The Effects of Data-based Instruction (DBI) for Students with Learning Difficulties in Korea: A Single-subject Meta-analysis

Dongil Kim¹, Seohyeon Choi²*

¹ Department of Education, Seoul National University, Seoul, Korea, ² Department of Educational Psychology, University of Minnesota, Minneapolis, MN, United States of America

* choi0836@umn.edu

Abstract

Data-based instruction (DBI) is an ongoing process to utilize students' data for determining when and how to intensify intervention. It is an educational approach that is suggested as effective to enhance achievements of struggling learners, particularly for those who did not respond to intensive intervention in usual ways. In Korea, DBI was introduced and applied for students with learning difficulties especially since 2000 when the first Korea curriculum-based measurement (CBM) was developed as the name of Basic Academic Skills Assessment. Despite a number of studies accumulated since then, there has been a lack of research that examined the level of evidence-based practice (EBP) of DBI research. Thus, the present study sought to synthesize the DBI research so far in Korea by analyzing the effectiveness of DBI for school-aged students with learning difficulties via meta-analysis and evaluating the quality of the research. In this study, a total of 32 single-subject design studies were used. Multilevel meta-analysis revealed that the mean effect size of DBI was statistically significant ($B = 1.34$) and there was significant variance across participants in effect sizes. The results from the conditional model showed that exceptionality type, the number of sessions, and the length of each session were significantly accountable for the variability of effect sizes. In addition, the results of the qualitative analysis revealed the acceptable quality of the overall DBI research with some limitations. Based on these findings, implications and study limitations were discussed.

Introduction

In general school classrooms, there are groups of students who have severe difficulties in acquiring and using basic learning skills. These are very diverse and heterogeneous groups, and may be affected by a variety of factors, including learning disabilities, dyslexia, emotional or behavioral problems, below-average or borderline intelligence, multicultural backgrounds, environmental deficits, and insufficient educational opportunities. The term 'learning difficulties' refers to the large group of students who exhibit severe problems with learning and need extra assistance with schooling [1]. This generic term reflects the willingness to provide proper
intervention and educational services to diverse students with or without internal causes, who exhibit severe difficulties in basic academic areas. It is also related to the OECD model of students with “special educational needs”, which encompasses disability, difficulties and social disadvantage [2, 3]. In this comprehensive and resource-based approach, heterogeneous groups of students can be inclusively involved [3], and they can be served before referral to special education eligibility.

Data-based instruction (DBI) is suggested as an effective approach to enhance academic outcomes of students with severe learning difficulties. DBI is also called ‘data-based instruction’ [4] or ‘data-based individualization’ [5]. This concept originated from the concepts of ‘data-based program modification’ suggested by the study of Deno & Mirkin [6] and ‘problem solving model’ in 1980s, which was used by Minneapolis Public Schools (MPS) as an alternative method of educational decision-making for learning disabilities and mild disabilities [7]. DBI is defined as a series of successive and systematic procedures in reading, mathematics, or behavior where students’ data of achievement are used to determine when and how to intensify and modify interventions [5].

To be specific, the procedures of DBI involve the following steps: (a) identifying a student’s current level of performance, (b) establishing a long-term academic goal, (c) implementing quality evidence-based intervention with fidelity while monitoring one’s progress frequently, (d) using data-based decision rules in order to determine whether instructional changes would be needed, (e) establishing a tentative hypothesis about the student’s specific needs and implementing changes in instruction based on the previous hypotheses, (f) evaluating the effectiveness of the instructional changes based on progress monitoring data, and (g) repeating these procedures until the student achieves the academic goal [8, 9]. A strong evidence base supports the efficacy of DBI for students with learning difficulties [10–12]. Moreover, DBI has positive influence on teachers’ instructional planning, leading them to make more specific plans, to make instructional adaptations more frequently, and to identify the targeted skills more appropriately [13, 14].

It is important to use a reliable measurement that is sensitive to the struggling students’ growth over a short period of time in order to make ongoing decisions in DBI [8]. In this purpose, curriculum-based measurement (CBM) is used to decide whether to raise the goal of instruction, keep instruction as-is, or change instruction [15]. CBM, which was first developed by Stanley Deno and his colleagues at the University of Minnesota, is a standardized measurement for assessing students’ academic competence and progress in the basic academic domains [16]. It is inexpensive and efficient to implement and has high adequacy in terms of validity and reliability [17]. Moreover, as a ‘general outcome measure’, the scores of CBM are considered to represent an individual’s generalized level of the corresponding domain [18].

In Korea, the concept of DBI was introduced and has been applied for teaching school-aged students with learning difficulties, especially since 2000 when the Korean CBM was developed as the name of Basic Academic Skills Assessment (BASA) [19, 20]. According to the study of Yeo, Hong, & Son [21] who reviewed the trend of CBM research in Korea from 1999 to 2014, BASA was found to be the most widely used CBM tool in Korea. So far, BASA has been developed in eight basic academic areas: reading, writing, mathematics, math word problems, vocabulary, reading comprehension, early mathematics, and early literacy. Since BASA includes a number of equivalent tests, it can be conducted at regular basis for progress monitoring in the process of DBI. For data-based decision rules, it recommends using the data-point method (i.e., to make instructional change when more than 4 successive scores below or more than 3 successive scores above the target line) and the slope-based method (i.e., to compare the slope of the progress line with the slope of the target line).
In educational practice, general and special teachers are required to use interventions which were scientifically proven. In the field of special education, there have been constant efforts to identify and implement evidence-based practices [22]. In order to examine whether the specific intervention and the studies that implemented it have some scientific evidence, it is first necessary to evaluate the quality of the individual studies in terms of study design and method [23]. For evaluating the quality of studies in special education field, the quality indicators (QIs) for four types of research methodologies (i.e., group experimental, correlational, single subject, and qualitative designs) were developed by the task force team at the Council for Exceptional Children’s (CEC) [23]. Specifically, Gersten et al. [24] identified QIs for group experimental and quasi-experimental studies, and Horner et al. [25] identified QIs for single-subject designs. Second, it should be proved in a number of studies that the effectiveness of the intervention is considerably large. In this purpose, meta-analysis is widely used to statistically synthesize the results from more than two separate studies.

In the present study, it aims to analyze the overall effectiveness of DBI for school-aged students with learning difficulties and the quality of research in Korea. The present study attempts to collect and synthesize only single-subject design studies. Specifically, it examines the quality of the studies using the QIs suggested by Horner et al. [25]. In addition, it synthesizes the effectiveness of those interventions via meta-analysis and identifies the potential variables to explain the variances of the effect sizes. As of now in Korea, there is a lack of research that specifically synthesizes the effectiveness of DBI. Although Yeo, Hong, & Son [21] synthesized CBM research in Korea, their research questions were focused on CBM and the aspects of technical adequacy. Moreover, it was not a meta-analytic review but a narrative one. Another literature review conducted by Jung [26] was focused on the theme of DBI, but only international studies were included. Therefore, the present study poses the following research questions:

RQ1: What are the characteristics and quality of studies on DBI implemented for students with learning difficulties?

RQ2: What is the average effect of DBI on basic academic skills for students with learning difficulties?

RQ3: To what extent have participant-, intervention-, DBI-related variables influence on the effectiveness of DBI for students with learning difficulties?

Methods

Search procedures

A comprehensive literature search was conducted using the Korean electronic databases RISS (Research Information Sharing Service), KISS (Korean studies Information Service System), and Nurimedia DBpia in order to retrieve studies that are written in Korean and published until December 1, 2020. Since the number of research on DBI for students with learning difficulties was not large, no restriction was set regarding dates of publication. For this search, keywords for students with learning difficulties (“learning difficulties”, “learning disabilities”, “at-risk”, “low achievement”, and “underachievement”), keywords for basic academic skills (“basic academic”, “basic learning”, “reading”, “writing”, and “math”), keywords related to DBI (“data-based instruction”, “evidence-based instruction”, “data-based individualization”, and “curriculum-based measurement”), and keywords for BASA (“Basic Academic Skills Assessment”, and “BASA”) were used in various combinations, and Korean terms were used for the search. Furthermore, reference lists both from prior syntheses and the included studies were
reviewed to encompass any possible studies to be analyzed. By including the keywords for BASA, it reduced the likelihood to miss the studies that did not use the term “DBI” explicitly but were grounded on DBI using BASA. This database search yielded 422 studies after duplicates removed. From these, a total of 390 studies were excluded from the final analyses based on the following inclusion and exclusion criteria.

