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Effects of Design Thinking Interventions on Educational Outcomes: A Meta-Analysis

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Abstract

The purpose of this study is to investigate effects of Design Thinking interventions on educational outcomes through meta-analysis. Research questions are as follows. First, what is the overall effect size of Design Thinking interventions on educational outcomes? Second, what is the effect size of Design Thinking interventions according to categorical variables? The researcher selected 21 studies through a systematic literature review and extracted statistical information to allow calculation of the effect size. Comprehensive Meta-Analysis Version 2 was used to conduct the overall analysis and moderator analyses. Results are as follows. First, the effect of Design Thinking interventions was 0.469 standard deviations, which had a moderate effect size and was educationally significant. Second, in subject areas, the results ranked in the order of computer 0.573, STEAM 0.544, science 0.502, engineering 0.487, education 0.361, liberal arts 0.342, health sciences 0.267, and English 0.073. Third, in school level, the results ranked in the order of secondary school 0.654, elementary school 0.535, and college 0.345. Fourth, for grade level, the effect size of combined 0.449 was larger than that of single-grade 0.331. Fifth, in the publication year category, the effect sizes of 2018~2022 0.488, 2012~2017 0.169 were in order. Sixth, for sample size, the effect sizes of 1-30 0.492, more than 30 0.369 were in order. The researchers discussed the results and provided suggestions for educators and researchers to implement Design Thinking in the future.

Keywords: Design Thinking; K-12 Education; Higher Education, Meta-Analysis

Introduction

The Fourth Industrial Revolution (4IR), introduced by artificial intelligence, machine learning, and virtual reality, is underway throughout society (Gleason, 2018). 4IR is an era of technological revolution that will fundamentally change the way of human life maintained until now. Scholars argue that the speed and scope of future social change will exceed expectations (Khoza, 2021; Naidoo & Singh-Pillay, 2020). Accordingly, citizens are facing new challenges in their field of expertise and are striving to enhance the core competencies necessary to successfully overcome the crisis.

Preparations to respond to social change should also be made in school education.

World Economic Forum (2015) argued that education reform is necessary to nurture talents who will successfully lead the future in the era of 4IR. Scholars have also analyzed the social demands for the necessity and direction of school education innovation, and have suggested curriculum and teaching methods to effectively implement them (Hess, 2017; Kim & Maloney, 2020). This is because, after graduation, students are the subjects who need to find their own professional field and perform work, and play a key role in nurturing the next generation. Therefore, teachers need to continuously support students to accurately recognize the problems they face in a changing society and to develop the ability to solve them through creative thinking. School education must constantly evolve so that students can think critically, solve problems cooperatively, and empathize with others in a forward-thinking education.

Recently, interest in Design Thinking (DT) is increasing as an innovative method for nurturing creative talents in school education (Lee, 2022). DT is a pedagogical framework that recognizes empathy as a key factor in learning. It is a creative learning method that repeatedly explores and solves problems cooperatively. In the process of DT, students think like designers and solve problems while understanding and empathizing with the behavior of people they encounter in their daily life and the underlying needs and motives (Rusmann & Ejsing-Duun, 2022). People practice the creative process by thinking in new ways and generating advanced ideas concretely. DT was introduced as a methodology for innovation and was initially used mainly in the fields of design, management, business, and engineering. It has been recognized as an innovative teaching and learning method in elementary and secondary schools and universities. DT is used in the process of implementing the curriculum of various subject areas. IDEO and Stanford University d.school (Hasso Plattner Institute of Design) introduced DT as a creative methodology that anyone, not just designers, could use.

Researchers have applied DT interventions in various subject areas for students because DT is an innovative and alternative instructional method. Educators use DT to engage students and help them experience real-world problem-solving processes aligned with curriculum content. However, the author has confirmed that there are no studies that systematically review the effects of previous studies on DT interventions and present future research directions though meta-analysis. Accordingly, the author recognized the need for comprehensive analysis and discussion of the effects of DT interventions through meta-analysis.

Meta-analysis is a statistical method that synthesizes previous studies to verify the effectiveness of a particular topic. Results of the meta-analysis can provide directions and suggestions for future research (Cooper, 2015). It can also contribute to the accumulation of knowledge in related fields and provide an important foundation.

