Co-Design and Field Testing of a Platform to Support the Screening of Learning Difficulties

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***Abstract*—The screening of specific learning disabilities faces many challenges, such as: 1) the lack of an educational alliance between schools, families, and clinicians; 2) the lack of quantitative data about children's difficulties and their progression over time; or 3) the inefficiency of access to care when it is truly needed. To address these issues, this work presents ESSENCE, a platform aimed at supporting schools throughout the entire process, from identifying children with difficulties to reporting cases to child neuropsychiatrists. Following an iterative co-design process with all relevant stakeholders, several system components were defined, developed, and refined with users' feedback. The final prototype was field-tested over one year by approximately 70 children, their teachers, and some clinicians. Compliance, the System Usability Scale, and custom satisfaction questionnaires were used to evaluate the system. Compliance was high, with at least five sessions conducted in 80% of the weeks. 82% of children reported good usability, and 92% were satisfied with the experience. The quantitative data collected through ESSENCE enhance the process of identifying specific learning disabilities, making it more targeted and beneficial for both children in need and the health-care system.**

***Index Terms*—Cloud-based platform, co-design, ed-tech, remote learning, serious games, specific learning disabilities (SLDs), teleconsultation.**

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I. Introduction

SCHOOL is a central part of children's lives. Beyond educational and social aspects, the first years of primary school are crucial for detecting and addressing potential learning disabilities [1], [2] before they become a threat to children's overall well-being. Indeed, difficulties in achieving school goals can lead to a deterioration of self-esteem, early school dropout [3], and a deprivation of lifelong opportunities.

To effectively detect and address learning disabilities, an educational alliance among schools, families, and clinicians is essential. However, schools often lack specialized personnel capable of critically assessing learning difficulties. As a result, the health-care system is frequently overwhelmed with unnecessary consultation requests.

Specific learning disabilities (SLDs) are characterized by skills that fall below expectation in reading (dyslexia), writing (dysgraphia and dysorthography), or calculating (dyscalculia), despite appropriate age, intelligence, and the absence of sensory-motor problems. SLDs cannot be resolved through standard training alone [4], but instead require specific training. For this reason, in classroom settings, teachers should monitor whether a child's skill development aligns with that of their peers. If a learning delay is suspected, teachers should inform parents and activate preclinical training programs. Only those children who show no improvement after this training should be referred to child neuropsychiatrists [5]. However, the evaluation of children's performance and their evolution during training relies on teachers' experience, with exercises typically conducted on paper. These methods lack quantification, whereas quantitative data could enable advanced analytics techniques and help refine the screening process.

An additional threat to early SLD identification emerged in the recent past, when COVID-19 forced over a billion students

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worldwide into remote learning [6]; children with SLDs faced increased difficulties [7]. When children returned to school, the number of cases with alarmingly low abilities dramatically increased, requiring the adaptation of diagnostic criteria and prompting to search for new solutions [2], [8]. Despite the challenges, the COVID-19 pandemic was a catalyst for exploring innovative interaction methods. Indeed, technology became increasingly accepted, and it can offer new ways of monitoring learning abilities over time. This principle is supported, for instance, by recent Italian guidelines [2], which encourage the use of technological solutions to better characterize learning difficulties.

Given this context, there is a need for technological solutions that leverage objective data to longitudinally assess children with learning difficulties and foster an educational alliance between schools, families, and the health-care service. Thus, the objective of this work is to co-design and evaluate a holistic platform—ESSENCE—through field testing to: 1) standardize and streamline the screening of SLDs; 2) longitudinally assess children's response to preclinical training; and 3) create a protected ecosystem to improve the efficiency of access to care.

The rest of this article is organized as follows. Section II introduces related works and highlights the need for a co-designed solution. Section III describes the co-design methodology. Section IV presents the outcomes of the co-design process, from concept development to field testing. Section V discusses the system's benefits, limitations, and potential applications. Finally, Section VI concludes this article.

II. Background

The market currently offers only partial solutions to meet the needs of early screening for SLDs. The evaluation and training of learning difficulties are implemented by platforms such as in *Ridinet* (Anastasis) [9], which allows personalized exercises and result monitoring with the support of parents and clinicians. However, schools are excluded from this framework, despite their key role in the screening process. *Dino* (PaperBox) [10] includes a module specifically designed for schools, but it focuses more on the evaluation of difficulties than on training, and lacks integration with a broader ecosystem of care. Another tool by Anastasis, *InTempo*, offers apps for training but struggles to engage children due to the absence of gamification elements. Other platforms focus on telemedicine only, without the possibility of remotely assessing learning through specific tests, such as *TiCuro* (Reply) [11]. None of these solutions are specifically designed to support schools in creating personalized programs tailored to individual students' needs or to facilitate connections with clinicians when necessary. Consequently, learning difficulties are often perceived as conditions requiring immediate clinical intervention, leading to early and unnecessary medicalization. This approach neglects the benefits of adopting a pedagogical strategy to address these issues at their onset. Thus, an integrated solution that considers diverse needs and supports the entire process—from difficulty to treatment—is still missing. Such a solution should leverage data analysis and visualization to provide valuable insights into students' profiles and school performance, while connecting students with a network of professionals.

The complexity of this problem requires continuous interaction with stakeholders, as it has been documented that top-down solutions in ed-tech and e-health initiatives usually lead to failure [12]. A holistic design framework for complex systems could instead be adopted [13]. End users should be involved from the beginning, either to inform functional requirements through a human-centered design approach or through proactive collaboration in a participatory design fashion [14]. Mapping users' expectations is crucial for understanding what can realistically be achieved through technology.

The development process should be iterative: feedback should be frequently collected to refine the solution, users' suggestions incorporated, and mock-ups cocreated with stakeholders to better align with their needs. Then, the system must be evaluated in the field, in a real-world scenario. Finally, an assessment of its impact and market adoption should be conducted [15].

This is the rationale behind the development of the ESSENCE platform, an acronym for "Empathic platform to personally monitor, Stimulate, enrich, and aSsist Elders aNd Children in their Environment" [16]. ESSENCE aims to bridge the gap between home, school, and clinic, supporting all children with a particular focus on optimizing the path toward clinical screening for those experiencing learning difficulties. This comprehensive solution builds on lessons learned from remote learning during the COVID-19 lockdown and capitalizes on the opportunities offered by advancements in e-learning and telemedicine technologies.

III. Methodology

The development process of the ESSENCE platform was inspired by the CeHRes roadmap [13], which involves users at different levels throughout all phases. The sequential steps are contextual inquiry, functional and technical requirements, iterative co-design, and field testing (see Fig. 1), and they are described in the following sections. Each step includes its objective, the tool used to achieve it, the location where activities were conducted, and the list of actors involved. The output of each step supports the subsequent phase. All experimental phases were conducted in accordance with relevant guidelines and regulations and in accordance with the Declaration of Helsinki. The protocol was approved by Politecnico di Milano Ethical Committee n. 04/2021. Participants and their parents signed informed consent forms to participate in the research activity.

A. Contextual Inquiry [see Fig. 1(a)]

At first, an internal brainstorming session with four clinicians (psychologists and child neuropsychiatrists) and four school professionals (teachers, school headmasters, and school office collaborators) belonging to the ESSENCE Consortium was carried out to gather information about the actors involved in the processes of learning and early detection of learning difficulties. This process primarily takes place in schools during routine activities, where learning difficulties can be observed. This was the starting point for understanding the potential benefits of technology to support early screening of learning delays.

To identify all the involved stakeholders, several observations have been made. First, ESSENCE's target population includes

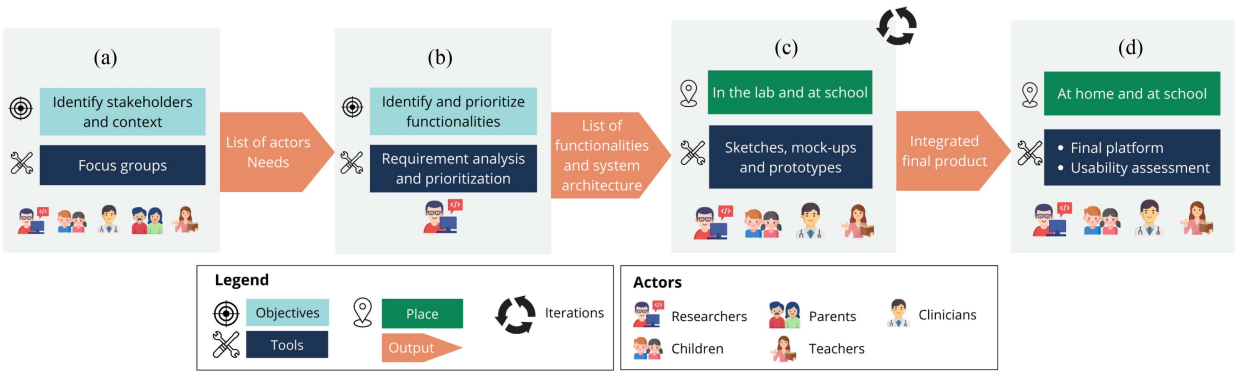

Fig. 1. Schema of the adaptation of the CeHRes roadmap to the development of ESSENCE, as described in Section III. Each step specifies the objective (light-blue boxes), the tools (dark-blue boxes), the actors involved (researcher, children, clinicians, parents, and teachers), the output of the step (orange arrows), and the place (green boxes). The circular arrow in step (c) refers to the iterative nature of the co-design process. (a) Contextual inquiry. (b) Functional and technical requirements. (c) Iterative co-design. (d) Field testing.

children attending the first and second years of primary school, as this period is crucial for effective early intervention [17] even though these children are still too young for a formal SLD diagnosis [2]. Since the learning process also involves the development of relational skills, children's schoolmates should be included. Teachers are involved, as well, both in the process of learning and in the early detection of learning difficulties. Parents, who support children and are expected to maintain efficient and constant communication with the school, are additional actors involved in the process. Finally, child neuropsychiatrists contribute by conducting early diagnoses of learning disabilities.