**Inclusion and exclusion criteria**

Among the preselected studies, only studies which met all the following criteria and had full text accessible were included in the analysis. First, studies with students with learning difficulties as participants were included. Terms such as “students with/at-risk of learning disabilities”, “struggling learners”, “low achievers”, and “under-achievers” were considered to fall within the category of students with learning difficulties. Studies for participants with intellectual disabilities were included in this study. Second, participants were school-aged children from six to eighteen. Third, studies that implemented intervention on basic academic skills (reading, writing, and math) and had dependent variables for those skills were included. There was no restriction in the type of intervention as long as basic academic skills were set as dependent variables. In several studies of which aims were beyond to determine the effectiveness of intervention (e.g., latent class analysis of struggling learners, examination of the applicability of RTI approach, or screening of students with learning disabilities), they were accepted when they had implemented the procedures of DBI on basic academic skills. Fourth, studies that conducted intervention following the principal rules of DBI (i.e., frequent progress monitoring and the use of data for ongoing instructional decision making) were included. Fifth, only the studies that used BASA as CBM tools were included for the analysis, which is the standardized and most frequently used monitoring tool and has high technical adequacy. Other researcher- and teacher-generated CBM were excluded, as they had been pointed out to have a lack of evidence of validity and reliability [8, 21]. Sixth, studies of single-subject designs providing enough quantitative statistics to calculate effect sizes were accepted. **Fig 1** below summarizes these procedures of literature selection according to the PRISMA 4-phase flow diagram.

**Coding procedures**

**Coding system for quality indicators.** QIs suggested by Horner et al. [25] were used to examine each study. However, it has been pointed out in the previous studies that these QIs have strict criteria and that evaluating in a dichotomous way is quite difficult [27, 28]. Thus, while the present study is primarily based on the QIs of Horner et al. [25], it evaluated the quality level of each indicator in a continuum using the 3-point Likert scale. For QI rating, it referred to the rubric suggested by Chard et al. [29] which was based on 4-point Likert scale. The individual study was interpreted as having a sufficient quality level when the average is above 2 points in each area.

For the inter-rater reliability of the qualitative analysis, in addition to the authors, a doctoral student majoring in special education who had understanding of QIs participated in the analysis. Two from single-subject design studies were randomly selected. For those studies, we rated together on a 3-point Likert scale, ensuring that we had the same understanding of the concept and evaluation standard. After that, the authors of the study conducted the analysis of QIs for 32 studies first. Then, the doctoral student reviewed the whole analysis results and identified the items that were rated differently. For the inconsistent items, we conducted an additional review and reached to the consensus through sufficient discussion. The reliability between two coders was 99.6%, which was calculated by dividing the number of consistent results by the sum of the number of both consistent and inconsistent results and multiplying it by 100.
A coding system for meta-analysis was developed by examining the prior coding systems designed for meta-analytic review on DBI [8, 30] as well as research on DBI concepts [5, 10, 26, 31]. The coding system for meta-analysis is presented in Table 1.

For the reliability of coding, the doctoral student in addition to the authors who had research experiences using meta-analysis was participated in coding for the meta-analysis as well. The authors specifically explained the coding system and the coding method. Afterwards, three studies were randomly selected and coded by the coders together. Then, the doctoral student reviewed the results that were firstly coded by the authors, checking for the disagreed items. The coders went through the process of additional review and sufficient discussion regarding the inconsistent items, resulting in consensus at the end. Through these procedures, the reliability of coding for meta-analysis was calculated as 98.86%.

**Effect size calculations and statistical analyses.** For 32 single-subject studies, the effect size calculation was conducted through the following procedures. First, the data points of each dependent variable were coded. When the study only contains the figures for outcome measures, a computer software program GetData Graph Digitizer (2013) was used to extract graphed data. Second, the standardized data points and the effect sizes were calculated using the method which had been suggested by Van den Noortgate & Onghena [32–34] and used in Wang, Cui, & Parrila [35], Wang, Parrila, & Cui [36], and Heyvaert et al. [37]. To be specific, in order to transform raw scores into standardized scores, the raw scores of the data points were subtracted from the mean scores of the data points within the baseline and intervention phases and then divided by the standardized deviation of the data points from the phases.
combined [35]. Then, the standardized mean score of the baseline phase was subtracted from each standardized score, which was to adjust the mean of the baseline to 0. In this way, the standardized score of the intervention phase could be considered as the treatment effect. However, it should be noted that the standardized effect size calculated in this way cannot be directly compared to those calculated from group experimental design studies due to the difference in calculation method [35].

To synthesize the effect sizes calculated from single-subject studies, multi-level meta-analysis via hierarchical linear modeling was implemented. Meta-analysis has been increasingly being applied to single-subject design as well [38]. There is no consensus yet about what is the best statistical method or effect size indices when synthesizing the results from single-subject design studies [39]. However, it was pointed out that synthesis of results from single-subject design studies...
studies tends to depend on visual analysis [32, 40], which was probably subjective and difficult to compare the effectiveness across different [35]. On the other hand, meta-analysis using hierarchical linear modeling is another promising approach [34, 41]. It can consider the issue of autocorrelation even when the number of measurements is relatively small and when the frequency of measurements is different across study participants [34, 42]. Before conducting the statistical analyses using hierarchical linear modeling, the normality assumption and the homogeneity assumption were tested based on the standardized scores. The Q-Q normality plot indicated that while some values deviate from the diagonal, most values do not appear to deviate significantly from what are expected for a random sample from a true normal distribution. The variance of the standardized scores across the phases and the participants were analyzed using the boxplots. The results revealed that there exists some variability across individuals especially for the baseline phases, but in overall, the medians and interquartile ranges are relatively consistent, indicating that the model meets the assumption of homogeneity of variance.

Statistical analyses were computed with HLM software program version 6 [43]. To be specific, the overall effect size and the heterogeneity of effect sizes between study participants were examined. In single-subject studies, each study includes different study participants, and each participant includes time series measurements, which represents the three-level model [44]. However, in the present study, the total number of single-subject studies was not enough to conduct a 3-level analysis. Thus, a 2-level meta-analysis was conducted. Level 1 represents the time series data points, and level 2 represents the participants of individual studies (see the following):

Level-1 Model: $Y_{ij} = \pi_{ij}(PHASE) + \epsilon_{ij}$  \hspace{1cm} $\epsilon_{ij} \sim N(0, \sigma^2)$

Level-2 Model: $\pi_{ij} = \beta_{10} + r_{ij}$  \hspace{1cm} $r_{ij} \sim N(0, \tau^2_{\omega})$

The two levels represent the hierarchical structure of outcome variables (level 1) and study participants (level 2). Level-1 model shows a regression equation for the outcome variable. In the model, the outcome variable, $Y_{ij}$, represents the standardized score of the data point for occasion $i$ and participant $j$; $\pi_{ij}$ represents the effect size that equals the standardized difference of means between the intervention and baseline; $PHASE$ is a dichotomous variable that represents the phase of each data point (i.e., 0 indicates that the data point is from the baseline phase and 1 indicates that the data point is from the intervention phase); $\epsilon_{ij}$ reflects a random error term. Level-2 model suggests that the effect size of its corresponding participant, $\pi_{ij}$, equals the mean effect size across all participants ($\beta_{10}$) plus a residual ($\gamma_{ij}$). Furthermore, an additional analysis was conducted corresponding to each basic academic domain of the outcome variables (i.e., reading, writing, and math).

After analyzing the mean effect sizes across study participants with the above unconditional model, several variables related to participants, intervention, and DBI were added to the model as predictors in order to examine their impacts on the effectiveness. These predictors were added respectively, which was to avoid the potential risk of multicollinearity [37]. An instance of the conditional model is as the following.

