A Meta-Analytic Reliability Generalization Study of the Computational Thinking Scale

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Abstract: This study aims to analyze the reliability generalization of the computational thinking scale. There are five dimensions of computational thinking: creativity, algorithmic thinking, cooperativity, critical thinking, and problem-solving. A Bonett transformation was used to standardize the reliability coefficient of Cronbach’s alpha. A random-effects meta-analysis was conducted since the heterogeneity among the studies was high. Results supported the RG of the computational thinking scale and its subdimensions, which were calculated as 0.843 for general, 0.799 for creativity, 0.848 for algorithmic thinking, 0.863 for cooperativity, 0.799 for critical thinking, and 0.817 for problem-solving. Besides that, the moderator analysis was conducted for the sample type, test length, country, and language of the study. According to the findings, there were no significant moderator effects on the reliability estimation.

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Keywords: Reliability Generalization, Meta-Analysis, Computational Thinking

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Introduction

Computational thinking (CT) can be defined as thinking processes that involve formulating problems, apart from programming skills (Clark, 2015; Denning, 2017). In other words, developing solutions to the problems via algorithms and steps are degrees of CT (Aho, 2012). For instance, individuals who have developed computational thinking focus on analyzing a problem, collecting data to solve the problem, and dividing the solution into sub-steps. These individuals are not concerned with the outcome of the problem, but with the solution process of the problem and how it applies to similar problems (Vaidyanathan, 2016). Developing the CT skills of individuals is not only useful to reach goals and find solutions; it also supports other skills such as thinking scientifically, doing arithmetic, reading, and writing (Grover & Pea, 2013; Papert, 1996; Wing, 2006). Hence, individuals with a high level of computational thinking are also expected to show high academic success in different fields (Lei et al., 2020). In the relevant literature, researchers generally prefer to explain the functions, skills, and related concepts of computational thinking rather than describing them. For example, the International Educational Technologies Community states that computational thinking includes the skills of creativity, algorithmic thinking, critical thinking, problem-solving, communication, and cooperation (ISTE, 2019). Therefore, it is not surprising that supporting computational thinking will also help to develop 21st-century skills such as problem-solving, logical reasoning, and analytical thinking (Hunt & Riley, 2014).

An important question about CT is how to measure it. The proposed measurement tools generally cope with this issue by focusing on different dimensions of CT. For example, Akyol (2019) developed a CT scale and assessed the following dimensions of CT: computational thinking, robotic coding and software, professional development, and career planning. In another scale developed by Tsai and his colleagues (2021), evaluation, abstraction, decomposition, generalization, and algorithmic thinking appear as sub-dimensions of CT (Tsai et al., 2021). Another measurement tool developed by Korkmaz et al. (2017) is the most frequently used scale to determine the level of CT in the relevant literature (Avcu & Ayverdi, 2020; Çakir & Yaman, 2018; Çevik et al., 2021; Karaçaltı & Korkmaz, 2018; Oluk et al., 2018; Özgür, 2020; Yaşlan & İkinci, 2020). Hence, this study aims to conduct a reliability generalization (RG) of the CT scale devised by Korkmaz et al. (2017)’s CT scale.

Reliability Generalization

Reliability is a problem related to the measurement precision of test scores. To solve this problem, researchers record the number of errors of repeated measurements and determine how precisely the scale measures the specified quality (McDonald, 1999). It can be said that reliability is the degree to which the measurements are free from random error. In addition, reliability means the consistency of the scores of individuals

‡: Supplementary materials are included for this article.
participating in a test (Anastasi, 1976). Therefore, the reliability of the scores obtained from a measurement tool must be investigated at every turn (Crocker & Algina, 2008). Cronbach’s alpha, a coefficient used in the literature to analyze and interpret reliability, can be dissimilar for each measurement even though the same scale is used because it is a sample-dependent coefficient. Interpreting the extent of observed effects requires an assessment of the reliability of the scores. Therefore, the reliability coefficients of the scores obtained from the scale for the analyzed data should be reported (Wilkinson, 1999). RG studies aim to explain the source of the variability in the reported reliability values in different applications of a scale through a meta-analysis study. According to Vacha-Haase (1998), RG can be used to estimate the pooled score reliability of the scale used in different studies. In other words, RG studies are carried out to determine the level and source of the difference between the reliability coefficient of the studies (Eser & Aksu, 2021; Liang et al., 2021; Olderbak et al., 2021; Opitz et al., 2020; Yoon et al., 2021).