The focus group (FG) methodology was employed to gather useful information about users' expectations and suggestions from the relevant stakeholders. Four online FGs were conducted in April 2021: 1) teachers; 2) clinicians; 3) parents; and 4) children. The Consolidated criteria for Reporting Qualitative research guidelines [18] were followed to plan the FGs. The Conductor was SB, male, university professor of human science with previous experience conducting FGs; a male school teacher experienced in special needs co-conducted the FG with children. Facilitators were: for teachers, one male and two female school teachers; for clinicians, a child neuropsychiatrist (SFo, female) and a psychologist (SFr, male); for parents, SFr; for children, a psychologist (MB, female). To prevent bias, interviewers did not disclose their expectations regarding the FG outcome.

Concerning study design, clinicians, teachers, and children were selected through purposive sampling, to represent all ESSENCE users in terms of role and age (children), while parents were snowball sampled through their children [15]. Participants were approached via e-mail. Six teachers, nine children, nine parents, and seven clinicians were involved, to allow active participation from all [19]. Data were collected through online meetings, due to COVID-19 restrictions. For children, a fairy-tale background was chosen, with a teddy bear as the interlocutor. They could answer with preprinted smiley or sad faces with the assistance of their parents.

Each FG started with a presentation of the project, explaining the importance of the educational alliance between the actors, and ESSENCE's supportive role in case of learning difficulties. A discussion followed the general idea presentation, focusing on participants' experiences and their view on the proposal (Phenomenology [15]). Mock-ups of possible functionalities were presented, using slides or videos. Then, discussion was encouraged to find strengths and limits. Finally, the Conductor summarized the group's responses with the assistance from the Observer. The duration varied between 1 and 1:15 h for all, except children (30 min) [20]. All FGs were recorded, and field notes were taken. A thematic analysis [21] was conducted on the notes and transcriptions using an inductive approach [15]. Two or three data coders proposed themes, which were reviewed to reach an agreement on theme names. Data analysis focused on identifying thematic relationships, allowing a framework to emerge without a priori hypotheses. The main themes resulting from FGs were analyzed and organized into a list of needs.

Output: The outputs of this phase were the final list of actors and their needs.

B. *Functional and Technical Requirements [see Fig. 1(b)]*

The needs identified have been translated into the set of ESSENCE functionalities [22]. The results originating from the FGs were useful for refining the original idea of supporting the educational process with the introduction of technology [23].

Output: The output of this phase comprises technical and functional requirements that collectively contributed to defining the ESSENCE platform. The platform was conveniently organized into Components, Functionalities, and Activities: a *Component* can be a hardware and/or software tool, such as a device, user interface, and application. A *Functionality* is the general application use case with all the interactions required between the user and the components involved. A single functionality may include multiple *Activities*, i.e., the specific interaction tasks between a user and the ESSENCE system.

C. *Iterative Co-Design [see Fig. 1(c)]*

Once the general idea was clear, the iterative co-design phase with the different stakeholders began: all actors actively contributed to building mock-ups and suggesting features [14]. These were then prioritized according to technical feasibility and

clinical usefulness. The process varied according to the functionality to be developed and the actors involved, but the main steps were common to all functionalities. First, paper- or slide-based mock-ups were proposed by the technical team, discussed, and integrated with stakeholders' suggestions. After that, a prototype with limited functionalities was developed and preliminarily tested in the laboratory to address the main usability issues. Then, a prototype with full functionalities was produced and tested by engineers, psychologists, child neuropsychiatrists, teachers, and children in protected environments, to further refine it.

Testing procedures followed the best practices for evaluating digital health interventions [15], with an explanation of the functionalities and a testing session followed by questionnaires. The main aspects investigated were usability—through the system usability scale (SUS) questionnaire [24], or its pictorial version for children (P-SUS) [25]—and satisfaction (SAT)—measured with custom questionnaires for the different target groups to evaluate specific functionalities. Questions were answered on a five-point Likert scale and analyzed based on their median scores and interquartile range (IQR). For each functionality, the period of testing, the participants recruited, and the evaluation questions were different (see Section IV-C). In addition, each group of users was stimulated to provide feedback to improve the overall experience.

ESSENCE architecture was incrementally improved in parallel to the functionalities. The platform's development adhered to a bottom-up approach [26], prioritizing modularity, reusability, and scalability. Each component was developed as an atomic unit, with well-defined interfaces to facilitate future integration. Stubs and drivers were used, enabling independent testing of each component. User testing allowed further refinements, enhancing ESSENCE's capability to operate effectively in real-world scenarios.

Output: The output of the co-design phase was the final version of each functionality. These functionalities were integrated into the final platform by defining communication flows between components. At this stage, ESSENCE was ready to be field-tested.

D. Field Testing [see Fig. 1(d)]

ESSENCE instances were deployed to users for extensive field testing. A primary school was selected to recruit children from the first and second grades, along with their teachers. They were provided with a tablet and used the platform from December 2021 to December 2022. Periodic meetings were organized with users and researchers to address issues that emerged only after extensive real-world usage, creating opportunities for system improvements. Supplementary Material S2 illustrates the organization of the field testing. Both children and the system were assessed with different tests. Regarding users' assessment, children were tested for school prerequisites before the deployment, using Raven's colored progressive matrices (nonverbal intelligence, [27]) and an extract of the WISC-IV battery (intelligence, [28]). Then, during the field testing, children were tested for school abilities with clinical tests, comprising reading [29], writing [30], and computation [31]. These tests were performed: 1) at the beginning of field testing (January 2022, initial evaluation); 2) at the end of the school year of the deployment (May 2022, interim evaluation); and 3) at the beginning of the subsequent school year (October 2022, final evaluation). Regarding technology assessment, the ESSENCE platform was evaluated by all actors after field usage in two modalities: at the point of need and with continuous usage.

1) Functionalities at the Point of Need: Some functionalities were designed for episodic use, activated when a need arose, such as observing a difficulty or contacting a clinician. The observation of difficulties coincided with users' assessment time points (initial evaluation, interim evaluation, and final evaluation). As for the contact with a clinician, specific sessions were organized. The first session was in October 2022 with a subgroup of the children involved in the field testing. The second session occurred in March 2023, with another subgroup of the recruited children, with a different setup. At the end of both sessions, children rated the P-SUS and a custom SAT questionnaire.

2) Continuous Usage of the Platform: Most of the provided functionalities could be accessed from users' tablets, and they were tested continuously in the whole field testing period. These functionalities mainly supported the training of learning abilities and the improvement of relational skills. Compliance for each functionality was evaluated through the median weekly usage time (in minutes) and the total accesses normalized by the number of users, considering different periods: (P1) from deployment to the end of the school year (December 2021–May 2022); (P2) summer vacation (June–August 2022); (P3) from the start of the new school year to the end of the field testing (September–December 2022). These periods were selected as the school year is central to children's life. Moreover, during P1, teachers were encouraged to organize weekly meetings with children to familiarize themselves with ESSENCE. Conversely, during P2 and P3, children were left free to use the platform at their discretion. The number of weeks with at least five sessions for each user was also computed. Children were then asked to provide feedback on each functionality at two different time points: the end of the school year of the deployment (May 2022, interim evaluation) and the beginning of the following one (October 2022, final evaluation). Through a SAT questionnaire. they were asked if they found each functionality: 1) fun and 2) useful. Positive answers were those with a score of at least 3 out of 4. Then, the overall system was rated with the (P-)SUS (at both time points) and a SAT questionnaire (final evaluation only) both by children and teachers. Questions asked whether they found the whole experience: 1) fun; 2) useful; and 3) whether they were satisfied with it. Whenever SUS and SAT were compiled twice, a paired t-test or Wilcoxon test was performed to assess significant differences ($p < 0.05$). Statistical analysis was performed in R 4.0.1.

IV. Results

A. Contextual Inquiry

The total duration of FG recordings was approximately 4 h. Some of the main themes are presented as follows.

