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ORIGINAL RESEARCH

A Game-Based Cognitive Intervention for Young Learners with Reading Difficulties

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Abstract

The study's primary contribution is a game-based cognitive intervention tool for young learners with reading difficulties. The second contribution is the game designer's guide tool, which provides a set of recommended design guidelines for designers, developers and researchers that create games for children. The tools were designed and developed in the ReaDi-STANCE project and are accessible on the project's platform (ReaDi-STANCE platform home page: https://www.cs.ucy.ac.cy/projects/readistance/). The platform has the following main modules integrated: a management support module, an algorithm module to rotate in a predefined order the games the child end-user plays, a prompting stages module to support the child end-user during gameplay, and a data analytics module that researchers can use. Two different groups of experts conducted two evaluations to evaluate: (1) a corpus of game design themes and guidelines for children, extracted from the respective literature, to develop the game designer's guide tool and (2) the extent of application of the design above guidelines in the game-based cognitive intervention tool. We present the intervention impact results and discuss their effect on improving reading skills in poor readers.

Keywords Child end-user · Digital tools F · Computer-assisted reading intervention · Game-based assessment · Early reading · PREP Cognitive Intervention

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Introduction

Early intervention is crucial to the prevention of reading difficulties. Two-thirds of poor readers can learn to read at age-expected levels with the appropriate early intervention [30]. Also, it is known that severe reading difficulties diagnosed after age eight are refractory to treatment [11]. The present study examined the contribution of computer-assisted reading intervention using game-based assessment. It focused on designing and testing the efficacy of an established intervention program with a cognitive focus, namely the PASS Reading Enhancement Program [23], as an online intervention for young learners with reading difficulties.

As general education classrooms become heterogeneous [9], both special and general education teachers and school psychologists need to have instructional techniques designed to meet their students' individual needs at their disposal. Consequently, education and psychology professionals need to be given guidelines that deliberately state what they should be doing to maximize learning outcomes for all students [14]. Without a consensus on appropriate remedial practices for treating reading difficulties that will be theory-driven and cost-effective, it is vital to design and test intervention programs in controlled experiments. We can attain this objective systematically for children at risk for or experiencing reading difficulties with the contribution of computer science. To achieve this, service providers need to learn to recognize that factors such as the type and severity of reading disabilities, the cognitive characteristics of the reader and the interaction between cognitive attributes and features of remediation may be necessary for predicting the effectiveness of remedial programs [25]. Second, available technology-based interventions need to be well-structured and flexible enough to support young readers in diverse settings. Indeed, a synthesis of relevant evidence suggests that computers have a positive, albeit small, effect ($d = 0.14$) in supporting struggling readers [4]. Nevertheless, digital interventions are more effective than conventional instruction methods, particularly in learning outcomes ($p < 0.05$) [4].

A cognitively focused intervention can meet such requirements. It starts from the premise that each child has enormous learning potential, only some of which is usually exploited in regular classroom instruction [7]. Thus, cognitively focused remediation could help the individual compensate for the experienced difficulties and remediate the observed weaknesses based on existing strengths [25]. Indeed, a recent review of research on cognitively focused instruction suggests that instruction designed for children with a particular cognitive deficit promotes more significant academic improvement than academically focused instruction alone [14].

In this paper, we present the digital tools hosted on the ReaDi-STANCE platform: (i) the Game-Based Cognitive Intervention (GBCI) Tool for young learners with reading difficulties and (ii) the Game Designer's Guide (GDG) Tool for game designers, developers, and researchers, enabling them to create games that are age-appropriate, educational, and friendly to child end-users. We report on our findings from internal and external expert reviews conducted with twelve experts to evaluate the digital tools. A technical description of the ReaDi-STANCE platform, architecture, and respective modules are presented. The paper is structured into six sections. After an Introduction in Section "Introduction", Section "Related Work" covers the Related Work, providing an overview of existing research in the field. Section "Methodology" outlines the methodology employed in the study, while Section "Readi-Stance Platform" introduces the ReaDi-STANCE platform and its digital tools. In Section "Results", the results obtained from expert reviews are presented and analyzed. Finally, Section "Conclusion/Future Work" concludes the paper and discusses potential avenues for future research.

Related Work

PREP

Remediation is what happens after instruction has failed. For example, reading intervention programs promote reading and spelling in children with reading difficulties by tackling critical precursor linguistic or cognitive skills [29]. Factors such as the type and severity of reading difficulties, the learner's cognitive and linguistic characteristics, and the interaction between aptitude and remediation features may be necessary for predicting the effectiveness of remedial programs [24]. Remediation is also typically given to small groups [3] or on an intensive one-to-one basis [10] depending on either student's ability level, intervention type or grade [31]. Furthermore, intensive reading interventions typically comprise increasingly difficult tasks [22].

Reviews on the efficacy of PREP can be found in several recent papers, e.g., [6, 14, 15, 21, 25]. Generally, PREP has produced positive results in terms of cognitive performance and reading ability in both non-transparent, e.g., [3, 8, 23, 26] and transparent orthographies, e.g., [22, 24]; with children at risk for reading difficulties in Kindergarten, e.g., [22], poor readers in Grades 1 and 2, e.g., [23, 25, 26], Grades 3 and 4, e.g., [6, 8] or Grades 5 and 6 [1]; with First-Nations children in Canada, e.g., [6, 12] or poor readers learning English as a second language [15]; in small groups [2, 3, 23] or on an intensive one-to-one basis [22, 24]; in comparison with other experimental groups receiving different treatment programs, such as phonics-based, e.g.,

[6, 25], meaning-based [23] or neuropsychologically-based programs [24]; and with designs including a follow-up component allowing examination of the long-term efficacy of PREP [22, 25]. This evidence shows a remedy for reading difficulties, particularly when the cognitive and linguistic processes lacking in learning to read are identified; then, the remedial benefits can be maximized. An aptitude-treatment interaction requires identifying the right aptitudes, which explain poor performance and are malleable.

Advances in computer-assisted intervention offer innovative support in reading acquisition and treating reading difficulties. Computer-based training to aid reading instruction has been primarily explored as an individual-oriented method, usually delivered intensively [32, 33]. It has been acknowledged as a more potent instrument in training the literacy skills of children with reading difficulties than paper-and-pencil remedial reading intervention methods [13], particularly when formal literacy begins, e.g., [30]. Its advantage over traditional reading remediation programs lies in the instantaneously flexible learning environment that promotes active and individual-oriented reading support. Computer speech prompts, user-friendly graphics, animation, and direct visual and audio feedback for correct and incorrect responses have developed highly motivating applications for young readers [29].

Computer-based reading training research indicates that an intervention program's efficacy is primarily determined by its structure and the skills it addresses [5]. Equally important, however, is the ease with which the user can run the program, interact with the learning material in a user-friendly environment, and maintain a high interest in learning and motivation, e.g., [27, 28]. The present study aimed to test the suitability of the PREP intervention as an online cognitive training program for reading difficulties while meeting all the requirements. The program encourages participants to engage in a series of game-like activities that help to improve their cognitive and reading-related abilities.

Game Design Guidelines for Child End-Users

"Child–computer interaction (CCI) is the branch within human–computer interaction (HCI) that studies the design, implementation and use of interactive computer systems for children" [36]. Research in this area is heavily driven by the interest in technology use in schools, mainly for educational and communication purposes. "Child friendly" UIs is an essential goal when designing, ensuring that interactions provide child end-users with a natural feel of control. Design requirements need to be even more relevant when the UIs focus on children with special needs.

Child end-users are unique in several ways [35]: Their goals while using computers are typically education or entertainment rather than productivity; they have a wide range of skills and abilities; and their experience with computers begins early and continues throughout their lives. Importantly, they are not miniature adult end-users; design principles formulated with adult end-users in mind cannot simply be scaled down. Child end-users have their own needs and goals, which cannot necessarily be addressed by tools designed for adult end-users.

Design principles recognize different levels of cognitive development through literacy levels and task guidance and are tailored to varying stages of cognitive development and imagination. Physical development is reflected in the types of input techniques that can be used and in the use of tangible UIs. Support for different emotional and social development is seen in the various opportunities to form relationships with others and the computer. Cognitive, physical, emotional, and social development design principles are founded on HCI, education, and psychology research. Regarding physical development, design principles focus on literacy, feedback and guidance, cognitive development, and imagination. For physical development, motor skills and tangibility are needed. For emotional and social development, motivation and engagement (UX), social interaction and collaboration [35] are required.

The high expectations of child end-users are presented in [34]. Since child end-users consume more time with devices than several years ago, they have more opportunities to understand how things can and should function online. Their expectations include tapping on and interacting with characters and pictures on UIs on touchscreens and desktop displays. In a touchscreen experiment, it was observed that several children tried tapping a non-touchscreen laptop. Another expectation observed is for websites to play sound or have animation. One pair of 8-year-old girls spent several minutes trying to get a page to play sound and animate so they could enjoy a game more.

Despite these higher expectations of interactivity, child end-users did not feel the same disappointment that adult end-users experienced when an app or site did not function as expected [34]. Although they did feel frustrated when designs were not as fast as they liked, they were also more accustomed to many games simply not working. They tend to shrug it off as a bug or something beyond their control, thus dealing better with this adverse UX than the adult end-user. Table 1 compares expectations for child and adult end-users on different aspects, which were used for the definition of the GDG tool and thereafter applied where applicable in the design of the "Games" module of the GBCI tool. Note that the GDG tool developed provides guidelines for all child end-users.

