). By using this form, the moderators (grade level, subject area, school location, treatment length, and report source) and effect size information (means and standard deviations of pre and post-tests) for each study were coded. Both researchers agreed on the selected information of the studies in Table 2.

Table 2. Selected study features and effect sizes

Author	Report source	Grade level	Intervention length (in weeks)	Subject area	School location	Effect sizes (*g*)	Var (*g*)	*n*
Ceylan, 2010	Master thesis	Undergrad	16	Biology	Rural	0.57	0.13	32
Erkol et al., 2010	Journal article	Undergrad	8	Physics	Urban	1.41	0.12	42
Erkol, 2011	Dissertation	Undergrad	8	Physics	Urban	1.49	0.06	80
Erol, 2010	Master thesis	8^{th}	6	Chemistry	Rural	1.21	0.06	79
Gencoglan, 2017	Master thesis	8^{th}	16	Chemistry	Rural	0.81	0.06	69
Guler, 2016	Master thesis	Undergrad	8	Physics	Urban	1.19	0.04	106
Karaca, 2011	Master thesis	Undergrad	16	Physics	Urban	0.49	0.07	62
Kingir, 2011	Dissertation	9^{th}	10	Chemistry	Urban	0.59	0.03	122
Tucel, 2016[a]	Master thesis	8^{th}	16	Biology	Rural	2.74	0.13	60
Ulu, 2015	Journal article	7^{th}	10	Physics	Urban	1.94	0.09	65
Unal, 2016	Dissertation	9^{th}	8	Biology	Rural	1.16	0.07	67

Note. [a]After calculating effect sizes for 11 studies, a sensitivity analysis was employed. Tucel (2016), an outlier with an effect size of 2.74, was excluded due to its extremely high effect size.

4. CALCULATION OF EFFECT SIZES

Standardized mean differences were calculated to examine the size of the treatment effect. One effect size was derived per study. The effect size calculation is based on the mean pre-post change in the study's treatment group minus the mean pre-post change in the control group, divided by the pooled pretest standard deviation. Morris (2008) claims that this approach renders a better effect size estimate in pre-test post-test control group designs. Effect sizes (*d*; Cohen, 1988) were computed by the standardized mean difference using the following formulas:

$$d = \frac{(\bar{X}_{\text{SWH POST}} - \bar{X}_{\text{SWH PRE}}) - (\bar{X}_{\text{TRADITIONAL POST}} - \bar{X}_{\text{TRADITIONAL PRE}})}{S_{POOLED\ PRE}}$$

$$S_{POOLED\ PRE} = \sqrt{\frac{(n_{\text{SWH}} - 1)*S^2_{\text{SWH PRE}} + (n_{\text{TRADITIONAL}} - 1)*S^2_{\text{TRADITIONAL PRE}}}{n_{\text{SWH}} + n_{\text{TRADITIONAL}} - 2}}$$

$$V_d = \frac{n_{\text{SWH}} + n_{\text{TRADITIONAL}}}{n_{\text{SWH}} * n_{\text{TRADITIONAL}}} + \frac{d^2}{2*(n_{\text{SWH}} + n_{\text{TRADITIONAL}})}$$

$$SE_d = \sqrt{V_d}$$

Each of the eleven studies provides necessary data in terms of both control and treatment groups' pre and post-test means and standard deviations for calculating effect sizes. After calculating Cohen's *d*, the correction for small sample bias (Hedges' *g*; Hedges & Olkin, 1985) was performed in Excel using the following formulas:

$$J = 1 - \frac{3}{4(n_{\text{SWH}} + n_{\text{TRADITIONAL}} - 2) - 1}$$

$$g = J \times d$$

$$V_g = J^2 * V_d$$

$$SE_g = \sqrt{V_g}$$

That is, the unit of analysis for the present study was the Hedges' effect size (*g*). Except for one study, the effect sizes (*g*) of the eleven studies were corrected by minimum .01 and maximum .04 standard deviations. Table 2 shows Hedges' *g* effect sizes and variances for each study beyond their study features. The range of effect sizes was from 0.49 to 2.74.

After calculating effect sizes for the eleven studies, a sensitivity analysis was employed. One of the master theses, Tucel (2016), an outlier with an effect size of 2.74, was excluded due to its extremely high effect size, which means the study did not fit well with the rest of the selected studies (Schwarzer, Carpenter, & Rucker, 2015). After eliminating Tucel (2016), we had ten studies for the meta-analysis. Having ten studies is acceptable according to Valentine, Pigott, and Rothstein (2010) that they argue that two studies are enough to conduct the meta-analysis. Additionally, we found several meta-analyses conducted with ten studies (e.g., Hosseini, Nazarzadeh, & Jahanfar, 2018; Rees, Quinn, Davies, & Fotheringham, 2016; Voutilainen, Saaranen, & Sormunen, 2017).

5. STATISTICAL ANALYSIS

To merge outcomes from the ten studies (k = 10), random-effects models were conducted using R version 3.5.3 (R Core Team, 2019), and the *metafor* package (Viechtbauer, 2010) was used to fit the models in this analysis. In the present study, we utilized the random-effects model, instead of the fixed-effects model, to analyze the effect sizes which may vary due to several factors rather than one (Hedges & Vevea, 1998). Random-effects models were conducted for the dataset by using the maximum likelihood method (REML) that provides mean effect sizes with confidence intervals, overall effect size with confidence intervals for random-effects, between-class homogeneity Q, and the I^2 index to quantify the heterogeneity.