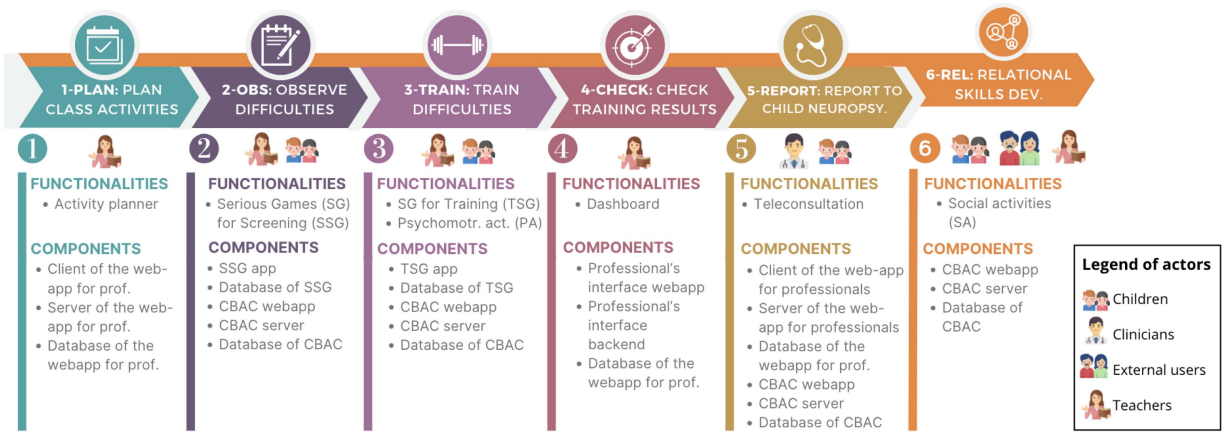

Fig. 2. Early SLD screening process phases (1–5) and the development of relational skills (6) at school. For each phase, the corresponding actors involved (teachers, children, clinicians, and external users; see Section IV-A), the ESSENCE functionalities involved, and the components needed to implement them are reported (see Section IV-B).

1) *Importance of the educational alliance for early screening:* Clinicians, teachers, and parents agreed that the online dialogue among them is very useful, and facilitated by the availability of test results. However, "*diagnosis can be made only in person.*" (clinician, teacher). A concern for remote screening was the copyright restrictions of clinical diagnostic tests (clinicians).
2) *Usefulness beyond the pandemic:* There was general appreciation for the proposed solution, as it helps counteract isolation. However, a clinician expressed concern that online activities might not be accepted once the pandemic ends. Moreover, "*It is important to maintain manual skills.*" (teacher).
3) *Assure online safety*: The online modality raised concerns. Teachers requested protection from external users and cyberbullying, as well as measures to limit excessive screen time. Clinicians emphasized that sensitive data must be shared exclusively among trusted individuals within the platform.
4) *Increase children's involvement in learning:* The idea of using games for learning was appreciated "*Because children like them very much*" (teacher), especially if there is the possibility of offering a wider selection (clinician).

Output of the contextual inquiry: ESSENCE actors were identified as children—both target users and their school mates—and professional users: teachers and clinicians. Indeed, these are the actors involved in the different phases of SLD screening, as reported in Fig. 2. Parents were not included as active users, but they can provide support to their children when interacting with technology.

The needs that emerged during FGs are reported in Table I (column *Need*), grouped according to FG themes.

B. Functional and Technical Requirements

As reported in Table I, users' needs were transformed into functional specifications and mapped to the different phases of the SLD screening process (see Fig. 2): 1-PLAN, 2-OBS, 3-TRAIN, 4-CHECK 5-REPORT, and 6-REL. Fig. 2 also reports the *Functionalities* and *Components* required in each phase. The details of the specific *Activities* included in each Functionality are reported in the Supplementary Material S1.

1) Description of Platform Functionalities: In the following, all the functionalities provided by ESSENCE are described and mapped to the SLD screening phases they belong to.

1) *Activity planner. [Phase 1-PLAN, Fig. 2(1)]:* It offers a graphical interface for the teacher to select and schedule *Activities* for the whole class or for a specific pupil. For each *Activity*, its parameters, the expected frequency of use, and the level of difficulty can be set. Moreover, the teacher can schedule the priority of each activity as: 1) compulsory—no other activity is possible; 2) suggested—the activity is marked as important; and 3) on demand—the activity has the lowest priority.
2) *Serious games for screening (SSGs). [Phase 2-OBS, Fig. 2(2)]:* SSGs are designed to detect alterations in the physiological laws intrinsic to handwriting, starting from drawing [32]. Indeed, features extracted by SSGs have proven to be effective in identifying children at risk of learning delay in the writing domain, even at the preliteracy stage [33], [34]. The SSGs *Functionality* comprises 3 *Activities*, as detailed in Supplementary Material S1-A.
3) *Serious games for training (TSGs). [Phase 3-TRAIN, Fig. 2(3)]:* Specifications of TSGs are inspired by typical school activities aimed at developing basic skills in reading, writing, and calculation. Different stimuli and difficulty levels allow for the training of children of different ages and abilities. A detailed description of the different TSG *Activities* is provided in Supplementary Material S1-A.
4) *Psychomotricity activities (PAs). [Phase 3-TRAIN, Fig. 2(3)]:* PAs offer a set of videos developed by a team of psychomotricists, in which a human tutor guides the child through engaging environments. Each video is designed to train different abilities, including emotional regulation, coordination, and breathing (see Supplementary Material S1-B).

TABLE I
TRANSLATION OF NEEDS THAT EMERGED FROM FGS INTO THE ESSENCE PLATFORM (SEE SECTION IV-A) AND THE CORRESPONDING MAPPING TO THE PHASES OF THE SLD SCREENING PROCESS (SEE FIG. 2)

Need	**Translation of needs to ESSENCE functional specifications**	**Mapping to SLD screening process phases**
Theme 1: Educational alliance for early screening		
Receive support for SLD screening	Serious games for screening to quantify difficulties and detect the risk of SLD	2–OBS
Results availability for successive usage	Possibility to view results in dashboards	4–CHECK
Possibility to integrate clinical tests (copyright issues)	Agreement with the test owner (Giunti Psychometrics) to implement digital tests for screening learning disabilities	5–REPORT
Theme 2: Useful beyond pandemic		
Complement school activities	Possibility to schedule serious games for training, adapted to school curricula	1–PLAN
Train manual skills	Video tutorials	3–TRAIN
Protect from social isolation	Virtual rooms to meet with classmates outside school	6–REL
Theme 3: Online safety		
Reduced screen time	Possibility to evaluate the time spent on games	4–CHECK
Avoid cyberbullying	Social activities in a protected environment with pre-defined users (supervised by teachers)	6–REL
Protect data	Data protection impact assessment, Data sharing agreement (GDPR-compliant)	Overall
Theme 4: Children involvement in learning		
Gamification	Serious games for learning with a narrative framework	3–TRAIN
Use of technology	Choice of appropriate hardware	Overall

Colors and numbers match those in Fig. 2.

5) *Dashboard. [Phase 4-CHECK, Fig. 2(4)]:* It allows the professionals to monitor the child's compliance with the planned activities and their performance.
6) *Teleconsultation. [Phase 5-REPORT, Fig. 2(5)]:* It allows clinical tests to be carried out inside a virtual room shared with the child. In this room, the clinician and the child can work on the same digital board and communicate via audio-video connection. The clinician selects and configures a specific clinical test, guides the child through the test, scores the test, views the results, and generates a report for each individual test as well as for the entire Teleconsultation session. The different clinical tests are detailed in Supplementary Material S1-B.
7) *Social activities (SAs). [Phase 6-REL, Fig. 2(6)]:* It comprises different *Activities*, which are collaborative or competitive games, such as jigsaw puzzles, draw-and-guess, and popular card games (see Supplementary Material S1-B). A group of users can play one of these *Activities* inside the same virtual room, where they can see and talk to each other while playing on the same digital board.

2) Description of the System Components: ESSENCE adopts a modular structure and is constituted of the following components that implement the aforementioned functionalities.

1) *The Community-Based Activity Center (CBAC):* It is a platform based on virtual rooms that allow multiple users to interact with each other through audio–video communication, while interacting with a digital board through the tablet touch screen, thus supporting multiplayer digital games [35]. It is implemented as a client–server architecture: the client is a webapp based on HTML5 and JavaScript that runs on a tablet, while the server is developed in NodeJS, hosted in the cloud. Real-time communication and synchronization among the users exploit the WebSocket protocol. The CBAC is also the access point for most of the ESSENCE functionalities. PAs, Teleconsultation, and SAs are accessed through virtual rooms of the CBAC, while SSGs and TSGs are implemented as separate apps and accessed through an intent call directly from the CBAC webapp.
2) *The SSGs app:* Developed in Unity3D, it implements the functionality SSGs.
3) *The TSGs app:* Developed in Unity3D, it implements the functionality TSGs.
4) *Webapp for Professionals:* It is a web interface (client) for professional users that allows them to plan activities for children (Activity Planner functionality), to schedule and access Teleconsultation, and to visualize the usage and the results of the ESSENCE activities (Dashboard functionality). It has been developed with the. NET framework, with the client side based on HTML5 and JavaScript, and the server side in C#.
5) *The ESSENCE manager:* It is the control unit that manages the platform. It provides users authentication, profiling and system configuration; it detects system malfunctioning and delivers notifications to the users (e.g., invitations for multiplayer games). This component includes the data center, i.e., the server that handles data storage inside a PostgreSQL database.