Level-1 Model: $Y_{ij} = \pi_{ij}(PHASE) + \epsilon_{ij}$  \hspace{1cm} $\epsilon_{ij} \sim N(0, \sigma^2)$

Level-2 Model: $\pi_{ij} = \beta_{10} + \beta_{11}(GRADE) + r_{ij}$  \hspace{1cm} $r_{ij} \sim N(0, \tau^2_{\omega})$

Additionally, there were several things considered in data analysis. First, when the intervention consisted of more than one phase, data from the very first intervention phase was coded to minimize the potential effect of confusing variables or time. In cases of the studies that
implemented intervention in RTI approach, the first tier was coded as baseline, and the second or third tier intervention was coded as intervention phase for the analysis. Second, the scores on negative measures were reverse-coded. Third, multiple effect sizes from the same study or the same participant were avoided because of their dependence [45]. Thus, when there were multiple measurements regarding the same construct, the representative one was adopted or the mean score was calculated when using the same scale. In contrast, when dependent variables were corresponding to different academic domains (e.g., reading fluency and computational skills), multiple effect sizes were calculated independently.

| Study | Number of participants (m,f) | Number of effect sizes |
|-------|------------------------------|------------------------|
| [63]  | 3 (0,3)                      | 6                      |
| [64]  | 3 (1,2)                      | 3                      |
| [65]  | 3 (3,0)                      | 6                      |
| [66]  | 1 (0,1)                      | 1                      |
| [67]  | 3 (2,1)                      | 3                      |
| [68]  | 3 (3,0)                      | 3                      |
| [69]  | 3 (1,2)                      | 3                      |
| [70]  | 3 (3,0)                      | 3                      |
| [71]  | 3                            | 3                      |
| [72]  | 3 (1,2)                      | 3                      |
| [73]  | 3 (1,2)                      | 3                      |
| [74]  | 3 (3,0)                      | 3                      |
| [75]  | 3 (2,1)                      | 3                      |
| [76]  | 3 (2,1)                      | 3                      |
| [77]  | 2 (1,1)                      | 2                      |
| [78]  | 6                            | 6                      |
| [79]  | 1 (0,1)                      | 1                      |
| [80]  | 2 (1,1)                      | 2                      |
| [81]  | 3 (3,0)                      | 3                      |
| [82]  | 3 (2,1)                      | 3                      |
| [83]  | 3 (3,0)                      | 3                      |
| [84]  | 3 (2,1)                      | 3                      |
| [85]  | 5 (3,2)                      | 5                      |
| [86]  | 5 (2,3)                      | 5                      |
| [87]  | 4 (2,2)                      | 8                      |
| [88]  | 4 (3,1)                      | 4                      |
| [89]  | 4 (2,2)                      | 4                      |
| [90]  | 3 (1,2)                      | 3                      |
| [91]  | 3 (2,1)                      | 3                      |
| [92]  | 3 (3,0)                      | 3                      |
| [93]  | 3 (2,1)                      | 3                      |
| [94]  | 3 (2,1)                      | 3                      |
| Total | 100                          | 119                    |

https://doi.org/10.1371/journal.pone.0261120.t002
Results

Characteristics of the studies

A total of 32 single-subject studies were selected for analysis. A total of 119 effect sizes from 1,601 data points and 100 participants were identified, which is summarized in Table 2.

Tables 3–6 present the characteristics of 32 single-subject studies in terms of general characteristics, participants-related characteristics, intervention-related characteristics, and DBI-related characteristics.

Table 3. General characteristics of the studies.

| Category               | N   | %   |
|------------------------|-----|-----|
| Year of publication    |     |     |
| 2005–2009              | 6   | 18.8|
| 2010–2014              | 8   | 25.0|
| 2015–2020              | 18  | 56.3|
| Type of publication    |     |     |
| Journal                | 14  | 43.8|
| Dissertation           | 18  | 56.3|
| Study design           |     |     |
| Multiple baseline      | 12  | 37.5|
| AB                     | 5   | 15.6|
| ABA                    | 3   | 9.4 |
| ABAB                   | 1   | 3.1 |
| Alternating treatment  | 1   | 3.1 |
| Other                  | 10  | 31.3|
| Total                  | 32  | 100 |

https://doi.org/10.1371/journal.pone.0261120.t003

Table 4. Participant-related characteristics of the studies.

| Category                     | N   | %   |
|------------------------------|-----|-----|
| Grade level                  |     |     |
| Elementary school            |     |     |
| Low (1–3)                    | 19  | 59.4| 87.6|
| High (4–6)                   | 7   | 21.9|
| Low + High                   | 2   | 6.3 |
| Middle school                |     |     |
| Low (1–3)                    | 19  | 59.4|
| High (4–6)                   | 7   | 21.9|
| Low + High                   | 2   | 6.3 |
| High school                  | 1   | 3.1 |
| Exceptionality type          |     |     |
| With or at risk of learning disability | 9 | 28.1|
| Low achievement              | 2   | 6.3 |
| Under achievement            | 14  | 43.8|
| Intellectual disability      | 5   | 15.6|
| Other                        | 2   | 6.3 |
| School type                  |     |     |
| General classroom            | 20  | 62.5|
| Special education classroom  | 6   | 18.8|
| Special school               | 1   | 3.1 |
| Mixed                        | 3   | 9.4 |
| Other                        | 2   | 6.3 |
| Total                        | 32  | 100 |

https://doi.org/10.1371/journal.pone.0261120.t004
Table 5. Intervention-related characteristics of the studies.

| Category                        | N   | %   |
|---------------------------------|-----|-----|
| **Number of sessions**          |     |     |
| 10–19                           | 23  | 71.9|
| 20–29                           | 7   | 21.9|
| Above 30                        | 2   | 6.3 |
| **Number of sessions per week** |     |     |
| 1                               | 5   | 15.6|
| 2                               | 25  | 78.1|
| 3                               | 2   | 6.3 |
| **Length of each session**      |     |     |
| 15–30 mins                      | 2   | 6.3 |
| 31–45 mins                      | 23  | 71.9|
| 46–60 mins                      | 6   | 18.8|
| NA                              | 1   | 3.1 |
| **Duration**                    |     |     |
| 4–9 wks                         | 22  | 68.8|
| 10–14 wks                       | 9   | 28.1|
| 15–19 wks                       | 1   | 3.1 |
| **Group size**                  |     |     |
| One-on-one                      | 23  | 71.9|
| Small (2–3)                     | 3   | 9.4 |
| Medium (4–6)                    | 2   | 6.3 |
| Mixed (One-on-one + group)      | 2   | 6.3 |
| NA                              | 2   | 6.3 |
| **Interventionist**             |     |     |
| Researcher                      | 24  | 75.0|
| Graduate students               | 2   | 6.3 |
| Researcher + Volunteer          | 1   | 3.1 |
| Peer                            | 1   | 3.1 |
| NA                              | 4   | 12.5|
| **Instructional setting**       |     |     |
| General classroom               | 16  | 50.0|
| Special education classroom     | 3   | 9.4 |
| Special school                  | 1   | 3.1 |
| Private center                  | 1   | 3.1 |
| Other                           | 5   | 15.6|
| NA                              | 6   | 18.8|
| **Basic academic domain (DV)**  |     |     |
| Reading                         |     |     |
| Early literacy                  | 1   | 3.1 |
| Reading fluency                 | 7   | 21.9|
| Fluency + comprehension         | 7   | 21.9|
| Early literacy + Fluency + comprehension | 1   | 3.1 |
| Writing                         | 6   | 18.8|
| Math                            |     |     |
| Early math                      | 1   | 3.1 |
| Calculation                     | 7   | 21.9|
| Reading + Writing               | 2   | 6.3 |
| **Total**                       | 32  | 100 |

https://doi.org/10.1371/journal.pone.0261120.t005
Table 6. DBI-related characteristics of the studies.

| Category                              | N  | %  |
|---------------------------------------|----|----|
| Type of CBM task (BASA)               |    |    |
| Early literacy                        | 1  | 3.1|
| Reading fluency                       | 16 | 50.0|
| Fluency + Comprehension               | 1  | 3.1|
| Writing                               | 6  | 18.8|
| Early math                            | 1  | 3.1|
| Math                                  | 7  | 21.9|
| Measurement frequency (monitoring)    |    |    |
| Every session                         | 20 | 62.5|
| Every 2–3 sessions                    | 9  | 28.1|
| Every 4 sessions                      | 2  | 6.3|
| Flexible                              | 1  | 3.1|
| Administrator of CBM                  |    |    |
| Interventionist                       | 24 | 75.0|
| Other                                 | 2  | 6.3|
| NA                                    | 6  | 18.8|
| Data-based decision rules             |    |    |
| Slope                                 | 1  | 3.1|
| Mastery criterion                     | 6  | 18.8|
| Slope + Data point                    | 7  | 21.9|
| Slope + Mastery                       | 1  | 3.1|
| Percentile                            | 3  | 9.4|
| Other                                 | 1  | 3.1|
| NA                                    | 13 | 40.6|
| Instructional change                  |    |    |
| Quantitative                          | 1  | 3.1|
| Qualitative                           | 6  | 18.8|
| Quantitative + Qualitative            | 3  | 9.4|
| NA                                    | 22 | 68.8|
| Total                                 | 32 | 100|

https://doi.org/10.1371/journal.pone.0261120.t006

Analysis of quality indicators

Table 7 presents the results of QI ratings for single-subject design studies. It was interpreted as having a sufficient quality level when the indicators were rated 2 or more.

