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Systematic Review

A Systematic Review of Working Memory Applications for Children with Learning Difficulties: Transfer Outcomes and Design Principles

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Abstract: Working memory (WM) is a crucial cognitive function, and a deficit in this function is a critical factor in learning difficulties (LDs). As a result, there is growing interest in exploring different approaches to training WM to support students with LDs. Following the PRISMA 2020 guidelines, this systematic review aims to identify current computer-based WM training applications and their theoretical foundations, explore their effects on improving WM capacity and other cognitive/academic abilities, and extract design principles for creating an effective WM application for children with LDs. The 22 studies selected for this review provide strong evidence that children with LDs have low WM capacity and that their WM functions can be trained. The findings revealed four commercial WM training applications—COGMED, Jungle, BrainWare Safari, and N-back—that were utilized in 16 studies. However, these studies focused on suggesting different types of WM tasks and examining their effects rather than making those tasks user-friendly or providing practical guidelines for the end-user. To address this gap, the principles of the Human–Computer Interaction, with a focus on usability and user experience as well as relevant cognitive theories, and the design recommendations from the selected studies have been reviewed to extract a set of proposed guidelines. A total of 15 guidelines have been extracted that can be utilized to design WM training programs specifically for children with LDs.

Keywords: cognitive load theory; design principles; learning difficulties (LDs); systematic review; user-centered design; WM training applications; working memory (WM)

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1. Introduction

There is an emerging interest in research that supports the idea that specific cognitive functions could be enhanced and thereby both the short- and long-term outcomes of individuals with neurodevelopmental deficits could be improved. One group that could specifically benefit from those interventions targeting specific cognitive deficits is children with learning difficulties.

Learning difficulties (LDs) can be defined as "a veiled disorder referring to a large heterogeneous group of individuals with a common marker of intra-individual variability (i.e., "unexpectedness"), representing a discrepancy between IQ and achievement" [1]. Learning difficulties do not affect general intellect, although they can cause a person to face problems in a traditional classroom setting [2]. Thus, children with LDs have normal intelligence, but this is not matched with their low learning potential or scholastic achievement [3].

Recently, WM deficit has been considered a significant contributing factor of LDs [4,5]. For instance, a meta-analysis of 29 studies revealed that all groups with LDs (with reading difficulties, mathematical difficulties, or both) showed deficits either in verbal or numerical WM [4]. In the current study, children with LDs refer to those children in mainstream classrooms who have a poor WM capacity, which hinders their learning process, and as a result, and who have lower academic achievements compared to their peers, irrespective of their normal intelligence.

"Working memory (WM) is a cognitive process whose primary function is to facilitate and enhance the capacity of encoding, storage, and retrieval essential for learning and a higher level of information processing" [6]. Working memory is essential for complex cognitive tasks such as learning, problem solving, mathematical reasoning, and language comprehension [7]. Research has revealed that improved WM capacity may improve academic outcomes, and ease new knowledge acquisition and skills for children with LDs [8,9].

According to the integrated model of Baddeley and Hitch [10], WM consists of four sub-systems, namely the main system (the central executive) and three slaving systems: the phonological loop, the visuospatial sketchpad, and the episodic buffer. The central executive is an attentional control system responsible for allocating attention within the WM system via focusing, dividing, and switching attention; the three slaving systems are the phonological loop, which is taking charge of holding and manipulating sounds and speech; the visuospatial system, which is performing a similar function with non-verbal materials; and the episodic buffer, which is acting as a coordinator to link between the various WM components and long-term memory [10]. Children with LDs often have limited WM capacity. This means that they fail to remember the required amount of information needed to be processed and held while learning new skills. As soon as those children are able to overcome their WM limits, they would be able to learn as effectively as others [11].

Research has suggested that WM capacity can be enhanced by intensive cognitive training because its underlying neural systems remain flexible throughout a person's lifespan [12,13]. The cognitive training focuses on enhancing the trainee's WM capacity mainly by expanding the extent of information that can be kept and manipulated in the WM components [14].

Furthermore, children with LDs often face a lower level of motivation. These challenges have been well documented in the literature [15,16].

Since children with LDs often have a limited WM capacity and a reduced level of motivation, this can be dealt with through two approaches. The first approach is to improve their limited WM capacity by designing engaging and motivational training applications [16,17]. The second is developing learning environments that minimize the load on students' WM (the cognitive overload that might hamper learning) [18]. The challenge in designing such applications is to consider the needs of this group of children (e.g., to have less demanding tasks), motivate them (e.g., embedding appropriate game elements and improving their experience with the application), and consider their cognitive characteristics (e.g., limited WM capacity) [19,20].

A significant gap in user-centered design is evident in the development of these cognitive programs. A notable example is COGMED, which is widely marketed to schools and clinical practices, that often cannot support its beneficial claims with empirical evidence (e.g., [21–23]).

Furthermore, the commercial cognitive programs (e.g., COGMED and N-back) used some extrinsic motivators, such as points and rewards, to motivate children and keep them engaged in the training. However, these extrinsic factors could not keep the children engaged in the daily training over the long term because they considered these extrinsic motivators as application assets and they became less fun to collect on their own [24,25], and this consequently increased the dropout percentage of those children during the training.

For more clarification, WM training should take place for 20 days in a 4- to 7-week period with sessions of approximately 30–45 min per day [14]. However, cognitive tasks usually require effort and can be considered repetitive and frustrating, which often impact negatively on participant engagement. Thereby, this might negatively influence the quality of the collected data and/or reduce the effect of the intended intervention [26]. Regarding tackling this problem, using game elements as a vehicle to provide learning and cognitive training can motivate and engage participants [26,27] because of the pleasure and the excitement that these activities offer. By contrast, other studies showed that applying different game elements could increase cognitive load levels via inducing unwanted stress or bringing new cognitive demands. These game elements could also divert the trainees from the main purpose [28–30]. Given that children with LDs often reveal lower intrinsic motivation [31], designing engaging interventions is essential. While some studies have explored incorporating game elements to boost motivation [26,27], they often lack a user-friendly approach that considers practical guidelines for end-users.

Therefore, the current study aims to conduct a systematic review to investigate the current cognitive applications and whether any design principles/guidelines were followed to create those applications.

1.1. The Present Study

This study aims to systematically review experimental studies on computerized WM applications designed for children with LDs. Specifically, we will carry out the following:

- Identify existing WM training programs, examining both research-based and commercially available options.
- Analyze their theoretical frameworks and empirical effects.
- Review key design principles that enhance user experience, engagement, and motivation, ultimately developing guidelines for designing effective cognitive applications tailored for children with LDs.

1.2. Systematic Literature Review Questions

1. What are the current cognitive applications implemented to train the WM of children with LDs and what is their theoretical underpinning?
2. What are the effects of these training applications on children's WM and other cognitive abilities?
3. What are the key design principles or frameworks that can be identified to enhance the design of such applications for children with LDs?

2. Materials and Methods

This systematic review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework [32]. The search strategy was conducted following standard practice as follows:

2.1. Search Strategies

The search was conducted between June 2024 and August 2024 across five electronic databases (Scopus, Cochrane, ERIC, Semantic Scholar, PubMed) with keywords: ("working memory") AND ("training" OR "application" OR "game") AND ("learning disabi*" OR "learning difficul*") AND NOT ADHD, and by scanning reference lists of peer-reviewed articles [33–35]. The Boolean operators (OR/AND) and search filters were used to obtain more focused articles.

2.2. Inclusion and Exclusion Criteria

Three hundred studies were screened for the inclusion and exclusion criteria (see Figure 1). To be included, a study had to target those children at primary schools with learning difficulties but with normal intelligence. The sample group had to receive computerized training using a program/application that aimed to enhance their WM skills. The study's design had to be either a randomized control trial or quasi-experiment with a training group and a control group (received no training or received different training) with pre- and post-tests. Studies were excluded based on the following criteria: (1) the sample did not consist of primary school children, (2) the study did not include children with learning difficulties, disabilities, special educational needs, specific learning disabilities, or poor working memory (WM) capacity, (3) the study lacked a WM intervention, (4) the study employed non-computerized WM interventions (e.g., paper-based methods), and (5) the study did not include a control group. Ultimately, 23 out of 300 studies met the inclusion criteria for the systematic review.