The study aimed to examine the RG of the computational thinking scale (Korkmaz & Bai, 2019; Korkmaz & Özden, 2015; Korkmaz et al., 2017). It consists of 29 questions in total divided into five sub-dimensions: creativity (8), algorithmic thinking (6), cooperativity (4), critical thinking (5), and problem-solving (6). The questionnaire was developed for undergraduate students and then it was adapted for middle school students. The adapted version of the questionnaire consists of 22 items with similar sub-dimensions. There were two main reasons for choosing this scale in this study. Firstly, although CT is mostly associated with computer science, it is a skill that can be associated with all other fields. Besides that, the number of related studies has increased with the increasing importance of CT (Kıyıcı & Yamak, 2021). Hence, it is important to ascertain the reliability of the instrument, and secondly, the mentioned scale is frequently used to assess CT in the literature (e.g. Avcu & Ayverdi, 2020). Since the language of the instrument is Turkish, the reliability can be generalized to the Turkish sample. To sum up, the present study aims to answer the following research questions:

i. What is the overall reliability estimate of the CT scale?

ii. To what extent does the reliability estimate of the CT scale vary by year and language of the article?

iii. To what extent does the reliability estimate of the CT scale vary by country or level of the participants?

**Method**

This study aimed to calculate the pooled reliability coefficient of the computational thinking scale (Korkmaz & Bai, 2019; Korkmaz & Özden, 2015; Korkmaz et al., 2017). For this aim, the recommendations of the Cochrane Handbook for systematic reviews of primary research were followed (Higgins et al., 2003). The findings of the study were reported according to the PRISMA statement for reporting systematic reviews and meta-analyses of studies (Liberati et al., 2009).

**Sample of Studies**

To identify studies, online databases such as Web of Science, the Educational Resources Information Center (ERIC), and Google Scholar were searched by the research-
ers. The title of the questionnaire was used as the keyword. Besides that, articles that cited the questionnaire development articles were investigated.

**Search Strategy**

The study selection process is shown in Figure 1 (Moher et al., 2009). As can be seen in the figure, the first step is database scanning. Studies applying the computational thinking scale developed by Korkmaz (2017) were determined by searching Google Scholar Academic, ProQuest, EBSCOhost, ERIC, ScienceDirect, Web of Science, and Taylor and Francis online databases. Searches of these databases have been conducted since 2015 when the “computational thinking” scale was developed and published. Besides that, the snowball technique was also used to reach the studies: the studies that cited the article at their reference list were also investigated. According to Korkmaz et al. (2017) and Korkmaz et al. (2015), all referenced studies were identified and it was
Table 1. Descriptive Features of the Included Studies.