Results from two-level meta-analysis

Results from the unconditional model: Mean effect size and heterogeneity. The results from the unconditional model are displayed in Table 8. The mean of the effect sizes across all participants was 1.34. It was significantly different from zero, suggesting that DBI was effective in improving basic academic skills of participating school-aged students with learning difficulties. Additionally, the $\chi^2$ statistic accompanying these variance components indicated that there was significant variability between the effect sizes among 100 participants in their effect sizes, suggesting the need to identify the possible predictors. Fig 2 visually shows 119 effect sizes from 100 participants and the variability between those effect sizes. In Fig 2, 0 and 1 on the x-axis represent the baseline and intervention phase respectively; the y-axis represents the standardized data points of outcome variables; and the slope of each line indicates the
standardized effect size of each dependent variable. Fig 2 also indicates that the effect sizes across participants were varying in a wide range.

**Mean effect size for each basic academic domain.** Additionally, mean effect size for each basic academic domain (reading, writing, and math) was calculated. Phonological recognition, word recognition, reading fluency, and reading comprehension skills were included as outcome variables in reading. The studies included in writing were measuring the qualitative and quantitative scores, and the studies included in math were assessing early mathematics skills (e.g., number recognition, counting) and computational skills. The results of the unconditional model for each area are shown in Table 9. For reading, 916 data points from 60 participants were included in the analysis, accounting for the largest proportion. 586 data points from 24

Table 7. QIs applied to single-subject design studies.

| Dimensions                      | Specific indicators                                                                 | Number of studies | M       |
|---------------------------------|-------------------------------------------------------------------------------------|-------------------|---------|
|                                 |                                                                                     | 1 (unsatisfied)   | 2 (partially satisfied) | 3 (satisfied) |
| Participants / setting          | participants characteristics (e.g., age, gender, disability, diagnosis)             | 0                 | 4       | 28      | 2.88    |
|                                 | process for selecting participants                                                  | 1                 | 5       | 26      | 2.78    |
|                                 | information about interventionists or teachers and comparability across conditions  | 21                | 7       | 4       | 1.47    |
|                                 | critical features of the physical setting                                           | 9                 | 17      | 6       | 1.91    |
| Dependent variable              | description of DV                                                                  | 0                 | 1       | 31      | 2.97    |
|                                 | measurement process                                                                | 0                 | 0       | 32      | 3.00    |
|                                 | measurement validity and description                                               | 0                 | 4       | 28      | 2.88    |
|                                 | measurement frequency                                                              | 0                 | 3       | 29      | 2.91    |
|                                 | data collected on reliability (e.g., IOA = 80%; Kappa = 60%)                      | 22                | 0       | 10      | 1.63    |
| Independent variable            | description of IV                                                                  | 0                 | 8       | 24      | 2.75    |
|                                 | IV manipulation                                                                    | 14                | 7       | 11      | 1.91    |
|                                 | fidelity of implementation                                                          | 22                | 1       | 9       | 1.59    |
| Baseline                        | DV measurement                                                                     | 3                 | 11      | 18      | 2.47    |
|                                 | description of baseline condition                                                   | 12                | 16      | 4       | 1.75    |
| Experimental control/Internal   | design demonstrates experimental effect                                             | 0                 | 0       | 32      | 3.00    |
| validity                        | design controls for common threats to internal validity (e.g., elimination of rival hypotheses) | 12                | 7       | 13      | 2.03    |
|                                 | patterns of results                                                                | 0                 | 0       | 32      | 3.00    |
| External validity               | replication of effects across participants, settings, or materials                  | 2                 | 11      | 19      | 2.53    |
| Social validity                 | social importance of DV                                                            | 0                 | 0       | 32      | 3.00    |
|                                 | social importance of magnitude of change in DV                                      | 0                 | 12      | 20      | 2.63    |
|                                 | practicality and cost effectiveness of implementation of IV                        | 22                | 5       | 5       | 1.47    |
|                                 | typical nature of implementation of IV                                              | 16                | 15      | 1       | 1.53    |

https://doi.org/10.1371/journal.pone.0261120.t007

Table 8. Results from the unconditional model.

| Fixed effect         | Coefficient | SE     | t        | df | p-Value |
|----------------------|-------------|--------|----------|----|---------|
| Slope ($\beta_0$)    | 1.341       | 0.078  | 17.224***| 99 | <0.001  |
| Random effect        |             |        |          |    |         |
| SD                   |             |        |          |    |         |
| Variance component   |             |        |          |    |         |
| $\chi^2$             |             |        |          |    |         |
| Slope ($\gamma_1$)   | 0.722       | 0.522  | 907.154***| 99 | <0.001  |
| Level-1 error term ($\epsilon$) | 0.852 | 0.725 |        |    |         |

*p < .05 **p < .01
***p < .001.

https://doi.org/10.1371/journal.pone.0261120.t008
study participants were identified in writing, and 275 data points from 22 participants were identified in math. The mean effect sizes for domains of reading, writing, and math, were 1.432, 1.520, and 1.091 respectively, and they were all significantly different from zero. Furthermore, in writing and math, there were significant variability across participants in effect sizes.

Results from the conditional model: Impact of the predictors. Several variables related to participants, intervention, and DBI were added respectively to the two-level model as predictors in order to examine their impacts on the variability of effectiveness. Each variable was dichotomously coded for the analysis. For the missing data, the list-wise deletion was used. Table 10 shows the coding systems for the Level-2 predictors.

Table 11 shows the results from the HLM model that included the characteristics related to participants as Level-2 predictors. The results indicated that the presence of intellectual disability significantly accounted for the variance in effect sizes ($B = 0.532$, $p = 0.019$). To be specific, the effect size was 1.304 for students with intellectual disabilities, whereas the effect size was 1.836 for those with learning difficulties without intellectual disabilities (i.e., with or at risk of learning disabilities, low or under-achievement, etc.). However, the effect sizes did not vary as a function of the other variables. It can be interpreted that the effectiveness of DBI was significant regardless of the grade level, classification of learning disabilities, classification of low or under-achievement, gender, and school type.