The hypothesis that there are no effect size differences between variables was tested by utilizing the between-class homogeneity test (hereinafter Q test; Hoaglin, 2016). Rejecting the Q test implies that the effect sizes (g) from the classes may not measure the same population parameter. That is to say, there is a statistically significant difference in the effect sizes for each variable. From an inferential perspective, the I^2 index acts as a complement to the Q test (Huedo-Medina, Sanchez-Meca, Marin-Martinez, & Botella, 2006). Huedo-Medina et al. interpreted the I^2 index as "the percentage of the total variability in a set of effect sizes due to true heterogeneity" (p. 194). To answer our first research question, an overall effect size was calculated by summing the effect sizes from the ten studies that included in the meta-analysis. To answer our second research question, the effect sizes of the moderators (grade level, subject area, school location, intervention length, and report source) were analyzed by random-effects models.

IV. RESULTS AND DISCUSSIONS

1. CHARACTERISTICS OF THE STUDIES

All studies in this review have quasi-experimental designs (a pre-post treatment-control design) and have a between-subject design featuring one control (traditional lecture) and one treatment group (the SWH approach). Moreover, as only one effect size was derived from each study, the effect sizes could be considered as independent, which means that they may not be estimated based on the same population parameter.

The goal of this study was to determine the overall effectiveness of the SWH approach on students' academic achievement. The results showed that the overall effect size (*g*) is 1.07, with the standard error of 0.14 and 95% CI [0.79, 1.36] (see Table 3). This can be regarded as a large effect (Cohen, 1988) that the SWH approach produced 1.07 standard deviation greater impact on students' achievement than traditional lecture-based classrooms.

Table 3. Overall effect of the relationship between the SWH approach and academic achievement

	N	*k*	*g* (*SE*)	95% CI LCI	95% CI HCI	*Q* (*df*)
Science Achievement						
Random Model	724	10	1.07 (0.14) ***	0.79	1.36	28.41 (9) ***

***$p < .001$

Further analyses showed that the significant heterogeneity existed Q (9) = 28.41, $p < .001$. The Q test resulted in a rejection of the null hypothesis that states that the study effects are equal. Rejecting the Q test shows that there is a statistically significant difference between the effect sizes of the included studies. Moreover, there is moderate variability within the sample, $I^2 = 68.65\%$. This result indicates the variability among the effects of the included studies. Therefore, we conclude that there is significant heterogeneity among study effects and that the random-effects model fits well. Due to this heterogeneous distribution, moderator analyses were conducted.

Figure 2 illustrates the forest plots for the included ten studies and the weighted overall effect for the random-effects model. The effect sizes of individual studies included in this meta-analysis were positive in general, meaning the effect sizes favor the SWH approach. Although Ceylan (2010) and Karaca (2011) had the confidence intervals intersecting zero (implying that it is uncertain whether there is a treatment effect; Cohen, 1988), the overall effect size is statistically significant in favor of the SWH approach (g = 1.07).

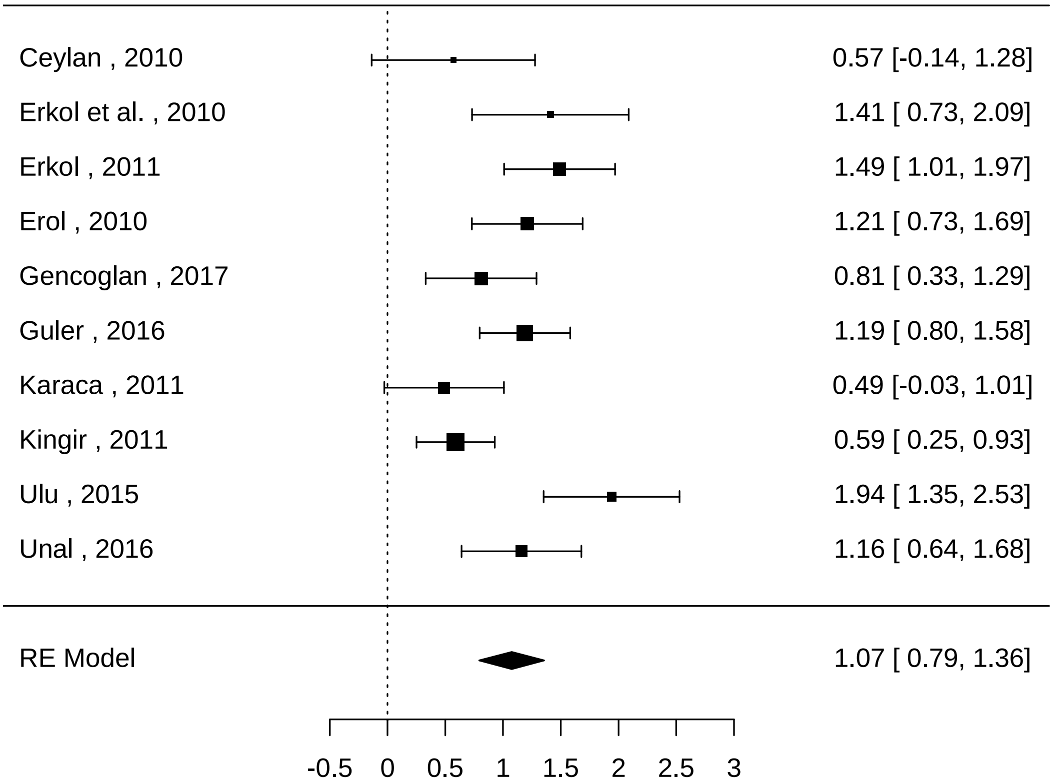

Figure 2. Forest plots of the ten effect sizes. The horizontal axis indicates the effect sizes. The effect size of RE model indicates the overall effect size.