<table>
<thead>
<tr>
<th></th>
<th>Frequency</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Year</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>1</td>
<td>1.9</td>
</tr>
<tr>
<td>2018</td>
<td>8</td>
<td>15.4</td>
</tr>
<tr>
<td>2019</td>
<td>7</td>
<td>13.5</td>
</tr>
<tr>
<td>2020</td>
<td>17</td>
<td>32.7</td>
</tr>
<tr>
<td>2021</td>
<td>19</td>
<td>36.5</td>
</tr>
<tr>
<td><strong>Item Number</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 item</td>
<td>2</td>
<td>3.8</td>
</tr>
<tr>
<td>22 item</td>
<td>22</td>
<td>40.4</td>
</tr>
<tr>
<td>27 item</td>
<td>1</td>
<td>1.9</td>
</tr>
<tr>
<td>29 item</td>
<td>30</td>
<td>53.8</td>
</tr>
<tr>
<td><strong>Language</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>English</td>
<td>32</td>
<td>61.5</td>
</tr>
<tr>
<td>Turkish</td>
<td>19</td>
<td>36.5</td>
</tr>
<tr>
<td><strong>Country</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td>1</td>
<td>1.9</td>
</tr>
<tr>
<td>China</td>
<td>2</td>
<td>3.8</td>
</tr>
<tr>
<td>Greece</td>
<td>2</td>
<td>3.8</td>
</tr>
<tr>
<td>India</td>
<td>1</td>
<td>1.9</td>
</tr>
<tr>
<td>Jakarta</td>
<td>1</td>
<td>1.9</td>
</tr>
<tr>
<td>Korea</td>
<td>1</td>
<td>1.9</td>
</tr>
<tr>
<td>Malaysia</td>
<td>1</td>
<td>1.9</td>
</tr>
<tr>
<td>Spain</td>
<td>1</td>
<td>1.9</td>
</tr>
<tr>
<td>Taiwan</td>
<td>3</td>
<td>5.8</td>
</tr>
<tr>
<td>TR</td>
<td>35</td>
<td>65.4</td>
</tr>
<tr>
<td>USA</td>
<td>1</td>
<td>1.9</td>
</tr>
<tr>
<td><strong>Gender of Participants</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>6,064</td>
<td>52.76</td>
</tr>
<tr>
<td>Male</td>
<td>5,430</td>
<td>42.24</td>
</tr>
</tbody>
</table>

seen that there were 349 studies in total. These studies were reviewed according to the research inclusion criteria.

The study group of the research seen in the Prisma flowchart consisted of 49 studies that comply with the criteria determined in this study by the researchers. In addition, for studies reporting more than one reliability coefficient for different study groups, each coefficient was coded separately. As a result, 52 Cronbach’s alpha coefficients were obtained from 49 studies (see Appendix A). The descriptive features of the studies are presented in Table 1.

**Inclusion and Exclusion Criteria**
To include articles in this RG study, the following criteria were considered: (i) the study had to be published, (ii) the study should be written in English or in Turkish, and (iii) the study had to report a reliability coefficient. Some studies reported the reliability coefficient of the original study instead of calculating a new one with their sample. Hence, they were not included in this meta-analysis.

**Data Analysis and Interpretation**

Reliability and validity are two important concepts of measurement. Reliability is related to the accuracy of the measurement process and the consistency of the scores of the same sample from the same test in two applications (Anastasi, 1976; McDonald, 1999). Depending on the sample characteristics, it can take different values for different samples despite using the same measurement instrument (Özdemir et al., 2020). The source and amount of these differences in the reliability coefficients are determined by RG analysis (Graham et al., 2006; Vacha-Haase, 1998).

The Cronbach alpha coefficient (Cronbach, 1951) is one of the most widely used reliability coefficients in social sciences (Bollen, 1989; Bonett & Wright, 2015). However, the use of the Cronbach alpha metric in the meta-analysis violates the normality assumption (Rodriguez & Maeda, 2006). To calculate Cronbach’s alpha mean coefficient, it is necessary to normalize the distribution and stabilize its variances (Yoon et al., 2021). In this study, Bonett’s (2002) transformation formula, presented below, was used.

\[ Li = \ln (1 - \alpha_i) \]

Where \( Li = \text{Bonett metric}, \alpha_i = \text{Cronbach alpha}, \ln \) is the natural logarithm.

After applying the Bonett transform, reliability synthesis was made and the obtained values were converted back to the original Cronbach’s alpha coefficient metric.

The heterogeneity between the reliability values of the studies included in the study was evaluated by calculating the Cochrane Q statistics and I2 index. Q statistics were applied to test the homogeneity assumption between alpha coefficients. The I2 index is a measure of heterogeneity (Higgins & Thompson, 2002). To interpret the results, the average effect sizes obtained with the Bonett transform, the lower and upper classes of the confidence interval, and the transformed Cronbach’s alpha metric were used. Additionally, they were evaluated according to the 0.70 criterion (Nunnally & Bernstein, 1994).

Significant heterogeneity was seen among the estimates of the reliability of the primary studies that were included in the RG of CT. Analogue ANOVA analysis with moderator analysis was performed to investigate the sources of this heterogeneity. These moderator variables are sample type, test length, country, and language.