Research questions are as follows. First, what is the overall effect size of DT interventions on educational outcomes? In this study, educational outcomes include

cognitive and affective domains. Second, what is the effect size of DT interventions according to categorical variables? According to Cooper (2015)'s recommendation, categorical variables consisted of study characteristics, methodological characteristics, design characteristics, and outcome characteristics.

Literature Review

Design Thinking

DT refers to a convergent way of thinking often used by designers to create innovative strategies (Lee, 2022). It also means the process of deriving creative solutions through collaborative problem solving and repetitive exploration. DT was introduced as a business strategy and management method applied by IDEO, an American design company (Gallagher & Thordarson, 2018). However, Stanford University operated various workshop programs, it became known as an educational methodology.

The main process of DT is divided into five stages (Curedale, 2013): Empathize, Define, Ideate, Prototype, and Test. First, empathize means identifying the needs of users. DT participants understand the problem they try to solve through empathic understanding, identify the causes, and fundamentally solve it. In this process, they conduct observation and interview to gain deeper understanding. Second, define refers to describing user's needs and problems elaborately. DT participants define the problem based on qualitative data collected in the first stage. Third, ideate is the stage of drawing up ideas and choosing the best way to come up with a solution to the problem. At this stage, DT participants present solutions from different perspectives and strive to find the most innovative solutions. Fourth, prototype is the step of realizing and implementing the selected idea in a visible form. DT participants provide feedback on the prototype and reflect the results to continuously improve the prototype. Fifth, test is the stage of evaluating the complete product. The goal of this stage is to understand the final product and users as deeply as possible.

Previous Review on Design Thinking

Main contents of prior research review on DT are as follows.

First, McLaughlin et al. (2019) reviewed qualitative studies on effects of DT in health professions education, since DT is often used as a problem solving framework to improve clinical outcomes and medical curriculum. Authors analyzed 15 papers and reported that all papers were published after 2009. In addition, they found six published papers highlighted the early stages of DT through lectures, small group discussions, and workshops. Additionally, the findings discussed impacts of DT on self-efficacy and participant experience.

Second, Bhandari (2022) synthesized previous studies on DT through systematic literature review, bibliographic analysis, and content analysis. Bhandari (2022) carefully analyzed the title, abstract, and keywords to find relevant literature on DT. As a result of the study, the author identified 16 research clusters in DT through content analysis: school education, design framework, digital learning, interdisciplinary area, product and project innovation, business model development, innovation and entrepreneurship, policy development, global challenges, design process, core of design thinking, creativity and framework, focus on service industry, strategy and leadership, professional and technical communication, and outcome-based learning.

Third, Rusmann and Ejsing-Duun (2022) summarized results of previous studies applying DT at the K-12 level. Authors reviewed how the literature described competencies that students developed through DT. Authors analyzed effects of DT, focusing on reasoning, problem setting, empathy, ideation, modeling, and process management. Additionally, they found that DT fostered competences such as communication, collaboration, and critical thinking in the K-12 context. However, there is no study that systematically review the effects of previous studies on DT interventions though meta-analysis.

Research Method

Methodology

This meta-analysis was conducted to synthesize effects of DT interventions. Meta-analysis is the highest level of statistical analysis for systematically evaluating effects of interventions (Cooper, 2015). The study follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2009) and recommendations of the Cochrane handbook for systematic reviews of interventions (Higgins et al., 2019).

Search Process

The researcher examined DT primary studies adopting experimental or quasi-experimental designs (Meline, 2006). The descriptors and keywords used in the search include: design thinking, AND effect, impact, evaluation, outcome. The following international databases were searched: ERIC, Google Scholar, ProQuest Dissertations & Theses Global, Scopus, and Web of Science. These databases together provide a comprehensive coverage of journal articles and conference proceedings.