Figure 3 shows the funnel plot of the studies included in the present meta-analysis. This graph aims to evaluate publication bias that significant results are more likely to be published than no significant results (Banks, Kepes, & McDaniel, 2012; Dickersin, 2005). A funnel plot is one of the most common methods to evaluate the validity of a meta-analysis with respect to publication bias (Sterne, Becker, & Egger, 2005). In Figure 3, the funnel plot looks approximately symmetrical, which means publication bias is unlikely in our sample (Sedgwick & Marston, 2015).

For further examination, we measured funnel plot asymmetry using the Egger's regression intercept test, which is based on a linear regression approach (Egger, Davey Smith, Schneider, & Minder, 1997). According to Egger et al., "the intercept provides a measure of asymmetry—the larger its deviation from zero the more pronounced the asymmetry" (p. 629). The Egger's regression method for the 10 effect sizes produced an intercept of 0.66 and a 95% CI [-0.77, 2.01]. The Egger's regression test suggested that there is no significant asymmetry ($p = 0.51$).

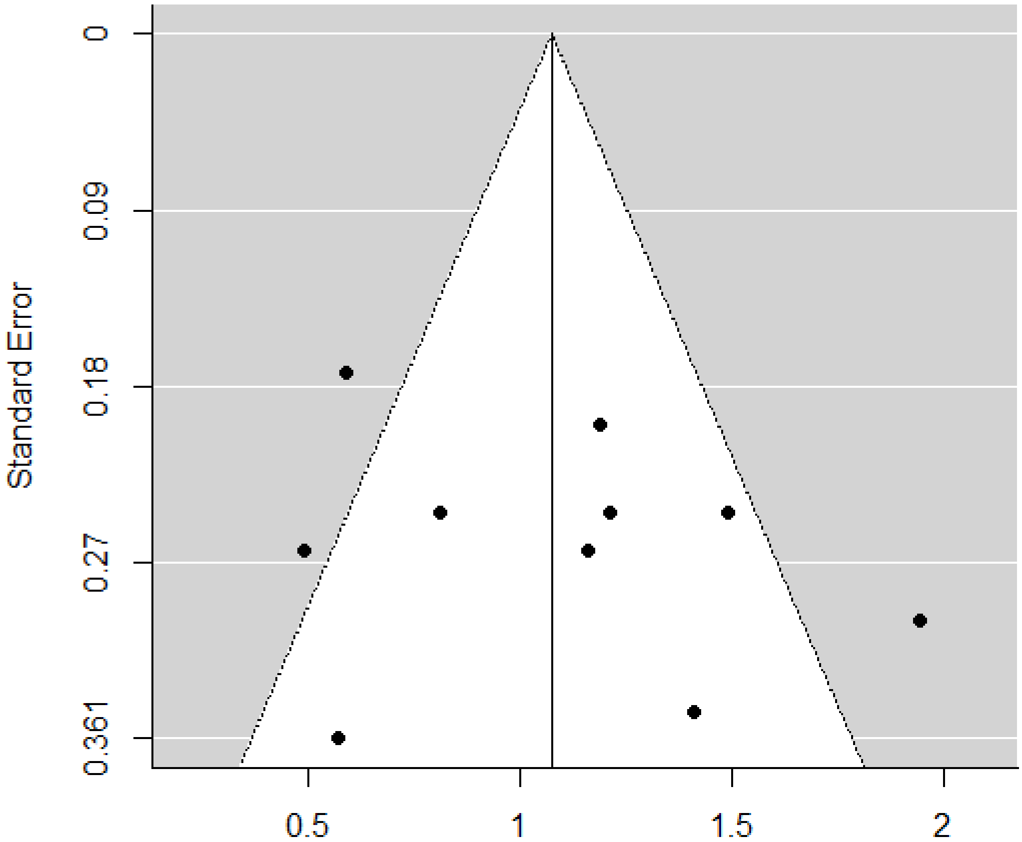

Figure 3. Funnel plot distribution of the ten effect sizes. The horizontal axis indicates the effect sizes.

2. MODERATOR ANALYSES

To investigate the effects of certain conditions, the moderator analyses were conducted. We included five moderators in the random-effects model: grade level (grade 7-9 and undergrad), subject area (biology, chemistry, and physics), school location (rural and urban), intervention length (less than or equal to eight weeks and greater than eight weeks), and report source (dissertations, journal articles, and master theses) (see Table 4).