Using this modular approach, each component has been developed using the most suitable software framework. They all share data through the cloud (see Section IV-B3).

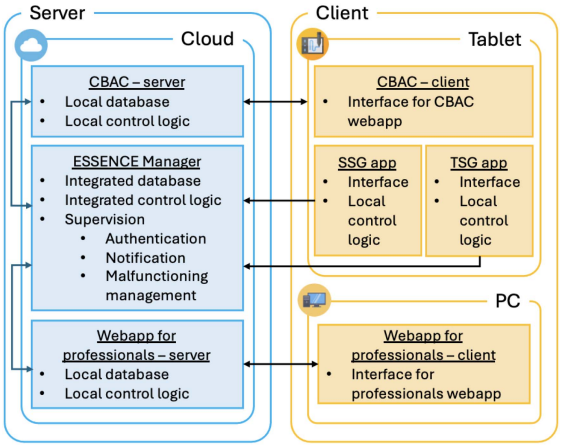

Fig. 3. ESSENCE client–server architecture, subdivided by the server side (on the left) and client side (on the right), as described in Section IV-B3.

3) Description of the Architecture: The ESSENCE architecture is shown in Fig. 3. It includes the following.

1) *Servers:* It hosts the server side of the CBAC, the Webapp for Professionals, and the ESSENCE Manager. Each server includes the data repository required by the corresponding functionalities, while the ESSENCE Manager integrates data coming from all system components. The servers are deployed on the cloud through Amazon Web Services, geographically limited to the European Union countries, in compliance with the EU General Data Protection Regulation. A cloud gateway, running an NGINX reverse proxy in combination with the ESSENCE Manager authentication module, is responsible for ensuring authenticated and secure communication between the cloud servers and the multiple in-house clients. Key built-in cybersecurity protection includes: data partitioning and pseudonymization, strong data encryption (Advanced Encryption Standard) during transfer (Transport Layer Security), and, at rest, cryptographic tokens (JSON Web Token) for authentication and authorization, and Layer 4 and Layer 7 firewalls.
2) *Client:* It comprises the client side of the CBAC, the Webapp for Professionals, and the SSG and TSG apps. These are deployed at home or at school on tablets endowed with an S-Pen for children, and on PCs or tablets for professionals.

C. Iterative Co-Design

Fig. 4 shows the typical *iter* followed by the different functionalities as guided by the co-design methodology. We started from paper material or brainstorming (I) and then produced a first digital mock-up (II) that was refined to obtain the final prototype (III). At each stage, testing with users was carried out and results are reported in Table II. In the following, the starting point and the refinement of the different functionalities are described.

1) Activity Planner (1-PLAN) and Dashboard (4-CHECK): Several iterations with clinicians, teachers, and technical partners produced the Webapp for Professionals. It was intended to be used by teachers and included both the 1-PLAN and 4-CHECK functionalities. A short demo of the interface was provided to eight teachers (all female), who were then asked to try some of the functionalities: the creation of a plan consisting of a set of training activities, the assignment of such activities to selected children, the visualization of the data collected from a specific user, and the visualization of the dashboard. Since the use of the platform was guided by a technician and data were associated with fake users to avoid tampering with already existing data, the SUS was not deemed appropriate, and it was replaced by the custom questionnaire reported in Table II, *1-PLAN and 4-CHECK* section.

2) 2-OBS: SSGs: The co-design of SSGs was performed before the beginning of the ESSENCE project on a sample of 177 kindergartners. A system usability score with mean (standard deviation) of 78.4 (15.0) was achieved on this component [36]. They have been integrated inside the ESSENCE platform.

3) 3-TRAIN: TSGs and PA: The co-design of the TSGs started with the sketches, inspired by textbook exercises, provided by clinicians to explain the game concept of each activity. Then, for all the reading, writing, and calculation activities included in the TSGs, clinicians carefully selected the set of stimuli presented to children. The stimuli used in reading and writing TSGs consisted of sentences and specific words. Each word was characterized by a graphical representation to reinforce its phonological decoding and phonological awareness [37], [38], a weight representing the frequency of use of the word, which corresponds to the assigned difficulty [39], and a set of distractors that are words or nonwords that can be easily confused with the target word. The stimuli used in calculation activities were numbers. Numbers were presented both in a concrete representation (e.g., number of stones) and encoded as Arabic numbers, and the mathematical operations were presented in order of difficulty (additions first, then subtractions, and finally multiplications). Fig. 4(a) reports the progressive development of the TSGs activity called “Speed reader” (cf. Supplementary Material S1). The game concept, represented in the Sketch [see Fig. 4(a)(I)], consisted of a sentence that should appear as text for a short time; then, characters would disappear, one at a time, at progressively higher speeds. After the text is read, the child should answer a question related to the text. Fig. 4(a)(II) and (a)(III) shows the mock-up of the displayed sentence to be read and the final prototype of the Speed Reader activity respectively. Gamification elements were added to the final prototype to increase children’s engagement [e.g., the anteater eating the characters to let them disappear shown in Fig. 4(a)(III)]. Moreover, sentences’ length was adapted to fit tablet screen.

A narrative framework with an avatar (Bianchetto), enemies, and a virtual guide were introduced in all activities of the TSGs. In addition, specific feedback during and at the end of each TSG was provided to summarize the performance, and prizes were given at the end of each activity. These prizes could be used in a shop to buy items to customize the avatar [e.g., the beard and the red hat in Fig. 4(b)(III)]. The co-design of the avatar customization is shown in Fig. 4(b). The initial Sketch on a

Fig. 4. Progressive refinement of ESSENCE functionalities, as described in Section IV-C. Rows, from top to bottom: example of TSGs [(a) Speed reader and (b) the shop to personalize the main character], example of Teleconsultation [(c) reading test—child view and (d) reading test—clinician view], and example of Social Activities [(e) jigsaw puzzle]. Columns: I) Sketch (brainstorming results, physical objects); II) Mock-ups; III) Final prototype. The English translation of the interfaces is available in Supplementary Material S3.

blackboard [see Fig. 4(b)(I)] was produced by children, starting from their brainstorming, and evolved toward the final prototype, which allowed for customizing clothes and appearance [see Fig. 4(b)(III)].

The development of PAs followed the same progression even if not reported in Fig. 4. Psychomotricists and children were involved to adjust relevant parameters, such as video duration and timing of the interaction.

The first testing round of TSGs and PAs occurred in June 2021 (Sections 3-TRAIN, Iteration 1, in Table II). Children tried 12 *Activities* (the first nine reading games, the first two writing games, and the first Math game listed in Supplementary

TABLE II
USABILITY AND SATISFACTION DURING ITERATIVE CO-DESIGN (SEE SECTION IV-C)

Iteration	Subjects	Item	Range	Median [IQR]
Webapp for Professionals: Activity Planner and Dashboard: **1-PLAN and 4—CHECK**				
1: Sep. 22	8 teachers (all F)	I was able to easily learn how to use the interface.	0-**4**	3.5 [1]
		The interface responds to my commands.	0-**4**	3 [1]
		The navigation to and the usage of the dashboard and the user's dossier are simple.	0-**4**	3.5 [1]
		The interface for the creation of a didactic plan is clear.	0-**4**	3.5 [1]
		The system quickly highlights any error (e.g., the omission of compulsory fields).	0-**4**	4 [0.25]
		The system always highlights errors in a comprehensible way.	0-**4**	3.5 [1]
Serious Games for Training : **3-TRAIN**				
1: Jun. 21	7 children (3 first-graders, 4 second-graders; 4 F, 3 M; 6-8 y.o.)	Was the activity easy?	0-**4**	3.5 [1.75]
		Was the activity fun?	0-**4**	4 [0.75]
		Was the activity boring?	**0**-4	0 [0]
2: Oct. 21	30 children (13 second-graders, 17 third-graders; 15 F, 15 M; 6-8 y.o.)	Was the activity easy?	0-**4**	3 [2]
		Was the activity fun?	0-**4**	4 [0]
		Was the activity boring?	**0**-4	0 [0]
Psychomotricity Activities : **3-TRAIN**				
1: Jun. 21	7 children (3 first-graders, 4 second-graders; 4 F, 3 M; 6-8 y.o.)	Was the activity easy?	0-**4**	2 [1.5]
		Was the activity fun?	0-**4**	4 [1]
		Was the activity boring?	**0**-4	0 [0]
2: Oct. 21	30 children (13second-graders, 17 third-graders; 15 F, 15 M; 6-8 y.o.)	Was the activity easy?	0-**4**	4 [2]
		Was the activity fun?	0-**4**	4[2]
		Was the activity boring?	**0**-4	0 [0]
Teleconsultation: **5-REPORT**				
1: Sep. 22	7 clinicians (a speech therapist, a psychologist, a medical doctor and 4 child neuropsychiatrists; all F)	SUS	0-**100**	90 [12.5]
		The interface of the tests is easy to use.	0-**4**	4 [0]
		I think the software could be useful during clinical practice.	0-**4**	4 [1]
		I think the software is able to replace an in-person evaluation with sufficient accuracy.	0-**4**	3 [1]
		I think the results interface is well organized and comprehensible.	0-**4**	4 [0.5]
Social Activities : **6-REL**				
1: Jun. 21	7 children (3 first-graders, 4 second-graders; 4 F, 3 M; 6-8 y.o.)	Was the activity easy?	0-**4**	3 [2]
		Was the activity fun?	0-**4**	4 [1]
		Was the activity boring?	**0**-4	0 [0.25]
2: Oct. 21	30 children (13 second-graders, 17 third-graders; 15 F, 15 M; 6-8 y.o.)	Was the activity easy?	0-**4**	4 [2]
		Was the activity fun?	0-**4**	4 [1]
		Was the activity boring?	**0**-4	0 [0]

Range: best score in bold. F = Female; M = Male.