Inclusion and Exclusion Criteria

Each primary study was considered to be appropriate if it met the following criteria

(1) investigated DT interventions for students attending K-12 schools and universities, (2) was implemented in school settings, (3) applied five DT stages such as empathize, define, ideate, prototype, and test, (4) reported dependent variables of educational outcomes, (5) provided quantitative data such as sample size, mean, and standard deviation. Primary studies not included in this meta-analysis had one or more of the following criteria: studies using qualitative designs; included only correlation or linear relationships between variables; provided insufficient statistical information to allow calculation of the effect size.

The literature search yielded 106 studies: 65 journal articles, 33 conference papers, and 8 dissertations. Of these, 23 studies were eliminated based on the title and abstract at the first screening. In addition, 62 studies in full texts did not meet the inclusion criteria. Ultimately, 21 studies were selected for the meta-analysis.

The data extraction procedure is represented in Figure 1.

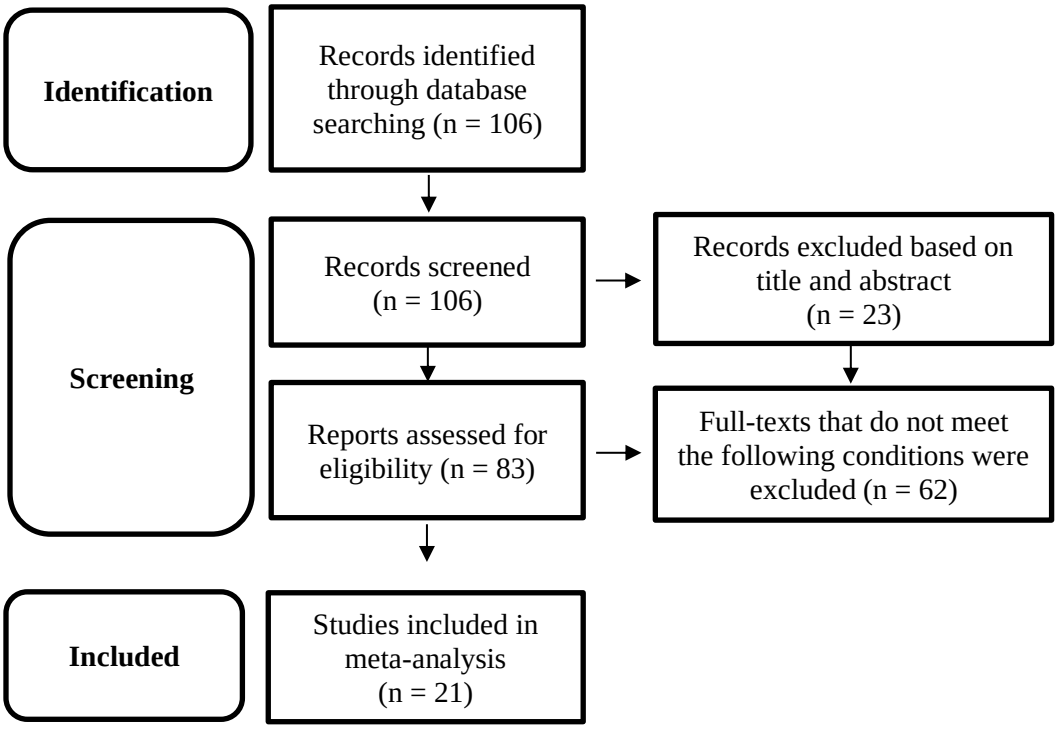

Figure 1: PRISMA flowchart

Data Extraction

A summary of the included studies containing specified characteristics is reported

in Table 1.