Table 4. Results of moderator analyses

Moderators	*N*	*k*	*g* (*SE*)	95% CI LCI	95% CI HCI	*Q* (*df*)
Grade level						0.04 (1)
Undergrad	322	5	1.11 (0.22)***	0.67	1.55	
Grade 7-9	402	5	1.05 (0.21)***	0.64	1.45	
Subject area						1.61 (1)
Biology	99	2	0.92 (0.29)**	0.35	1.49	
Chemistry	270	3	0.84 (0.18)***	0.48	1.20	
Physics	355	5	1.29 (0.23)***	0.83	1.75	
School location						0.38 (1)
Rural	247	4	0.99 (0.13)***	0.72	1.25	
Urban	477	6	1.16 (0.23)***	0.72	1.60	
Intervention length						2.82 (1)*
≤8 weeks	374	5	1.27 (0.11)***	1.06	1.49	
>8 weeks	350	5	0.87 (0.26)***	0.36	1.38	
Report source						4.16 (1)**
Dissertations	269	3	1.06 (0.27)***	0.52	1.59	
Journal Articles	107	2	1.70 (0.26)***	1.19	2.22	
Master Theses	348	5	0.90 (0.15)***	0.60	1.20	

***$p < .001$, **$p < .05$, *$p < .10$

In Table 4, the three moderators (grade level, subject area, and school location) did not significantly influence estimating the effectiveness of the SWH. In other words, effect sizes did not vary by grade level, subject area, and school location. On the other hand, the Q statistic of the intervention length was significant at $p < .10$ level. That is, intervention length was more likely related to estimating the size of the treatment effect (the effectiveness of the SWH). Although large effects of the SWH approach were observed in both treatment lengths (less than or equal to eight weeks, $g = 1.27$ and greater than eight weeks, $g = 0.87$), the results indicated that the SWH approach was especially effective when the duration of the treatment was shorter or equal to eight weeks.

Another significant result from the Q statistic was observed in source of reports ($p < .05$). This indicates that report types (dissertation, journal articles and master theses) were more likely related to the estimation of the treatment effect. That is, the effect size of the studies that is published in journal articles ($g = 1.70$) is significantly higher than those of dissertation ($g = 1.06$) and master theses ($g = 0.90$).

3. DISCUSSIONS

This study investigates how the SWH approach improves students' academic achievement in Turkey. Using a meta-analysis, this study synthesized the results of effect sizes from the ten studies (N = 724). The selected ten studies were valid to be used for the meta-analysis because the results from the random-effects model analysis showed that they are heterogeneous (Hedges & Vevea, 1998). The overall effect size of the ten studies was g = 1.07, indicating a positive impact of the SWH approach on academic achievement. This result affirms the findings from other studies that the SWH approach is effective in the improvement of students' academic achievement (Hand et al., 2016; Lamb et al., 2020). Importantly, this study found similar results by demonstrating the effectiveness of the SWH in a quantitative manner while Hand et al. (2020) used a systematic review approach.

Additionally, this study strengthens the findings of Hand et al. (2020) through the moderator analyses that the SWH approach positively impacts Turkish students' academic achievement in multiple grades, subjects, and school locations. One question that comes with this finding is what makes this consistent effectiveness of the SWH approach across grade levels, subject areas, and school locations. We conjecture that the SWH approach emphasizes epistemic practices in the classrooms, which allows students learn science while engaging with multiple forms of social interactions. Villanueva et al. (2012) also argue that "the SWH allows students to practice and engage in expert ways of thinking through asking questions, conducting investigations, developing claims and evidentiary explanations" (p. 200). As a language is considered an essential tool for knowledge generation, the SWH approach has a positive impact on students regardless of grade levels, subject areas, and school locations.

Interestingly, the findings of this study showed that there is a significant difference in the effect of the SWH approach based on intervention length. The larger effect was associated with shorter treatment length (less than or equal to eight weeks: g = 1.27) than longer treatment length (more than eight weeks: g = .87). This result is aligned with the findings from Chanlen (2013) that time is a critical factor for the impact of the SWH. However, our finding is different from Hand et al. (2020) that one of the conditions ensures the positive impact of the SWH approach is long-term intervention. Considering the previous studies about intervention length of the SWH were mostly conducted outside of Turkey (e.g., Chen et al., 2016; Hand et al., 2004; Lamb et al., 2020), we speculate that the effectiveness of the SWH is influenced by the cultural background of the classroom environment, and the duration of the intervention is particularly important for its effectiveness (Bangert-Drowns, Hurley, & Wilkinson, 2004). Even so, we open a need for future research on how (specifically) long the SWH experience positively influences academic achievement depending on cultural backgrounds.

Furthermore, our findings indicated that the impact of the SWH was reported differently depending on report source. We found that the studies in peer-reviewed journals had larger effects than those in dissertations and master theses while all types of reports had significant effects. This does not mean that differences in effect sizes among reports significantly influence the overall effect size of the SWH based on the results from funnel plot analysis and Egger's regression intercept method (Egger et al., 1997; Sterne et al., 2005). However, we conjecture that the editors and reviewers of journals favor to publish significant results in which published journal articles are more likely to have positive results (Rothstein, Sutton, & Borenstein, 2005).

In sum, the findings of this study tell that students who learn science through the SWH approach in Turkey significantly improved academic achievement regardless of grade levels, subject areas, and school locations. That is, the findings in the study are not different from those in previous studies highlighting the impact of the SWH on various learning settings. Therefore, this meta-analytic review study suggests that the SWH approach is distinguished when compared to traditional, knowledge-replicative instruction and essential when it comes to the improvement of academic achievement.