Table 12 shows the results from the model that included the intervention-related variables as Level-2 predictors. The number of sessions and the length of each session were the only
predictors that significantly accounted for the variability in effect sizes across participants. Specifically, while the effect size was 1.552 when the intervention was provided less than 19 sessions, it was 0.984 when the intervention was continued for a longer period. In addition, whereas the effect size was 1.281 when the time per session was less than 45 minutes, it was

Table 9. Results from the unconditional model for reading, writing, and math.

|                | Coefficient | SE   | t    | df  | p-Value |
|----------------|-------------|------|------|-----|---------|
| **Reading**    |             |      |      |     |         |
| Slope ($\beta_{10}$) | 1.432       | 0.090| 15.939| 59  | <0.001  |
| Random effect  | SD          | Variance component | $\chi^2$ | df  | p-Value |
| Slope ($\gamma_{1j}$) | 0.633       | 0.400| 429.965| 59  | >0.500  |
| Level-1 error term ($\epsilon_{ij}$) | 0.833       | 0.694|       |     |         |
| **Writing**    |             |      |      |     |         |
| Slope ($\beta_{10}$) | 1.520       | 0.165| 9.188| 23  | <0.001  |
| Random effect  | SD          | Variance component | $\chi^2$ | df  | p-Value |
| Slope ($\gamma_{1j}$) | 0.782       | 0.611| 370.814| 23  | <0.001  |
| Level-1 error term ($\epsilon_{ij}$) | 0.802       | 0.643|       |     |         |
| **Math**       |             |      |      |     |         |
| Slope ($\beta_{10}$) | 1.091       | 0.188| 5.815| 21  | <0.001  |
| Random effect  | SD          | Variance component | $\chi^2$ | df  | p-Value |
| Slope ($\gamma_{1j}$) | 0.823       | 0.678| 208.508| 21  | <0.001  |
| Level-1 error term ($\epsilon_{ij}$) | 0.847       | 0.718|       |     |         |

*p < .05 **p < .01 ***p < .001.

https://doi.org/10.1371/journal.pone.0261120.t009

Table 10. Coding system for the Level-2 predictors.

| Predictors                         | Coding |
|------------------------------------|--------|
|                                    | 0      | 1      |
| **Participant-related variables**  |        |        |
| Grade level                        | Elementary school | Middle or high school |
| Exceptionality type                | with or at risk of learning disability | Without or not at risk of learning disability |
| With low or under-achievement     | Without low or under-achievement |
| With intellectual disability      | Without intellectual disability |
| Gender                             | Male   | Female |
| School type                        | General classroom | Other than general classroom |
| **Intervention-related variables** |        |        |
| Number of sessions                 | 19 sessions or less | More than 19 sessions |
| Number of sessions per week        | 1      | 2–3    |
| Length of each session             | 45 minutes or less | More than 45 minutes |
| Duration                           | 9 weeks or less | More than 9 weeks |
| Group size                         | One-on-one | Group |
| **DBI-related variables**          |        |        |
| Measurement frequency for monitoring | Every session | Every 2 or more sessions |
| Data-based decision rule           | Including slope-based rule | Without including slope-based rule |
| Instructional adaptation           | Specified | Not specified |

https://doi.org/10.1371/journal.pone.0261120.t010
1.889 when each session was longer than 45 minutes. It was found that the effect sizes did not
significantly vary as a function of the number of sessions per week, duration, and group size.

Table 13 presents the results from the model including DBI-related variables as predictors. The coefficients of the variables were not significant, which indicated that the variation of the
effect sizes among participants was not explained by the variables related to the features of
DBI. It can be interpreted that the effect of intervention based on DBI was significant regard-
less of the specific variables related to DBI. However, it should be noted that the information
about DBI process was not sufficient in many studies.

**Discussion**

The purpose of this study was to identify the effectiveness of DBI for students with learning
difficulties in Korea. Furthermore, the overall quality of the research that implemented data-
based instruction for those students was determined in the study. The overall findings with
respect to the research questions and directions for future research and practice were discussed
below.

**Research trends on DBI**

It was identified that research on DBI for students with learning difficulties have been con-
ducted constantly in Korea since 2000s. It indicates that there has been a continuous need to
support diverse students with learning difficulties and ongoing efforts to apply DBI for those
students. The review of the studies revealed that most of the studies were conducted for ele-
mentary school students in general classroom. Reading fluency was set as the outcome variable
with the highest ratio. It is consistent with the previous findings that more than 80% of stu-
dents with learning disabilities have difficulties in reading [46] and that reading fluency is a
highly reliable indicator of the overall reading abilities, encompassing several linguistic skills

---

**Table 11. Results of the conditional model with participant-related variables as predictors.**

| Fixed effect | Coefficient | SE  | t     | df | p-Value |
|--------------|-------------|-----|-------|----|---------|
| Grade level  | 0.043       | 0.161| 0.267 | 79 | 0.790   |
| Exceptionality type | Learning disability | -0.237 | 0.201| -1.184 | 79 | 0.240 |
| exceptionality type | Low or under-achievement | -0.034 | 0.177| -0.195 | 79 | 0.846 |
| exceptionality type | Intellectual disability | 0.532 | 0.222| 2.394* | 79 | 0.019 |
| Gender       | 0.352       | 0.177| 1.988 | 79 | 0.050   |
| School type  | 0.312       | 0.184| 1.694 | 79 | 0.094   |

*p < .05 **p < .01 ***p < .001.

**Table 12. Results of the conditional model with intervention-related variables as predictors.**

| Fixed effect                      | Coefficient | SE  | t       | df | p-Value |
|-----------------------------------|-------------|-----|---------|----|---------|
| Number of sessions                | -0.568      | 0.189| -3.001* | 79 | 0.004   |
| Number of sessions per week       | -0.222      | 0.225| -0.989  | 79 | 0.325   |
| Length of each session            | 0.608       | 0.212| 2.870*  | 79 | 0.005   |
| Duration                          | -0.193      | 0.189| -1.019  | 79 | 0.311   |
| Group size                        | 0.006       | 0.217| 0.026   | 79 | 0.979   |

*p < .05 **p < .01 ***p < .001.

---
As for the characteristics of intervention, the results reveal that the most studies consisted of a total of 10 to 19 sessions, twice a week, and 31 to 45 minutes per session. Regarding characteristics of DBI, CBM for reading fluency was most frequently used, and students’ progress was measured every session in the most studies. Additionally, the slope-based method and the point-based method were mostly used together, and instructional adaptation was mostly conducted in qualitative aspects.

Despite these efforts to implement DBI in research and practice, it was identified that many studies did not report sufficient information about the principles or procedures of DBI in a systematic way. For instance, about half of the studies did not provide specific information on instructional change and data-based decision rules. It was revealed in the previous finding that the frequency and quality of instructional changes have significant impact on the students’ achievement [10]. It not only benefits the students with learning difficulties but also teachers teaching them. For instance, in the study of McMaster et al. [15], teachers who conducted DBI made instructional adaptations more frequently in more various aspects, specifically based on convincing data rather than their intuition. Thus, future research and practice are needed to follow the procedures of DBI more systematically and to present the related information sufficiently.

### Quality of research on DBI

The overall quality of the studies was quite high. To be specific, 14 out of 22 QIs in single-subject design were rated as 2 points or more. Moreover, except for two, all studies scored an average of 2 points or higher. It indicates that research on DBI for school-aged student with learning difficulties have a sufficient quality in terms of research design and method. However, there were a few indicators scored below 2, which can be considered systematic weaknesses across studies. Specifically, in the future research, indicators regarding description of interventionist, comparability of interventionists across conditions, fidelity of intervention, manipulation of independent variable, and reliability of data collection are especially needed to be reported explicitly for the more reliable results.

### Effectiveness of DBI

The effectiveness of DBI for school-aged students with learning difficulties was found to be quite high. The mean effect size from single-subject design studies was 1.34 and statistically significant. Although it cannot be directly compared with the effect sizes extracted from the meta-analysis of group design studies, it reveals that DBI is quite effective to improve basic academic skills of students with learning difficulties. It was suggested that students with learning difficulties tend to acquire and develop their learning skills at a slower pace than their peers [50, 51]. It was also reported that for those students, intensifying intervention in a generic way is sometimes not enough to increase their achievement [5, 52]. Considering these previous findings, the result of the present study indicates that DBI is highly effective and suitable for

| Fixed effect                          | Coefficient | SE   | t     | df  | p-Value |
|---------------------------------------|-------------|------|-------|-----|---------|
| Measurement frequency for monitoring  | -0.164      | 0.185| -0.886| 79  | 0.378   |
| Data-based decision rule              | -0.356      | 0.207| -1.714| 79  | 0.090   |
| Instructional adaptation              | -0.301      | 0.194| -1.547| 79  | 0.126   |

*p < .05 **p < .01 ***p < .001.

https://doi.org/10.1371/journal.pone.0261120.t013
those students. In addition, the use of CBM in DBI for assessing their achievement and growth seems to account for this large effectiveness. According to the previous finding, CBM tools can measure the ability and growth of students with learning difficulties in a more sensitive way [53]. For instance, CBM in reading measures the reading abilities with texts that are equivalent and comparatively easy-to-read across different grades [18]. Thus, the large effectiveness of DBI can be explained by the use of adequate measure for students with learning difficulties, and it should be noted that it is not only difficult but also unfair sometimes to check the progress of struggling learners with the identical measure used for those without learning difficulties.