Table 1 Comparison of child and adult end-users [34]

Level of difference	Aspect compared	Child end-user	Adult end-user
Same	Following UI conventions	Preferred	Preferred
Same	User control	Preferred	Preferred
Same	First reactions	Quick to judge site (and to leave if no good)	Quick to judge site (and to leave if no good)
Same	Willingness to wait	Want instant gratification	Limited patience
Small Difference	Multiple/redundant navigations	Very confusing	Slightly confusing
Small Difference	*Back* button	Used in apps and websites when prominent, but browser *back* button not used (for young child end-user) Relied on (for older child end-user)	Relied on
Small Difference	Reading	Not at all (for youngest child end-user) Tentative (for young child end-user) Scanning (for older child end-user)	Scanning
Small Difference	Readability level	Each child end-user's grade level	8th to 10th grade text for broad consumer audiences
Small Difference	Font size	14 points (young child end-user) 12 points (older child end-user)	12 points (up to 14 points for senior end-user)
Small Difference	Scrolling	Avoid (for young child end-user) Some (for older child end-user)	Some
Small Difference	Standard gestures on touch-screens (tap, swipe, drag)	Large, simple actions (young child end-user) Easy and well-liked (older child end-user)	Easy and well-liked
Small Difference	Search	More extensive reliance on bookmarks than search, but older child end-users do search	Main entry point to the Web
Big Difference	Goal in visiting websites	Entertainment	Getting things done Communication/community
Big Difference	Exploratory behaviour	Like to try many options Mine-sweeping the screen	Stick to the main path
Big Difference	Real-life metaphors e.g., spatial navigation	Very helpful for pre-readers	Often distracting or too clunky for online UI
Big Difference	Physical limitations	Slow typists Poor mouse control	None (unless they have disabilities)
Big Difference	Animation and sound	Liked	Usually disliked
Big Difference	Advertising and promotions	Cannot distinguish from real content	Ads avoided (banner blindness); promos viewed skeptically
Big Difference	Disclosing private info	Usually aware of issues: hesitant to enter info	Often recklessly willing to give out personal info
Big Difference	Age-targeted design	Crucial, with very fine-grained distinctions between age groups	Unimportant for most sites (except to accommodate senior end-users)

Comparison of Related Applications

Section "PREP" pointed out that the efficacy of an intervention program is dependent on the ease in which the user can run the program, interact with the learning material in a user-friendly environment, and maintain a high interest in learning and motivation, e.g., [27, 28]. Having this in mind, the idea of the ReaDi-STANCE platform was born and considered as ideal to test the suitability of the PREP intervention as an online cognitive training program for reading difficulties, encouraging participants to engage in a series of game-like activities that help improve their cognitive and reading-related abilities.

Table 2 compares the most recent and relevant applications to the ReaDi-STANCE platform. The applications were selected via literature review and analysis of their features. Analyzing the design and technical characteristics of similar applications helped to explore the current intersection between theory-driven reading intervention programs and computer-assisted remediation for children at risk for or experiencing reading difficulties. Additionally, it helped the design and development team of the ReaDi-STANCE platform to recognise, contrast, discover, connect, and value the application of game design guidelines for child end-users with reading difficulties, as discussed in Section "Game Design Guidelines for Child End-Users", in practice. This

Table 2 Related applications to the ReaDi-STANCE platform

Name	Type	Description	Cost
PBS Kids (https://pbskids.org/games)	Online Games, Educational Videos	PBS Kids tries to improve the learning of children by strengthening critical thinking, imagination	Free (Video is restricted to US and territories)
Starfall Reading (https://www.starfall.com)	Online Games	Public service program to teach children to read with phonics (Kids with dyslexia)	Free
Nessy (https://www.nessy.com)	Online Interactive Games	Interactive games for kids with dyslexia or learning disabilities	Paid
Language Tune-up Kit (http://www.jwor.com)	Online Games	Computer-based program for learners with reading disabilities	Paid
Reading Rockets (https://www.readingrockets.org/)	Web platform	Activities for struggling readers. Children with disabilities can benefit from the same language and literacy activities as all young children	Free

in turn enabled them to transfer the theoretical knowledge and practical applications observed of the design guidelines to the design of the games for the Game-Based Cognitive Intervention Tool of the ReaDi-STANCE platform.

Games feature elements including rules, goals, interaction, feedback, problem solving, story, and fun were compulsory elements for comparable applications. Withal, the selection of related applications was also based on three specific criteria. First, the application should support a digital approach to learning; hence, it should be either a website/web application or a mobile application. Second, the application should primarily assist children or individuals with reading difficulties since expanding the search beyond children returned more applications for review. Some examples include dyslexia or reading difficulties, ADHD, or learning disabilities in general. Third, the table considers cost (i.e. free or paid) to make a comprehensive comparison between these and the ReaDi-STANCE platform, which offers its games at no cost, supported by instructional videos on how to play the games and supports the child end-user where required. The ReaDi-STANCE platform is discussed in more detail in Section "Readi-Stance Platform".

Comparing the applications in Table 2 to the ReaDi-STANCE platform, they offer a variety of resources, including courses, quizzes, and video games. Most are available for free, and all of them are accessible today. Some applications focus more specifically on one category; for instance, Nessy is designed for kids with learning disabilities, whereas PBS Kids is a broader application. All the games mentioned above are in English, while there was nothing available in Greek, which the ReaDi-STANCE platform covers. The absence of a consensus on appropriate remedial practices, particularly in Greek, further enhances the platform's novelty. It is also emphasized that the design of the games in the GBCI Tool was theoretically driven and grounded on the Planning, Attention, Simultaneous, and Successive (PASS) theory of intelligence and cognitive functioning and the PASS Reading Enhancement Program (PREP; [8, 23]). Thus, the online intervention was designed to improve selected aspects of children's information-processing skills and increase their word reading and decoding abilities [26].

In summary, the ReaDi-STANCE platform has unique features that set it apart from similar platforms. The platform's games are designed based on theoretical research and are integrated into the GBCI tool. These games focus on improving the information-processing skills of young learners. Additionally, the ReaDi-STANCE platform offers these games in Greek, making them more accessible to Greek-speaking child end-users.

Methodology

This section presents the methodology applied to design, develop, and evaluate the two digital tools hosted on the ReaDi-STANCE platform.

1. The evaluation of digital tool 1 (GDG tool) assessed the grouping of game design guidelines for child end-users into these categories and the relevance of specific guidelines against specific themes.
2. The evaluation of digital tool 2 (GBCI tool) assessed the application of the game design guidelines for child end-users in the "Games" module of the GBCI tool.

The systematic approach followed is presented below. Next, the profiles of experts who evaluated each digital tool are presented. Subsequently, the research methods and data analysis techniques employed are presented. A short presentation of the findings related to the efficacy of the online *e*-PREP application is also provided.

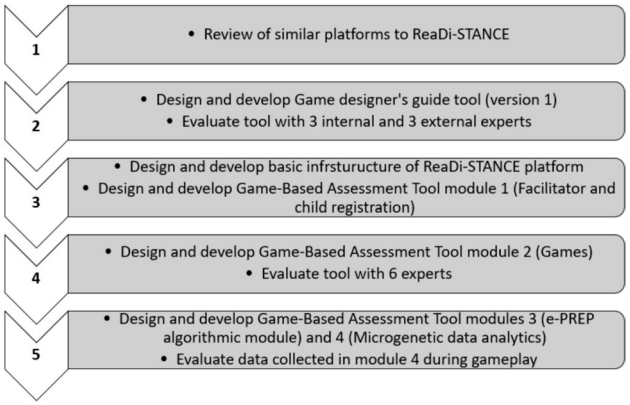

Fig. 1 The five stages of the methodology

Participants As the study primarily focuses on the technical implementation of the *e*-PREP online application, we provide preliminary data on participating children to side-assess the effectiveness of the *e*-PREP. Thirty-three Grade 1 children with no history of speech, language, attention, neurological, or hearing difficulties participated in the study. They were selected from schools from general and special education classes. Teachers nominated children from their classes who they thought had reading difficulties to identify children with reading difficulties. These children were then given reading fluency tests (word-reading and phonemic decoding tasks; ERS-AB battery, [37]) to ensure that they met the Diagnostic and Statistical Manual of Mental Disorders (DSM-V [38]) criteria for reading difficulties. Ten children who scored at least one standard deviation below the age group mean on these fluency tasks and were within the average range on both verbal (Vocabulary, WISC-V-GR, [39]) and non-verbal ability tasks (Matrices, CAS-GR, [40]) were included in the reading difficulties (RD) group. Twenty-three children who did not have reading difficulties were matched to the RD group on verbal and non-verbal ability, Wilks' $\lambda = 0.852$, $F(2, 30) = 2.60$, $p =$ ns, age, $F(1, 31) = 2.63$, *ns*, gender, χ^2 $(1, 33) = 0.41$, *ns*, parental education, χ^2 $(6, 33) = 2.96$, *ns*. The RD group received the *e*-PREP intervention which consisted of 20 30-min sessions, administered individually over a four-week period during school hours by certified special education teachers or trained graduate psychology students. Trained research assistants frequently assessed treatment integrity through direct observation (20% of the sessions). Also, following each visit, they debriefed with the teachers.

Approach To employ a systematic approach during the technical implementation phase of the project, the methodology defined consisted of 5 stages, as presented in Fig. 1. Results presented in Section "RESULTS" of this paper relate to stages 2 and 4 specifically. Module 1 (outcome of stage 3) and modules 3 and 4 (outcomes of stage 5) are introduced in the paper but are not included in the validation process. The stages of the methodology are:

1. In this stage, a review of similar applications was conducted (comparison presented in Section "Comparison of Related Applications").
2. In this stage, digital tool 1 was designed, developed, and evaluated by 3 external experts from the field of HCI (evaluation results presented in Section "Intervention Outcomes on Reading Performance").
3. In this stage, the design and development of the ReaDi-STANCE platform commenced, focusing solely on module 1 at this point (module 1 purpose presented in Section 4.2.1).
4. In this stage, digital tool 2 (i.e. module 2) was designed, developed, and evaluated. Influenced by the design of digital tool 1, it was reviewed by six experts with different backgrounds and expertise in gaming (evaluation results presented in Section 5.2.1).
5. In this stage, modules 3 and 4 were developed in parallel, including the algorithm for game rotation and respective data analytics collected during gameplay for research purposes (the purposes of the modules are presented in Sects. 4.2.3 and 4.2.4, respectively). Researchers in Psychology use data collected from module 4, and its accuracy and reliability were evaluated by both the research and development teams.

