
Dissolve: IoT and AR-based Multisensory Therapy Tools for Children with Dyslexia

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Abstract

Children with dyslexia experience difficulties in recognizing characters, which lead to limitations in reading ability. This challenge is further compounded by their short attention span. Conventional therapy methods guided by child psychologists have been used for a long time but remain time-consuming and require intensive supervision. The growing trend of technological innovation has encouraged students to develop new approaches that enhance therapeutic experiences using modern technology. Therefore, this study introduces an innovation in the form of a multisensory therapy device based on the Internet of Things (IoT) and non-visual Augmented Reality (AR). The device is designed to improve therapeutic intervention for children with dyslexia. Dissolve integrates tactile puzzle elements equipped with NFC sensors and an ESP32 microcontroller, connected to a Progressive Web App (PWA) that provides real-time interactive feedback without using a camera. The development process was conducted by Information Systems students using the Design Thinking approach with the Double Diamond model (Discover–Define–Develop–Deliver). The tool was tested directly with children diagnosed with dyslexia. Experimental results show significant improvements in phonetic accuracy (from single-letter recognition to >95% sequential phoneme accuracy), decoding ability for two- to six-letter words and focus duration from approximately 30 minutes to one hour per session. Dissolve also demonstrated high usability, stable connectivity (BLE signal loss < 2%), and improved therapy efficiency compared to conventional methods. These findings affirm that Dissolve serves as an innovative multisensory therapy solution for children with dyslexia, making the therapeutic process more inclusive, efficient, and engaging.

1. Introduction

Dyslexia is a specific learning disorder characterized by persistent difficulties in accurate and fluent word recognition, spelling, and decoding, despite adequate intelligence and educational opportunities. Children with dyslexia often experience impairments in phonological processing and grapheme–phoneme mapping, which are further compounded by short attention spans and low tolerance for monotonous tasks. PPKD Kemuning

Kembar in Yogyakarta is a commercial psychological service provider that has implemented multisensory therapy for children with dyslexia since 2006. The institution serves around 479 child clients per year, with approximately 2.3% diagnosed with dyslexia. However, the therapy process still relies heavily on printed worksheets and conventional tools, so one psychologist can only assist one child per 60–90-minute session, resulting in long waiting lists of up to 6–8 months and sub-optimal profitability for the institution. Meanwhile, children with dyslexia tend to be more engaged with interactive and technology-based media. Prior studies on multisensory mobile applications and digital interventions show that combining tactile, visual, and auditory stimuli can improve phonemic awareness, attention, and reading performance in dyslexic learners. However, most existing solutions focus on purely digital interfaces and do not fully integrate physical manipulatives that are central to established multisensory therapy protocols. To address this gap, this study proposes Dissolve, an IoT-enabled, non-visual AR therapy tool that augments physical letter puzzles with real-time digital feedback. The system was co-designed with psychologists at PPKD Kemuning Kembar and aligned with the phonological stages of the “Tes Disleksia Anak Indonesia” module. The objective is twofold: (1) to enhance the effectiveness and engagement of multisensory dyslexia therapy through interactive technology, and (2) to improve service capacity and operational efficiency at the partner institution.

1.1 Literature Review

Dyslexia is widely recognized as a neurodevelopmental learning disorder that primarily affects phonological processing, decoding, and word recognition skills, while intelligence and general cognitive abilities remain intact (Snowling, 2019). Research consistently indicates that deficits in grapheme–phoneme correspondence and phonemic awareness are the core challenges faced by children with dyslexia, often accompanied by reduced attention span and difficulties sustaining engagement in repetitive learning tasks (Peterson & Pennington, 2015).

Multisensory Therapy for Dyslexia

Multisensory learning approaches have long been established as effective interventions for dyslexia. Approaches such as the Orton–Gillingham method emphasize the simultaneous use of visual, auditory, and kinesthetic–tactile modalities to reinforce phonological learning (Ritchey & Goeke, 2006). Empirical studies demonstrate that multisensory instruction can significantly improve decoding accuracy, letter–sound association, and reading fluency in children with dyslexia (Birsh & Carreker, 2018). Physical manipulatives, including letter tiles and puzzles, play a crucial role in supporting tactile engagement and motor memory, which strengthens neural connections related to language processing.