No matter how appropriate the methodology, the bias of the studies included in the meta-analysis may reduce the validity of the results (Becker, 2005). To eliminate this risk, the funnel plot asymmetry test, Egger’s regression test, Begg and Mazumdar’s rank correlation test, and Rosenthal’s error protection number method were used to determine the publication bias status of primary studies. Comprehensive Meta-Analysis V2 free trial version was used for the aforementioned analyses.

**Results**
Publication Bias

In this study, the funnel scatter plot of the studies included in the meta-analysis, that is, the 52 observed studies, is exposed. The presence of tiny circles representing primary studies in the funnel means that primary studies are gathered around the average effect size. The fact that the studies are located symmetrically around the mean effect size in the funnel scatter plot shows that there is a meta-analysis without publication bias (Figure 2).

According to the Egger regression test, there is no bias in primary studies (t (48) = 0.398; P = 0.692, P < 0.05), but the finding needs to be tested with other methods as well (Table 2). If the Egger regression test and the funnel plot are evaluated together, the funnel plot of research without publication bias is symmetrical and the regression line is expected to coincide with the line in the center of the funnel plot (Sterne et al., 2005).

According to the Egger regression test applied to the reliability values of the primary studies included in the RG, the upper limit of the 95% confidence interval was
Table 3. Begg and Mazumdar Rank Correlation Test Results for Studies Used Korkmaz’s (2017) CT Scale.

<table>
<thead>
<tr>
<th>Hypothesis</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Kendall's S statistic (P-Q)</td>
<td>-55</td>
</tr>
<tr>
<td>Kendall's tau without continuity correction</td>
<td></td>
</tr>
<tr>
<td>Tau</td>
<td>-0.04493</td>
</tr>
<tr>
<td>z-value for tau</td>
<td>0.46007</td>
</tr>
<tr>
<td>P-value (1-tailed)</td>
<td>0.32273</td>
</tr>
<tr>
<td>P-value (2-tailed)</td>
<td>0.64547</td>
</tr>
<tr>
<td>Kendall's tau with continuity correction</td>
<td></td>
</tr>
<tr>
<td>Tau</td>
<td>-0.04412</td>
</tr>
<tr>
<td>z-value for tau</td>
<td>0.4517</td>
</tr>
<tr>
<td>P-value (1-tailed)</td>
<td>0.32574</td>
</tr>
<tr>
<td>P-value (2-tailed)</td>
<td>0.65148</td>
</tr>
</tbody>
</table>

Table 4. Rosenthal Error Protection Number Test Results for Studies Used Korkmaz’s (2017) CT Scale.

<table>
<thead>
<tr>
<th>Observed Studies</th>
<th>The number of studies that can ensure that P is greater than 0.05</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z</td>
<td>P</td>
</tr>
<tr>
<td>-116.729</td>
<td>&gt; 0.001</td>
</tr>
</tbody>
</table>

-2.88 and the limit inferior was 1.93. The value calculated for the regression line constant of 95 out of 100 studies to be conducted with other similar samples using the computational thinking scale developed by Korkmaz (2017) will be between the upper and lower limits of the 95% confidence interval.

It is also important to evaluate the Begg and Mazumdar rank correlation results, which quantify the result of the funnel plot, instead of the interpretation of the funnel plot, which depends on the researcher. The rank correlation between the standardized effect sizes and the standard errors of these values is 0, indicating that there is no publication bias (Hunter & Schmidt, 2004).

Begg and Mazumdar rank correlation tests were applied to statistically test that the study sample selected was not biased (Table 3). According to the Begg and Mazumdar rank correlation test, the publication bias test does not make sense (τ = -0.045; P = 0.65). According to the analysis results shown in the chart, the primary studies included in this meta-analysis study were not biased. Rosenthal (1979) calculated the error-proof number (N) to find the summary of statistical significance (p-value) when there was little or no heterogeneity among the effect sizes of primary studies.