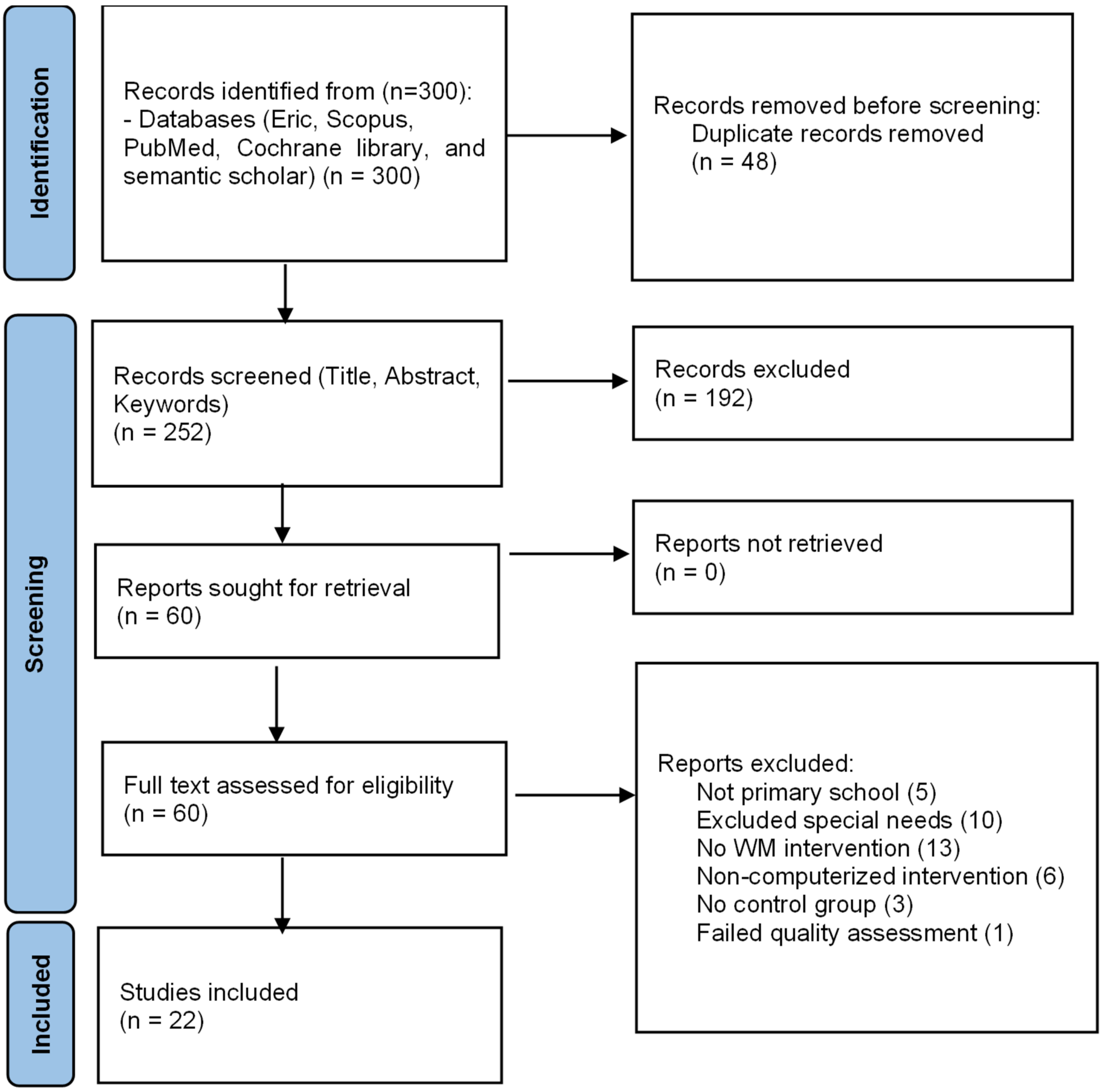

Figure 1. Flow diagram for the search and inclusion criteria for studies in this review.

2.3. Quality Assessment

The quality of the 23 studies was assessed according to the 5 dimensions used by Connolly et al. [36]. Each paper was read and given a score of 1–3 across the five criteria described below, where 3 indicates high, 2 indicates medium, and 1 indicates low on that criterion:

1. How appropriate is the research design for addressing the question or sub-questions of this review (higher weighting for inclusion of a control group)? Papers were coded as follows:
   - High = 3, e.g., Randomized Control Trial (RCT)
   - Medium = 2, e.g., quasi-experimental controlled study
   - Low = 1, e.g., case study, single subject-experimental design, pre-test/post-test design.
2. How appropriate are the methods and analyses (checking the methodological appropriateness, the representation of the target population in the sample, the completeness of the outcome data, and the significance of the measurements)?
3. How generalizable are the findings of this study to the target population with respect to the size and representativeness of the sample? To what extent would the findings be relevant across age groups (6–13 years), gender, sample diagnosis, etc.?
4. How relevant is the particular focus of the study (including conceptual focus, context, sample, and measures) for addressing the question or sub-questions of this review?
5. To what extent can the study findings be trusted in answering the systematic review questions?

Each paper was scored on a scale of 1 to 3 based on these five dimensions, resulting in total scores varying between 5 and 15. A high-quality paper was considered to have a score of 9 or higher out of 15 (i.e., 60% or higher quality) and was included in the current research.

2.4. Inter-Rater Reliability (Consistency and Reliability of Coding)

Two researchers revised all 23 included papers, then assessed the quality of the papers independently. The inter-rater reliability (ρ) for the total scores was 0.88, showing a good agreement between the two coders concerning the quality of the papers. The results also revealed that 22 out of 23 papers achieved 60% or higher quality and these papers were reviewed.

2.5. Data Extraction

Relevant information about the research design/methodology, intervention participants (including sample diagnosis, number, and age), type of intervention, and methods, as well as the reported outcomes, was summarized. The studies were independently reviewed, and any discrepancies were resolved through discussion. Further steps in the data synthesis process involved identifying general themes from the studies to extract information pertinent to the current research questions.

3. Results

Tables 1 and 2 provide the collected information from the included studies (22 studies) in this systematic review. Table 1 focuses on critical aspects of each study's location, quality assessment rating, participant demographics (sample size, age range, and diagnoses), the type of WM intervention or program used, and the study's design and methodology.

Table 1. The study location, quality, demographic sample characteristics, and methodology from the included studies (22 studies) in the review.

Study/Location/Quality (%)	Sample Diagnosis/ Number/Age	Study Design/Methodology
	COGMED	
Bergman-Nutley and Klingberg [37] Sweden, 80%	Children with WM deficits. N = 480, aged 7–12 Y	QE: The training group (176) with WM deficits and typical passive control group (304). The study recruited the training group from a set of clinics that provide COGMED training for children/adults. The chosen children already had COGMED training during summer and were tested five times as a part of their training either in the clinic or at home before conducting the study.

Table 1. *Cont.*

Study/Location/Quality (%)	Sample Diagnosis/ Number/Age	Study Design/Methodology
Dahlin [38] Sweden, 80%	Children with special educational needs (literacy difficulties) N = 57, aged 9–12 Y	The training group (42) and passive control group (15)
Dunning et al. [39] UK, 93%	Children with low WM N = 47, aged 7–9 Y	RCT: Randomized Controlled Trial (adaptive CWMT (15), non-adaptive CWMT (19) passive control group)
Holmes et al. [40] UK/86.7%	Children low WM N = 42, aged 9–11 Y	QE: Controlled (adaptive vs. non-adaptive training group)
Holmes et al. [41] UK, 73%	Children with specific language disabilities/children with low language abilities. N = 27, aged 8–10 years	QE: Two training groups (language learning disabilities (N = 12) and typical language performance (N = 15)) received COGMED training.
McKenzie [42] USA, 73%	Children with LDs N = 36, aged 7–8 Y	QE: Training group (18) received COGMED training. Passive control (18). Both groups received reading intervention in the previous year.
Partanen et al. [43] Sweden, 100%	Children with special educational needs (SEN) from 10 schools N = 64, age 8–9 Y	RCT: Randomized Controlled Trial (group1 (20): WM training group 2: WM training + metacognitive strategy training control group 3 (24))
Roberts et al. [44] Australia, 87%	Children low WM N= 452, aged 6–7 Y	RCT: Randomized Controlled Trial training group and passive control group
Ang et al. [45] Singapore, 86.7%	Children with LDs N= 111, aged 7 Y	QE: Two training groups: updating training, COGMED vs. two control groups: active control, passive control.
	Jungle	
Nelwan and Kroesbergen [46] Netherlands, 73.3%	Children with LDs. N = 64 aged 9–12 Y	QE: Three groups of children were assigned and trained in two periods: (1) jungle WM training first, followed by math training, (2) math training first, followed by jungle WM training, and (3) a control group that received math training only.
Nelwan et al. [47] Netherlands, 73.3%	Children with LDs N = 48 aged 9–12 Y	QE: Training group (23) received one high coaching session per week, passive control group (25).
Alloway and Alloway [48] The UK, 60%	Children with LDs N = 15 aged 12–13	QE: Training group (8), active control group, received targeted educational support (7).
Alloway, Bibile and Lau [49] The UK, 86.7%	Children with LDs N = 94, aged 10–11 Y	QE: Two control groups (non-active and active), and one training group. The active control group received low-frequency training (once a week) while the training group received high-frequency training (four times a week).
	BrainWare Safari	
Avtzon [50] USA, 86.7%	Children with specific learning disabilities N = 40 Aged 7–9 Y	QE: Training group (20) received BrainWare Safari training. Passive control (20) received their usual special education routine.
Shokoohi-Yekta et al. [51] Iran, 60%	Children with LDs N = 35 aged 7–12 Y	QE: Training group (15) received BrainWare Safari training. Passive control (20) received an academic education at school.
	Phonological and visuospatial (N-back)	
Yang et al. [52] China, 73.3%	Children with developmental dyslexia N = 11 aged 9–11 Y	QE: Experiment 1: training group (13) received phonological (N-back) training. Active control (12) received the idiom King video game. Experiment 2: training group (12) received visuospatial (N-back) training. Active control (12) received pull the carrot game.
	Adopted WM training tasks.	
Chen et al. [3] China, 73.3%	Children with LDs N = 54 aged 9–11 Y	QE: Randomized (active training (26) vs. passive control group (28).
Zhang et al. [5] China, 66.7%	Children with LDs N = 65 (45 with LDs and 20 without), aged 10–13 Y	QE: Adaptive training a group with LDs vs. two non-adaptive control groups (control group with LDs and normal group).