Reviewing stage 2 more closely, it was iterative and consisted of two evaluations, with internal and external experts participating. First, a corpus of literature for the research field needed to be defined based on title, keywords, and abstract. The corpus in this study included a selection of 43 manuscripts published from 2007–2018, with specific attention to game design guidelines for child end-users. The manuscript publication period (i.e. 2007–2018) was influenced by the ReaDi-STANCE project's duration (2019–2021). Since the ReaDi-STANCE platform needed to be designed and developed per the project's defined deadlines, the corpus covers the period 2007–2018 since it was the starting point of the technical work in the project.

A systematic review of the manuscripts followed, extracting, and synthesizing guidelines and themes. The output from this was the identification of 7 themes and 96 guidelines. An internal expert review was then conducted by 3 HCI experts to refine the initial themes and guidelines. From the initial set of 96 guidelines, 63 focused on child end-users aged 6–8 were selected and categorized into the existing themes, classifying the guidelines within these and eliminating similar guidelines to avoid redundancy. Each guideline thus forms part of a theme. Jakob Nielsen's well-known 10-usability heuristics [17] inspired many of these for UI design, while other guidelines were based on the relevant

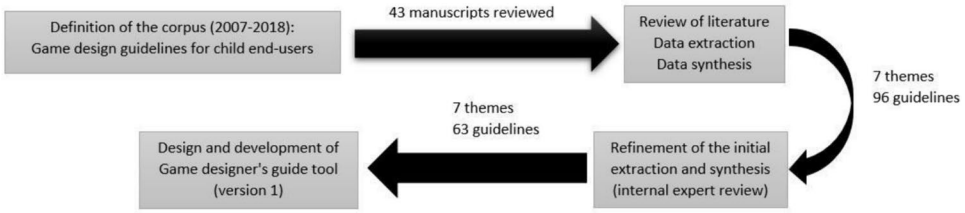

Fig. 2 The internal process followed to complete stage 2 of the methodology

Table 3 Profiles of the experts

No	Gender	Country	Education level	Current position	Years of experience	Design guidelines and heuristics experience
1	Female	Cyprus	Postgraduate (Ph.D)	Researcher /Academic	26	Expert
2	Male	UK	Postgraduate (Ph.D)	Researcher /Academic	11	Expert
3	Male	Dubai	Postgraduate (Ph.D)	UX Designer / Researcher /Project manager	16	Expert

Table 4 Profiles of the experts

No	Gender	Age Group	Education Level	Current Position	Years of Experience
1	Female	35–44	Postgraduate	Researcher in the gaming field	11 or more
2	Male	45–54	Postgraduate	Researcher in the reading field	11 or more
3	Male	18–24	Postgraduate	UX Designer	3–5
4	Female	25–34	Postgraduate	Researcher in the gaming field	0–2
5	Male	25–34	Postgraduate	Web/Mobile/Game Developer	6–10
6	Male	35–44	Postgraduate	Game Developer	11 or more

outcomes of this research study. The resulting themes are Graphical Representation (21 guidelines), Emotional Development (6 guidelines), Format and Accessibility (9 guidelines), Gameplay and Tutoring (9 guidelines), Performance and Evaluation (8 guidelines), Physical Development (6 guidelines) and Teaching and Learning (4 guidelines).

Figure 2 summarises the internal process followed in stage 2 of the methodology, leading to the design and development of digital tool 1 (version 1). In a second iteration, three external experts evaluated this version. The results are presented in Section "Intervention Outcomes on Reading Performance".

Experts Profiles

In this section, the profiles of the experts that evaluated both digital tools are presented.

GDG Tool Evaluators Three external experts evaluated the GDG tool. All the experts have completed their Ph.D. and had many years (i.e. minimum 10+) of experience, mainly as researchers. Two experts were from the Academic field, and one was practising in Industry, contributing to views from both worlds. All are considered experts in the use of design guidelines and heuristics. Their profiles are presented in Table 3.

GBCI Tool Evaluators Six external experts evaluated the GBCI tool. All the experts have completed the postgraduate higher education level (Master's or Ph.D.), and most had more than six years of experience, mainly (4 out of 6 participants) as researchers, designers, and developers in the gaming field. Thus, the sample size, albeit relatively small, was composed of qualified experts with more than six years of experience in the field. Their profiles are presented in Tables 4 and 5.

The sample further denotes that they are game design and development experts since they have been involved in several diverse projects that produced games for Unity, mobile and web platforms.

Research Methods

The evaluation of the GDG tool focused on assessing the grouping of game design guidelines for child end-users into theme categories and the relevance of specific guidelines against specific themes. The evaluation of the GBCI tool) assessed the application of the game design guidelines for

Table 5 Profiles of the experts

No	Researching /designing / developing games in general	Researching /designing /developing games for children users	Use of any guidelines when working on games	Type of games used in a professional capacity
1	Intermediate	Intermediate	Yes	Online Games, Mobile Games
2	Novice	Novice	No	Online Games
3	Novice	No experience	Yes	Unity Games, Online Games, Mobile Games, VR Games
4	Intermediate	Intermediate	Yes	Virtual Worlds, Online Games, Mobile Games
5	Intermediate	Intermediate	Yes	Unity Games, Online Games, Mobile Games
6	Intermediate	Intermediate	Yes	Unity Games, Mobile Games

child end-users in the "Games" module (i.e. module 2) of the GBCI tool. Next, the two methods used to collect experts' quantitative and qualitative data are mentioned.

Expert Review Usability inspection methods are applied to assess the usability of products in Human–Computer Interaction. It is achieved by identifying usability problems or violations using the User Interface (UI). A usability problem is defined as "*any aspect of a user interface that is expected (or observed) to cause users problems for some salient usability measure (e.g. learnability, performance, error rate, subjective satisfaction), which can be attributed to a single design aspect*" [16, 19].

An expert review is a usability inspection method done by field experts [18]. It requires them to use their practical skills and theoretical knowledge of guidelines and standards. Such practical skills enable them to evaluate the conformance of a particular design. Nielsen [18] points out that it is one of the most popular methods and allows for quick, cost-effective, and easy evaluation of a UI design. Three to five experts are sufficient to discover an average of 75% of usability problems on the UI [18]. In total, three expert reviews were conducted in this study:

1. Three internal experts evaluated and refined the initial corpus of themes and game design guidelines for child end-users. Once consensus was reached on the final set of themes and guidelines, using the process depicted in Fig. 2, the respective online surveys for each digital tool could be designed.
2. Three external experts evaluated digital tool 1 (version 1). During their review, the experts were provided with a supporting document listing the resulting themes and respective descriptions. They then completed an online survey.
3. Six external experts evaluated digital tool 2. The system was reviewed by experts who had used the games before completing the online survey administered to them.

Online Survey Online surveys were designed as evaluation instruments for the external experts' reviews. Two different ones were designed to evaluate each digital tool. Google forms were used as they provide a quick and handy approach to administering the tool and collecting quantitative and qualitative expert views.

Data Analysis

Descriptive statistics were used to summarise and explain the data—both evaluations related to the game design guidelines and themes. As previously mentioned, there are seven themes, each with its set of guidelines: Graphical Representation (21 guidelines), Emotional Development (6 guidelines), Format and Accessibility (9 guidelines), Gameplay and Tutoring (9 guidelines), Performance and Evaluation (8 guidelines), Physical Development (6 guidelines) and Teaching and Learning (4 guidelines).

For the GDG tool, a 3-point Likert scale with options for "Disagree", "Not Sure" and "Agree" was administered. The survey items focused on evaluating the grouping of design guidelines into theme categories and the relevance of specific guidelines against specific themes. Regarding relevance, this applied only to guidelines where no consensus was agreed upon regarding their categorization into a theme following the internal evaluation. Additionally, experts could share their qualitative views on guidelines for which they "Disagree" or were "Not Sure" on their theme categorization and propose its re-categorization into another existing or new theme they recommend. The three participating HCI experts were asked to review each guideline and theme. The estimated average time to complete the survey was about 1.5 h.

For the GBCI tool, a 3-point Likert scale with options for "Disagree", "Not Sure" and "Agree" was likewise administered. The survey items focused on evaluating the application of game design guidelines for child end-users in the "Games" module of the GBCI tool. Additionally, experts could share their qualitative views on guidelines they "Disagree" within their use of the "Games" module. Their feedback would help determine whether the non-use of a specific guideline was due to the context of the game, consequently

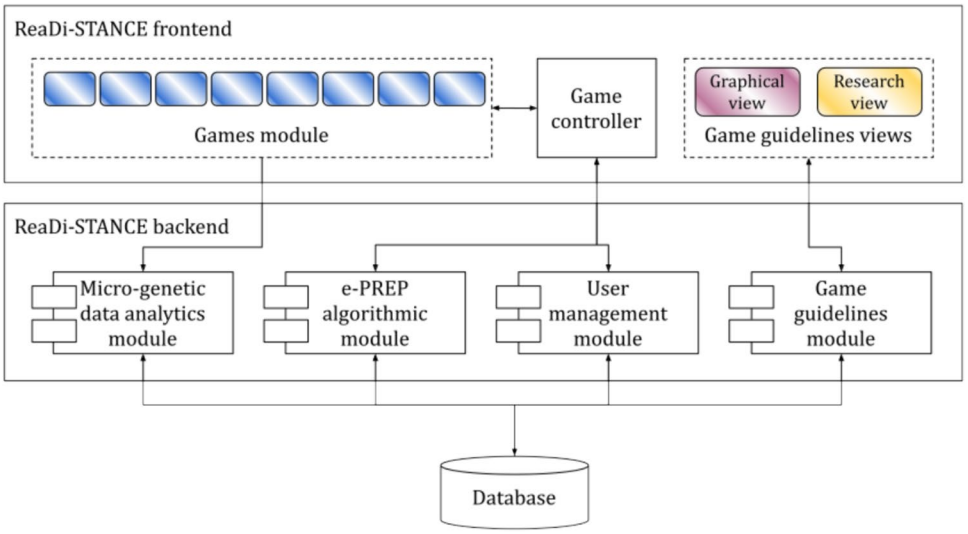

Fig. 3 ReaDi-STANCE Platform System Architecture

making it not applicable for use or whether it could have been used in the specific context but was not considered. The six experts who participated were asked to explore the GBCI tool of the ReaDi-STANCE platform and to specifically interact with the "Games" module by playing all its games, as presented to them by the algorithmic module (see Section 4.2.3). Experts completed the online survey after interacting with the "Games" module. The estimated average time for exploring the "Games" module and completing the online survey was about 3 h.