The Rosenthal fail-safe number calculated for primary investigations is 7,301 (Table 4). This value is statistically significant since P < 0.05. This figure states that for P > 0.05, 7,301 studies should be conducted in the opposite direction of the studies included in the meta-analysis with a zero-effect size value. A ratio \[1 < N / (5k+10)\] be-
between Rosenthal’s calculated error protection number (N) and the number of primary studies in the meta-analysis (k) has been proposed (Mullen, et al., 2001) at 28, indicating that the results of the meta-analysis are robust against publication bias and that the overall reliability estimate of primary studies is unlikely to affect the combined alpha coefficient of the current meta-analysis.

Data from the funnel plot, the Egger regression test, Beg and Mazumdar’s rank correlation, and Rosenthal’s fail-safe N tests show the absence of publication bias. Considering the results of all analyzes, it was determined that publication bias is not a serious threat affecting the RG estimation.

### Results of the Estimate of the Pooled Reliability of the Computational Thinking Scale and Subscales

The Cronbach’s alpha (α) coefficients and heterogeneity test results in the random-effects model are shown in Table 1. Cochrane Q parameter and Higgins I² values were calculated to test the heterogeneity of primary studies. It was decided to use the random-effects model in the meta-analysis according to the results of heterogeneity tests.

As seen in Table 5, the Q (df = 49) value for the total CT scale was found to be 1093.756 (P < 0.001). The Q value calculated according to the chi-square (X²) table is above the limit, with 49 degrees of freedom and a confidence interval of 0.05 (df = 49; X²(0.05) = 66.339). Therefore, it can be said that there is heterogeneity among studies. The I² value (95.520) calculated for the heterogeneity test indicates a high level of heterogeneity. The random-effects model was used in this study as there was heterogeneity among primary studies. The overall Cronbach’s alpha coefficient of the total CT scale was calculated as 0.843 (95%, 0.823 – 0.863) according to the random-effects model.

The meta-analysis of the RG of the CT scale is presented in the forest plot in Figure 3. When Figure 3 is examined, it is seen that the reliability coefficients calculated in the Bonett type of all primary studies included in the analysis are significant. It was also observed that the Cronbach’s alpha values of primary studies were between 0.70 and 0.965.

Heterogeneity tests were also performed for the sub-dimensions of the scale and creativity (Q (df = 32) = 822.182), algorithmic thinking (Q (df = 32) = 0.432), cooperation (Q (df = 32) = 420.606), critical thinking (Q (df = 34) = 433.779), and prob-

### Table 5. Results on the Estimate of Pooled Reliability of the Computational Thinking Scale and Subscales.

<table>
<thead>
<tr>
<th>Subscale</th>
<th>α</th>
<th>SE</th>
<th>Z</th>
<th>LL</th>
<th>UL</th>
<th>df</th>
<th>Q</th>
<th>I²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computational Thinking</td>
<td>0.843</td>
<td>0.065</td>
<td>-28.551*</td>
<td>0.823</td>
<td>0.863</td>
<td>49</td>
<td>1093.756*</td>
<td>95.520</td>
</tr>
<tr>
<td>Creativity</td>
<td>0.799</td>
<td>0.078</td>
<td>-20.618</td>
<td>0.765</td>
<td>0.827</td>
<td>32</td>
<td>822.182*</td>
<td>96.108</td>
</tr>
<tr>
<td>Algorithmic Thinking</td>
<td>0.848</td>
<td>0.064</td>
<td>-29.677*</td>
<td>0.828</td>
<td>0.866</td>
<td>32</td>
<td>532.432*</td>
<td>93.990</td>
</tr>
<tr>
<td>Cooperation</td>
<td>0.863</td>
<td>0.056</td>
<td>-33.956</td>
<td>0.833</td>
<td>0.866</td>
<td>32</td>
<td>420.606*</td>
<td>92.392</td>
</tr>
<tr>
<td>Critical Thinking</td>
<td>0.799</td>
<td>0.055</td>
<td>-28.920*</td>
<td>0.776</td>
<td>0.820</td>
<td>34</td>
<td>433.779*</td>
<td>92.162</td>
</tr>
<tr>
<td>Problem Solving</td>
<td>0.817</td>
<td>0.068</td>
<td>-25.104*</td>
<td>0.791</td>
<td>0.839</td>
<td>34</td>
<td>665.07*</td>
<td>94.888</td>
</tr>
</tbody>
</table>