Material S1) and all the PAs and answered the questions as reported in Table II. All the results were positive (median above 3), except for PAs, which were deemed not easy (median [IQR] of 2 [1.5]). Qualitative suggestions for TSGs were analyzed by clinicians to make sure that changes did not alter the main clinical objective of each game. In general, some graphical and usability improvements were made. Moreover, the adaptation of the difficulty of each game, based on children's performance in previous sessions, was introduced to avoid frustration, while keeping the games challenging.

A second testing round occurred in October 2021 (Sections 3-TRAIN, Iteration 2 in Table II), with children from a different school. Children tried all the 18 games listed in Supplementary Material S1 and watched the PAs. When asked about potential improvements, children expressed the desire to play more levels in the TSGs and more games. Noticeable improvements were observed for PAs (see Table II). This reflects that the correct duration of videos was finally achieved.

4) 5-REPORT: Teleconsultation: A preliminary phase of screening for candidate tests was performed, considering their paper version as the starting point. For example, the paper version of the reading test De.Co.Ne [29] presented three columns of words to be read, as in Fig. 4(c)(I)—an extract of the child's sheet, and Fig. 4(d)(I)—an extract of the clinician's sheet, with indications of the number of syllables and frequency of use of each word by means of symbols, and space for scoring time and errors. The test was initially implemented as such [see Fig. 4(c)(II) and (d)(II)]. However, three issues were raised by clinical partners during the first co-design iteration: in the child interface: 1) columns should be presented one at a time, as in the paper version of the test, where the other columns are hidden by the clinician with a sheet; 2) each column should be scored separately; and 3) the font size should be the same as the fonts printed on paper. Several mock-ups were provided. In the end, three different screens containing one column each were implemented [see Fig. 4(c)(III)] with separate timers for each screen. Moreover, Fig. 4(e)(III) shows a further improvement of the Teleconsultation functionality, which provided scoresheets for an automatic conversion from raw scores to age-matched percentiles. More details on the development of the Teleconsultation functionality can be found in [40]. To address copyright issues, an agreement was signed with Giunti Psychometrics S.r.l., an international leader in neuropsychological assessment and the owner of the original Italian version of the implemented tests.

To test the usability of the Teleconsultation functionality, a testing session was organized in September 2022 (see Table II, 5-REPORT section). The software was briefly explained to the clinicians. Then, they were asked to carry out one of the proposed tests, with one of the developers playing the role of the child. The available tests were: 1) a sublexical reading test (PLS [41]); 2) a words and nonwords reading test (De.Co.Ne [29]); and

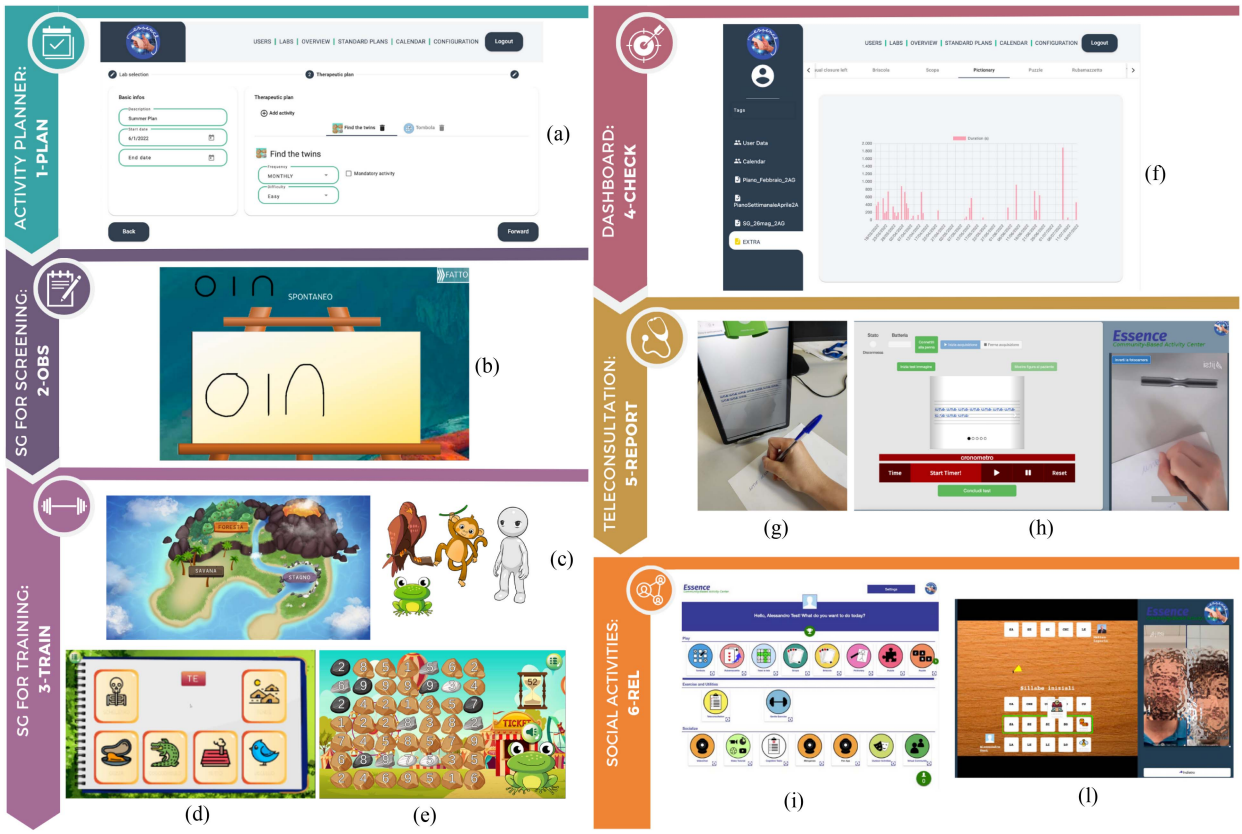

Fig. 5. (a)–(l) Result of the iterative co-design, showing the interfaces of the different functionalities described in the Output paragraph of Section IV-C. An English translation of the interfaces is available in Supplementary Material S4.

3) a words and nonwords writing test (DDE-2 [42]). All of these tests were carried out on the tablet. For the writing tests (DDE-2, words and nonwords) the S-Pen was used to write on the tablet touchscreen. Preliminary tests showed that users found this tool intuitive and useful: no further modification was required.

After this session, an additional writing test was developed, i.e., the BVSCO-3 [30]. This test was more complex because of the elaborate setup, as described in [40]. The child had to write on a sheet of paper. To allow the clinician to see what the child was writing, the tablet was positioned vertically on a tablet stand next to the sheet of paper, with a mirror-cam placed on the front-facing camera. At the end of the test, the user was asked to take a picture of the sheet, for the records.

5) 6-REL: SAs: Classical social games inspired the implementation of SAs [e.g., the jigsaw puzzle in Fig. 4(e)(I)]. Some of them were refined starting from [35] [see Fig. 4(e)(II)] and through interaction with clinicians to fit children's needs, e.g., words for Draw-and-Guess were chosen by psychologists to be easily represented by children; the Puzzle game was enriched with cartoon-like images and transparent template (Fig. 4(e)(III), the lady's image in the background suggests the location of the puzzle pieces). In addition, the lower part of the board included different bars (one per player) representing the level of puzzle completion to allow players to view everyone's performance during the competitive game [see Fig. 4(e)(III)]. Three new activities with an educational purpose were designed and developed, i.e., Bingo of Words, Tessilatela (weave the net), and Ruba Mazzetto (steal the deck). All the activities are detailed in Supplementary Material S1.

Iterative testing was performed during June and October 2021 with the same group of children who tested TSGs and PAs. The games with an educational purpose were tried in the October session only, as they were not available yet in the June session. Improvements were observed following the refinements between the tests (Table II, 6-REL section).