**Variability across participants in effect sizes**

The analysis of single-subject design studies revealed that there was significant variance across participants in effect sizes. The results from the conditional model showed that exceptionality type, the number of sessions, and the length of each session were significantly accountable for the variability of effect sizes.

Regarding the difference according to the presence of intellectual disabilities, the cognitive characteristics of students with intellectual disabilities seem to be associated to the comparatively lower effect size. In the present study, the number of participants with intellectual disabilities was 14, and the number of effect sizes was 17 in total. The average of their IQ was 55.9, which is within the range of mild intellectual disability. The previous findings suggested that students with mild intellectual disabilities have educational needs distinguished from other students because of their cognitive features [54, 55]. However, since the number of effect sizes was relatively small, it would require careful interpretation. Furthermore, it should be rather emphasized that the effectiveness of DBI for students with intellectual disabilities was significant as well and still was quite high (ES = 1.304). It means that DBI is quite effective and applicable for students with intellectual abilities as well as students without disabilities. Snyder & Ayres [56] suggested that widely used measurement for basic academic skills such as the Woodcock Reading Mastery Test (WRMT) and Comprehensive Test of Phonological Processing (CTOPP-2) are not suitable for those students due to its difficulty and unfamiliarity. In contrast, the general outcome measures such as CBM are regarded as more appropriate to evaluate the reading level and progress of students with intellectual disabilities [57]. Moreover, CBM is also recommended when making IEP goals for students with intellectual disabilities in the areas of reading, writing, and mathematics [58]. Thus, consistent with the previous findings, the results of the present study indicate that DBI and CBM can be applied for teaching students with intellectual disabilities.

Next, regarding the variance resulted from the number of sessions and the length of each session, more research is needed in the future. There are some inconsistent findings related to what is the most effective duration and length of sessions for DBI. For example, in the study of McMaster et al. [15], where conducted DBI in writing for 20 weeks, recommended that teachers conduct interventions at least three times a week, 20 ~ 30 minutes per session. In another study, the total number of weeks of DBI was found to significantly predict the improvement of students’ progress [59]. Therefore, further research on the optimal duration of intervention and time per session in DBI is needed.

**Need of teacher support for DBI in Korea**

When implementing DBI, the provision of support for teachers has been constantly suggested as the variable that significantly increases its effectiveness [8, 15]. However, there were very few research that provided teacher support. In the study of Choi & Kwon [60], it was revealed...
that many teachers in Korea were struggling with difficulties due to the lack of knowledge and information about instructional adaptations. Therefore, it is required to provide understandable information and constant support for special and general teachers for implementing DBI. For instance, What Works Clearinghouse (WWC) platform from the U.S. Department of Education, which allows teachers to search, compare, and evaluate DBI for each basic academic area, and National Center on Intensive Intervention (NCII), which provides a tool chart and a checklist for monitoring progress and changing instruction, could be referred [61].

Study limitations

Findings of the present study should be interpreted in light of the following limitations. First, although the studies which met the selection criteria were included in the analysis, sufficient information related to DBI such as data-based decision rules and instructional changes were missing in many of them. Thus, there was a limit to analyze the impact of the probable predictors on variance in the effect sizes. Future study is needed to include more detailed information about DBI process, and there is need to analyze and compare the moderating effect of diverse variables. Second, two-level meta-analysis instead of three-level meta-analysis was implemented to synthesize the effect from single-subject design studies. It is recommended to conduct three-level meta-analysis of single-subject studies when there are more studies accumulated. Third, for calculating and synthesizing the effect sizes from single-subject design studies, the statistical method suggested by Van den Noortgate & Onghena [32–34] and applied by Wang, Cui, & Parrila [35], Wang, Parilla, & Cui [36], and Heyvaert et al. [37] was used. However, since there is no consensus yet for synthesizing the results of single-subject studies, it is necessary to calculate and compare the effect sizes calculated from various statistical methods. Moreover, future study is needed that considers the variability of the students’ previous achievement levels more in depth when interpreting the effect sizes. Fourth, in this study, only studies which used BASA as CBM tools were included for the analysis. It was because BASA was the standardized CBM widely used in basic academic areas in Korea. However, there is need that more various CBM tools with high validity and reliability should be developed and standardized in Korea. Then, future study is needed to synthesize the effectiveness and quality of DBI research using various CBM tools. Fifth, the mean effect size of DBI for each basic academic area was identified, but the difference in effectiveness depending on the specific focus of intervention or strategies was not analyzed in this study. Therefore, in the future study, the difference in effect sizes of DBI as function of specific instructional methods or contents should be examined. Sixth, in the present study, the QIs of Horner et al. [25] were used to evaluate the quality of individual studies. However, there is still need to examine the quality of the studies based on various criteria, especially beyond the aspects of research designs or methods. For example, Shin [61] argued that the criteria suggested by Fuchs, Fuchs, & Malone [62] and NCII, which reflect perspectives of teachers, should be considered when evaluating the quality of DBI.

Supporting information

S1 Checklist. PRISMA 2009 checklist. (DOCX)
S1 File. (DOCX)
Author Contributions

Conceptualization: Dongil Kim.
Data curation: Dongil Kim, Seohyeon Choi.
Formal analysis: Seohyeon Choi.
Funding acquisition: Dongil Kim.
Investigation: Dongil Kim, Seohyeon Choi.
Methodology: Dongil Kim, Seohyeon Choi.
Resources: Seohyeon Choi.
Supervision: Dongil Kim.
Validation: Seohyeon Choi.
Writing – original draft: Seohyeon Choi.
Writing – review & editing: Dongil Kim.