Table 1: Characteristics of studies included in this meta-analysis

Study	Design	Publication	Level	Sample	Subject
Brannon (2022)	NCG	Dissertation	College	76	Education
Kim (2020)	OG	Journal	College	59	Health science
Kim and Koo (2019)	OG	Journal	College	69	Engineering
Kim and Lee (2018)	NCG	Journal	Elementary	16	Liberal arts
Kim et al. (2018)	OG	Journal	Secondary	75	Science
Kuo et al. (2021)	NCG	Journal	College	41	Engineering
Lee (2017)	NCG	Journal	College	99	Liberal arts
Lee (2020)	OG	Journal	Middle	52	Computer
Lee and Tae (2017)	NCG	Journal	Elementary	56	Steam
Lee and Yoon (2021)	OG	Journal	College	46	Education
Nam et al. (2019)	NCG	Journal	College	38	Education
Oishi (2012)	OG	Dissertation	College	104	Engineering
Seo and Kim (2017)	OG	Journal	College	22	Computer
Seo and Kim (2018)	OG	Journal	Elementary	28	Computer
Seong (2019)	OG	Journal	College	51	English
Shin et al. (2019)	OG	Journal	College	114	Computer
Thi-Huyen et al. (2021)	OG	Journal	College	120	Liberal arts
Won et al. (2019)	OG	Journal	College	41	Design thinking
Yoo (2017)	OG	Journal	College	39	Health science
Yoo (2018)	OG	Journal	College	41	Health science
Yoo (2020)	OG	Journal	College	35	Health science

Note. NCG: Non-equivalent Control Group, OG: One Group

Coding Reliability

The researcher developed a coding manual in consultation with colleagues. Three coders have more than several years of teaching and research experiences in education and hold doctoral degrees. All coders coded 21 primary studies together. After extracting the data, three coders compared and validated them. Inter-rater reliability was very good at 0.92. If there was a disagreement in the coding process, three coders solved it through discussion.

Data Analysis

The researcher calculated effect size and 95% confidence intervals by using Comprehensive Meta-Analysis (CMA) Version 2. The overall effect size was weighted by the inverse of variance. The researcher inspected forest plots visually and calculated Q statistic and I2 statistic (Cooper et al., 2019). For the reason, the researcher used a random-effects model for the overall analysis and moderator analyses. The study was used as a unit for calculation of overall effect size while the effect size was used as a unit for calculating moderator analyses according to Cooper (1989)'s shifting unit of analysis.

The researcher interpreted effect sizes according to previously discussed standards (Cohen, 2013; Wolf, 1986). Cohen (2013) introduced that if an average effect size of 0.2 or less, it is small, 0.5 is moderate, and if it is greater than 0.8, it is large. Wolf (1986) discussed that an effect size of 0.25 or more was educationally significant, and an effect size of 0.50 or more was clinically significant.

Results

Description of Effects

The 21 studies with 1,222 subjects were reported. The statistical method provided 133 effect sizes.

Overall Analysis

Figure 2 shows the descriptive statistics for all 21 studies and includes forest plots, variances, and standard errors.