ReaDi-STANCE Platform

In this section, we present the ReaDi-STANCE platform, which consists of two digital tools: the GDG tool and the GBCI tool. The GDG tool is a resourceful tool that offers guidance to game designers, equipping them with the necessary resources to design, develop, and conduct further research on engaging and effective games for children. The GBCI tool comprises four modules:

User management module: This module is the platform's central hub for user management and handles facilitator and child registration.
Games module: With a collection of eight interactive games, this module provides engaging gaming experiences for users.
e-PREP algorithmic module: This module implements the *e*-PREP algorithm and the Prompting stages and incorporates proven algorithmic techniques [22] to facilitate learning.
Micro-genetic data analytics module: This module records user interaction data during gameplay and analyzes it to gain insights into user behaviour and performance (see [5]).

These modules were integrated into the platform as software plugins to ensure seamless integration and adherence to specifications. Rigorous testing procedures were conducted post-integration to confirm the successful integration and proper functionality of all modules. In the subsequent sections, we provide a detailed presentation of each module within the platform's overall architecture.

Architecture

Figure 3 depicts the ReaDi-STANCE platform's architecture, which follows a typical web application structure. It consists of a front-end component, a back-end component, and a MySQL database management system. Each component contains multiple sub-components that contribute to the platform's functionality.

The database is the foundation for storing essential data for both digital tools in the ReaDi-STANCE platform. Implemented as a MySQL database management system, it contains various tables that cater to the requirements of the platform's digital tools.

The back-end component encompasses all modules mentioned earlier, excluding the games module. Additionally, it includes a game-guidelines module specifically designed to support the GDG tool. This module filters and presents relevant guidelines from the database, serving them to the front end.

The front end exposes the GBCI tool[1] and the GDG tool.[2] It incorporates the games module, which interacts with the micro-genetic data analytics module via a well-defined REST API interface. This interaction facilitates the processing and recording user interactions during gameplay into the database. Within the front end, a game controller fulfils two crucial roles. First, it manages Identity and Access Management processes by communicating with the user management module. Second, it communicates with the *e*-PREP algorithmic module, controlling the sequencing and delivery of games to the users.

The front end also provides users access to the game guidelines from the GDG tool. These guidelines are categorized and presented from various perspectives, as further explained in subsequent sections. It is worth noting that since the game designer's guide tool does not require user authentication before access, its front end components do not necessitate interactions with the game controller.

Game-Based Cognitive Intervention Tool

The GBCI tool is a key component of the ReaDi-STANCE platform that allows for the evaluation and measurement of users' skills and abilities through interactive gameplay. It offers eight games or tasks to engage users, particularly young children and those with reading difficulties or learning disabilities. By analyzing user interactions and performance data recorded by the Micro-genetic Data Analytics Module, the tool provides valuable insights and assessments of users' progress and areas for improvement, contributing to personalized and compelling learning experiences. In what follows, we offer more details on the modules that make up the GBCI tool.

User Interface The user interface of the GBCI Tool has been designed to provide an intuitive and engaging experience for both facilitators and student end-users. Upon accessing the platform, facilitators are guided through a streamlined registration process where they input essential student details such as ID, first name, and surname. Additionally, students are prompted to personalize their profiles by selecting avatars, enhancing their sense of ownership and engagement within the ecosystem. Once registered, students are seamlessly integrated into the dashboard, where facilitators list them for easy access and management. This centralized hub serves as a convenient platform for monitoring student activities, accessing game analytics, and tracking progress across various cognitive skills and educational objectives. Within the dashboard, facilitators can select individual student profiles to inspect and gain access to the student's game performance and analytics data. A core interface of the tool is the Games module, where a visually stimulating grid layout presents eight interactive games as colourful icons. Each game includes detailed descriptions, instructions, and real-time performance metrics to guide student gameplay and facilitate learning. Furthermore, dedicated pages for each game offer comprehensive insights into student progress, empowering them to monitor their advancement and skill development. A centralized progress tracking page aggregates data from all games and game levels to give facilitators a holistic view of student performance.

User Management Module The user management module handles user-related tasks within the platform while adhering to GDPR guidelines. To register a child (referred to as a student) as a user on the platform, their student ID, first name, surname, and avatar are required. However, the facilitator's responsibility, typically a teacher or trainer, is registering the child on the platform and establishing a child-facilitator intervention relationship.

To maintain consistency in data access, if multiple facilitators are involved in administering interventions to a specific child, the facilitator and student IDs initially registered must remain the same throughout the intervention case. This ensures that the specific child's data remains associated with the correct facilitator(s). The platform lists the registered students, allowing them to select them for gameplay or view their analytics data from their gameplay experiences. This feature enables facilitators and students to conveniently track progress and assess performance based on the recorded analytics data.

Games Module Eight games were developed and divided into two sets of stages (i.e., sets A and B). The games are also divided into global, non-alphabetic exercises (named "Pro") and bridging or alphabetic activities (called "Alpha"). The difficulty and complexity of levels increase as the student progresses. The aim is for the student to complete as many levels as possible in each game. Participants must achieve an 80% success rate to progress to the next difficulty level within the same task. Each game begins with the main menu consisting of two options: "Start" to initialize the game and "Instructions" to read instructions and guidelines about the specific game. Furthermore, each level of the game requires a certain amount of time for the student to complete. If the student does not meet the level requirements in the allotted time or answers incorrectly, then the student is guided to Prompting Stages (see Section 4.2.3). For each correct answer, the student receives a message on the screen indicating whether an item is answered correctly. If the answer is incorrect, the student receives an encouraging message to try again.

Through the games, participants develop visual scanning and verbal working memory skills, perception and attention,

[1] ReaDi-STANCE platform home page: https://www.cs.ucy.ac.cy/projects/readistance/

[2] ReaDi-STANCE platform game designer's guide tool: https://www.cs.ucy.ac.cy/projects/readistance/index.php/guide

Table 6 Games of the game-based cognitive intervention tool

No	Name	Description	Levels
1	Joining Shapes	This game aims to create rows with geometric shapes by joining lines and following verbal instructions. The skills developed are visual scanning, verbal working memory, and successive processing	Alpha (22) Pro (36)
2	Window Sequencing	This game aims to reproduce various shapes that vary in colour and shape. Skills developed are verbal working memory, perception, attention, and successive processing	Alpha (120) Pro (96)
3	Tracking	This game aims to search for and locate a stimulus (e.g., a house) through a path captured on a large map. Skills developed are organization and planning, visual scanning, working memory and processing speed	Alpha (20) Pro (25)
4	Related Memory	This game aims to pair two puzzle pieces to produce a single image. Skills developed are visual working memory, simultaneous processing, perception, and attention	Alpha (80) Pro (48)
5	Shape Design	This game aims to reproduce a puzzle with a complex combination of different shapes in colour, shape, and size. The skills developed are proximity and spatial relationships, thus, simultaneous processing and associative strategies	Alpha (30) Pro (37)
6	Connecting Letters	This game aims to determine the connection between letters or emojis between the left and right sides. Skills developed are visual scanning to define relationships and using successive processing as a memory strategy	Alpha (72) Pro (36)
7	Matrix	This game aims to reproduce a series of letters or pictures based on an anchor. It develops skills in visual scanning, working memory, and attention	Alpha (58) Pro (48)
8	Transportation Matrices	This game aims to reproduce a series of transportation pictures in the order they are presented from the initial sample. Skills developed are visual scanning, successive processing, verbalization, prediction, categorization, and discrimination	Alpha (120) Pro (28)

organization and planning, processing speed, verbal-spatial and simultaneous processing skills, successive processing, behavior inhibition, categorization and discrimination, and associative strategies.

In addition, analytics from every game are stored, such as the time an object takes to drag, the time it takes to complete the game level, or the number of clicks (see Section 4.2.4). Table 6 describes the game and presents the number of levels each has in its Pro (Global) and Alpha (Bridging) versions.

e-PREP Algorithmic Module The *e*-PREP algorithmic module implements the *e*-PREP algorithm and the Prompting stages. The *e*-PREP algorithm defines a rotation between the games as follows: the student starts the rotation when first attempting to play a game: the first game, Connecting Letters Pro. The first time a student plays a game, set A is used, considered the standard game. Set B is a similar difficulty version of the game that allows additional training at a given level. In addition to sets A and B, there are several difficulty levels (DL) per game and set. The student always starts from set A and the minimum DL. As the student successfully progresses through the game levels, the DL increases until it reaches the maximum DL for that game and set. If a user completes the maximum DL, they progress to the next game regardless of the set they are currently in.

In case the student makes a mistake, the prompting stages are utilized. The prompting stages aim to support the student when the level of a game is not completed successfully in the allotted time or when an answer provided by the student is incorrect. There are three prompting stages, which are activated in turn based on a student's unsuccessful attempt (either due time elapsing or inaccurate answer): Prompting Stage 1: The student is guided via a video tutorial with visual and audio instructions and then asked to repeat the task to ensure understanding. Prompting Stage 2: Auditory instructions are provided if the student cannot complete the task after Prompting Stage 1. Prompting Stage 3: If the student cannot complete the task after Prompting Stage 2, the facilitator intervenes to encourage the student with identification tasks and targeted guidelines. If the student can still not complete the task after Prompting Stage 3, then the attempt is considered unsuccessful; the student proceeds to the next game and, at the same time, one of the following happens: in case the student was in set A of the game, the next time they will play the particular game they will be navigated to the beginning of set B of that game. If the student was in set B of the game, the game is removed from the order of games.

Game rotation happens as follows: the student rotates between Pro games. If a pro game is completed, then the pro game is replaced by the alpha version of the same game while the rotation continues.