Table 1. *Cont.*

Study/Location/Quality (%)	Sample Diagnosis/ Number/Age	Study Design/Methodology
	Developed a training program (Research-based)	
Luo et al. [53] China, 66.7%	Children with dyslexia N = 30, aged 8–11 Y,	QE: The training group (15) and the active control group received low-dose training (15).
Ramezani et al. [54] Iran, 80%	Children with dyslexia N = 36 aged 8 Y	RCT (36 children, 7 dropped out): Control group used VWM (18 children). Intervention group used a VWM-balance program (18 children).
Maehler et al. [55] Germany, 73.3%	Children with and without dyslexia. N = 139 aged 8–9 Y	QE: Four groups: Dyslexia: 84 (43 trained, 41 untrained) Control: 69 (27 trained, 28 untrained)
Muñez et al. [56] Singapore, 80%	Children with math LDs N = 428, aged 7 Y	RCT (each group ~107 children): • WM training group. • WM plus numeracy (NWM) training group. • Numeracy (NUM) training group. Active control (AC) group.

3.1. WM Training Applications Used (What Are the Cognitive Applications Implemented to Train WM of Children with LDs and What Is Their Theoretical Underpinning?)

Cognitive intervention can be defined as a method to treat or improve cognitive functioning including oral and written language, reasoning, attention, executive functions, and perceptual processing [57]. In this systematic review, the cognitive applications are computerized WM training applications/programs that aim to improve WM functions, language abilities (reading and writing skills), academic achievement (language and mathematics), fluid intelligence, and other cognitive functions like attention. The applications under discussion fall into one of two categories: they were created either for commercial purposes or to support research endeavors.

As is shown in Table 1, 16 out of 22 studies applied a set of commercial WM training applications such as COGMED (9 studies), Jungle (4 studies), and BrainWare Safari (2 studies), and N-back (1 study). Notably, only two studies adapted existing training tasks for WM training, while four studies developed their own unique computerized WM training applications.

To illustrate, COGMED was the most commonly used application by the included studies as nine of those studies [37–45] applied the COGMED WM training application to train the WM capacity of children with learning difficulties at primary schools. It is a web-based cognitive training program designed to improve ADHD symptoms either in children or adults. It is widely used to improve individuals'short-term memory and WM by increasing their capacity. It is available in three versions: JM for the pre-school age group (4–6 years), RM for the school age group (7–18 years), and QM for adults. The program includes a series of exercises (around 10), such as storing a sequence of vocalized verbal information, immediate recall of visuospatial items (a group of lamps illuminating consecutively), instant recall of a series of numbers in reverse order, and immediate serial recall of visuospatial information combined with processing (remembering the sequence of lamps illuminating consecutively after altering their positions). The user should be trained for an average of 40 min per session, 5 days a week, for a 5–8-week period. COGMED includes some of the motivational features such as positive feedback (verbal) and provides the user with his best scores.

The Jungle was the second-most-common application, where four of the studies [46–49] used the Jungle WM training application to train WM. It is a web-based application designed to train the WM of children aged 7–16 years old. It consists of three computerized games to train different aspects of the WM; each game has 30 levels, and the level of difficulty increases as the child proceeds. The Quicksand game includes memory and the later use of word endings. The Code Breaker game includes a mental rotation of letters.

The River Crossing game includes sequential memory of mathematical solutions. The child trains three times/week for 8 weeks. The child plays 10 trials per session per game for a total of 30 trials each day, during 30 min of training. In order to motivate the trainees, the Jungle program provides the children with positive verbal feedback and a display of the best scores.

Two studies used the BrainWare safari (BWS) program [50,51]. It is a cognitive training program that contains 20 exercises to train 41 cognitive skills in the form of video games. The training falls into six groups: visuospatial WM, Visual Sustained Attention, Visual Selective Attention, Visual Figure Ground, Visual Processing Speed, and Visual Motor Integration. BrainWare Safari is available via the website: http://mybrainware.com (accessed on 14 November 2024). The training takes 30 sessions, 50–60 min a day, 5 days a week for 6 weeks [51].

Only the study of Yang et al. [52] used N-Back as a cognitive training paradigm to train WM functions. N-back consists of phonological and visuospatial training tasks. Phonological tasks require listening to a series of auditory stimuli to recall them back. Visuospatial tasks require looking at a series of visual stimuli in a specific location to recall them back. The study trained the children for 15 min, five days a week for three weeks.

Two studies adapted three computerized WM training tasks to train the updating ability as one of the aspects of the central executive system of WM for children with LDs [3,5]. The Animal training task involved recalling the last three images from a series of presented images on the screen. The Letters and the Location training tasks are like the Animal training tasks; the trainees were asked to recall the last three letters from a series of presented letters on the screen in the Letters tasks, and the last three locations of a cartoon in the location task. The training lasted from 20–28 days of training, 45 min/day (5 days per week).

Only a handful of studies have taken the approach of developing their own unique WM training programs or applications for research purposes [53–56].

For example, the study of the authors of [53] developed their own training program written with C language for children with dyslexia. The program contains visual–spatial, visual–verbal, and central executive tasks to train different components of WM. The children were trained for 40 min daily for five weeks. Similarly, The study of Maehler et al. [55] developed a computer-based training program called AGENT 8–1–0, designed to enhance WM capacity and efficiency in children aged 8 to 10 years. The training program consisted of 10 games designed based on Baddeley's model of working memory, incorporating game-like elements to engage the participants. The training program consisted of 18 sessions in total, spread across 3 sessions per week for 6 weeks. Each session lasted 45 min.

3.2. What Are the Effects of These Training Applications on Children's WM or Other Cognitive/Academic Abilities?

Table 2 provides a comprehensive overview of how the WM training applications impacted both WM as a near transfer and other cognitive/academic skills as a far transfer.

Table 2. Shows the results of post- and follow-up training on WM and other cognitive/academic performance.

Study	Results of Post- and Follow-Up Training on WM and Other Cognitive/Academic Performance
	COGMED
Bergman-Nutley and Klingberg [37]	Post-training: The results showed an improvement in WM capacity, arithmetic performance, and following instructions after the training period.
Dahlin [38]	Post-training: The WM training improved the children's WM capacity and reading comprehension in the training group, but no improvement occurred in the other two tests of word decoding and orthography. Follow-up (6 months): The improved reading comprehension was maintained 6 months after the training, but no improvement occurred in the other two tests of word decoding and orthography.

Table 2. *Cont.*

Study	Results of Post- and Follow-Up Training on WM and Other Cognitive/Academic Performance
Dunning et al. [39]	Post-training: The adaptive training group showed improvements in Visual Short-Term Memory (VSSTM), Visual–Spatial Working Memory (VSWM) and Verbal Working Memory (VbWM) in post-training measures though not in Verbal Short-Term Memory (VbSTM). No improvements in either literacy, numeracy, or WM demanding classroom tasks occurred after the training. Follow-up (a year): VbWM revealed maintained improvement after a year. No improvements in literacy, numeracy, or WM demanding classroom tasks occurred one year after the training.
Holmes et al. [40]	Post-training: Adaptive group showed improvement in VSSTM, VSWM, and VbWM but not in VbSTM compared to the non-adaptive group. Adaptive training did not lead to a significant boost to IQ, literacy, or numeracy. Follow-up (6 months): The improvement in VSSTM, VSWM, and VbWM was sustained 6 months later. Only numeracy was improved, but no improvements were revealed in IQ or literacy 6 months later.
Holmes et al. [41]	Post-training: A significant improvement in VSSTM in both training groups has been found. However, the verbal IQ and the language level in the training group with low language abilities were lower than a typical group. Exploratory analyses showed that the children with low verbal IQs made greater gains in verbal-span-like WM tasks, while children with higher verbal IQs achieved greater gains in VSSTM after the training.
McKenzie [42]	Post-training: The WM capacity improved after the training period. However, no improvement was transferred to reading fluency and comprehension.
Partanen et al. [43]	Post-training: Results revealed the WM performance was improved in favor of the metacognitive intervention. No transfer to arithmetic or reading and writing skills were identified after training in any of the two training groups. Follow-up (6 months): The improvement in WM was maintained in VSWM 6 months after the training. However, no transfer to arithmetic or reading and writing skills was identified in any of the two training groups.
Roberts et al. [44]	Follow-up (6, 12, or 24 months): The VSSTM improved temporarily after six and twelve months. However, this improvement was not maintained after two years. No evident benefits to academic outcomes (reading, math, and spelling scores as primary outcomes) were found at 12 or 24 months. This lack of effect is also seen in the parent and teacher ratings of attention, social–emotional difficulties, and quality of life.
Ang et al. [45]	Post-training: The results showed some general improvements in the trained tasks either in the training program or COGMED; however, these improvements neither transferred to other similar untrained WM tasks nor math. Follow-up (6 months): The improvement in WM led to better performance of a similar task to the trained tasks. However, this improvement in WM did not result in better math performance.
	The Jungle
Nelwan and Kroesbergen [46]	Post-training: A possible improvement in VbWM in the short term, but none on VSWM. The performance of the children, who had WM training first, was better after math training than the performance of those who did not have WM training first or did not receive WM training.
Nelwan et al. [47]	Post-training: After WM training, the highly coached group performed better compared to the low-coached group in VSWM but not on VbWM. The highly coached group performance in math was better than the low-coached group.
Alloway and Alloway [48]	Post-training: The WM, the crystallized intelligence, and academic attainment (math) were improved post-training compared to the control group.
Alloway et al. [49]	Post-training: Significant improvements in VbWM, VSWM, and spelling have been seen in the training group. No improvement was transferred to math performance. Follow-up (8 months): The effect of the training was maintained for 8 months in all areas (WM, spelling), except in math.