Note: k = number of reliability coefficients; SE = standard error; 95% confidence interval upper limit (UL) and lower limit (LL); df = degrees of freedom; Q = heterogeneity statistic representing total variance; I² = heterogeneity index; *p < 0.05.
lem-solving \((Q (df = 34) = 665.07)\). 92.392; \(I^2_{\text{Critical Thinking}} = 93.162\%\); \(I^2_{\text{Problem Solving}} = 94.888\%\) indicate a high level of heterogeneity. As a result of the heterogeneity tests of the sub-dimensions, it was decided to use the random effects model for each dimension. According to the Cronbach’s alpha coefficient random-effects model, creativity was calculated as 0.799 (95% CI: 0.765 – 0.827), algorithmic thinking 0.848 (95% CI: 0.828 – 0.866), cooperation 0.863 (95% CI: 0.833 – 0.886), critical thinking 0.799 (95% CI: 0.776 – 0.820), and problem-solving was calculated as 0.817 (95% CI: 0.791 – 0.839).

**The Relationship between Moderating Variables and Reliability Estimates**
Table 6. The effect of Moderator Variables on the Reliability Estimate.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Category</th>
<th>k (%)</th>
<th>α</th>
<th>95%</th>
<th>$Q_a$</th>
<th>df</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Length</td>
<td>15</td>
<td>2 (4)</td>
<td>0.700</td>
<td>0.370</td>
<td>0.857</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>21 (40)</td>
<td>0.835</td>
<td>0.798</td>
<td>0.865</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>1 (2)</td>
<td>0.900</td>
<td>0.733</td>
<td>0.963</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>29</td>
<td>26 (54)</td>
<td>0.854</td>
<td>0.826</td>
<td>0.878</td>
<td>4.667</td>
<td>3</td>
</tr>
<tr>
<td>Sample Type</td>
<td>Middle school</td>
<td>18 (36)</td>
<td>0.844</td>
<td>0.803</td>
<td>0.877</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>High school</td>
<td>6 (16)</td>
<td>0.849</td>
<td>0.777</td>
<td>0.898</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Undergraduate</td>
<td>22 (46)</td>
<td>0.842</td>
<td>0.805</td>
<td>0.872</td>
<td>0.081</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Teachers</td>
<td>2 (2)</td>
<td>0.854</td>
<td>0.715</td>
<td>0.925</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Country</td>
<td>Asia</td>
<td>2 (4)</td>
<td>0.785</td>
<td>0.621</td>
<td>0.878</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Europe</td>
<td>3 (6)</td>
<td>0.800</td>
<td>0.652</td>
<td>0.885</td>
<td>1.751</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Turkey</td>
<td>35 (73)</td>
<td>0.838</td>
<td>0.814</td>
<td>0.860</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Far East</td>
<td>8 (17)</td>
<td>0.823</td>
<td>0.760</td>
<td>0.869</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Language</td>
<td>English</td>
<td>30 (63)</td>
<td>0.857</td>
<td>0.832</td>
<td>0.879</td>
<td>2.909</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Turkish</td>
<td>18 (37)</td>
<td>0.819</td>
<td>0.775</td>
<td>0.854</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The primary investigations of the study appear to show significant heterogeneity. It is important to identify the source of this heterogeneity. Sample type, language (categorical), test length, and (continuous) moderator of primary studies are examined as variables. Differences between subgroups are analyzed using the analogous ANOVA approach. To examine whether subgroups of all moderator variables were equally reliable, they were analyzed according to the mixed-effects model.

As seen in Table 6, it was determined that sample type, test length, country, and language variables did not affect the reliability of the measurements; in other words, there was no statistically significant difference between the subgroups ($P_{Test Length} = 0.198; P_{Sample type} = 0.994; P_{Country} = 0.781; P_{Language} = 0.088$).