Microgenetic Data Analytics A microgenetic data analytics module was developed and integrated into the platform. Its purpose is to collect and record user interaction data during intervention tasks. Facilitators and researchers can then analyze the collected analytics data [5]. Of course, the various intervention tasks have different requirements, and users may interact differently with each one of the tasks (through mouse clicks, mouse drags, or rotations) within a specific game. Nevertheless, the microgenetic data analytics module

Table 7 Themes of the Game Designer's Guide Tool

No	Name	Description	Guidelines
1	Emotional Development	Emotional development refers to the ability to recognize, express, and manage feelings at different stages of life and to have empathy for the feelings of others. The development of these emotions, which include both positive and negative emotions, is primarily affected by the design and development of such games	13
2	Format and Accessibility	Game accessibility gives as many players the best opportunity to experience a game completely. Video game accessibility is considered a subfield of computer accessibility, which studies how software and computers can be made accessible to users with various types of impairments	19
3	Gameplay and Tutoring	Gameplay guidance refers to the goals and the outcomes not being superficial or too straightforward. Tutoring refers to either direct guidance, where the player is explicitly provided with aid, and indirect, where the players often don't even realize that they are being guided	11
4	Graphical Representation	Visual design is analyzed according to dynamic visual images, semiotics, and interaction. The analysis of visual design provides structure aimed at showing how games attribute aesthetical value to gameplay and how elements of visual design and game design combine their inherent qualities to form a game	25
5	Performance and Evaluation	Performance is a critical aspect of a game's effectiveness. Performance is a multidimensional structure that changes its measurement depending on various factors. It could be defined as the results of the game experience, strategic objectives, gamer's satisfaction, and the user's contribution to the game experience because of the strongest link between them	13
6	Physical Development	The physical development theme in building games is centred around using physical movement and manipulating objects to build and create structures or solve problems. This theme can help children develop their fine and gross motor skills, as well as their hand–eye coordination and spatial awareness	11
7	Teaching and Learning	A video game can teach and improve the learning skills of the player, allowing them to take active roles by exploring, operating, or interacting. Iteration and discovery become two significant aspects of teaching and learning through a game-playing experience	4

allows recording the analytics from user-intervention task interactions and securely stores them in the platform's database in a usable format.

Game Designer's Guide Tool

The game designer's guide is an invaluable resource for game designers and developers, providing them with a comprehensive set of guidelines to create games that cater to the specific needs of children with learning disabilities. With its focus on age-appropriate and educational content, the guide equips designers with the knowledge and insights required to craft games entertaining and beneficial for young audiences.

As a web-based tool, the game designer's guide offers a user-friendly platform where designers can access a wealth of information and guidance. It starts by helping designers understand the unique characteristics and requirements of children with learning disabilities, ensuring that game concepts are tailored to their specific needs. By deeply understanding the target audience, designers can create games that align with participants' cognitive abilities, communication skills, and learning styles.

One key feature of the game designer's guide is its provision of themes and guidelines tailored explicitly to designing successful games for child end-users. These resources assist designers in selecting appropriate themes that resonate with children's interests and promote engagement. Moreover, the guide delves into different age ranges and developmental stages, offering valuable insights into designing relevant and suitable games for specific age groups.

The guide goes beyond aesthetics and age appropriateness; it emphasizes incorporating educational elements into game design. It provides practical suggestions and tips on developing games that support children's learning and development, such as integrating educational content, fostering problem-solving skills, and promoting critical thinking. By utilizing these recommendations, designers can ensure that their games provide valuable educational experiences while maintaining an enjoyable gameplay experience.

Graphical View The Graphical View feature of the game designer's guide organizes the extensive collection of guidelines into various thematic categories, as listed in Table 7. These themes cover a broad spectrum of game design considerations, from fostering emotional development to enhancing teaching and learning experiences for players. Each theme encompasses a series of guidelines thoughtfully listed and described within the guide.

The purpose of the Graphical View is to provide a visual representation of the guidelines, allowing designers to navigate and explore the different themes easily. By categorizing the guidelines based on their intended goals and outcomes, designers can quickly identify the areas they want to focus on within their game design process.

Table 8 Mean differences (in standard scores) and main effects of time, group, and interaction between *e*-PREP and Control groups on the reading measures

Variables	Groups		*F*-values					
	e-PREP ($n=10$)	Control ($n=23$)	Measurement Point		Interaction		Group	
	M (SD)	M (SD)						
Word Reading Fluency	83.23 (8.26)	102.35 (6.29)	15.31	***	14.12	*	15.65	***
	92.52 (7.96)	**102.60 (8.20)**						
Phonemic Decoding Fluency	83.55 (10.04)	102.21 (7.47)	12.25	***	11.01	**	33.74	***
	96.78 (11.27)	**102.47 (9.77)**						

Values for pre-test in plain fonts; values for post-test in bold fonts

* $p<0.05$. ** $p<0.01$. *** $p<0.001$

Furthermore, to enhance the clarity and understanding of each guideline, the Graphical View includes graphical examples that showcase how the guideline can be applied in practice. These visual representations serve as concrete illustrations, enabling designers to visualize how the guideline can be implemented within their game designs. Where applicable, the Graphical View references an existing game or platform where the rule is applied and indicates whether it was used in the ReaDi-STANCE platform.

Research View The Research View in the GDG tool grants users direct access to individual game guidelines, offering them a valuable resource to enhance their game design process. These guidelines are specifically tailored for young children, including those with disabilities. By providing unrestricted access to these guidelines, the Research View empowers users to explore and apply them according to their design requirements and goals. One of the key features of the Research View is the ability to define filters that allow users to refine their search and narrow down the scope of guidelines. Users can utilize filters based on themes, targeted age ranges, and other relevant criteria to focus on the specific guidelines that align with their intended game design objectives. This functionality streamlines the research process, enabling users to access the most relevant and applicable guidelines to their specific design context. To further facilitate research, the Research View enables data to be exported into various formats such as CSV, XLS, and PDF for further data analysis.

Results

Intervention Outcomes on Reading Performance

The mean differences and main effects of time, group, and interaction between *e*-PREP and control groups on the reading measures are shown in Table 8. Values are represented in standard scores (with a mean of 100 and a SD of 15). Results obtained through Repeated Measures ANOVA, for each of the dependent measures, indicated that the main effect for measurement points, the main group and interaction effects were significant for both reading tests. These results indicate that the *e*-PREP group improved significantly compared to control group through the 5-week intervention.

Results—Game Designer's Guide Tool—GDG

The feedback provided by experts plays a vital role in continuously enhancing the GDG Tool for young learners with reading difficulties. The online survey sought expert input to gather comprehensive and well-informed opinions about determining and categorizing themes in the Designer's Guide Tool. The feedback from experts helps identify strengths and areas for improvement, ensuring that the GDG Tool is tailored to the specific requirements and learning styles of young child end-users facing reading challenges. The collected feedback was instrumental in driving future iterations and updates to optimize the learning experience. The online survey was based on the User Interface Design Guidelines by Nielsen and Molich [32], and the survey questions were divided into quantitative and qualitative sections, categorized into the following themes:

(1) Aesthetic and minimalist design.
(2) Match between the system and the natural world.
(3) User control and freedom.
(4) Consistency and standards.
(5) Error prevention.
(6) Flexibility and efficiency of use.
(7) Emotional Development.
(8) Reward.
(9) Performance and Evaluation.
(10) Teaching and Learning.
(11) Simple interaction.
(12) Accessibility.
(13) Visual design.

The results for three of these themes of this survey are shown in Fig. 4. In the first theme, *aesthetic and minimalist design*, experts unanimously agreed that necessary text

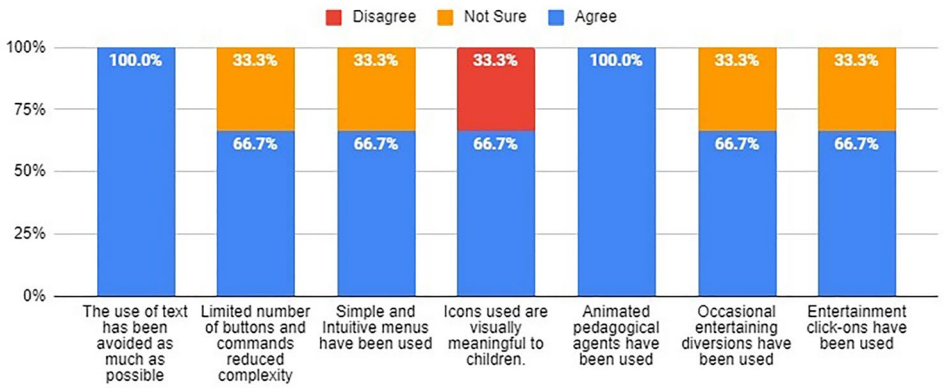

Fig. 4 Experts' Evaluation for Themes 1, 2, and 7

is included in the current theme. They also decided on the simplicity and intuitiveness of the menus but noted that the terms 'simplicity' and 'intuitiveness' are subjective. To provide more accurate feedback, it would be helpful to provide specific definitions for these terms. Two experts agreed regarding the limited number of buttons and commands and the complexity reduction. However, the third expert argued that reducing buttons and commands may require more time for users to adapt and become familiar with the environment.

Moving on to the next theme, Visibility of system status, two out of three experts were unsure about using extensive menus and sub-menus, primarily due to accessibility concerns. They suggested that providing a user guide would be more helpful. Regarding graphical feedback and its effect on user actions, one expert disagreed, stating that graphical feedback is not universally beneficial and should be adaptable to the purpose and content of the game. However, all experts agreed on the effectiveness of audio and animation for functionality indication. The experts also expressed concerns about the complexity caused by displaying the player's exploration history of environments, suggesting that it may increase interaction complexity and refer to 'recognition rather than recall,' which can be placed under the theme Visibility of system status. In the subsequent questions about the effectiveness of viewing feedback and skills improvement and the focus on primary goals and user errors, experts were unsure about their inclusion in the current theme, as it depends on the game's aim and difficulty level. Specialists suggested using techniques for multiple navigations, including accessibility and adaptability to the user's profile.

Moving on to the Match between the system and the real-world theme, experts had varying opinions about the visual meaningfulness of icons to children. One expert argued that the semiotics and standard icons in a game should be based on the characteristics of the target audience. Similar answers were given regarding using metaphors and icons during game interaction. In the User control and freedom theme, experts highlighted the negative impact that on-screen actions and interactions might have. They agreed that the player should have control over the interaction and be able to use different navigation methods during the game experience.