6) Integrated Platform: The iterative testing led to technical and functional improvements of the platform as a whole. During trials conducted in October, the system was tested under heavy workloads, as 10–15 children used several functionalities simultaneously, which required a stable Internet connection. It was observed that the current Authentication server could not handle the volume of requests, so its capacity was increased. To further reduce the amount of data transferred over the Internet, the CBAC was equipped with a caching mechanism that stored previously downloaded resources locally, reducing the need to be downloaded again, thus reducing the bandwidth requirement.

Output of the iterative co-design: The final result of the iterative co-design phase was the final prototype, which communicates and interacts with the users as a unique system that comprehensively addresses learning needs. Fig. 5 summarizes the different interfaces of the ESSENCE system used throughout the various phases of the SLD screening process. Fig. 5(a) shows the interface of the Activity Planner that allows the user to

select, for each activity, the configuration parameters, the level of difficulty, and the priority of execution (e.g., Compulsory or Suggested). Fig. 5(b) shows the interfaces of the SSGs specifically for the *Activity* Copy Sequence, which asks the child to copy the symbols printed in the upper left corner in the modality printed above the canvas (here, spontaneous) [32]. As for TSGs, the Isle of Learning (the access point of all TSGs activities) is shown, together with the narrative framework's characters—the hawk for reading, the monkey for writing, and the frog for calculation, who help Bianchetto (Little White, the main character) find its colors [see Fig. 5(c)]. Then, examples of reading (Fig. 5(d), Syllable game) and calculation (Fig. 5(e), Find the twins) *Activities* are shown. As for reading, the child needs to indicate the picture starting with the syllable in the upper part of the screen (here, TE); as for calculation, the frog asks the child to press the stones where a specific number is printed (here, 6). Fig. 5(f) shows an example of the Dashboard, with red bars indicating the performance for the activity selected on the bar on the left. As for the Teleconsultation, the patient's [see Fig. 5(g)] and clinicians' [see Fig. 5(h)] screens of the writing test BVSCO-3 [30] are shown. The patient sees on the tablet screen what needs to be written and is vocally guided by the clinician, who sees the writing hand thanks to the mirror cam mounted on the tablet front-facing camera. Other elements on the clinician's screen are useful for setting up the test, like the timer. As for SAs, the CBAC interface [see Fig. 5(i)]—with colorful buttons to choose the *Activities*—and the Bingo of words [see Fig. 5(l)]—where children uncover the card with the initial or final syllable corresponding to the one chosen by the teacher—are shown.

Videos of the final prototypes of the *Functionalities* and *Activities* are available in a repository [43].

D. Field Testing

A total of 21 first- and 45 second-graders participated in field testing: 30 were female and 36 were male, 7.3 $\pm$ 0.6 years old, with intelligence and school abilities within the normal range. The only domain falling below normality was graphomotor fluency [30], which was below two standard deviations for both first- and second-graders. Eight teachers from recruited children classes, all female, participated, along with four female clinicians who were involved in testing Teleconsultation.

1) Functionalities at the Point of Need: The observation proposed by ESSENCE specifically targeted the handwriting domain, and it was compared to a clinical gold standard [30] to evaluate its capability to predict learning difficulties. To identify children with difficulties in handwriting, the SSGs were scheduled through the Activity Planner as compulsory *Activities* at the three predefined time points (initial, interim, and final evaluation). A machine learning model was built leveraging features extracted by SSGs during initial and interim evaluation as predictors, and the handwriting speed test [30] collected during the final evaluation as target variable. It emerged that a logistic classifier was capable of predicting children's handwriting abilities with an area under the precision–recall curve of 0.95 [44].

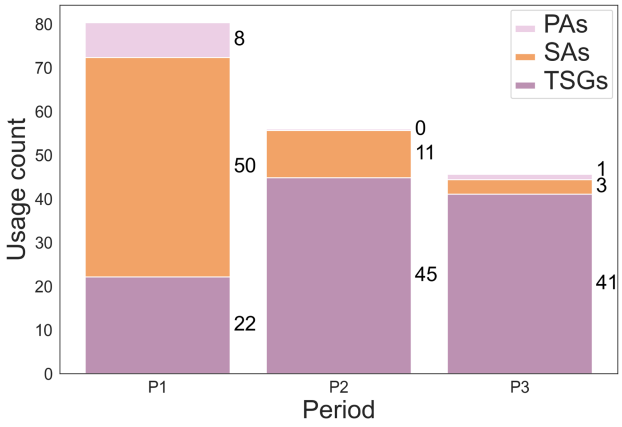

Fig. 6. Total usage of the ESSENCE platform during the field testing across periods P1, P2, and P3, categorized by type of functionality, and normalized by the number of active users in each period.

Testing of Teleconsultation is reported in [40]. The first session included one reading test and one writing test administered via the tablet with its pen. 20 children were involved (ten second- and ten third-graders; ten females and ten males; aged 6.5–8.5 years old). The P-SUS score achieved was 87.5 [12.5]. In the second session, the BVSCO-3 handwriting test was performed in the setting described in Section IV-C4 and shown in Fig. 5(g) and (h), with pen and paper, a mirror cam, and the request to take a picture of the written product. Eighteen children were involved (eight second- and ten third-graders; eight females and ten males; aged 7–9 years old). The P-SUS score achieved was 78 [17.5]. The P-SUS for the Teleconsultation was lower when such a complex setup was proposed than the configuration with tablet and S-pen only. However, it was always well above the acceptability threshold of 68 [45].

2) Continuous Usage of the Platform: None of the participants voluntarily dropped out due to lack of satisfaction. Instead, five children moved to other schools and some teachers retired at the end of P1. Compliance was very good. The median usage [IQR] of the platform during the whole field testing was 16.5 [33.25] min per week. During the school year of the deployment (P1), the platform was accessed for a median of approximately 24.5 [3.4] min per week. During P2 and P3, the platform was accessed for 12.6 [24.5] and 10.9 [5.0] min per week, respectively. Fig. 6 shows the number of sessions normalized by the number of users, divided by TSGs, PAs, and SAs. The number of weeks during which at least five sessions were present for all users was 36 weeks out of 45, i.e., 80% of the field testing period, which also included summer vacation. This implies that the usage was continuous in the whole time frame. During P1, SAs were the most used functionality, as they included the videochat functionality, which served as the starting point of the sessions teachers organized to help children familiarize themselves with the system. In the long term, TSGs became the most used functionality. Indeed, gamification elements added during the field testing—such as the in-game shop co-designed with children—contributed to increasing children's commitment [46].

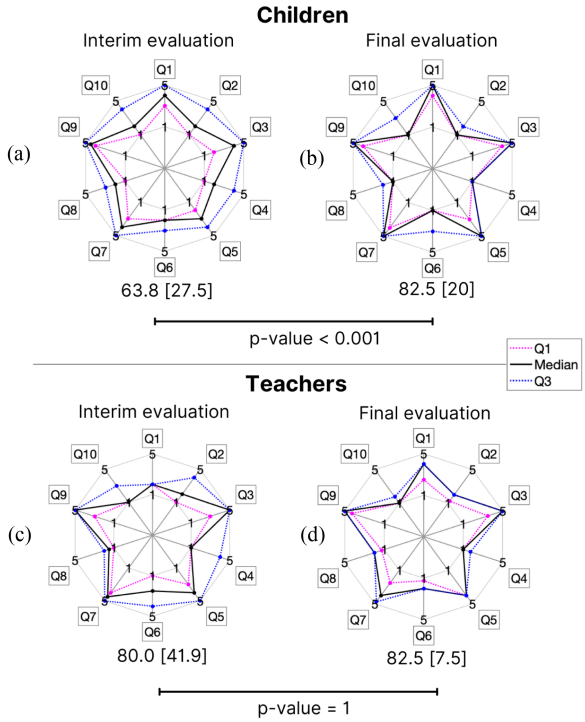

Fig. 7. SUS scores: (a) interim evaluation, children, (b) final evaluation, children, (c) interim evaluation, teachers, and (d) final evaluation, teachers. The score for the ten SUS questions are reported on the axes. Good results form a star pattern, as positive and negative questions alternate. Solid black lines indicate the median; dotted lines represent the first (magenta) and third (blue) quartiles. Below each graph, the median and IQR of the total score, along with the *p*-value from the Wilcoxon test.

TABLE III
SATISFACTION RESULTS ON SINGLE FUNCTIONALITIES

	Fun			**Useful**		
	interim	*final*	*p-value*	*interim*	*final*	*p-value*
TSGs	3 [2]	4 [0]	**<0.001**	2 [2]	4 [1]	**<0.001**
PAs	3 [1]	3 [2]	0.156	3.5 [1]	3 [2]	**0.016**
SAs	3 [1]	4 [1]	0.139	3.5 [1]	3 [2]	**0.001**

Significant differences are shown in bold.

Fig. 7 shows the results of the SUS and P-SUS questionnaires administered in the interim and final evaluation to both children and teachers. 82% of children rated the system above 70 points in the P-SUS, which can be considered a good result. Significant improvements ($p < 0.001$) were observed between the two time points [see Fig. 7(a) and (b)]. The median SUS score for teachers exceeded the acceptability threshold at both time points [see Fig. 7(c) and (d)], as well. However, the question regarding their willingness to use the system frequently did not receive positive ratings.