Table 2. *Cont.*

Study	Results of Post- and Follow-Up Training on WM and Other Cognitive/Academic Performance
	The Computerized WM updating training.
Chen et al. [3]	Post-training: The children's WM capacity and fluid intelligence were improved after the training. However, no improvements were seen in the children's academic performance (math and language). Follow-up (6 months): The improvement in children's WM capacity and their fluid intelligence was maintained six months after the training. However, the improvement in the academic performance (math performance) was delayed six months after the training.
Zhang et al. [5]	Post-training: The training group showed a significant improvement in WM updating compared to the control groups, while they did not exhibit considerable improvement in fluid intelligence after training. The training group demonstrated lower language and math performance than the normal control group.
	BrainWare Safari
Avtzon [50]	Post-training: The results showed greater improvements were seen in STM and VbWM, compared to executive function and processing speed. The reading and math performance of the children was improved after the training.
Shokoohi-Yekta et al. [51]	Post-training: The results showed that the VSWM component was improved post-training compared to the passive group.
	Phonological and visuospatial (N-back)
Yang et al. [52]	Post-training: The children's VbWM and VSWM performance in experiments 1 and 2 were improved using N-back. Experiment 1 showed an improvement in phonological awareness (corresponding to VbWM), and experiment 2 showed improvement in the orthographic awareness skill (corresponding to VSWM). The results revealed that both experiments showed improvements in the fast word naming skills compared to the control group. No difference in motivations or level of attitude was revealed among the groups.
	Developed a training program (research-based)
Luo et al. [53]	Post-training: The WM training improved the WM capacity of dyslexic children and their reading skills. The improvement in reading skills is positively correlated with the improvement in WM.
Ramezani et al. [54]	Post-training: Both the VWM-B and VWM groups showed significant improvements in WM capacity, reading skills, and postural control compared to baseline. Follow-up: The VWM-B group maintained their improvements in WM capacity and reading skills at a significantly higher level than the VWM group.
Maehler et al. [55]	Post-training: Improved visuospatial working memory in typical children and central executive in children with dyslexia, but no phonological loop improvements for either group. Follow-up (3 months later): No significant long-term improvements in working memory for either group.
Muñez et al. [56]	Post-training: Both the Numeric-only and Numeric-WM groups exhibited significant enhancements over the control group in non-symbolic numerical discrimination and number line estimation tasks. Additionally, the Numeric-WM group demonstrated notable improvement in math achievement compared to the control group. Follow-up: The Numeric-WM group maintained significant gains over the control group in non-symbolic numerical discrimination, number line estimation, and math achievement, whereas the Numeric-only group did not sustain such improvements.

Firstly, regarding the immediate effect (post-training) on the WM (near transfer effect), all the studies have shown a significant positive effect of the training applications on improving the WM capacity of children (e.g., Visual Short-Term Memory (VSSTM), Visual–Spatial Working Memory (VSWM), Verbal Short-Term Memory (VSTM), Verbal Working Memory (VbWM), and central executive. However, there are some variations in the pattern of those observed effects among the included (22) studies. For example, Dunning et al. [39] and Holmes et al. [40] showed a significant improvement in VSSTM, VSWM, and VbWM of those children undertaking the training, but not in VbSTM compared to the non-adaptive group. Similarly, Nelwan and Kroesbergen [46] revealed a possible improvement in VbWM in the short term, but no improvement was found on VSWM after the training. Conversely, Nelwan et al. [47] showed that the highly coached group performed better than the low-coached group in VSWM but not in VbWM.

Secondly, regarding the immediate effect (post-training) on other cognitive/academic abilities (far transfer effect), 18 out of the 22 included studies assessed the effect of the training applications on other cognitive/academic abilities (e.g., math, reading, language, literacy, fluid intelligence, spelling, and writing).

In detail, math was the most common ability measured by the 18 studies, where 13 out of those 18 studies worked on evaluating whether any improvement occurred on math. Only 6 out of those 13 studies reported a significant positive effect [37,46–48,50,56]. Six out of those 18 studies tested the improvements in the reading skills; four of them indicated that WM training can enhance reading skills [38,50,53,54]. Although five studies tested IQ ability, only two studies, those of Alloway and Alloway [48] and Chen et al. [3], demonstrated a significant positive effect on fluid intelligence. Finally, six studies tested the effect of the training on language ability and none of them showed any positive effect.

Thirdly, regarding the maintained effect (follow-up measure) on WM and other cognitive/academic abilities, 11 studies performed further follow-up on the measures 3 to 24 months after the training. Out of these, ten studies examined the maintained effect of WM training on children's WM. All 10 studies showed a positive improvement in children's WM 3 to 24 months after the training. However, Roberts et al. [44] found only a temporary improvement in VSSTM at 6 and 12 months after the training, but this improvement disappeared after two years. Furthermore, Maehler et al. [55] found no significant long-term improvements in WM for either the training or control groups.

Similarly, 10 out of the 11 studies measured the sustained effect on different cognitive/academic abilities such as WM, math, reading, language, and fluid intelligence. However, there are some variations in the pattern of those observed maintained effects among the included (10) studies.

For instance, Chen et al. [3] showed a positive maintained effect of the training on children's WM capacity and other cognitive/academic abilities (e.g., fluid intelligence, math, and language). Conversely, Roberts et al. [44] reported that no maintained effect was revealed on WM or other cognitive/academic abilities (e.g., VSWM, VbWM, reading, math, spelling, the parent and teacher ratings of attention, social–emotional difficulties, and quality of life) after 6, 12, and 24 months of the training, although a temporary improvement was found in VSSTM after 6 and 12 months after the training.

It is noted that math was the most common academic ability measured in the follow-up stage, followed by language, literacy, and reading. While eight studies assessed the maintained effect of WM on children's math performance, only three studies revealed a maintained effect on math [3,40,56]. Likewise, two out of three studies reported a maintained effect on reading comprehension 6 months after the training [38,54]. Finally, none of the four studies showed maintained improvement in language performance after the training.

3.3. What Are the Key Design Principles or Frameworks That Can Be Identified to Enhance the Design of Such Applications for Children with LDs?

The focus of all the studies is to suggest different types of WM tasks and examine their effect rather than offering them in a user-friendly way or suggesting practical guidelines targeting the end-user. It is noted that 16 studies used four commercial WM training programs (COGMED, Jungle, BrainWare Safari, and N-back). Generally, the focus of the four programs is to enhance the trainee's WM capacity by expanding the amount of information that can be kept and manipulated in the WM components. The four programs shared some points. For example, the difficulty level of the user tasks increases while the trainee progresses to higher levels to provide a consistent challenge to children's cognitive ability. The programs provide the children with positive verbal feedback, points, and a display of the best scores to motivate them during the training. However, none of these programs was designed based on suggested guidelines or design frameworks taking the needs and characteristics of the children with LDs into consideration. Additionally, none of these programs evaluated the children's perceived experience of any program during the training period or targeted the Arab world.

In addition, the four programs are commercial ones, with COGMED being the highest cost. A clear example is a longitudinal study [44] that reported that the COGMED intervention cost A$1035 per child for a total of 452 school children. Therefore, this study does not recommend COGMED because of the high cost, the loss of classroom time during the training, and the lack of maintained effect.

On the other hand, four studies developed their own WM app/programs [53–56] to train different WM components. Three of the studies indicated that the WM training programs should incorporate an adaptive, gamified, and interactive design to effectively engage young participants. The program should feature visually engaging elements, along with clear audio and visual instructions for tasks, supported by demonstrations. Additionally, the WM programs should implement a reward system, including badges and points for correct responses, and incorporate a storyline in which children work together with a character, such as the private investigator, Anton. However, Luo et al. [53] created a computerized cognitive training application, written in C language, so it lacks a childish user interface. As a result, it impacts upon children's motivation. This is the only study applied to this program, so not enough information or data are available. This program is only available in the Chinese language.