4. LIMITATIONS AND FUTURE DIRECTIONS

The current meta-analysis study complements the literature and provide evidence to the relationship between the SWH approach and academic achievement in Turkey. Although this study highlighted the effectiveness of the SWH, we acknowledge limitations which can be suggestions for future studies. The first limitation arises from our selection criteria focusing on only academic achievement outcomes and regular classroom settings. Specifically, some studies were excluded because they only provided critical thinking test scores (Kucuk Demir, 2014) or provided learning outcomes of specific groups such as gifted and talented students (Sahin, 2016) and seasonal agricultural worker students (Arli, 2014). We value the findings from those studies that highlight the effect of the SWH through students' critical thinking skills and multiple classroom settings, but these studies were excluded due to the scope of the current study.

Second, as the current study only reviewed the studies conducted in Turkey, future research could expand the selection criteria of the literature to other countries or classroom settings (e.g., face-to-face vs. online classrooms). This expansion allows researchers to increase sample sizes and amplify the effect of the SWH approach across various learning environments.

V. CONCLUSIONS

As promoting problem-solving skills is key to success nowadays, science learning environments become more effective through immersive, knowledge generative learning rather than traditional, knowledge replicative learning. In this regard, implementing the SWH approach to science classrooms is critical because it promotes students' learning through epistemic practices. The SWH approach creates rich generative learning environments in which students solve problems through multiple social interactions mediated by language. As the number of classrooms implementing the SWH approach in Turkey has increased, this study examined the effectiveness of the SWH approach on Turkish students' academic achievement. The current study revealed the positive effect of the SWH approach on academic achievement regardless of grade levels, subject areas, and school locations. This implies that the SWH approach values the fundamental role of epistemic practices in learners' development of knowledge and skills. Therefore, the SWH approach can be successful in multiple learning settings.

REFERENCES

References marked with an asterisk indicate studies included in the meta-analysis.

Ardasheva, Y., Norton-Meier, L., & Hand, B. (2015). Negotiation, embeddedness, and non-threatening learning environments as themes of science and language convergence for English language learners. *Studies in Science Education*, *51*(2), 201–249.

Arli, E., E. (2014). *The impacts of argumentation based science inquiry approach on seasonal agricultural worker students' academic achievement and thinking skills (Argümantasyon Tabanli Bilim Öğrenme Yaklaşiminin (ATBO) Mevsimlik Tarim İşçisi Konumundaki Dezavantajli Öğrencilerin Akademik Başarilari ve Düşünme Becerilerine Etkisi).* (Master Thesis). Retrieved from Databases of National Thesis Center of the Council of Higher Education.

Asterhan, C. S., & Schwarz, B. B. (2016). Argumentation for learning: Well-trodden paths and unexplored territories. *Educational Psychologist*, *51*(2), 164–187.

Bae, Y., Fulmer, G., Hand, B., & Hansen, W. (2018, March 10–13). *Rasch analysis of measuring students' epistemic language practices in science learning* [Conference presentation]. National Association for Research in Science Teaching (NARST), Atlanta, GA, United States.

Bae, Y., Fulmer, G. W., & Hand, B. M. (2021). Developing latent constructs of dialogic interaction to examine the epistemic climate: Rasch modeling. *School Science and Mathematics*, *121*(3), 164–174.

Bangert-Drowns, R., Hurley, M., & Wilkinson, B. (2004). The effects of school-based writing-to-learn interventions on academic achievement: A meta-analysis. *Review of Educational Research, 74*(1), 29-58.

Banks, G. C., Kepes, S., & McDaniel, M. A. (2012). Publication bias: A call for improved meta-analytic practice in the organizational sciences. *International Journal of Selection and Assessment*, *20*(2), 182–196.

Bayraktar, S. (2001). A meta-analysis of the effectiveness of computer-assisted instruction in science education. *Journal of Research on Technology in Education, 34*(2), 173–188.

Bendixen, L. D., & Feucht, F. C. (2010). *Personal epistemology in the classroom: Theory, research, and implications for practice*. Cambridge: Cambridge University Press.

Bergstrom, J. C., & Taylor, L. O. (2006). Using meta-analysis for benefits transfer: Theory and practice. *Ecological Economics*, *60*(2), 351–360.

Borenstein, M., Hedges, L. V., Higgins, J. P., & Rothstein, H. R. (2011). *Introduction to meta-analysis*. Hoboken, NJ: John Wiley & Sons.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). *How people learn* (Vol. 11). Washington, DC: National academy press.

Brod, G. (2020). Generative learning: Which strategies for what age? *Educational Psychology Review*, https://doi.org/10.1007/s10648-020-09571-9.

Buehl, M. M., & Fives, H. (2016). The role of epistemic cognition in teacher learning and praxis. In J. A. Greene, W. Sandoval, & I. Braten (Eds.), *Handbook of epistemic cognition* (pp. 247-264). New York, NY: Taylor and Francis Inc.

Burr, J. E., & Hofer, B. K. (2002). Personal epistemology and theory of mind: Deciphering young children's beliefs about knowledge and knowing. *New Ideas in Psychology*, *20*(2–3), 199–224.