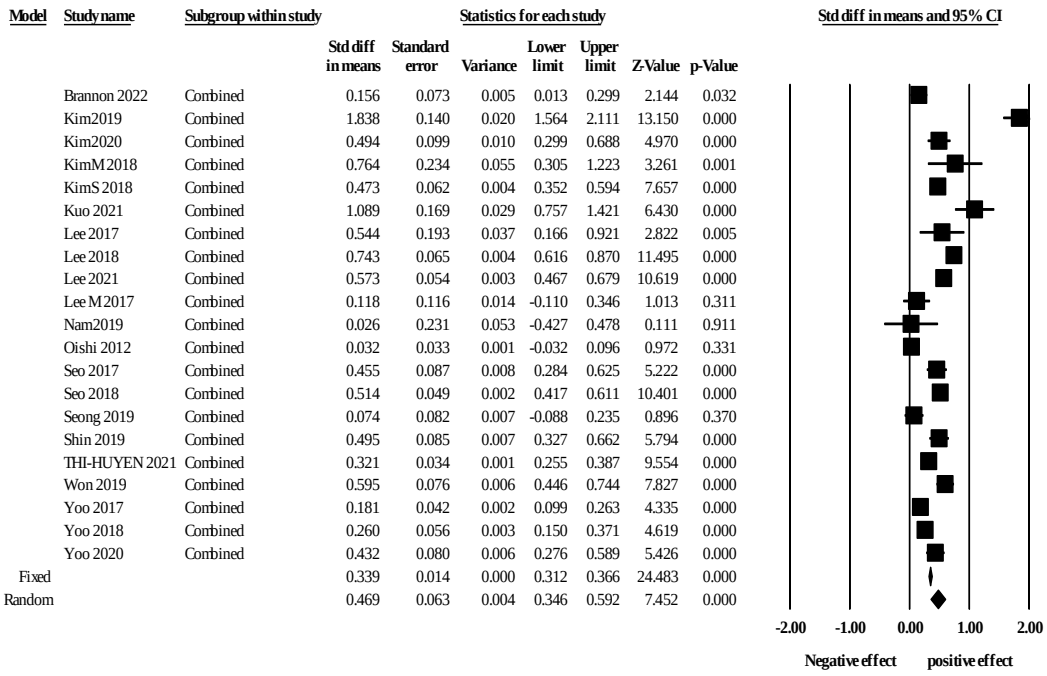

Figure 2: Forest plots for 21 studies

The results of the homogeneity test are listed in Table 2. The effect sizes for the primary studies were heterogeneous.

Table 2: Results of the homogeneity test

N	ES	SE	-95% CI	+95% CI	Q	p value
21	0.339	0.014	0.312	0.366	360.208	0.000

Note. N: number of studies, ES: effect size, SE: standard error, CI = confidence interval

The effect of DT interventions was 0.469 standard deviations (Table 3), which had a moderate effect size and was educationally significant.

Table 3: The overall result of meta-analysis

Number of Studies	Effect Size	Standard Error	-95% Confidence Interval	+95% Confidence Interval
21	0.469	0.063	0.346	0.592

Moderator Analyses

This analysis was conducted to identify the source of variability and moderators, which affect the direction and degree of relation and difference among moderators (Hedges & Vevea, 1998).

Effect Sizes by Moderators Related to Study Characteristics

Variables related to study characteristics were school level, grade level, gender, professional development, and publication year (Table 4). In school level, the results ranked in the order of secondary school 0.654, elementary school 0.535, and college 0.345. For grade level, the effect size of combined 0.449 was larger than that of single-grade 0.331. Regarding gender, the result for both 0.458 was higher than that of female students 0.173 and male students 0.136. In the professional development category, the effect sizes of no 0.451, yes 0.209 were in order. In the publication year category, the effect sizes of 2018~2022 0.488, 2012~2017 0.169 were in order.

Table 4: Moderator analyses by study characteristics

Moderator	Category	k	ES	SE	-95% CI	+95% CI	Q
School Level	Elementary	24	0.535	0.054	0.429	0.640	15.265***
	Secondary	10	0.654	0.094	0.469	0.839	
	College	99	0.345	0.035	0.276	0.414	
Grade Level	Single-grade	49	0.331	0.037	0.260	0.403	4.195*
	Combined	84	0.449	0.044	0.362	0.535	
Student Ability	Full range	114	0.396	0.032	0.332	0.459	0.788
	Gifted & Talented	7	0.536	0.161	0.222	0.851	
	Underachieving	12	0.429	0.118	0.197	0.660	
Gender	Both	111	0.458	0.035	0.390	0.527	33.692***
	Female	11	0.173	0.042	0.090	0.256	
	Male	11	0.136	0.074	-0.010	0.282	
Professional Development	Yes	23	0.209	0.034	0.144	0.275	23.552***
	No	110	0.451	0.037	0.379	0.522	
Orientation Training	Yes	85	0.421	0.042	0.337	0.504	0.546
	No	48	0.375	0.044	0.288	0.462	
Publication Year	2012~2017	36	0.169	0.037	0.096	0.242	37.181***
	2018~2022	97	0.488	0.037	0.416	0.560	

Note. k = number of effect size, ES = effect size, SE = standard error, CI = confidence interval

*p<0.05, ***<0.001

Effect Sizes by Moderators Related to Methodological Characteristics

The type of research design and sample size were variables related to methodological characteristics (Table 5). For sample size, the effect sizes of 1-30 0.492, more than 30 0.369 were in order.

Table 5: Moderator analyses by methodological characteristics

Moderator	Category	k	ES	SE	-95% CI	+95% CI	Q
Research Design	One Group	102	0.416	0.034	0.349	0.484	1.661
	NCG	31	0.320	0.066	0.191	0.450	
Sample Size	1-30	47	0.492	0.049	0.395	0.589	3.949*
	More than 30	86	0.369	0.037	0.297	0.442	

Note. k = number of effect size, ES = effect size, SE = standard error, CI = confidence interval, NCG = non-equivalent control group

*p<0.05

Effect Sizes by Moderators Related to Design Characteristics

Variables related to design characteristics were duration of treatment and frequency of session (Table 6). In duration of treatment, the effect sizes were ranked as 5-8 weeks 0.54, more than 12 weeks 0.418, less than 5 weeks 0.417, and 9-12 weeks 0.032.