In the Consistency and standards theme, all experts agreed that all items should be consistent. However, consistency of item positions was suggested to be included under the Aesthetic and minimalist design theme. The categorization related to the predictability of link targets, functionality, and general interaction was indicated under the Visibility of the system status theme.

The next theme, Error prevention, received unanimous agreement regarding icons that do not distract the player from the primary task. However, experts were unsure about the effectiveness of options to suppress distracting content, emphasizing the importance of users feeling comfortable and familiar with the game environment.

Regarding the theme of Flexibility and efficiency of use, experts agreed on the importance of fast and understandable communication in a game and the usage of touchscreens. However, there were doubts about the real impact on players due to the game's complexity. Precise definitions of terms would be helpful in this regard. The inclusion of encouragement of cooperation in the current theme was also doubted, suggesting it should be placed under the Accessibility theme. Experts disagreed about whether the difference in interfaces based on different actions should be included in the User control and freedom theme.

Moving on to the theme of Emotional development, one expert expressed concerns about which theme should be allocated without providing any specific proposal. Similar uncertainties regarding occasional entertaining diversions were observed in the answers. There was agreement on the effectiveness of animated pedagogical agents and expressive, domain-specific agents for emotional development. However, experts disagreed on the supportiveness of on-screen character interventions, as it depends on the type and aim of the game. Regarding distractions from screen character interventions, experts were not entirely sure due to a lack of

clear understanding. There were positive responses regarding interest in activities and game content, but further clarification was suggested. One of the three evaluators proposed using exciting and likeable animations and sound effects under the Reward theme.

In the Reward theme, experts unanimously agreed that rewards delivered at appropriate times and frequencies can help players complete game goals. However, they were unsure about the structure of supportive rewards and did not provide any additional suggestions.

The next theme, Player Performance and evaluation, received agreement from specialists that the player's performance can be measured based on the number of errors, accomplishments, and duration. However, there was disagreement on including supportive activities via the player's progression at the beginning of each level.

All experts agreed that whether the game should not overshadow the teacher's presence is related to the Teaching and Learning theme.

Regarding the theme of Simplicity of interaction, all experts argued that the simplicity of mouse interaction and one-click interfaces are relevant. However, there were uncertainties about whether the use of mouse buttons for an extended period should be included in this theme, without any specific suggestion.

Moving on to the theme of Accessibility, there were differences in answers regarding using numbered lists rather than bullet point lists, finding it illogical. Nevertheless, all experts agreed on the relevance of voice captions, audio/voice-overs that read words aloud, and significant and straightforward actions for standard gestures on touchscreens.

In the second section of the survey, which concerned the classification of specific arguments into the mentioned themes, most experts agreed that vivid colours and shapes should be included in the Aesthetic and minimalist design theme. Regarding the relevance of goals to the educational content, answers were divided into three categories: Consistency and standards, Match between the system and the real world, and Teaching and Learning. Most experts suggested that goals and the development of students' capacities should be included under the Match between the system and the natural world category. Thematic concepts and their correlation with the goals of educating children were placed under the themes of Match between the system and the natural world and Teaching and Learning and Relevance. Regarding the size of items and the distance between them in children's games, most experts classified it under the theme of Accessibility. Structured content was integrated into the Visibility of system status theme, and the form of buttons was categorized under the Consistency and standards theme. Experts unanimously agreed that the font enlargement tool for web browsers should be included under the Accessibility theme.

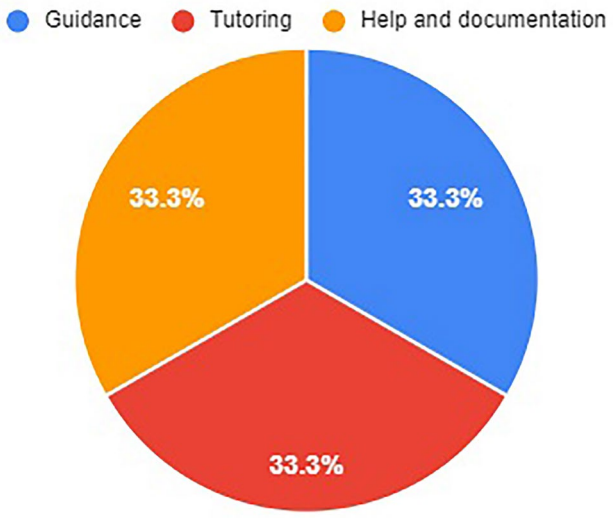

Fig. 5 Experts' Evaluation of the Argument's Theme Categorization: The tip system used suggestions for upcoming moves

Three different categorizations emerged regarding the contrast of colours: Visibility of the system status, Accessibility, and Visual design. Similarly, for the argument of text justification, two themes were suggested: Accessibility and Aesthetic and minimalist design.

Reducing CAPS to a minimum yielded three different categorizations: Accessibility, Visibility of the system status, and Visual design. Easy understanding of instructions was unanimously placed in the Guidance theme, while difficulty levels were included in the Challenge theme. The activities that contributed to expanding complexity were suggested to be included in the Flexibility and efficiency of use theme. At the same time, the tip system and interaction were classified under the Tutoring theme (see Fig. 5).

Regarding whether a game is a complementary tool for a child's education, experts suggested it should be placed under the Teaching and Learning theme. The support of screen readers was argued to be included in the Help and documentation theme.

The questionnaire concluded with an open-ended question soliciting the experts' overall opinions. They replied that the themes overlap, are redundant, and the principles are unclear. They suggested that short descriptions of each term would help designers, developers, and researchers better understand the themes.

Results—Game-Based Cognitive Intervention Tool—GBCI

Quantitative Results and Recommendations The ReaDISTANCE games were then evaluated and rated by the

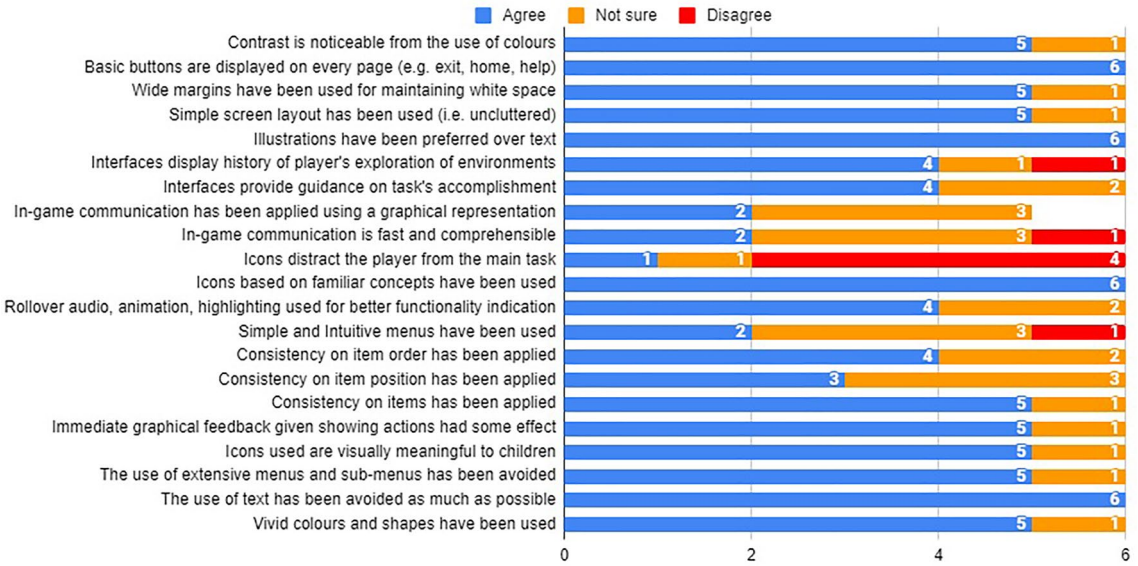

Fig. 6 Evaluation of Guidelines related to Graphical Representation

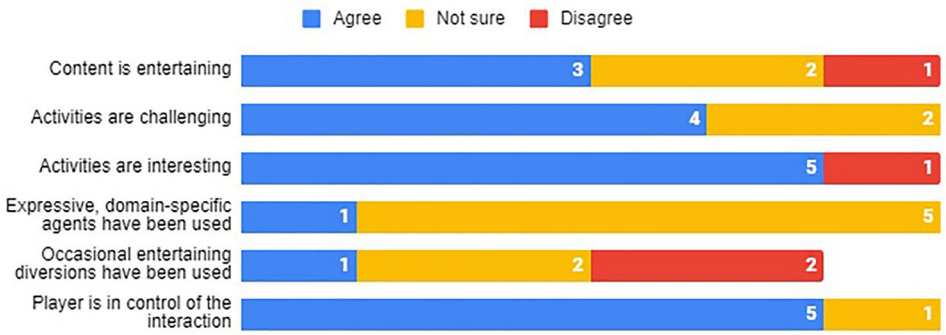

Fig. 7 Evaluation of Guidelines Related to Emotional Development

experts in terms of proper use of game design guidelines for child end-users.

The assessment questionnaire first evaluated adherence to the guidelines related to graphical representation. Figure 6 clearly shows that, on average, 5 out of 6 experts agree that the proposed guidelines for Graphical Representation have been addressed in the different games they engaged with. The "Not Sure" rating can be attributed to the expert "Researcher in the reading field" because the participant is not accustomed to the terminology used in game development. Last, the "Icons distract the player from the main task" is a negative question, and thus, the response results are inverted in this case, with 4 out of 6 experts responding positively.

The evaluation continued with the Guidelines related to Emotional Development. On average, 4 out of 6 experts responded positively regarding adherence to the ReaDiSTANCE games to the Emotional Development guidelines. The experts agreed that the "Player is in control of the interaction" and that the "Activities are challenging" and the "Activities are interesting". Also, experts indicated via their responses regarding two guidelines that the game needed more entertaining. Finally, it is interesting to examine the wording/meaning of the guideline "Expressive, domain-specific agents have been used", since 5 out of 6 experts were "Not Sure" if this guideline has been applied (see Fig. 7).