Finally, WM training usually requires effort and can be considered repetitive, and this is because WM training is a daily training lasting from 3 weeks [52] to 3 months [50]. Therefore, the included studies used some extrinsic motivators, such as points and rewards to motivate children and keep them engaged in the training. However, these extrinsic factors could not keep the children engaged in the daily training over the long term because they considered these extrinsic motivators as application assets that became less fun to collect on their own [24,25], and this consequently increased the dropout percentage of those children during the training.

Therefore, the included studies suggested some recommendations to design supportive and motivational WM applications for the children with LDs as follows:

3.4. Recommendations Targeting the WM Tasks

1. The studies suggested that it is better to use a range of tasks to train different components of WM, such as visuospatial tasks including pattern recognition, remembering the location, etc.; verbal tasks including recalling a sequence of objects, text, or numbers in order or reverse order; and central executive tasks including backward processing, and updating or inhibiting tasks.
2. The number of elements required to be remembered in WM tasks should progressively increase to challenge the children's WM capacity, and the tasks should consist of a set of levels while the difficulty level of each task increases as the trainee progresses to higher levels [45].
3. All studies recommended adjusting the level of difficulty during training. The difficulty of tasks is consistently adjusted throughout the training process, considering each child's WM capacity and enabling them to perform at their optimal limits.
4. It is recommended to provide the children with some effective strategies during the training to minimize the WM overload, such as rehearsal training and simplifying the training activities [49]. Likewise, Partanen et al. [43] recommended combining WM training with metacognitive techniques to support children with SEN.

3.5. Recommendations Targeting the User

1. To enhance motivation and engagement among children during training, it is essential to provide positive and immediate verbal feedback throughout the sessions and to display the participants' best scores at the conclusion of the training [38,40,46,55]. Additionally, offering a reward system, such as badges and points for correct answers [45,55], incorporating a storyline in which children collaborate with a character, such as the private investigator, Anton [55], and providing tangible rewards (e.g.,

stationery items) at the end of each session or after every five completed training sessions can further encourage engagement and participation [39,53].

2. It is recommended to observe the children with attentional and learning problems during the training period to identify the issues facing them and provide them with immediate feedback and some strategies. This could motivate them and help to obtain the desired results [47].
3. It is recommended to provide the facilitator with a booklet to simplify the training process [51].
4. It is recommended to link the assessment to the cognitive intervention, meaning that selecting the appropriate intervention according to the cognitive deficits. For example, if the trainee has only a phonological deficit, he should be provided with only one phonological WM task rather than mixed (visual and phonological) tasks. This could help to reduce the training time [50,52].
5. Finally, Nelwan and Kroesbergen [46] recommended that future research has to take into consideration the precise planning of the intervention program, the proper support of the children during their training periods, and probably a reward system encouraging the children to do their best during measurements.

3.6. Recommendations Targeting the Environment (Learning Materials)

1. The WM training tasks should be selected cautiously to be more interesting for children, and this could be helpful for children in enhancing the training effects [3].
2. The training program should incorporate an adaptive, gamified, and interactive design to effectively engage young participants. It should include visually appealing elements along with clear audio and visual task instructions, accompanied by demonstrations [55].

4. Discussion

This systematic review (SR) aims to identify the current computer-based WM training applications and their theoretical underpinning, exploring their effect on improving WM capacity and other cognitive/academic abilities, and extracting a set of design principles for designing an effective WM application for children with LDs.

The findings revealed four commercial WM training applications utilized in 16 of the 22 selected studies, namely COGMED (9 studies) Jungle (4 studies), BrainWare Safari (2 studies), and N-back (1 study). Additionally, four studies developed their own WM programs, while two studies incorporated specific tasks from existing applications.

Regarding the near transfer effect of these commercial/research-based programs on WM, the results generally showed an immediate positive effect in the WM training programs reviewed after the training. This shows that it is possible to train WM capacity through computerized training applications, which may lead to diminished problems facing children with LDs during their learning.

The results showed inconsistency in the immediate- and long-term transfer effects of commercial and research-based programs on various cognitive and academic performances, such as math, language, reading fluency and comprehension, spelling, writing, and fluid intelligence. Math was the most frequently measured ability, with 13 out of 18 studies evaluating it, but only 6 reported significant improvements [37,46–48,50,56]. For reading skills, four out of six studies found positive effects from working memory (WM) training [38,50,53,54]. Of the five studies on IQ, only two showed significant gains in fluid intelligence [3,48]. None of the six studies on language ability reported positive effects. In follow-up assessments, math remained the most commonly measured ability, with only three out of eight studies showing sustained improvements [3,40,56]. Similarly, two out of three studies found maintained effects on reading comprehension after 6 months [38,54], while none of the four studies showed lasting improvements in language performance.

Additionally, Peijnenborgh et al. [58] generally supports these findings, showing reliable short-term improvements in verbal working memory, visuospatial working memory, and word decoding in children with learning disabilities after training. These improvements were sustained over time for up to eight months. However, the study did not find consistent evidence for far transfer effects to other cognitive or academic skills. Also, Sala and Gobet [59] found that while there were positive near transfer effects on memory tasks, there was no significant evidence of far transfer to other cognitive or academic skills. However, the most recent meta-analysis study of Rodas et al. [60] found that improvements in working memory were often due to biases in measurement, and there was no significant evidence of far transfer to fluid intelligence. Therefore, to better understand how WM training improves WM capacity and academic performance in children, further studies should be conducted or even longitudinal studies over a couple of years.

This SR sought to identify key design principles for creating effective WM applications tailored to children with LDs. By analyzing the four identified commercial WM training programs, this study uncovered several shared features that contributed to their success such as providing the children with positive verbal feedback, points, and a display of the best scores to motivate them during the training. However, the WM tasks used in these programs are not based on more real-life-like situations, are not presented in a meaningful context, or did not intrinsically motivate the trainee during the training period.

Furthermore, four studies have created their own WM training programs and recommend that these programs incorporate a reward system—such as points, badges, or unlocking new levels—to enhance trainee engagement and further motivate and encourage children's progress.

Moreover, although none of these programs were designed based on suggested guidelines or design frameworks taking the needs and characteristics of the children with LDs into consideration, the selected studies mentioned some recommendations that can be categorized as recommendations targeting the WM tasks, the user, and the environment.

4.1. Suggestions for Design Guidelines

Based on this SR, some recommendations were identified but there was no definite set of designed guidelines. Therefore, the researchers reviewed the Human–Computer Interaction (e.g., usability and user experience) and some cognitive theories to derive more guidelines for covering how best to design the WM tasks and meeting the characteristics of those children of LDs, as shown in Table 3. The rationale behind choosing cognitive load theory and its frameworks is to extract some principles to develop less-demanding tasks that suit the limited WM capacity of children with LDs. Similarly, the rationale behind HCI concepts is to derive some principles to improve children's experience with the cognitive applications, and the rationale behind using the game elements is to motivate the children intrinsically.

Table 3. Shows the suggested guidelines and the reason behind proposing them.

Guideline	Reason for Suggestion
Guidelines for designing the learning environment (application interface design)	
Use consistent elements throughout the application (e.g., characters, colors, backgrounds, buttons, icons, etc.).	Aesthetically, to improve the user interface.
Minimize distracting elements (e.g., movement, scrolling, background music, the competition time) in the application.	"Individuals learn better when non-essential words, pictures, and sounds are excluded rather than included" [61]. Therefore, to minimize the distraction level during the training, background music should be avoided. Additionally, the competition time should be avoided as research such as [62] revealed that it increases the users' anxiety and thereby increases the cognitive load.
In case of providing help, the helper/guide should have a user-friendly tone and use affirmative language with familiar words.	"Individuals learn better when the narration is spoken in a human voice rather than a machine voice. The voice principle was supported in three out of three experiments, with a median effect size of d = 0.78" [63]