Table 6: Moderator analyses by design characteristics

Moderator	Category	k	ES	SE	-95% CI	+95% CI	Q
Duration of Treatment	Less than 5 weeks	53	0.417	0.045	0.328	0.506	52.256***
	5-8 weeks	23	0.540	0.059	0.425	0.656	
	9-12 weeks	9	0.032	0.051	-0.069	0.133	
	More than 12 weeks	48	0.418	0.056	0.307	0.529	
Frequency of Session	1-10	30	0.319	0.061	0.200	0.438	5.743
	11-20	50	0.422	0.055	0.314	0.530	
	More than 20	24	0.513	0.058	0.400	0.626	

Note. k = number of effect size, ES = effect size, SE = standard error, CI = confidence interval

***<0.001

Effect Sizes by Moderators Related to Outcome Characteristics

Variables related to outcome characteristics were domains of learning, cognitive domain, affective domain, and subject areas (Table 7). In cognitive domain, the results ranked in the order of achievement score 0.984, critical thinking 0.828, creativity 0.517, design thinking mindset 0.344, and problem solving 0.297. For affective domain, the results ranked in the order of self-efficacy 1.036, sociability 0.663, emotional intelligence 0.659, career consciousness 0.423, interest in learning 0.403, empathy 0.251, resilience 0.222, collaboration 0.116, learning attitude 0.036, career development agency 0.032, and self-esteem 0.015. In subject areas, the results ranked in the order of computer 0.573, STEAM 0.544, science 0.502, engineering 0.487, education 0.361, liberal arts 0.342, health sciences 0.267, and English 0.073.

Table 7: Moderator analyses by outcome characteristics

Moderator	Category	k	ES	SE	-95% CI	+95% CI	Q
Domains of Learning	Cognitive domain	94	0.439	0.035	0.371	0.507	2.919
	Affective domain	39	0.323	0.059	0.208	0.437	
Cognitive Domain	Achievement score	1	0.984	0.141	0.708	1.259	43.751***
	Creativity	46	0.517	0.055	0.409	0.625	
	Critical thinking	1	0.828	0.151	0.532	1.124	
	Design thinking mindset	8	0.344	0.099	0.149	0.538	
	Problem solving	35	0.297	0.037	0.225	0.370	
Affective Domain	Career consciousness	1	0.423	0.121	0.187	0.660	82.539***
	Career development	9	0.032	0.051	-0.069	0.133	
	Collaboration	1	0.116	0.201	-0.278	0.511	
	Emotional intelligence	5	0.659	0.178	0.311	1.007	
	Empathy	9	0.251	0.054	0.145	0.357	
	Interest in learning	2	0.403	0.186	0.038	0.767	
	Learning attitude	1	0.036	0.326	-0.604	0.675	

Moderator	Category	k	ES	SE	-95% CI	+95% CI	Q
	Resilience	1	0.222	0.142	-0.056	0.500	
	Self-efficacy	2	1.036	0.689	-0.314	2.386	
	Self-esteem	1	0.015	0.326	-0.624	0.655	
	Sociability	3	0.663	0.297	0.081	1.244	
Subject Areas	Computer	32	0.573	0.050	0.475	0.670	113.743***
	Education	26	0.361	0.066	0.232	0.490	
	Engineering	15	0.487	0.130	0.233	0.741	
	English	3	0.073	0.185	-0.290	0.436	
	Health sciences	30	0.267	0.036	0.197	0.338	
	Liberal arts	16	0.342	0.081	0.184	0.501	
	Science	4	0.502	0.148	0.213	0.792	
	STEAM	2	0.544	0.193	0.166	0.921	

Note. k = number of effect size, ES = effect size, SE = standard error, CI = confidence interval

***<0.001

Publication Bias

To identify the publication bias, the researcher adopted the funnel plot and the rank correlation test. First, the funnel plot was considerably symmetrical in Figure 3. Second, Kendall's tau was 0.119 and p was 0.45 in the rank correlation test (Begg & Mazumdar, 1994), which means that it is difficult to see that a significant correlation existed. In summary, two methods above suggest that publication bias is unlikely in the current research.