Castro-Alonso, J. C., Wong, R. M., Adesope, O. O. & Paas, F. (2021). Effectiveness of multimedia pedagogical agents predicted by diverse theories: A meta-analysis. *Educational Psychology Review,* https://doi.org/10.1007/s10648-020-09571-9.

Cavagnetto, A. R. (2010). Argument to foster scientific literacy: A review of argument interventions in K–12 science contexts. *Review of Educational Research*, *80*(3), 336–371.

*Ceylan, C. (2010). *Implementing the science writing heuristic approach in science laboratory activities* (*Fen laboratuvar etkinliklerinde argümantasyon tabanli bilim öğrenme-ATBO yaklasiminin kullanimi)* (Master thesis). Retrieved from Databases of National Thesis Center of the Council of Higher Education.

Chanlen, N. (2013). *Longitudinal analysis of standardized test scores of students in the science writing heuristic approach* (Doctoral dissertation). Retrieved from ProQuest. (https://doi.org/10.17077/etd.wyhaht63).

Chen, Y.-C. (2011). *Examining the integration of talk and writing for student knowledge construction through argumentation* (Doctoral dissertation). Retrieved from ProQuest. (https://doi.org/10.17077/etd.85rfjnr9).

Chen, Y.-C., Hand, B., & Park, S. (2016). Examining elementary students' development of oral and written argumentation practices through argument-based inquiry. *Science & Education. 25*, 277-320.

Cohen, J. (1988). *Statistical power analysis for behavioral sciences* (2nd ed.). Mahwah, NJ: Lawrence Erlbaum Associates.

Crombie, I. K., & Davies, H. T. (2009). What is meta-analysis?, *Hayward Medical Communications*, Retrieved from https://www.betterevaluation.org/sites/default/files/Meta-An.pdf

Dickersin, K. (2005). Publication bias: Recognizing the problem, understanding its origins and scope, and preventing harm. In H. R. Rothstein, A. J. Sutton, & M. Borenstein (Eds.), *Publication bias in meta-analysis: Prevention, assessment and adjustments* (pp. 75–98). Chichester, UK: John Wiley & Sons.

Egger, M., Davey Smith, G., Schneider, M. and Minder, C. (1997). Bias in meta-analysis detected by a simple, graphical test. *British Medical Journal, 315*, 629–634.

Engin, M. (2017). Contributions and silence in academic talk: Exploring learner experiences of dialogic interaction. *Learning, Culture and Social Interaction*, *12*, 78–86.

*Erkol, M. (2011). *Investigation the effects of the Science Writing Heuristic Approach on science teacher candidates' physics laboratory achievements* (*Yaparak yazarak bilim öğrenme yaklaşiminin fen bilgisi öğretmen adaylarinin fizik laboratuari başarilarina etkisinin araştirilmasi)* (Doctoral dissertation). Retrieved from Databases of National Thesis Center of the Council of Higher Education.

*Erkol, M., Kisoglu, M., & Buyukkasap, E. (2010). The effect of implementation of science writing heuristic on students' achievement and attitudes toward laboratory in introductory physics laboratory. *Procedia-Social and Behavioral Sciences, 2*(2), 2310–2314.

*Erol, G. (2010). *An evaluation based on exercising the science writing heuristic method and multiple writing activities on the subject of acid and bases (Asit baz konusunun çoklu yazma etkinlikleri ve yaparak yazarak bilim öğrenme metodu kullanilarak öğretilmesinin değerlendirilmesi*) (Master thesis). Retrieved from Databases of National Thesis Center of the Council of Higher Education.

Feucht, F. C. (2010). Epistemic climate in elementary classrooms. In L. D. Bendixen & F. C. Feucht (Eds.), *Personal epistemology in the classroom: Theory, research, and implications for practice* (pp. 55–93). Cambridge, UK: Cambridge University Press.

Fulmer, G. W., Hwang, J., Ding, C., Hand, B., Suh, J. K., & Hansen, W. (2021). Development of a questionnaire on teachers' knowledge of language as an epistemic tool. *Journal of Research in Science Teaching*, 58(4), 459-490. https://doi.org/ 10.1002/tea.2166

*Gencoglan, D. M. (2017). *The effects of argumentation based science learning approach based on authentic case studies on the success, attitude and scientific process skills of 8th grade students in the "acids and bases" Lesson* (*Otantik örnek olay destekli argümantasyon tabanli bilim *öğrenme yaklaşiminin 8. sinif öğrencilerininin "asitler ve bazlar" konusundaki başarilarina, tutum ve bilimsel süreç becerilerine etkisi)* (Master thesis). Retrieved from Databases of National Thesis Center of the Council of Higher Education.

Glynn, S. M., & Muth, K. D. (1994). Reading and writing to learn science: Achieving scientific literacy. *Journal of Research in Science Teaching*, *31*(9), 1057–1073.

*Guler, C. (2016). *The effect of "argumentation based science learning approach"on academic success of science teacher candidates and their opinions about the approach (Fen laboratuvari derslerinde kullanilan "argümantasyon tabanli bilim öğrenme" yaklaşiminin, fen bilgisi öğretmen adaylarinin akademik başarilarina etkisi ve yaklaşim hakkindaki görüşleri)* (Master thesis). Retrieved from Databases of National Thesis Center of the Council of Higher Education.