Table 3. *Cont.*

Guideline	Reason for Suggestion
Alert users to errors or possible errors, e.g., before the exit or cancel orders.	To improve the UX and dimmish the cognitive overload.
Use sufficient contrast between the text and background, and the text's font should be clear and readable (e.g., using sans-serif fonts such as Arial, Verdana, Helvetica, and Tahoma)	Research recommends using clear and readable fonts with individuals with LDs, such as sans-serif fonts [64].
Guidelines for designing the learning materials	
Presenting the working memory activities in the form of a meaningful story is recommended.	Presenting the application's content in a meaningful and amusing story to aid children to explore connections among the application activities [65]; thereby, they will be kept motivated during the training period.
The application's activities are short, simple, and have their own goals, and the difficulty level of each activity increases as the trainee progresses to higher levels.	Individuals learn better when a narrated animation is offered in segments according to the user's pace compared to a continuous unit [66]. Short activities could be used to diminish the imposed cognitive load level and keep children engaged and attentive during the training [24]. Points could be used to encourage children during the training because points represent their progress and can be considered immediate feedback and a reward. Since the level of difficulty increases as the trainee reaches the higher levels, this could keep the child excited and motivated to reach higher levels.
Minimize text input and rely on spoken (e.g., providing a narration option) and visual inputs (e.g., using a visual password).	"Individuals learned more deeply from pictures and spoken words than from pictures and printed words" [66]. Therefore, a narration option and a visual password could be used to enhance the UX and dimmish the cognitive overload.
Present a summarizing report regarding the trainee's achievement by the end of each activity and every session or set of activities.	Progress reports could be used to reward the child after each activity and at the end of each training session. This report could motivate the child to complete all activities to obtain the treasure. Badges could be used, as a reward, to represent the children's achievements and performance after each training session. Badges could be used along with points and levels to further motivate the children, particularly after each training session.
Highlight the most important elements, such as the options chosen by the users.	Individuals learn in a better way when adding cues to highlight the essential material [61]. Furthermore, the most important elements should be highlighted to be more obvious and accessible for children, improving the UX.
Proposed user guidelines	
Allow the user to be in control of the application via support elements, self-paced progression, navigation.	To improve the UX and dimmish the cognitive overload.
Provide the users with help (either auditory or visual) whenever they need it throughout the application.	Individuals learn better from a multimedia message when they realize the information and features of the key components before the study begins [66] A virtual assistant is used to help the child throughout the application (game element).
The application should be intrinsically motivating, such as being in the form of a contest between the child and a virtual competitor.	Internal competition promotes intrinsic motivation to keep children motivated during the training [30], while extrinsic motivator's effect appeared to fade over time [24]. Therefore, external competition with other children could be avoided, and instead, internal competition (virtual competitor) employed to minimize the anxiety imposed by competition with others, thereby decreasing cognitive load.

4.1.1. Cognitive Load Theory

Cognitive load theory explains how the information processing load caused by learning tasks can affect an individuals' ability to process novel information and to construct schema in long-term memory [67]. It is based on the fact that human cognitive processing is heavily restricted by the limited working memory capacity. It differentiates between three kinds of cognitive processing demands that occur in WM during learning [68]: extraneous cognitive load, which deals with the design material; intrinsic cognitive load, which is influenced by the complexity of the presented material; and Germane cognitive load, which is desirable as it is required to understand the material [67].

4.1.2. Human–Computer Interaction Concepts: Usability and User Experience (UX)

The Human–Computer Interaction (HCI) seeks to understand and support human beings interacting with and through technology to build interfaces that are accessible, easy to use, and efficient. A successful user interface must respect the limits of human cognitive processing [69] and attempts to diminish the cognitive overload to improve usability. As a result, it can also free up mental resources that could be directed to maximize the understanding of the educational content—especially for individuals with a deficiency in WM capacity [68].

Usability heuristics were originally proposed to ensure that the user interface of a system is easy to use and functional [70]. Jackob Nielsen produced the most common 10 heuristics for designing a usable user interface [71]: visibility of system status; the match between the system and the real world; user control and freedom; consistency and standards; error prevention; recognition rather than recall; flexibility and efficiency of use; aesthetic and minimalist design; helping users recognize, diagnose, and recover from errors; and help and documentation. Therefore, a set of principles (e.g., consistency, aesthetic and minimalist design, help and error messages, and user control and freedom) were chosen to decrease the extraneous cognitive load by excluding non-essential material, making the application's user interface easy to use and attractive.

As is shown in Table 3, some beneficial guidelines targeting the WM tasks were extracted, such as presenting all of the WM tasks in a meaningful story to keep the user motivated and engaged in the training. In addition, these guidelines also focused on the user. For example, the application should be intrinsically motivating, such as a contest between the child and a virtual competitor. Furthermore, the guidelines targeting how to design the material were helpful as it was recommended to keep consistency between the used elements (e.g., characters, colors, backgrounds, buttons, icons, etc.), and to minimize the distracting elements as much as possible to suit the limited WM capacity of those children with LDs.

4.2. The Final Set of the Suggested Guidelines

By merging the recommendations extracted from the 22 included studies from this SR and the guidelines derived from the UX and cognitive load theories in Table 3, a final set of guidelines (see Table 4) was developed to cover the WM tasks, the user, and the environment.

4.3. Limitations

The results of this SR regarding the effectiveness of the identified WM programs should be treated with caution because this SR does not include a meta-analysis to estimate the precise effect size of these WM training programs on children.

The SR excluded children with ADHD because not all children with ADHD have LDs; only around 20% of those children have a cognitive deficit [58,72]; therefore, only one-fifth of those children will benefit from such cognitive applications. ADHD can be treated using medicine or cognitive therapy. And finally, children with ADHD often have a problem with timing and/or motivation.

Table 4. The proposed guidelines for designing the training application.

Guidelines for Designing the Learning Environment (Application Interface Design)
1. Use consistent elements throughout the application (e.g., characters, colors, backgrounds, buttons, icons, etc.).
2. Minimize distracting elements (e.g., movement, scrolling, background music, the competition time) in the application.
3. In case of providing help, ensure the helper/guide has a user-friendly tone and use affirmative language with familiar words.
4. Alert users to errors or possible errors (e.g., before the exit or cancel orders).
5. Use sufficient contrast between the text and background, and the text's font should be clear and readable (e.g., using sans-serif fonts such as Arial, Verdana, Helvetica, and Tahoma)
Guidelines for designing the learning materials
1. Present the working memory activities in the form of a meaningful story.
2. Use a range of activities to train different components of WM, (e.g., verbal, visual, and central executive activities).
3. The application's activities should be short, simple, and have their own goals, and the difficulty level of each activity should increase as the trainee progresses to higher levels.
4. Minimize text input and rely on spoken (e.g., providing a narration option) and visual inputs (e.g., using a visual password).
5. Present a summarizing report regarding the trainee's achievement by the end of each activity and every session or set of activities.
6. Highlight the most important elements, such as the options chosen by the users.
Proposed user guidelines
1. Allow the user to be in control of the application via support elements, self-paced progression, and navigation.
2. Ensure that the application provides constructive feedback (positive in tone and short) on a user's actions for correct and incorrect answers.
3. Provide the users with help (either auditory or visual) whenever they need it throughout the application.
4. Ensure that the application is intrinsically motivating, such as being in the form of a contest between the child and a virtual competitor.

5. Conclusions

This study provides a collection of strong evidence that children with LDs have a low WM capacity, and WM functions can be trained. The improved WM can support children in gaining a set of academic abilities (e.g., reading comprehension). The findings revealed four commercial WM training applications—COGMED, Jungle, BrainWare Safari, and N-back—utilized in 16 of the 22 selected studies. Additionally, four studies developed their own WM programs, while two studies incorporated specific tasks from existing applications. The focus of the selected studies was suggesting different types of WM tasks and examining their effect rather than offering those tasks in a user-friendly way or suggesting practical guidelines targeting the end user. Those selected studies mentioned some recommendations that can be categorized as recommendations targeting the WM tasks, the user, and the environment. In addition to the previously mentioned recommendations, the researchers conducted a review of the Human–Computer Interaction principles, specifically focusing on usability and the user experience, as well as relevant cognitive theories. This review aimed to establish additional guidelines for effectively designing working memory tasks that cater to the needs of children with learning difficulties. A total of 15 proposed guidelines were identified, which are especially useful for designers and educators developing interventions for children with learning difficulties (LDs). These guidelines can be employed to create working memory training programs tailored for children with LDs. They align with educational science themes and support the advancement of practical and effective educational interventions.