Table III reports children's results for each *Functionality* during the field testing in terms of SAT. Considering 3 or 4 as positive ratings in a scale from 0 to 4, SAs were rated as fun by 77% of them; TSGs were rated fun by 91% of children and useful by 75% of them. The system overall was considered pleasant by 92% of children; 92% of them were satisfied with the experience and 79% of them found it useful. Also, teachers found the experience fun (4 [1]) and useful (4 [0.5]), and they were satisfied with the experience (4 [1]). 100% of them found the field testing experience to be enjoyable.

V. DISCUSSION

The treatment of SLDs is of primary importance for the future of children, as literacy is a social determinant of health [47]. However, the screening process still needs to be optimized. In this work, we presented ESSENCE, a holistic platform that facilitates the management of learning difficulties while fostering the alliance between families, schools, and clinicians.

ESSENCE allows users to plan class or individual activities with an Activity Planner, by adapting activity parameters based on each child's needs. Existing systems usually focus on only children/patients with difficulties only (e.g., [9]). Instead, involving peers in the training is more inclusive and easier to manage than organizing one-to-one or small-group activities.

ESSENCE allows for identifying learning difficulties through SSGs. The example proposed investigates alterations typical of dysgraphia, starting from drawing instead of writing. Other solutions usually evaluate handwriting (e.g., [48]), which is mastered years later than ESSENCE's target age. Such a preventive approach is one of ESSENCE's strengths, allowing for early intervention at the stage when effectiveness is highest [17], but it is still too early for a formal diagnosis [2]. As SSGs rely on neurophysiological principles, they also provide insights into the underlying reasons for the difficulty they predict, thanks to explainable artificial intelligence (AI) techniques [33].

ESSENCE allows for training children both individually, with TSGs and PAs, and collectively, with SAs. The preventive approach mentioned earlier is shared with these activities, e.g., visual attention and phonological awareness are addressed instead of reading [49]. Comparable solutions [10] usually overlook psychomotricity aspects, relational aspects, and executive functions, which are instead crucial for the development of academic skills [50].

ESSENCE also offers the possibility to review results through Dashboards. As the system includes all the phases of the screening process, data collected during the observation can be leveraged as a starting point for the training, which is then made adaptive based on previous results. In this way, a data-driven approach allows for shaping and personalizing the intervention to each individual's need.

Finally, ESSENCE offers a Teleconsultation functionality, which integrates synchronous evaluation with test performance. It does not simply replicate in-presence tests, as usually done by similar applications [9], [11]. In fact, it enriches the original paper-based tests with quantitative data—such as the trace written during handwriting tests [40]—which plays a crucial role in diagnosing SLDs [2]. Teleconsultation is such a valuable functionality that Giunti Psychometrics, a leader in neuropsychological assessment with tests available in 28 languages, signed an agreement with the ESSENCE Consortium to develop a digital version of its tests.

Supplementary Material S5 provides a functional comparison with other existing solutions, with a focus on the different phases of the process of screening of SLDs, and it is clear that a complete

solution is still lacking. ESSENCE's added value is not only the constellation of its functionalities, but the creation of a protected ecosystem in which it is possible to centralize children's data from all the SLD screening process phases. From a technological perspective, this degree of integration will allow the introduction of AI to provide notifications, alerts, and feedback to the relevant users at the point of need. For example, when Serious Games were employed to predict learning difficulties, the results achieved were promising, with an accuracy of 0.71 with the Letter Tracing game [38] and an area under the precision–recall curve of 0.95 with the SSGs [44]. From the users' perspective, ESSENCE also implements the educational alliance that is key for the early screening of SLDs. Indeed, teachers, clinicians, and families can cooperate to perform a first step to distinguish learning delays from SLDs.

To better adhere to the needs of these actors, ESSENCE's development was driven by co-design principles [13], [23]. Good results were achieved during iterative testing, and they were confirmed after prolonged real-world usage lasting one year. The results on compliance are promising, with users being active for 80% of the weeks of the field testing. However, screen time was not excessive (16.5 [33.25] min per week), as serious games were designed to make didactic activity fun without inducing addiction. The increase in time devoted to activities that can be performed alone (TSGs) during the field testing suggests that the exploitation of all the functionalities should be mediated by teachers, who encourage and coordinate multiplayer activities as well. This is consistent with the original idea behind ESSENCE, which was thought to be a support to school activities.

Usability improvements were noticeable in children, from a median of 63.8 [27.5] during the interim evaluation to 82.5 [20] during the final evaluation. This was possible because the system was never frozen. ESSENCE's modular structure will allow continuous improvements. TSGs can include other games, e.g., the Tachistoscope, which significantly improved reading abilities of second graders after only three weeks of training [51]. Moreover, different tools can be proposed to observe difficulties and to perform teleconsultation. On this topic, after the end of the field testing, a massive data collection campaign was conducted leveraging a smart ink pen to produce normative data for handwriting screening [52].

A limitation of the field testing was that children were left free to choose from a rich set of activities, which resulted in a limited amount of data for each activity. In the future, structured data collection will allow for building AI algorithms, providing alerts on anomalous behaviors, and automatically suggesting children who need a teleconsultation.

VI. Conclusion

In this article, we provided a novel platform to support the learning process and facilitate the screening of learning difficulties through the use of technology. Although the ESSENCE platform was created to address the need for remote solutions during the COVID-19 pandemic, its usefulness extends far beyond this crisis. Indeed, addressing SLDs early costs up to 2000% less than the downstream impact of the disease if ignored [53]. By providing prompt assistance to children and improving access to health services when necessary, ESSENCE will bring significant benefits to our communities.

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Authors' contribution: Project coordination and funding: SFe. Theoretical development and protocol definition: FL, SFo, NAB, CT, SFe. Focus groups and clinical design: MB, SFr, SB, SFo. Activity planner and Dashboard development: LM Serious games development: LGD, CP. Teleconsultation, CBAC and Social activities development: NB, ML, MA. Architecture and ESSENCE Manager development: AS, AK. Data acquisition: LGD, CP, ST, MM, FL, NB, ML, MA, SFo. Data analysis: LGD, CP, ST, MM, FL. Manuscript writing: LGD, CP. Manuscript revision and approval: All authors.

References

[1] A. Overvelde and W. Hulstijn, "Handwriting development in grade 2 and grade 3 primary school children with normal, at risk, or dysgraphic characteristics," *Res. Devlop. Disabilities*, vol. 32, no. 2, pp. 540–548, 2011.

[2] Guideline on the Management of Specific Learning Disabilities (Linea Guida Sulla Gestione dei Disturbi Specifici Dell'apprendimento), Italian Ministry of Health, Rome, Italy, 2022.

[3] M. McCloskey and B. Rapp, "Developmental dysgraphia: An overview and framework for research," *Cogn. Neuropsychol.*, vol. 34, nos. 3/4, pp. 65–82, 2017.

[4] Diagnostic and Statistical Manual of Mental Disorders: DSM-5, American Psychiatric Association, Washington, DC, USA, 2013.

[5] Italian Ministry of Instruction University and Research, "Law october 8th, 2020, n. 170. new rules on specific learning disabilities in schools. (legge 8 ottobre 2010, n. 170. nuove norme in materia di disturbi specifici di apprendimento in ambito scolastico)," in *Gazzetta Ufficiale* no. 244, 18 Oct. 2010.

[6] UNICEF, "COVID-19: Are children able to continue learning during school closures?," 2020. Accessed: Dec. 27, 2024. [Online]. Available: https://data.unicef.org/resources/remote-learning-reachability-factsheet/

[7] C. Termine et al., "Investigating the effects of COVID-19 lockdown on Italian children and adolescents with and without neurodevelopmental disorders: A cross-sectional study," *Curr. Psychol.*, vol. 42, pp. 8615–8631, 2023.

[8] M. K. Colvin, J. Reesman, and T. Glen, "Reforming learning disorder diagnosis following COVID-19 educational disruption," *Nat. Rev. Psychol.*, vol. 1, no. 5, pp. 251–252, 2022.

[9] "Anastasis." Accessed: Jan. 15, 2025. [Online]. Available: https://www.anastasis.it/

[10] "Paperbox." Accessed: Dec. 27, 2024. [Online]. Available: https://www.paperbox.health/

[11] "Ticuro." Accessed: Dec. 27, 2024. [Online]. Available: https://www.reply.com/ticuro-reply/

[12] J. Carroll et al., "Current understanding, support systems, and technology-led interventions for specific learning difficulties," UK Government report, Council for Science and Technology, London, UK, 2020.

[13] L. J. E. van Gemert-Pijnen et al., "A holistic framework to improve the uptake and impact of ehealth technologies," *J. Med. Internet Res.*, vol. 13, no. 4, 2011, Art. no. e1672.