Discussion

The present study aimed to investigate the overall reliability of the CT scale and the variability that can be explained by the moderators via the RG of meta-analysis. The CT scale was developed by Korkmaz et al. (2017) and adapted for different ages and languages (e.g. Korkmaz & Bai, 2019; Korkmaz & Özden, 2015). There are five subdimensions of CT in the scale: creativity, algorithmic thinking, cooperation, critical thinking, and problem-solving. To achieve these aims, research studies that used a CT scale and reported the reliability coefficient were examined. The reliability estimates of primary research showed high variability ($I^2 = 95.52$). This implies that the reliability of CT scale scores cannot be generalized to different contexts or populations. Furthermore, the variability, which was determined as $I^2$, refers to the real differences among studies. Hence, the RG would be useful for the questionnaire (Graham et al., 2006; Vacha-Haase, 1998). Moreover, since $I^2$ is significant, the random effect method was used while calculating the reliability coefficient across the reliability estimations (Borenstein et al., 2009).
Fifty-five studies used the CT scale and reported the reliability coefficient of the scores. The average reliability coefficient was calculated as 0.840. Besides that, a reliability estimation was also calculated for each dimension and found 0.799 for creativity, 0.848 for algorithmic thinking, 0.863 for cooperation, 0.799 for critical thinking, and 0.817 for problem-solving. Hence, the findings of the current study suggest that the reliability coefficients not only for the overall scale but also for sub-dimensions were within the acceptable range (Clark & Watson, 1995; DeVellis, 1991; Nunnally & Bernstein, 1994).

To investigate the variability of scores from the subcategories, the moderator analysis was conducted by using mixed-effect models. There were four different variables as moderators: the language of the article (English versus Turkish), test length (15, 22, 27 versus 29 items), country of study (Asia, Europe, Turkey, or Far East countries), and sample type (middle-school, high school, undergraduate, and teachers). As seen in Table 6, none of the moderator variables was significant, which means that there were no significant differences among subgroups in terms of the reliability coefficient. Regarding the effect of the sample type, previous research also suggested no reliability differences among groups. For instance, Hess et al. (2014) compared the reliability coefficients of perceived ease of use, perceived usefulness, and behavioral intentions of questionnaires for students and non-students and the findings of the study supported that there was no moderation effect of the sample type. Concerning the length of the scale, the findings of previous research are mixed. While some of them offer a significant effect (e.g. Streiner, 2003), others suggest no significant difference between the short or long form of the scale (e.g. Negrin et al., 2017). Supporting this discrepancy, Niemi et al. (1986) investigated the impact of the length of the scale on reliability and recommended that reliability does not always increase with the number of items. Last but not least, some studies also propose no significant effect on either the language of the scale or the country where data was collected (e.g. Sen, 2021).

There are some limitations of the current study, including the conversion of Cronbach’s alpha coefficients to Bonett’s (2002) parameter, performing the analysis in the CMA program, and examining the sample type, test length, country, and language variables as sources of reliability measurement errors. Different reliability parameters in the literature consider different sources of measurement error. In future research, reliability estimates using other reliability parameters such as Hakstian and Whalen (1976) and Fisher Z can be evaluated by examining them. Furthermore, depending on whether it belongs to the definition and measurement, if RG has not been done, the reliability value of each study must be reported. However, in the database scanning process of this meta-analysis, many studies included the reliability values reported by Korkmaz (2017) instead of reporting the reliability of their measurements. This has reduced the number of primary studies that can be included in the RG study. Besides that, it was seen that the applications of the primary research of the study were mostly made in computer science and science teaching-related fields. CT is explained as the thought process involved in solving a problem (Curzon & McOwan, 2018; Denning, 2017). Considering that these intellectual processes can also be encountered in the solution of problems in different fields, it is necessary to consider CT in the teaching of different fields.

To sum up, this study supported the RG of the CT scale. At this point, it may be useful to remember that reliability is defined as the level of explanation of the phenomenon related to the conceptual structure that is expected to be measured with a scale (Şencan, 2005). However, reliability is a value of the data, not the scale (APA, 2020; Vacha-Haase, 1998). The reliability and validity of the scores obtained from the meas-
urement tools must be investigated (Smith, 1987). Researchers are recommended to refer to a published RG study of the scale used or to report the reliability values of their measurements.

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Appendix I

Studies Used in the Meta-Analysis


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