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References

1. Swanson, H.L.; Sáez, L. Memory Difficulties in Children and Adults with Learning Disabilities. In *Handbook of Learning Disabilities*; The Guilford Press: New York, NY, USA, 2003; pp. 182–198.
2. Mencap Learning Difficulties. Available online: https://www.mencap.org.uk/learning-disability-explained/learning-difficulties (accessed on 17 January 2021).
3. Chen, X.; Ye, M.; Chang, L.; Chen, W.; Zhou, R. Effect of Working Memory Updating Training on Retrieving Symptoms of Children With Learning Disabilities. *J. Learn. Disabil.* **2017**, *51*, 507–519. [CrossRef]
4. Peng, P.; Fuchs, D. A Meta-Analysis of Working Memory Deficits in Children with Learning Difficulties: Is There a Difference Between Verbal Domain and Numerical Domain? *J. Learn. Disabil.* **2016**, *49*, 3–20. [CrossRef] [PubMed]
5. Zhang, H.; Chang, L.; Chen, X.; Ma, L.; Zhou, R. Working Memory Updating Training Improves Mathematics Performance in Middle School Students with Learning Difficulties. *Front. Hum. Neurosci.* **2018**, *12*, 154. [CrossRef] [PubMed]
6. Dehn, M.J. *Working Memory and Academic Learning: Assessment and Intervention*; John Wiley & Sons: Hoboken, NJ, USA, 2008.
7. Gathercole, S.E.; Alloway, T.P.; Willis, C.; Adams, A.-M. Working Memory in Children with Reading Disabilities. *J. Exp. Child Psychol.* **2006**, *93*, 265–281. [CrossRef]
8. Cowan, N.; Alloway, T. The Development of Working Memory in Childhood. In *The Development of Memory in Infancy and Childhood*; Psychology Press: East Sussex, UK, 2008; pp. 303–342.
9. Swanson, H.L.; Alloway, T.P. Working Memory, Learning, and Academic Achievement. In *APA educational Psychology Handbook, Vol 1: Theories, Constructs, and Critical Issues*; American Psychological Association: Washington, DC, USA, 2012; pp. 327–366, ISBN 978-1-4338-0997-2.
10. Baddeley, A. The Episodic Buffer: A New Component of Working Memory? *Trends Cogn. Sci.* **2000**, *4*, 417–423. [CrossRef] [PubMed]
11. Gupta, P.K.; Sharma, D.V. Working Memory and Learning Disabilities: A Review. *Int. J. Indian Psychol.* **2017**, *4*, 111–121. [CrossRef]
12. Klingberg, T.; Fernell, E.; Olesen, P.J.; Johnson, M.; Gustafsson, P.; Dahlström, K.; Gillberg, C.G.; Forssberg, H.; Westerberg, H. Computerized Training of Working Memory in Children With ADHD-A Randomized, Controlled Trial. *J. Am. Acad. Child Adolesc. Psychiatry* **2005**, *44*, 177–186. [CrossRef]
13. Mahncke, H.W.; Connor, B.B.; Appelman, J.; Ahsanuddin, O.N.; Hardy, J.L.; Wood, R.A.; Joyce, N.M.; Boniske, T.; Atkins, S.M.; Merzenich, M.M. Memory Enhancement in Healthy Older Adults Using a Brain Plasticity-Based Training Program: A Randomized, Controlled Study. *Proc. Natl. Acad. Sci. USA.* **2006**, *103*, 12523–12528. [CrossRef] [PubMed]
14. Wong, A.S.; He, M.Y.; Chan, R.W. Effectiveness of Computerized Working Memory Training Program in Chinese Community Settings for Children with Poor Working Memory. *J. Atten. Disord.* **2014**, *18*, 318–330. [CrossRef] [PubMed]
15. Zisimopoulos, D.A.; Galanaki, E.P. Academic Intrinsic Motivation and Perceived Academic Competence in Greek Elementary Students with and without Learning Disabilities. *Learn. Disabil. Res. Pract.* **2009**, *24*, 33–43. [CrossRef]
16. Saputra, M.R.U. LexiPal: Design, Implementation and Evaluation of Gamification on Learning Application for Dyslexia. *Int. J. Comput. Appl.* **2015**, *131*, 37–43.
17. Melby-Lervåg, M.; Hulme, C. Is Working Memory Training Effective? A Meta-Analytic Review. *Dev. Psychol.* **2013**, *49*, 270–291. [CrossRef] [PubMed]
18. MacCormack, J.; Matheson, I. Understanding Working Memory and Learning Disabilities. *LD@school*. 2015. Available online: https://www.ldatschool.ca/understanding-working-memory-and-lds/ (accessed on 30 August 2024).
19. Cooper, G. Research into Cognitive Load Theory and Instructional Design at UNSW. *Univ. New South Wales Aust.* **1998**. Available online: https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=bc89064e3b0478b2a504e9a317b77797c3dc2207 (accessed on 30 August 2024).
20. Ottersen, J.; Grill, K.M. Benefits of Extending and Adjusting the Level of Difficulty on Computerized Cognitive Training for Children with Intellectual Disabilities. *Front. Psychol.* **2015**, *6*, 1233. [CrossRef] [PubMed]
21. Owen, A.M.; Hampshire, A.; Grahn, J.A.; Stenton, R.; Dajani, S.; Burns, A.S.; Howard, R.J.; Ballard, C.G. Putting Brain Training to the Test. *Nature* **2010**, *465*, 775–778. [CrossRef]

22. Hulme, C.; Melby-Lervåg, M. Current Evidence Does Not Support the Claims Made for CogMed Working Memory Training. *J. Appl. Res. Mem. Cogn.* **2012**, *1*, 197–200. [CrossRef]
23. Shipstead, Z.; Hicks, K.L.; Engle, R.W. Cogmed Working Memory Training: Does the Evidence Support the Claims? *J. Appl. Res. Mem. Cogn.* **2012**, *1*, 185–193. [CrossRef]
24. Boendermaker, W.J.; Gladwin, T.E.; Peeters, M.; Prins, P.J.M.; Wiers, R.W. Training Working Memory in Adolescents Using Serious Game Elements: Pilot Randomized Controlled Trial. *JMIR Serious Games* **2018**, *6*, e10. [CrossRef]
25. Marcelle, E.T.; Ho, E.J.; Kaplan, M.S.; Adler, L.A.; Castellanos, F.X.; Milham, M.P. Cogmed Working Memory Training Presents Unique Implementation Challenges in Adults With ADHD. *Front. Psychiatry* **2018**, *9*, 388. [CrossRef]
26. Lumsden, J.; Edwards, E.A.; Lawrence, N.S.; Coyle, D.; Munafò, M.R. Gamification of Cognitive Assessment and Cognitive Training: A Systematic Review of Applications and Efficacy. *JMIR Serious Games* **2016**, *4*, e11. [CrossRef]
27. Dichev, C.; Dicheva, D. Gamifying Education: What Is Known, What Is Believed and What Remains Uncertain: A Critical Review. *Int. J. Educ. Technol. High. Educ.* **2017**, *14*, 9. [CrossRef]
28. Katz, B.; Jaeggi, S.; Buschkuehl, M.; Stegman, A.; Shah, P. Differential Effect of Motivational Features on Training Improvements in School-Based Cognitive Training. *Front. Hum. Neurosci.* **2014**, *8*, 242. [CrossRef] [PubMed]
29. Nebel, S.; Schneider, S.; Rey, G.D. From Duels to Classroom Competition: Social Competition and Learning in Educational Videogames within Different Group Sizes. *Comput. Hum. Behav.* **2016**, *55*, 384–398. [CrossRef]
30. Turan, Z.; Avinc, Z.; Kara, K.; Goktas, Y. Gamification and Education: Achievements, Cognitive Loads, and Views of Students. *Int. J. Emerg. Technol. Learn. IJET* **2016**, *11*, 64–69. [CrossRef]
31. Lepper, M.R.; Corpus, J.H.; Iyengar, S.S. Intrinsic and Extrinsic Motivational Orientations in the Classroom: Age Differences and Academic Correlates. *J. Educ. Psychol.* **2005**, *97*, 184–196. [CrossRef]
32. Page, M.J.; McKenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Akl, E.A.; Brennan, S.E.; et al. The PRISMA 2020 Statement: An Updated Guideline for Reporting Systematic Reviews. *BMJ* **2021**, *372*, n71. [CrossRef]
33. Randall, L.; Tyldesley, K. Evaluating the Impact of Working Memory Training Programmes on Children—A Systematic Review. *Educ. Child Psychol.* **2016**, *33*, 34–50. [CrossRef]
34. Rossignoli-Palomeque, T.; Perez-Hernandez, E.; González-Marqués, J. Brain Training in Children and Adolescents: Is It Scientifically Valid? *Front. Psychol.* **2018**, *9*, 565. [CrossRef]
35. Aksayli, N.D.; Sala, G.; Gobet, F. The Cognitive and Academic Benefits of Cogmed: A Meta-Analysis. *Educ. Res. Rev.* **2019**, *27*, 229–243. [CrossRef]
36. Connolly, T.M.; Boyle, E.A.; MacArthur, E.; Hainey, T.; Boyle, J.M. A Systematic Literature Review of Empirical Evidence on Computer Games and Serious Games. *Comput. Educ.* **2012**, *59*, 661–686. [CrossRef]
37. Bergman-Nutley, S.; Klingberg, T. Effect of Working Memory Training on Working Memory, Arithmetic and Following Instructions. *Psychol. Res.* **2014**, *78*, 869–877. [CrossRef] [PubMed]
38. Dahlin, K.I.E. Effects of Working Memory Training on Reading in Children with Special Needs. *Read. Writ.* **2011**, *24*, 479–491. [CrossRef]
39. Dunning, D.L.; Holmes, J.; Gathercole, S.E. Does Working Memory Training Lead to Generalized Improvements in Children with Low Working Memory? A Randomized Controlled Trial. *Dev. Sci.* **2013**, *16*, 915–925. [CrossRef] [PubMed]
40. Holmes, J.; Gathercole, S.E.; Dunning, D.L. Adaptive Training Leads to Sustained Enhancement of Poor Working Memory in Children. *Dev. Sci.* **2009**, *12*, F9–F15. [CrossRef] [PubMed]
41. Holmes, J.; Butterfield, S.; Cormack, F.; van Loenhoud, A.; Ruggero, L.; Kashikar, L.; Gathercole, S. Improving Working Memory in Children with Low Language Abilities. *Front. Psychol.* **2015**, *6*, 519. [CrossRef]
42. McKenzie, G.A. *Intensive and Systematic Training in Working Memory: Does It Have Validity for Improving Reading Achievement?* Indiana University of Pennsylvania: Indiana, PA, USA, 2016.
43. Partanen, P.; Jansson, B.; Lisspers, J.; Sundin, Ö. Metacognitive Strategy Training Adds to the Effects of Working Memory Training in Children with Special Educational Needs. *Int. J. Psychol. Stud.* **2015**, *7*, p130. [CrossRef]
44. Roberts, G.; Quach, J.; Spencer-Smith, M.; Anderson, P.J.; Gathercole, S.; Gold, L.; Sia, K.-L.; Mensah, F.; Rickards, F.; Ainley, J.; et al. Academic Outcomes 2 Years After Working Memory Training for Children With Low Working Memory: A Randomized Clinical Trial. *JAMA Pediatr.* **2016**, *170*, e154568. [CrossRef]
45. Ang, S.Y.; Lee, K.; Cheam, F.; Poon, K.; Koh, J. Updating and Working Memory Training: Immediate Improvement, Long-Term Maintenance, and Generalisability to Non-Trained Tasks. *J. Appl. Res. Mem. Cogn.* **2015**, *4*, 121–128. [CrossRef]
46. Nelwan, M.; Kroesbergen, E.H. Limited Near and Far Transfer Effects of Jungle Memory Working Memory Training on Learning Mathematics in Children with Attentional and Mathematical Difficulties. *Front. Psychol.* **2016**, *7*, 1384. [CrossRef]
47. Nelwan, M.; Vissers, C.; Kroesbergen, E.H. Coaching Positively Influences the Effects of Working Memory Training on Visual Working Memory as Well as Mathematical Ability. *Neuropsychologia* **2018**, *113*, 140–149. [CrossRef]
48. Alloway, T.; Alloway, R. The Efficacy of Working Memory Training in Improving Crystallized Intelligence. *Nat. Preced.* **2009**. Available online: https://www.nature.com/articles/npre.2009.3697.1 (accessed on 30 August 2024).
49. Alloway, T.P.; Bibile, V.; Lau, G. Computerized Working Memory Training: Can It Lead to Gains in Cognitive Skills in Students? *Comput. Hum. Behav.* **2013**, *29*, 632–638. [CrossRef]