[14] E. B.-N. Sanders and P. J. Stappers, "Co-creation and the new landscapes of design," *Co-Design*, vol. 4, no. 1, pp. 5–18, 2008.

[15] Monitoring and Evaluating Digital Health Interventions: A Practical Guide to Conducting Research and Assessment, World Health Organization, Geneva, Switzerland, 2016.

[16] "Essence—Empathic platform to personally monitor, stimulate, enrich, and assist elders and children in their environment," Accessed: Dec. 27, 2024. [Online]. Available: https://cordis.europa.eu/project/id/101016112/en

[17] M. Kadar, F. Wan Yunus, E. Tan, S. C. Chai, N. A. RazaobRazab, and D. H. M. Kasim, "A systematic review of occupational therapy intervention for handwriting skills in 4–6 year old children," *Aust. Occup. Ther. J.*, vol. 67, no. 1, pp. 3–12, 2020.
[18] A. Tong, P. Sainsbury, and J. Craig, "Consolidated criteria for reporting qualitative research (COREQ): A 32-item checklist for interviews and focus groups," *Int. J. Qual. Health Care*, vol. 19, no. 6, pp. 349–357, 2007.
[19] I. McLafferty, "Focus group interviews as a data collecting strategy," *J. Adv. Nurs.*, vol. 48, no. 2, pp. 187–194, 2004.
[20] R. A. Krueger, *Focus Groups: A Practical Guide for Applied Research*. Newbury Park, CA, USA: Sage, 2014.
[21] V. Braun and V. Clarke, "Using thematic analysis in psychology," *Qual. Res. Psychol.*, vol. 3, no. 2, pp. 77–101, 2006.
[22] I. L. Bongers, D. C. Buitenweg, R. E. Van Kuijk, and C. Van Nieuwenhuizen, "I need to know: Using the CeHRes roadmap to develop a treatment feedback tool for youngsters with mental health problems," *Int. J. Environ. Res. Public Health*, vol. 19, no. 17, 2022, Art. no. 10834.
[23] L. Van Velsen, J. Wentzel, and J. E. Van Gemert-Pijnen, "Designing ehealth that matters via a multidisciplinary requirements development approach," *JMIR Res. Protoc.*, vol. 2, no. 1, 2013, Art. no. e2547.
[24] J. Brooke et al., "SUS—A quick and dirty usability scale," *Usability Eval. Ind.*, vol. 189, no. 194, pp. 4–7, 1996.
[25] J. Baumgartner, N. Frei, M. Kleinke, J. Sauer, and A. Sonderegger, "Pictorial system usability scale (P-SUS) developing an instrument for measuring perceived usability," in *Proc. CHI Conf. Hum. Factors Comput. Syst.*, 2019, pp. 1–11.
[26] K. R. Fowler, "Introduction to good development," in *Developing and Managing Embedded Systems and Products*, K. R. Fowler and C. L. Silver, Eds. Oxford, U.K.: Newnes, 2015, ch. 1, pp. 1–38.
[27] J. Raven, "Raven progressive matrices," in *Handbook of Nonverbal Assessment*. Berlin, Germany: Springer, 2003, pp. 223–237.
[28] L. G. Weiss, D. H. Saklofske, A. Prifitera, and J. A. Holdnack, *WISC-IV Advanced Clinical Interpretation*. New York, NY, USA: Elsevier, 2006.
[29] S. Franceschini, S. Bertoni, L. Ronconi, M. Molteni, S. Gori, and A. Facoetti, "Batteria de. co. ne. per la lettura. strumenti per la valutazione delle abilità di lettura nelle scuole primarie," *Dislessia*, vol. 13, pp. 319–347, 2016.
[30] C. Cornoldi, A. M. Re, and P. E. Tressoldi, *BVSCO-2–Batteria per la Valutazione Clinica Della Scrittura e della Competenza Ortografica (Battery for the Clinical Evaluation of Handwriting and Orthographic Competence)*. Florence, Italy: Giunti Psychometrics, 2013.
[31] C. Cornoldi, D. Lucangeli, and M. Bellina, *Test for Calculation Abilities and Problema Solving (Test AC-MT 6-11-Test di valutazione delle abilità di calcolo e soluzione di problemi-NUOVA EDIZIONE)*. Trento, Italy: Edizioni Erickson, 2012.
[32] L. G. Dui et al., "A tablet app for handwriting skill screening at the preliteracy stage: Instrument validation study," *JMIR Serious Games*, vol. 8, no. 4, 2020, Art. no. e20126.
[33] L. G. Dui et al., "Identification and characterization of learning weakness from drawing analysis at the pre-literacy stage," *Sci. Rep.*, vol. 12, no. 1, 2022, Art. no. 21624.
[34] E. Lomurno, L. G. Dui, M. Gatto, M. Bollettino, M. Matteucci, and S. Ferrante, "Deep learning and procrustes analysis for early dysgraphia risk detection with a tablet application," *Life*, vol. 13, no. 3, 2023, Art. no. 598.
[35] M. Luperto et al., "Integrating social assistive robots, IoT, virtual communities and smart objects to assist at-home independently living elders: The MoveCare project," *Int. J. Social Robot.*, vol. 15, pp. 517–545, 2023.
[36] L. G. Dui, F. Lunardini, M. Matteucci, and S. Ferrante, "Play-draw-write: Usability and acceptance of a tablet app for the early screening of handwriting difficulties in kindergartners," *in Proc. Nat. Congr. Bioengi. Proc.*, 2020, pp. 1–4.
[37] J. C. Ziegler and U. Goswami, "Reading acquisition, developmental dyslexia, and skilled reading across languages: A psycholinguistic grain size theory," *Psychol. Bull.*, vol. 131, no. 1, pp. 3–9, 2005.
[38] L. G. Dui et al., "Letter tracing: A serious game to teach handwriting and assess proficiency through machine learning," in *Proc. 46th Annu. Int. Conf. IEEE Eng. Med. Biol. Soc.*, 2024, pp. 1–4.
[39] I. Chiari and T. De Mauro, "The new basic vocabulary of Italian: Problems and methods," *Rivista di statistica applicata/Italian J. Appl. Statist.*, vol. 22, no. 1, pp. 21–35, 2012.
[40] L. G. Dui et al., "Co-design of a remote evaluation tool for handwriting disorders," in *Proc. Int. Conf. Neurorehabil.*, 2024, pp. 319–323.
[41] G. Calgaro, E. Toffalini, and C. Cornoldi, "La prova di lettura sublessicale–PLS per la valutazione delle abilità di lettura di bambini di prima primaria," *Dislessia*, vol. 15, no. 2, pp. 209–224, 2018.
[42] G. Sartori, R. Job, and P. E. Tressoldi, *Batteria per la Valutazione Della Dislessia e Disortografia Evolutiva [Test Battery for the Assessment of Developmental Dyslexia and Dysorthographia]*. Florence, Italy: Giunti Organizzazioni Speciali, 2007.
[43] "Functionalities Video Repository." [Online]. Availaible: https://doi.org/10.5281/zenodo.15131801
[44] L. G. Dui et al., "Serious games for a technology-enhanced early screening of handwriting difficulties," in *Proc. IEEE EMBS Int. Conf. Biomed. Health Informat.*, 2023, pp. 1–4.
[45] J. R. Lewis, "Measuring perceived usability: The CSUQ, SUS, and UMUX," *Int. J. Hum.–Comput. Interact.*, vol. 34, no. 12, pp. 1148–1156, 2018.
[46] C. Piazzalunga et al., "Co-design of a points-based reward system to boost motivation in children and improve adherence to learning serious games," *in Proc. Nat. Congr. Bioengi.*, 2023, pp. 1–4.
[47] A. Darren, D. Nancy, S. Stacey, and P. Michael, "Literacy and health outcomes: A systematic review of the literature," *J. Gen. Intern. Med.*, vol. 19, no. 2, pp. 1228–1239, 2004.
[48] "Dynamilis." Accessed: Dec. 27, 2024. [Online]. Available: https://dynamilis.com/
[49] C. Piazzalunga, L. G. Dui, C. Termine, M. Bortolozzo, M. Matteucci, and S. Ferrante, "Investigating visual perception impairments through serious games and eye tracking to anticipate handwriting difficulties," *Sensors*, vol. 23, no. 4, 2023, Art. no. 1765.
[50] S. Graham, K. R. Harris, and N. Olinghouse, "Addressing executive function problems in writing," in *Executive Function in Education: From Theory to Practice*. New York, NY, USA: Guilford Press, 2007, pp. 216–236.
[51] C. Piazzalunga et al., "Evaluating the efficacy of a serious game in enhancing word reading speed," in *Proc. 17th Eur. Conf. Games Based Learn.*, vol. 17, no. 1, 2023, pp. 523–530.
[52] S. Toffoli et al., "Digital characterization of primary school pupils' handwriting with a sensorized ink pen," in *Proc. 46th Annu. Int. Conf. IEEE Eng. Med. Biol. Soc.*, 2024, pp. 1–4.
[53] Boston Consulting Group, "The economic impact of dyslexia," pp. 1–37, 2020.

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