References

1. van Kraayenoord CE, Elkins J. Learning difficulties in numeracy in Australia. Journal of Learning Disabilities. 2004 Jan; 37(1):32–41. https://doi.org/10.1177/00222194040370010401 PMID: 15493465
2. Organisation for Economic Co-operation and Development. Transforming disability into ability: policies to promote work and income security for disabled people. Paris: OECD; 2003.
3. Robson C. Students with disabilities, learning difficulties and disadvantages: Statistics and indicators. OECD: Organisation for Economic Cooperation and Development; 2005.
4. Fuchs D, Fuchs LS, Stecker PM. The “blurring” of special education in a new continuum of general education placements and services. Exceptional Children. 2010 Apr; 76(3):301–23.
5. National Center on Intensive Intervention (NCII) at American Institutes for Research. Data-based individualization: A framework for intensive intervention. ERIC Clearinghouse; 2013.
6. Deno SL, Mirkin P. Data-based program modification: A manual. Council Exceptional Children; 1977.
7. Marston D, Myuskens P, Lau M, Canter A. Problem-solving model for decision making with high-incident disabilities: The Minneapolis experience. Learning Disabilities Research & Practice. 2003 Aug; 18(3):187–200.
8. Jung PG, McMaster KL, Kunkel AK, Shin J, Stecker PM. Effects of data-based individualization for students with intensive learning needs: A meta-analysis. Learning Disabilities Research & Practice. 2018 Aug; 33(3):144–55.
9. Lembke ES, McMaster KL, Smith RA, Allen A, Brandes D, Wagner K. Professional development for data-based instruction in early writing: Tools, learning, and collaborative support. Teacher Education and Special Education. 2018 May; 41(2):106–20.
10. Stecker PM, Fuchs LS, Fuchs D. Using curriculum-based measurement to improve student achievement: Review of research. Psychology in the Schools. 2005 Nov; 42(8):795–819.
11. Fuchs LS, Fuchs D, Hamlett CL. Effects of instrumental use of curriculum-based measurement to enhance instructional programs. Remedial and Special Education. 1989 Mar; 10(2):43–52.
12. Poch AL, McMaster KL, Lembke ES. Usability and feasibility of data-based instruction for Students with intensive writing needs. The Elementary School Journal. 2020 Dec 1; 121(2):197–223.
13. Capizzi AM, Fuchs LS. Effects of curriculum-based measurement with and without diagnostic feedback on teacher planning. Remedial and Special Education. 2005 May; 26(3):159–74.
14. Fuchs LS, Deno SL, Mirkin PK. The effects of frequent curriculum-based measurement and evaluation on pedagogy, student achievement, and student awareness of learning. American Educational Research Journal. 1984; 21(2):449–60.
15. McMaster KL, Lembke ES, Shin J, Poch AL, Smith RA, Jung PG, et al. Supporting teachers’ use of data-based instruction to improve students’ early writing skills. Journal of Educational Psychology. 2020 Jan; 112(1):1.
16. Deno SL. Curriculum-based measurement: The emerging alternative. Exceptional children. 1985 Nov; 52(3):219–32. https://doi.org/10.1177/001440285605200303 PMID: 2934262
17. Romig JE, Therrien WJ, Lloyd JW. Meta-analysis of criterion validity for curriculum-based measurement in written language. The Journal of Special Education. 2017 Aug; 51(2):72–82.
18. Deno SL, Fuchs LS, Marston D, Shin J. Using curriculum-based measurement to establish growth standards for students with learning disabilities. School Psychology Review. 2001 Dec; 30(4):507–24.
19. Kim DI. Basic Academic Skills Assessment (BASA): reading. Seoul: Hakjisa; 2008.
20. Espin C, McMaster KL, Wayman MM, Rose S, editors. A measure of success: The influence of curriculum-based measurement on education. U of Minnesota Press; 2012.
21. Yeo SS, Hong SD, Son JY. Literature synthesis on curriculum-based measurement (CBM) research in Korea: Focused on the technical adequacy. The Journal of Learning Disabilities. 2014; 11(3):187–213.
22. Baron J. Identifying and Implementing Education Practices Supported by Rigorous Evidence: A User Friendly Guide. Journal for Vocational Special Needs Education. 2004; 26:40–54.
23. Odom SL, Brantlinger E, Gersten R, Horner RH, Thompson B, Harris KR. Research in special education: Scientific methods and evidence-based practices. Exceptional Children. 2005 Jan; 71(2):137–48.
24. Gersten R, Fuchs LS, Compton D, Coyne M, Greenwood C, Inocenti MS. Quality indicators for group experimental and quasi-experimental research in special education. Exceptional Children. 2005 Jan; 71(2):149–64.
25. Horner RH, Carr EG, Halle J, McGee G, Odom S, Wolery M. The use of single-subject research to identify evidence-based practice in special education. Exceptional Children. 2005 Jan; 71(2):165–79.
26. Jung PG. Characteristics and effects of data-based individualization on student achievement: A literature review. The Korea Journal of Learning Disabilities. 2018; 15(1):165–192.
27. Jitendra AK, Burgess C, Gajria M. Cognitive strategy instruction for improving expository text comprehension of students with learning disabilities: The quality of evidence. Exceptional Children. 2011 Jan; 77(2):135–59.
28. An YJ, Lee MJ. Analysis of video modeling interventions for people with intellectual disabilities using quality indicators. Journal of Intellectual Disabilities. 2020; 24(2):195–220.
29. Chard DJ, Ketterlin-Geller LR, Baker SK, Doabler C, Apihchatabutra C. Repeated reading interventions for students with learning disabilities: Status of the evidence. Exceptional Children. 2009 Apr; 75(3):263–81.
30. Filderman MJ, Toste JR, Didion LA, Peng P, Clemens NH. Data-based decision making in reading interventions: A synthesis and meta-analysis of the effects for struggling readers. The Journal of Special Education. 2018 Nov; 52(3):174–87.
31. Jung PG, Shin JH, McMaster KL. The application of data-based instruction to writing instruction: A case example of a student at risk for writing difficulties. Special Education Research. 2016; 15(4):61–80.
32. Van den Noortgate W, Ongena P. Combining single-case experimental data using hierarchical linear models. School Psychology Quarterly. 2003; 18(3):325–46.
33. Van Den Noortgate W, Ongena P. Hierarchical linear models for the quantitative integration of effect sizes in single-case research. Behavior Research Methods, Instruments, & Computers. 2003 Feb; 35(1):1–0. https://doi.org/10.3758/bf03195492 PMID: 12723775
34. Van den Noortgate W, Ongena P. The aggregation of single-case results using hierarchical linear models. The Behavior Analyst Today. 2007; 8(2):196–208.
35. Wang SY, Cui Y, Parrilla R. Examining the effectiveness of peer-mediated and video-modeling social skills interventions for children with autism spectrum disorders: A meta-analysis in single-case research using HLM. Research in Autism Spectrum Disorders. 2011 Jan 1; 5(1):562–9.
36. Wang SY, Parrilla R, Cui Y. Meta-analysis of social skills interventions of single-case research for individuals with autism spectrum disorders: Results from three-level HLM. Journal of Autism and Developmental Disorders. 2013 Jul; 43(7):1701–16. https://doi.org/10.1007/s10803-012-1726-2 PMID: 23212808
37. Heyvaert M, Maes B, Van Den Noortgate W, Kuppens S, Ongena P. A multilevel meta-analysis of single-case and small-n research on interventions for reducing challenging behavior in persons with intellectual disabilities. Research in Developmental Disabilities. 2012 Mar; 33(2):766–80. https://doi.org/10.1016/j.ridd.2011.10.010 PMID: 22100975
38. Kratochwill TR, Levin JR. Single-case intervention research: Methodological and statistical advances. American Psychological Association; 2014.
39. Gage NA, Lewis TJ. Hierarchical linear modeling meta-analysis of single-subject design research. The Journal of Special Education. 2014 May; 48(1):3–16.
40. Brossart DF, Parker RI, Olson EA, Mahadevan L. The relationship between visual analysis and five statistical analyses in a simple AB single-case research design. Behavior Modification. 2006 Sep; 30 (5):531–63. https://doi.org/10.1177/014544503261167 PMID: 16894229

41. Jenson WR, Clark E, Kircher JC, Kristjansson SD. Statistical reform: Evidence-based practice, meta-analyses, and single subject designs. Psychology in the Schools. 2007 May; 44(5):483–93.

42. Raudenbush SW, Bryk AS. Hierarchical linear models: Applications and data analysis methods. Sage; 2002. https://doi.org/10.2466/pms.2002.94.2.671 PMID: 12027363

43. Raudenbush SW, Bryk AS, Cheong YF, Congdon R, Du Toit M. HLM 6: Hierarchical linear and nonlinear modeling. Scientific Software International, Inc., Lincolnwood, IL. 2004. https://doi.org/10.1146/annurev.publhealth.25.050503.153925 PMID: 15015912

44. Van den Noortgate W, López-López JA, Marín-Martínez F, Sánchez-Meca J. Three-level meta-analysis of dependent effect sizes. Behavior Research Methods. 2013 Jun; 45(2):576–94. https://doi.org/10.3758/s13428-012-0261-6 PMID: 23055166

45. Hedges LV, Tipton E, Johnson MC. Robust variance estimation in meta-regression with dependent effect size estimates. Research Synthesis Methods. 2010 Jan; 1(1):39–65. https://doi.org/10.1002/jrsm.5 PMID: 26056092

46. Kim MK, Bryant DP, Bryant BR, Park Y. A synthesis of interventions for improving oral reading fluency of elementary students with learning disabilities. Preventing School Failure: Alternative Education for Children and Youth. 2017 Apr; 61(2):116–25.

47. Abbott M, Wills H, Miller A, Kaufman J. The relationship of error rate and comprehension in second and third grade oral reading fluency. Reading Psychology. 2012 Jan 1; 33(1–2):104–32. https://doi.org/10.1080/02702711.2012.630613 PMID: 24319307

48. Fuchs LS, Fuchs D, Hosp MK, Jenkins JR. Oral reading fluency as an indicator of reading competence: A theoretical, empirical, and historical analysis. Scientific Studies of Reading. 2001 Jul 1; 5(3):239–56.

49. Katzir T, Kim Y, Wolf M, O’Brien B, Kennedy B, Lovett M, Morris R. Reading fluency: The whole is more than the parts. Annals of Dyslexia. 2006 Mar 1; 56(1):51–82. https://doi.org/10.1007/s11881-006-0003-5 PMID: 17849208

50. Bast J, Reitsma P. Analyzing the development of individual differences in terms of Matthew effects in reading: Results from a Dutch longitudinal study. Developmental Psychology. 1998 Nov; 34(6):1373. https://doi.org/10.1033/0012-1649.34.6.1373 PMID: 9823518

51. FRANCIS H. Patterns of reading development in the first school. British Journal of Educational Psychology. 1992 Jun; 62(2):225–32.