Gunel, M., Kingir, S., & Geban, O. (2012). Analysis of argumentation and questioning patterns in argument-based inquiry classrooms (Argümantasyon tabanlı bilim öğrenme (ATBÖ) yaklaşımının kullanıldığı sınıflarda argümantasyon ve soru yapılarının incelenmesi). *Eğitim ve Bilim, 37*(164), 316-330.

Hand, B. M. (2007). *Science inquiry, argument and language: A case for the science writing heuristic*. Rotterdam: Sense Publishers.

Hand, B. (2017). Exploring the role of writing in science: A 25-year journey. *Literacy Learning: The Middle Years, 25*(3), 16.

Hand, B., Chen, Y.-C., & Suh, J. K. (2020). Does a knowledge generation approach to learning benefit students? A systematic review of research on the Science Writing Heuristic Approach. *Educational Psychology Review*, https://doi.org/10.1007/s10648-020-09550-0.

Hand, B., Hohenshell, L., & Prain, V. (2004). Exploring students' responses to conceptual questions when engaged with planned writing experiences: A study with year 10 science students. *Journal of Research in Science Teaching*, *41*(2), 186–210.

Hand, B., & Keys, C. W. (1999). Inquiry investigation. *The Science Teacher*, *66*(4), 27-29.

Hand, B., Norton-Meier, L. A., Gunel, M., & Akkus, R. (2016). Aligning teaching to learning: A 3-year study examining the embedding of language and argumentation into elementary science classrooms. *International Journal of Science and Mathematics Education*, *14*(5), 847–863.

Hand, B., Shelley, M. C., Laugerman, M., Fostvedt, L., & Therrien, W. (2018). Improving critical thinking growth for disadvantaged groups within elementary school science: A randomized controlled trial using the Science Writing Heuristic approach. *Science Education*, *102*(4), 693–710.

Hedges, L., & Olkin, I. (1985). *Statistical methods for meta-analysis*. San Diego, CA: Academic Press.

Hedges, L. V., & Vevea, J. L. (1998). Fixed-and random-effects models in meta-analysis. *Psychological Methods*, *3*(4), 486.

Hoaglin, D. C. (2016). Misunderstandings about Q and 'Cochran's Q test'in meta□analysis. *Statistics in Medicine*, *35*(4), 485-495.

Hosseini, V. M., Nazarzadeh, M., & Jahanfar, S. (2018). Interventions for reducing fear of childbirth: A systematic review and meta-analysis of clinical trials. *Women and Birth*, *31*(4), 254-262.

Huedo-Medina, T. B., Sánchez-Meca, F., Marín-Martínez, F., & Botella, J. (2006). Assessing heterogeneity in meta-analysis: Q Statistic or I^2 index? *Psychological Methods, 11*(2), 193–206.

Huerta, M., & Garza, T. (2019). Writing in science: Why, how, and for whom? A systematic literature review of 20 years of intervention research (1996–2016). *Educational Psychology Review*, 1–38.

Jimenez-Aleixandre, M. P. J., & Crujeiras, B. (2017). Epistemic practices and scientific practices in science education. In K.S. Taber & B. Akpan (Eds.), *Science education: An international course companion* (pp. 69–80). Rotterdam: Sense Publishers.

*Karaca, D. (2011). *Effect of the use of Science Writing Heuristic (SWH) in general physics laboratory-I lesson on teacher candidates' achievement and scientific process skills* (*Yaparak yazarak bilim öğrenmenin (YYBO) genel fizik laboratuari-I dersinde öğretmen adaylarinin akademik başarilarina ve bilimsel süreç becerilerine etkisi)* (Master thesis). Retrieved from Databases of National Thesis Center of the Council of Higher Education.

Kelly, G. J. (2011). Scientific literacy, discourse, and epistemic practices. In C. Linder, L. Ostman, D. A. Roberts, P. Wickman, G. Ericksen, & A. MacKinnon (Eds.), *Exploring the landscape of scientific literacy* (pp. 61–73). New York, NY: Routledge.

*Kingir, S. (2011). *Using the science writing heuristic approach to promote student understanding in chemical changes and mixtures* (Doctoral dissertation). Retrieved from Databases of National Thesis Center of the Council of Higher Education.

Kingir, S., Geban, O. & Gunel, M. (2013). Using the science writing heuristic approach to enhance student understanding in chemical change and mixture. *Research in Science Education, 43*, 1645–1663.

Kucuk Demir, B. (2014). *The effect of the argumentation based science learning approach on students' mathematical achievement and skills of creative thinking (Argümantasyon Tabanli Bilim Öğrenme Yaklaşiminin Öğrencilerin Matematik Başarilarina ve Yaratici Düşünme Becerilerine Etkisi)*. (Doctoral dissertation). Retrieved from Databases of National Thesis Center of the Council of Higher Education.

Lamb, R., Hand, B., & Kavner, A. (2020). Computational modeling of the effects of the science writing heuristic on student critical thinking in science using machine learning. *Journal of Science Education and Technology*, 1–15.

Manz, E. (2015). Representing student argumentation as functionally emergent from scientific activity. *Review of Educational Research*, *85*(4), 553–590.

McDermott, M. A., & Hand, B. (2010). A secondary reanalysis of student perceptions of non-traditional writing tasks over a ten year period. *Journal of Research in Science Teaching*, *47*(5), 518–539.