Format and Accessibility are fundamental themes that include guidelines that ensure that accessibility and formatting issues are covered to facilitate the end-users playing the games. On average, 4 out of 6 experts have responded positively regarding the assessment and adherence of the game's design and development to the format and accessibility guidelines. Specifically, one of the essential guidelines that refers to "Feedback on user's actions has been used" has been positively assessed, and all experts indicated that the games fully adhere to this requirement. At the same time, also 4 out of 6 experts indicated that "Content is structured and facilitates overview and orientation". Game developers and researchers were "Not Sure" in terms of the guideline

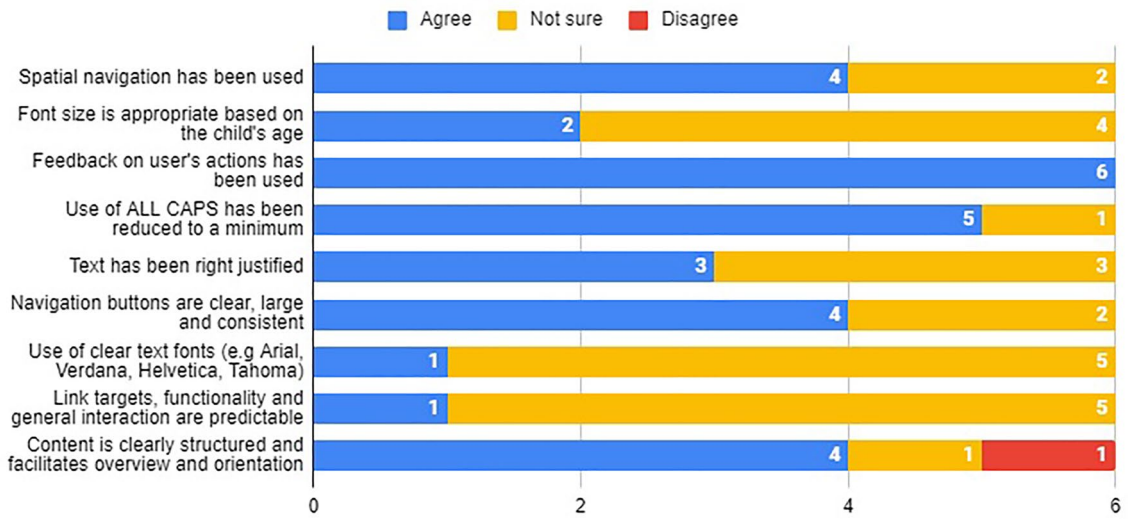

Fig. 8 Evaluation of Guidelines related to Format and Accessibility

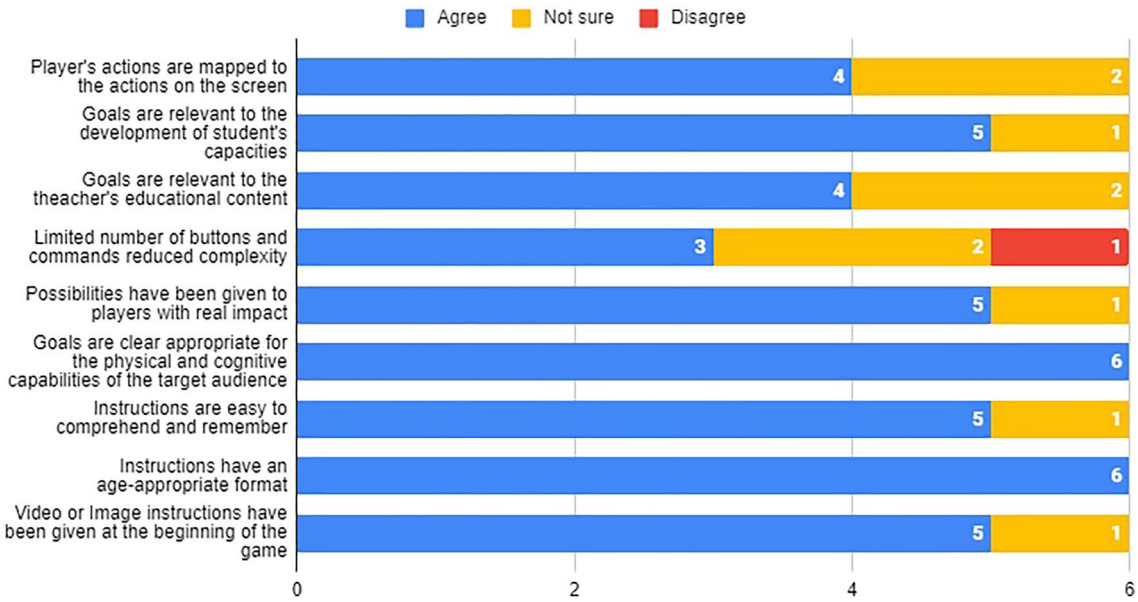

Fig. 9 Evaluation of Guidelines related to Gameplay and Tutoring

"Font size is appropriate based on the child's age", which may indicate that this guideline is not clear, may be subjective and not apparent even to expert developers, i.e., the right size for buttons (see Fig. 8).

Regarding Gameplay and Tutoring, it is essential to note that all experts have indicated that goals and instructions are appropriate for the target group, i.e., the children and that goals are relevant to developing the students' capabilities. The rest of the guidelines are positively assessed by at least 4 out of 6 experts, whereas in many cases, the experts that have not responded positively were "Not Sure" about a guideline. It is crucial in terms of all themes to check the wording/meaning as in many cases, experts were "Not Sure", rather than "Disagree", which indicates that a guideline has not been met (see Fig. 9).

Moreover, in terms of guidelines related to performance and evaluation (see Fig. 10), the experts have assessed the adherence of the ReaDi-STANCE games to performance and evaluation exceptionally well. Specifically, all experts have pointed out that different difficulty levels have been included, the various game levels support increasing complexity, and the activities support the player's progression

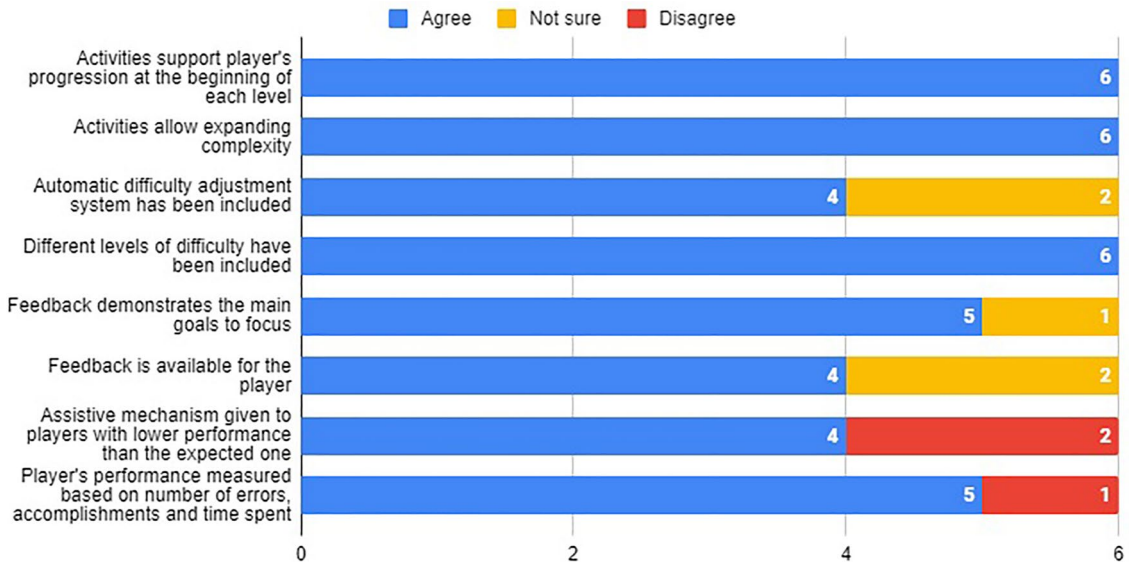

Fig. 10 Evaluation of Guidelines related to Performance and Evaluation

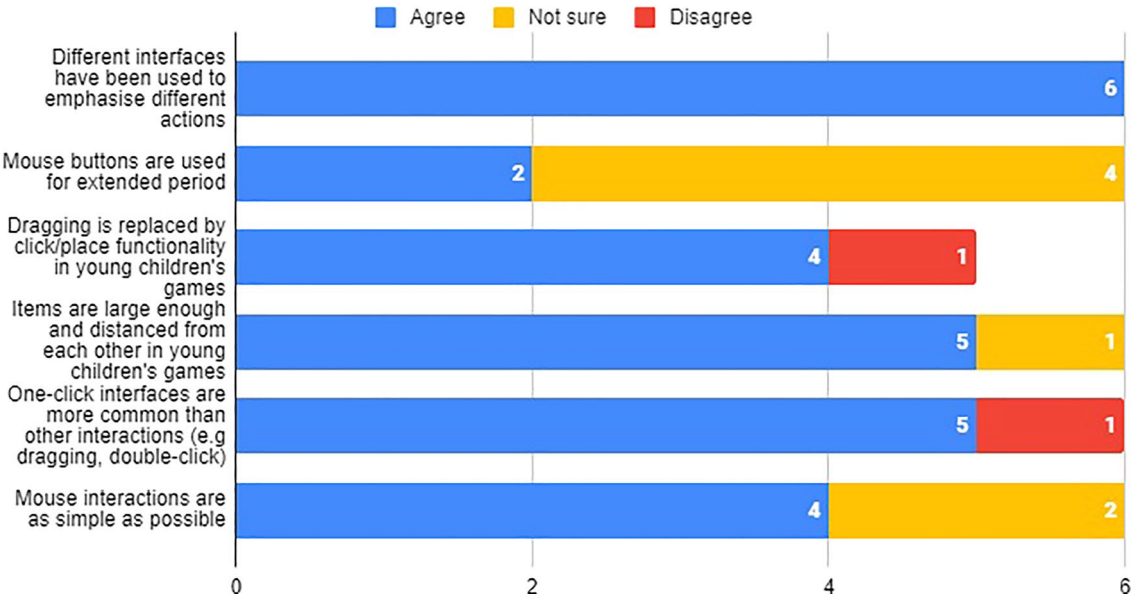

Fig. 11 Evaluation of Guidelines Related to Physical Development

from the beginning of each level. In addition, nearly all experts indicated that feedback is provided to the user, which supports the child in focusing on the game's primary goals. The player's performance has also been measured. Three guidelines resulted in "Not Sure" responses, indicating that the wording/meaning of these guidelines may need to be refined.