52. Fuchs D, Fuchs LS. Rethinking service delivery for students with significant learning problems: Developing and implementing intensive instruction. Remedial and Special Education. 2015 Mar; 36(2):105–11.

53. Shin J, Espin CA, Deno SL, McConnell S. Use of hierarchical linear modeling and curriculum-based measurement for assessing academic growth and instructional factors for students with learning difficulties. Asia Pacific Education Review. 2004 Jun; 5(2):136–48.

54. Sabornie EJ, Cullinan D, Osborne SS, Brock LB. Intellectual, academic, and behavioral functioning of students with high-incidence disabilities: A cross-categorical meta-analysis. Exceptional Children. 2005 Oct; 72(1):47–63.

55. Kirk S, Gallagher JJ, Coleman MR. Educating exceptional children. Cengage Learning; 2014 Feb 7.

56. Snyder SM, Ayres K. Investigating the usage of reading curriculum-based measurement (CBM-R) to formatively assess the basic reading skills of students with intellectual disability. Education and Training in Autism and Developmental Disabilities. 2020 Mar 1; 55(1):60–74.

57. Wallace T, Tichá R, Gustafson K. Study of General Outcome Measurement (GOMs) in Reading for Students with Significant Cognitive Disabilities: Year. RIPM Technical Report; 2008 Mar.

58. Matttaital C. Using CBM to help Canadian elementary teachers write effective IEP goals. Exceptionality Education International. 2011 Jan; 21(1):61–71.

59. Bresina BC, McMaster KL. Exploring the relation between teacher factors and student growth in early writing. Journal of Learning Disabilities. 2020 Jul; 53(4):311–24. https://doi.org/10.1177/0022219420913543 PMID: 32274958

60. Choi SM, Kwon TH. Analysis of the problem and present state of instructional adaptation in elementary social subject. Journal of Intellectio n Disabilities. 2009; 11(1):183–98.

61. Shin JH. Re-conceptualizing an intervention intensity for students with learning disabilities: Focusing on teachers’ selection of evidence-based instruction and instructional modification. The Korea Journal of Learning Disabilities. 2019; 16(3):93–113.

---

43. Raudenbush SW, Bryk AS, Cheong YF, Congdon R, Du Toit M. HLM 6: Hierarchical linear and nonlinear modeling. Scientific Software International, Inc., Lincolnwood, IL. 2004. https://doi.org/10.1146/annurev.publhealth.25.050503.153925 PMID: 15015912
62. Fuchs LS, Fuchs D, Malone AS. The taxonomy of intervention intensity. Teaching Exceptional Children. 2018 Mar; 50(4):194–202.

63. Shim MO, Park HO. The effect of E-NIE program on the reading fluency and writing of a student with intellectual disabilities. The Journal of Developmental Disabilities. 2015; 19(3): 123–146.

64. Kwon HJ. The effects of cognitive processing training based on PASS Reading Enhancement Program (PREP) on the reading speed and accuracy of the student with mild mental retardation [master’s thesis]. Kongju National University; 2014.

65. Cho GH. The effects of Readers Theater program on reading fluency and reading comprehension of reading underachievers [master’s thesis]. Seoul National University; 2008.

66. Choi JK. A study on the meaning of goal setting and effects of intervention within curriculum-based measurement. Asian Journal of Education. 2008; 9(2): 89–112.

67. You EK. The effects of national language differentiated instruction on reading ability of underachievers in national language [master’s thesis]. Daegu National University of Education; 2016.

68. Kim KH. The effects of children’s poem program based on the balanced approach to language education on reading skills of the underachieved students in Korean language. [master’s thesis]. Daegu National University of Education; 2017.

69. Lee HJ, Lee TS. The effects of language experience approach utilizing graphic organizer on writing abilities of students with mild intellectual disabilities. Journal of Special Education. 2019; 26(1): 87–108.

70. Kwon DY, Kang OR. The effects of mathematical learning through the play activities on computation abilities and mathematical attitudes of low-achieving students. The Korea Journal of Learning Disabilities. 2007; 4(2): 71–91.

71. Yu JW. Effects of written expression on written ability and fluency for students with learning difficulties in middle school [master’s thesis]. Chonnam National University of Education; 2010.

72. Han YS. Effects of book discussion activities on writing achievements for at-risk students with learning disabilities in writing [master’s thesis]. Daegu National University of Education; 2014.

73. Park SH, Lee KJ. Effects of whole language approach with fairy tales on reading abilities of students with learning difficulties. The Journal of Korea Elementary Education. 2015; 26(2). 231–245.

74. Lee EO. A study on the effects of writing book reports using a peer tutoring writing skills improvement of the student with severe learning disability [master’s thesis]. Chonnam National University of Education; 2015.

75. Kwon MY. Effects of the mindfulness-based reading intervention on the attention behavior and reading fluency of students with learning disabilities. Journal of Special Education & Rehabilitation Science. 2015; 52(2): 1–29.

76. Shin SJ, Kang OR. The effects of synthetic phonics training based on explicit instruction on word recognition, oral reading fluency and spelling of students at risk for dyslexia. The Korea Journal of Learning Disabilities. 2018; 15(3), 103–134.

77. Kim DI, Koh HJ, Yi HL. BASA implementation for children with learning disabilities: The one-year CBM case study in Korea. The Journal of Special Education: Theory and Practice. 2014; 15(1): 193–213.

78. Kim BR. The effects of RTI as an intervention and diagnostic approach for at-risk students in mathematics [master’s thesis]. Gyeongin National University of Education; 2011.

79. Ko YS, Song JH. A case study on learning consulting for children with poor mathematics. Journal of School Psychology and Learning Consultation. 2019; 6(1): 1–25.

80. Kim MJ, Lee JW, Lee DC. The effect of reading guidance through smart learning on reading fluency of students with intellectual disability. Journal of Special Education. 2014; 21(2): 196–220.

81. Lee JY. The effect of story retelling activities on reading abilities of ADHD-risk students [master’s thesis]. Daegu National University of Education; 2015.

82. Kim MK, Lee KJ. Effects of reverse-role tutoring on reading fluency and academic self-confidence of at-risk readers. The Korea Journal of Learning Disabilities. 2015; 12(2): 185–201.

83. Gil YM. The effect of collaborative writing with classical literature on writing achievements for underachievers in Korean language [master’s thesis]. Daegu National University of Education; 2015.

84. Seul YG. A study on change in reading abilities of children with reading disabilities through interested reading programs [master’s thesis]. Yosu National University; 2005.

85. Kim DI, Shin HYG, Kim HU, Cho EJ. An analysis of the effects of the synthetic phonics program on phonological awareness skills of underachieving children. The Journal of Special Children Education. 2018; 20(2): 25–50.

86. Hwang AH. The effects of teaching phonics through direct instruction and fluency training on reading for poor readers [master’s thesis]. Duksung Women’s University; 2012.
87. Ahn SJ. The effect of scaffolding intervention program to improve reading achievement in elementary students with poor reading [master’s thesis]. Seoul National University; 2018.

88. Choi EJ. The effects of reading strategy training on reading disorder children’s reading ability and reading attitude [master’s thesis]. Daegu University; 2006.

89. Jung KJ, Lee HJ. The study on the applicability of response to intervention. Korean Journal of Special Education. 2009; 44(2): 313–339.

90. Song PR, Kim DI. The effects of subitizing based numbers sense intervention on number sense and counting for students at-risk of MLD. The Korea Journal of Learning Disabilities. 2020; 17(1), 127–157.

91. Kim ES. Applicability research of direct instruction addition and subtraction program for mathematical underachievers in elementary school [master’s thesis]. Seoul National University; 2015.

92. An MS. The effects of computer assisted instruction on the addition and subtraction computation performance of middle school students with intellectual disabilities [master’s thesis]. Dankook University; 2012.

93. Jeong CM. The effect of creative summary note on writing achievements for underachievers in Korean language [master’s thesis]. Daegu National University of Education; 2015.

94. Kim DI, An YJ, Cho EJ, Choi SH. A case study of individualized reading fluency program for students at-risk of learning disabilities. Journal of Research in Curriculum & Instruction. 2020; 24(6): 589–601.