50. Avtzon, S.A. Effect of Neuroscience-Based Cognitive Skill Training on Growth of Cognitive Deficits Associated with Learning Disabilities in Children Grades 2-4. *Learn. Disabil. Multidiscip. J.* **2012**, *18*, 111–122.
51. Shokoohi-Yekta, M.; Lotfi, S.; Rostami, R.; Motamed-Yegane, N.; Khodabande-Lou, Y.; Habibnezhad, M. Brain Training by BrainWare® Safari: The Transfer Effects on the Visual Spatial Working Memory of Students with Reading Problems. *AWERProcedia Inf. Technol. Comput. Sci.* **2013**, *4*, 1046–1052.
52. Yang, J.; Peng, J.; Zhang, D.; Zheng, L.; Mo, L. Specific Effects of Working Memory Training on the Reading Skills of Chinese Children with Developmental Dyslexia. *PLoS ONE* **2017**, *12*, e0186114. [CrossRef] [PubMed]
53. Luo, Y.; Wang, J.; Wu, H.; Zhu, D.; Zhang, Y. Working-Memory Training Improves Developmental Dyslexia in Chinese Children. *Neural Regen. Res.* **2013**, *8*, 452–460. [CrossRef]
54. Ramezani, M.; Behzadipour, S.; Pourghayoomi, E.; Joghataei, M.T.; Shirazi, E.; Fawcett, A.J. Evaluating a New Verbal Working Memory-Balance Program: A Double-Blind, Randomized Controlled Trial Study on Iranian Children with Dyslexia. *BMC Neurosci.* **2021**, *22*, 55. [CrossRef]
55. Maehler, C.; Joerns, C.; Schuchardt, K. Training Working Memory of Children with and without Dyslexia. *Children* **2019**, *6*, 47. [CrossRef]
56. Muñez, D.; Lee, K.; Bull, R.; Khng, K.H.; Cheam, F.; Rahim, R.A. Working Memory and Numeracy Training for Children with Math Learning Difficulties: Evidence from a Large-Scale Implementation in the Classroom. *J. Educ. Psychol.* **2022**, *114*, 1866–1880. [CrossRef]
57. Beaumont, J. Chapter 27—Clinical Neuropsychology in Rehabilitation. In *Physical Management in Neurological Rehabilitation (Second Edition)*; Stokes, M., Ed.; Mosby: Oxford, UK, 2004; pp. 461–468, ISBN 978-0-7234-3285-2.
58. Peijnenborgh, J.C.A.W.; Hurks, P.M.; Aldenkamp, A.P.; Vles, J.S.H.; Hendriksen, J.G.M. Efficacy of Working Memory Training in Children and Adolescents with Learning Disabilities: A Review Study and Meta-Analysis. *Neuropsychol. Rehabil.* **2016**, *26*, 645–672. [CrossRef]
59. Sala, G.; Gobet, F. Working Memory Training in Typically Developing Children: A Meta-Analysis of the Available Evidence. *Dev. Psychol.* **2017**, *53*, 671–685. [CrossRef]
60. Rodas, J.A.; Asimakopoulou, A.A.; Greene, C.M. Can We Enhance Working Memory? Bias and Effectiveness in Cognitive Training Studies. *Psychon. Bull. Rev.* **2024**, *31*, 1891–1914. [CrossRef] [PubMed]
61. Mayer, R.E.; Fiorella, L. Principles for Reducing Extraneous Processing in Multimedia Learning: Coherence, Signaling, Redundancy, Spatial Contiguity, and Temporal Contiguity Principles. In *The Cambridge Handbook of Multimedia Learning*; Mayer, R.E., Ed.; Cambridge Handbooks in Psychology; Cambridge University Press: Cambridge, UK, 2014; pp. 279–315, ISBN 978-1-107-61031-6.
62. Hwang, M.-Y.; Hong, J.-C.; Cheng, H.-Y.; Peng, Y.-C.; Wu, N.-C. Gender Differences in Cognitive Load and Competition Anxiety Affect 6th Grade Students' Attitude toward Playing and Intention to Play at a Sequential or Synchronous Game. *Comput. Educ.* **2013**, *60*, 254–263. [CrossRef]
63. Mayer, R.E. Personalization, Voice, and Image Principles. In *Multimedia Learning*; Cambridge University Press: Cambridge, UK, 2009; pp. 242–262, ISBN 978-0-511-81167-8.
64. Friedman, M.G.; Bryen, D.N. Web Accessibility Design Recommendations for People with Cognitive Disabilities. *Technol. Disabil.* **2007**, *19*, 205–212. [CrossRef]
65. Nicholson, S. Two Paths to Motivation through Game Design Elements: Reward-Based Gamification and Meaningful Gamification—Google Search. In Proceedings of the iConference 2013 Proceedings, Denton, TX, USA, 12–15 February 2013; pp. 671–672.
66. Mayer, R.E.; Pilegard, C. Principles for Managing Essential Processing in Multimedia Learning: Segmenting, Pre-Training, and Modality Principles. In *The Cambridge Handbook of Multimedia Learning*; Mayer, R.E., Ed.; Cambridge Handbooks in Psychology; Cambridge University Press: Cambridge, UK, 2014; pp. 316–344, ISBN 978-1-107-61031-6.
67. Sweller, J.; van Merriënboer, J.J.G.; Paas, F. Cognitive Architecture and Instructional Design: 20 Years Later. *Educ. Psychol. Rev.* **2019**, *31*, 261–292. [CrossRef]
68. Hollender, N.; Hofmann, C.; Deneke, M.; Schmitz, B. Integrating Cognitive Load Theory and Concepts of Human–Computer Interaction. *Comput. Hum. Behav.* **2010**, *26*, 1278–1288. [CrossRef]
69. Janet, P.T.; Albers, J. *Measuring Cognitive Load to Test the Usability of Websites*; University of Memphis: Memphis, TN, USA, 2007.
70. Hermawati, S.; Lawson, G. Establishing Usability Heuristics for Heuristics Evaluation in a Specific Domain: Is There a Consensus? *Appl. Ergon.* **2016**, *56*, 34–51. [CrossRef]
71. Nielsen, J. 10 Heuristics for User Interface Design: Article by Jakob Nielsen. Available online: https://www.nngroup.com/articles/ten-usability-heuristics/ (accessed on 31 August 2019).
72. Sonuga-Barke, E.; Bitsakou, P.; Thompson, M. Beyond the Dual Pathway Model: Evidence for the Dissociation of Timing, Inhibitory, and Delay-Related Impairments in Attention-Deficit/Hyperactivity Disorder. *J. Am. Acad. Child Adolesc. Psychiatry* **2010**, *49*, 345–355. [CrossRef]