The assessment of different elements related to Physical Development indicates that the guidelines have been respected, and the games have been well received by 5 out of 6 experts on this theme. However, the guideline "Mouse buttons are used for an extended period" seems that the experts may not understand it since 4 out of 6 experts responded, "Not Sure". This can be received as a failure to realize the scope and wording/meaning of this guideline, which calls for refining the text related to the guideline (see Fig. 11).

Another significant theme related to child games is Teaching and Learning. The ReaDi-STANCE games have been positively assessed by 5 out of 6 experts in terms of their use as a "Complementary tool for the child's education",

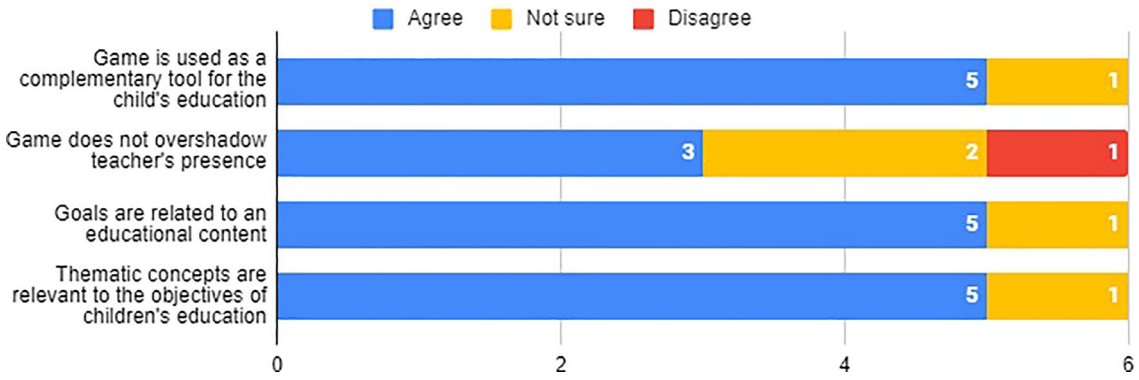

Fig. 12 Evaluation of Guidelines related to Teaching and Learning

the "Goals are related to an educational content" and the "Thematic concepts are relevant to the objectives of the children's education". As shown in Fig. 12, the guideline "Game does not overshadow teacher's presence" is the only one that is not well received by experts, with two experts indicating "Not Sure" and one expert "Disagree" which points out that the wording/meaning is not clearly understood. The text needs to be refined to be more explicitly understood.

Based on the rating provided by the experts, some insights can be extracted. The design and development team prioritizes these based on the rating scale for the severity of usability problems [20]. The scale is as follows and applies also to Section 5.3.3:

0 = I'm not at all convinced that this is a usability problem at all
1 = Cosmetic problem only: need not be fixed unless extra time is available on the project
2 = Minor usability problem: setting this should be given low priority
3 = Major usability problem: significant to fix, so should be given high priority and
4 = Usability catastrophe: fixing this before releasing the product is imperative.

Qualitative Results and Suggestions for Improvements
The expert participants' free-text answers provided valuable comments that can be used to assess and improve the game and the guidelines qualitatively. It is important to denote that the game was positively received by the experts with comments such as:

"The concept and philosophy of game development are interesting, and a lot of work has been done to implement all those games."
"They will surely make a handy resource for a teacher (both for F2F and online instruction)."

Experts also had the opportunity to provide comments at the end of the questionnaire. It was pointed out that the concept and the game development philosophy were fascinating procedures, and a large amount of work has provided some excellent results. The whole platform is a handy resource for facilitators of face-to-face education and online instruction. Moreover, it does not overshadow the facilitator's presence since it is an assistive technology that can be used along with the facilitator's instructions.

Despite the experts' overall positive results, areas were pointed out for further improvements on a potential updated platform release. Beyond the additional use of specific guidelines not adequately observed in the design, as discussed in Section "Results—Game Designer's Guide Tool—GDG", other improvements are listed in Table 9. Therefore, the participants provided a list of improvements that need to be made to fully abide by the above appraisal comments (see Table 10).

Overall, the *e*-PREP intervention program, delivered through the ReaDi-STANCE online platform, has once again demonstrated its effectiveness in enhancing the reading abilities of struggling early readers, corroborating previous evidence (e.g., [23, 25]). Compared to the control group, the children who underwent the *e*-PREP intervention showed significant improvements in their reading performance based on their pre- to post-test scores on real-word and pseudoword reading fluency measures. As a cognitively based intervention, the *e*-PREP program improves reading performance by training several cognitive factors that underlie reading, such as information processing skills, working memory, attention, or planning. The *e*-PREP program is effective when delivered intensively and one-to-one, making it suitable for additional training on reading skills. The program's adaptation to an online tool meets all the necessary criteria for success. These findings have implications for interventions that address reading challenges at their onset when formal literacy begins.

Table 9 Guidelines Improvement Recommendations based on Evaluation

Guideline	Recommendation
Several guidelines for "Graphical Representation" are included	The wording of several guidelines needs to be refined, and an explanation must be provided to clarify its scope and meaning
Font size is appropriate based on the child's age	4 out of 6 responded "Not Sure". This may indicate that this guideline is unclear and subjective and may not even be apparent to expert developers when evaluating this, i.e., the right size for buttons. It needs to be refined
A limited number of buttons and commands reduced complexity	2 out of 6 responded, "Not Sure". The phrase is a bit ambiguous and may need to be rephrased
Mouse buttons are used for an extended period	The experts may not understand the guideline since 4 out of 6 responded, "Not Sure." Therefore, the text related to the guideline needs to be refined
The game does not overshadow the teacher's presence	Several experts responded, "Not Sure". This guideline needs to be refined and clarified so that it may not always be relevant, i.e. if the game is performed without teacher supervision

Table 10 Potential improvements and their priority rating

Severity	Improvement
3	Drag and drop functionality needs to be improved to better respond to the user's cursor movement
3	Improve the correct condition to the next level, as you always need an answer
2	Add a stop button to multiple audio sources so that users can stop the first and listen to the second without listening to both simultaneously
1	More software/hardware is needed as an assistive mechanism for some players with lower performance
2	Make the response rate faster from one activity to the next
3	Add a pause button if the child needs a break in timed activities
3	Enable the facilitator to be able to proceed to the following activities when it is evident that the child has mastered an activity to avoid tiredness and boredom

Conclusion/Future Work

The present study examined the contribution of computer-assisted reading intervention. It focused on designing and evaluating the efficacy of an established intervention program with a cognitive focus, namely the PASS Reading Enhancement Program (PREP; [8, 23]), as an online computer-assisted intervention (*e*-PREP) for a group of young learners with reading difficulties. The ReaDi-STANCE platform delivered the GBCI tool that provides 8 games that support children with reading difficulties and the GDG tool that facilitates researchers, designers and developers in the design and development of games for all child end-users. In addition to presenting the ReaDi-STANCE platform, findings from an expert review were conducted with internal and external experts to evaluate the digital tools hosted on the platform, namely, the GDG tool and the GBCI tool. The expert reviews' results were positive but pointed to improvements for both digital tools.

Regarding limitations, although 3–5 experts are considered an ideal sample in expert reviews, efforts were made to recruit more experts. Recruiting teachers and child end-users to evaluate the usability of the ReaDi-STANCE platform and the GBCI tool was primarily impacted by the COVID-19 pandemic, prohibiting school visits for evaluations. In addition, it should be noted that open-source software was used to design and develop the platform and its digital tools for a broader impact. Proprietary software for gaming development would lead to a platform with an enhanced UX.

Building upon the existing research and evaluations conducted in the ReaDi-STANCE project, future work could further develop and enhance the GBCI tool for young learners with reading difficulties. This would involve refining the existing tool based on the feedback and insights gained from the evaluations conducted by the groups of experts. Specifically, the following areas could be explored:

1. Expansion of Game Content: The GBCI tool could include a broader range of reading-related activities and challenges to cater to different reading difficulties. This would involve creating new game modules or levels that address specific aspects of reading comprehension, vocabulary acquisition, phonics, or other relevant skills.

2. Personalization and Adaptivity: Incorporating personalized and adaptive features into the tool could help tailor the reading intervention to the specific needs of individual learners. The tool could dynamically adjust the game's difficulty level, pacing, or content to provide an optimal learning experience by analyzing the data collected from the child end-users' gameplay.
3. Gamification Elements: Exploring the integration of additional gamification elements could further enhance the engagement and motivation of young learners. This could include rewards, badges, leaderboards, or collaborative gameplay options to foster a sense of competition, achievement, and social interaction among users.
4. Accessibility and Usability Improvements: Conducting user testing and incorporating user feedback could improve the tool's accessibility and usability. This would involve ensuring the tool is intuitive, user-friendly, and accessible for children with different cognitive profiles.
5. Long-term Impact Assessment: Conduct a longitudinal study to evaluate the long-term effectiveness and impact of the GBCI tool on improving the reading skills of young learners with reading difficulties. This could involve tracking participants' progress over an extended period and analyzing the data to assess the sustained benefits of the intervention.

By focusing on these areas, future work can contribute to developing and refining the GBCI tool, ultimately providing a more effective and engaging reading intervention for young learners with reading difficulties.

Regarding the GDG tool, future efforts can be directed to another iteration based on the experts' feedback and re-evaluating the tool with a new set of experts. Moreover, further filtering options for the guidelines could be considered, and the corpus of manuscripts could be extended to cover related manuscripts for 2019-2023.

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Data availability The authors confirm that the data supporting the findings of this study are available within the article.

Conflict of Interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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