Ministry of National Education (MoNE). (2013). *Fen bilimleri dersi öğretim programi (İlkokul ve*

Ortaokul 3, 4, 5, 6, 7 ve 8. Sınıflar) [Science curriculum (Elementary and Middle School Grade 3, 4, 5, 6, 7 and 8)]. Ankara: MoNE Publishing.

Ministry of National Education (MoNE). (2018). *Fen bilimleri dersi öğretim programi (İlkokul ve Ortaokul 3, 4, 5, 6, 7 ve 8. Sınıflar) [Science curriculum (Elementary and Middle School Grade 3, 4, 5, 6, 7 and 8)]*. Ankara: MoNE Publishing.

Morris, S. B. (2008). Estimating effect sizes from pretest-posttest-control group designs. *Organizational Research Methods, 11*(2), 364–386.

Muis, K. R., & Duffy, M. C. (2013). Epistemic climate and epistemic change: Instruction designed to change students' beliefs and learning strategies and improve achievement. *Journal of Educational Psychology*, *105*(1), 213–225. https://doi.org/10.1037/a0029690

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academies Press.

Norris, S. P., & Phillips, L. M. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education*, *87*(2), 224–240. https://doi.org/10.1002/sce.10066

Organisation for Economic Co-operation and Development. (2017). *Education at a glance 2017: OECD indicators*. Paris: OECD Publishing.

R Core Team (2019). *R: A language and environment for statistical computing.* R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Rees, E. L., Quinn, P. J., Davies, B., & Fotheringham, V. (2016). How does peer teaching compare to faculty teaching? A systematic review and meta-analysis. *Medical teacher*, *38*(8), 829-837.

Rothstein, H. R., Sutton, A. J., & Borenstein, M. (2005). *Publication bias in meta-analysis: Prevention, assessment and adjustments*. Chichester, UK: John Wiley & Sons Ltd.

Sahin, E. (2016). *The effect of argumentation based science learning approach (ABSL) on academic success, metacognition and critical thinking skills of gifted students (Argümantasyon Tabanlı Bilim Öğrenme Yaklasımının (ATBÖ) Üstün Yetenekli Öğrencilerin Akademik Basarılarına, Üstbilis ve Elestirel Düsünme Becerilerine Etkisi)*. (Doctoral dissertation). Retrieved from Databases of National Thesis Center of the Council of Higher Education.

Schwarzer, G., Carpenter, J. R., & Rücker, G. (2015). *Meta-analysis with R*. Switzerland: Springer.

Sedgwick, P., & Marston, L. (2015). How to read a funnel plot in a meta-analysis. *British Medical Journal*, *351*. doi: https://doi.org/10.1136/bmj.h4718

Sterne, J. A., Becker, B. J., & Egger, M. (2005). The funnel plot. In H. R. Rothstein, A. J. Sutton, & M. Borenstein (Eds.), *Publication bias in meta-analysis: Prevention, assessment and adjustments* (pp. 75–98). Chichester, UK: John Wiley & Sons.

Tucel, S. T. (2016). *Exploring the effects of science writing heuristic (SWH) approach on the eight grade students' achievement, metacognition and epistemological beliefs* (Master thesis). Retrieved from Databases of National Thesis Center of the Council of Higher Education.

*Ulu, C., & Bayram, H. (2015). Effects of the argumentation based inquiry approach on students' concept learning levels (Argümantasyon Tabanlı Bilim Öğrenme Yaklaşımına Dayalı

Laboratuvar Etkinliklerinin 7. Sınıf Öğrencilerinin Kavram Öğrenmelerine Etkisi: Yaşamımızdaki Elektrik Ünitesi). *Pamukkale Üniversitesi Eğitim Fakültesi Dergisi, 37* (37), 61-75. Retrieved from http://dergipark.org.tr/pauefd/issue/33862/374978

*Unal, S, (2016). *The effect of case study and science writing heuristic based method of learning science about life based approach on teaching environmental subjects in biology course* (*Biyoloji dersi çevre konularinin öğretiminde yaşam temelli yaklaşima dair örnek olay inceleme ve araştirma sorgulama temelli bilim öğrenme yöntemlerinin etkisi)* (Doctoral dissertation). Retrieved from Databases of National Thesis Center of the Council of Higher Education.

Valentine, J. C., Pigott, T. D., & Rothstein, H. R. (2010). How many studies do you need? A primer on statistical power for meta-analysis. *Journal of Educational and Behavioral Statistics*, *35*(2), 215–247.

Viechtbauer, W. (2010). Conducting meta-analyses in R with the metafor package. *Journal of Statistical Software, 36*(3), 1–48.

Villanueva, M. G., Taylor, J., Therrien, W., & Hand, B. (2012). Science education for students with special needs. *Studies in Science Education*, *48*(2), 187–215.

Voutilainen, A., Saaranen, T., & Sormunen, M. (2017). Conventional vs. e-learning in nursing education: A systematic review and meta-analysis. *Nurse Education Today*, *50*, 97-103.

Yaman, F. (2018). Effects of the science writing heuristic approach on the quality of prospective science teachers' argumentative writing and their understanding of scientific argumentation. *International Journal of Science and Mathematics Education*, *16*(3), 421–442.