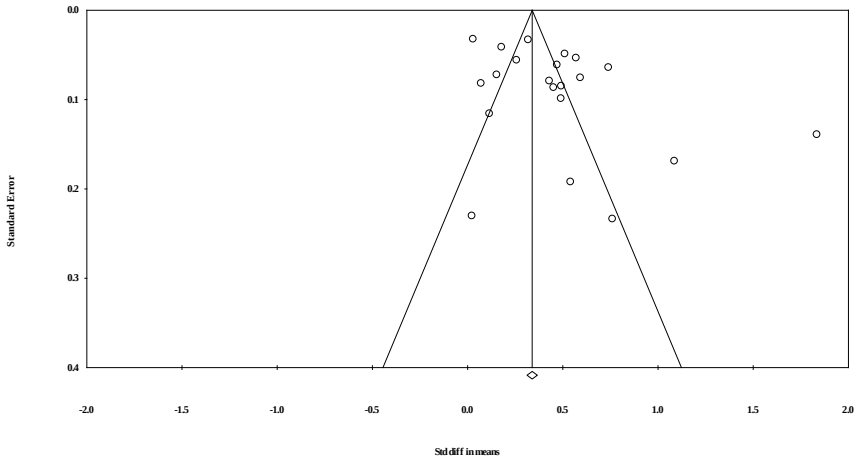

Figure 3: Funnel plot

Discussion

The purpose of this study is to find out effects of DT interventions on educational outcomes through meta-analysis. Discussion of the findings is as follows.

First, the overall effect size of the DT interventions is 0.469, which can interpret as a moderate effect size. The results are noteworthy in that any research on the effects of DT interventions through meta-analysis has not yet been published. Results in this study confirm that the instructional method based on the DT intervention is effective for educational outcomes. Gallagher and Thordarson (2018) explain that having participants interact to solve specific challenges in DT can help them achieve educational goals.

Second, the results on effect sizes of the cognitive domain are in the order of academic achievement 0.984, critical thinking 0.828, creativity 0.517, design thinking 0.344, and problem-solving 0.297. It is interesting to note that the DT intervention has the largest effect size for academic achievement. Given that the goals of schooling include improving academic achievement, these findings may provide a basis for considering the introduction of DT interventions in multiple subject areas.

Third, the results on effect sizes of the affective domain are self-efficacy 1.036, sociability 0.663, emotional intelligence 0.659, career consciousness 0.423, learning interest 0.403, empathy 0.251, resilience 0.222, collaboration 0.116, learning attitude 0.036, career development subject 0.032, and self-esteem 0.015. Self-efficacy refers to one's judgment or evaluation of one's ability to perform a specific task and is a critical variable in achieving individual learning goals (Bandura, 1997). The reason why DT interventions have the largest effect on self-efficacy is that students actively participate in problem-solving and immediately check productive results, so their confidence increases accordingly.

Fourth, the results on effect sizes at the school level are 0.654 for secondary school, 0.535 for elementary school, and 0.345 for university. The fact that the effect size for secondary schools is the largest is consistent with the prior finding of middle and high school students' perceptions and satisfaction with participatory learning programs (Kim et al., 1996). The level of cognitive development of middle and high school students is similar to that of adults (Piaget, 2000). Secondary students' interest and desire to solve social problems are high. Therefore, the researcher found that secondary students' passion for solving given problems through cooperation with pure perspectives in interventions.

Fifth, the results on effect sizes of the grade level were in the order of combined 0.449 and single-grade 0.331. These results support Kim et al. (2018)'s claim that DT interventions are more effective when students with different levels of intellectual ability generate ideas through multiple strategies and problem-solving methods from their perspectives. Kim et al. (1996) also explained that students with various viewpoints and achievement levels should mix to solve problems creatively in participatory learning programs.

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