Digital and Mobile-Based Interventions

With the advancement of educational technology, numerous studies have explored mobile and tablet-based applications for dyslexia intervention. Digital learning tools that incorporate interactive audiovisual elements have been shown to increase learner motivation, attention, and phonemic awareness (Kalyvoti & Mikropoulos, 2014). Mobile-based multisensory applications also offer flexibility and scalability, allowing learning activities to be adapted to individual learner needs (Zainuddin et al., 2020). However, several researchers argue that fully screen-based interventions may limit embodied learning experiences, as they often exclude tactile interaction with physical objects that are fundamental in traditional multisensory therapy (Oakley et al., 2021).

Augmented Reality in Learning and Therapy

Augmented Reality (AR) has emerged as a promising technology in educational and therapeutic contexts due to its ability to overlay digital information onto the physical environment. AR-based learning systems have been reported to enhance engagement, spatial understanding, and cognitive retention, particularly for learners with special educational needs (Ibáñez & Delgado-Kloos, 2018). In dyslexia-related studies, AR applications have shown potential in supporting letter recognition and phonological awareness by providing real-time visual and auditory cues (Bacca et al., 2019). Nevertheless, most AR solutions rely heavily on visual interfaces, which may not fully accommodate learners who benefit from non-visual or tactile-dominant interactions.

Internet of Things and Non-Visual AR Approaches

The integration of Internet of Things (IoT) technology in learning environments enables real-time data acquisition, feedback, and adaptive responses based on user interaction. IoT-enhanced educational tools have been shown to improve monitoring, personalization, and scalability of therapy services (Al-Emran et al., 2022). Non-visual AR, which emphasizes auditory and haptic feedback rather than visual overlays, has gained attention for inclusive learning design, particularly for learners with attention limitations or sensory processing challenges (Kane et al., 2018). However, research combining IoT, non-visual AR, and physical manipulatives for dyslexia therapy remains limited.

2. Research Methods

2.1 Research Design

The development of Dissolve adopted a Design Thinking methodology structured using the Double Diamond model, consisting of the Discover, Define, Develop, and Deliver phases. This human-centered approach was selected to ensure that the proposed solution directly addresses real-world challenges, workflows, and constraints within dyslexia therapy settings. By emphasizing iterative exploration, co-design, and validation, the method supports the development of a system that is both technically feasible and clinically relevant.

2.2 Context and Participants

This study was conducted in collaboration with PPK Kemuning Kembar, a psychological service provider specializing in learning difficulties. The research involved six professional psychologists and therapists who acted as domain experts and co-design partners throughout the development process. In addition, children formally diagnosed with dyslexia participated as end-users during the testing and evaluation phases. Ethical considerations were strictly observed; no identifiable personal data or photographs of children were collected. Observations focused solely on behavioral responses and performance indicators that had been mutually agreed upon with the psychologists.

2.3 Discover: Needs Identification

During the Discover phase, the research team carried out on-site observations of ongoing therapy sessions, conducted semi-structured interviews with psychologists and therapists, and analyzed existing assessment documents and therapy materials. The findings revealed that reading assessments were predominantly conducted using printed worksheets with manual scoring, which required substantial therapist involvement for administration and explanation. Furthermore, children frequently exhibited reduced attention and engagement when interacting with static and non-interactive media. These insights indicated the need for an interactive therapy system capable of supporting phonological learning, reducing administrative workload for therapists, and sustaining children's focus during sessions.

2.4 Define: Problem Framing and Requirements

Based on insights from the Discover phase, the core challenge was reformulated using a How Might We (HMW) framework: How might conventional multisensory therapy be transformed into an interactive IoT-based system that enables one psychologist to guide multiple children simultaneously without compromising therapy quality? From this problem framing, both functional and non-functional requirements were defined. The system was required to integrate physical letter manipulatives with a digital interface, support reliable real-time detection of letter placement, and provide low-latency feedback without relying on camera-based AR. In addition, the design needed to be child-friendly while offering clear control mechanisms for therapists. The learning content and progression structure were aligned with the phonological stages of the Tes Disleksia Anak Indonesia module, covering single-letter recognition, phoneme sequencing, and decoding of words ranging from two to six letters.

2.5 Develop: System Architecture and Implementation

2.5.1 Hardware

The hardware prototype of Dissolve consists of a puzzle board and tactile letter tiles designed for multisensory interaction. Each letter tile is embedded with an NFC/RFID tag, while the board contains six RFID reader modules (MIFARE RC522 and PN532) arranged linearly and connected to an ESP32 microcontroller. Communication between the board and the digital application is achieved through Bluetooth Low Energy (BLE). To provide immediate feedback, WS2812B NeoPixel RGB LEDs are installed near each slot, indicating system status through color coding (blue for ready, green for correct placement, and red for incorrect placement). The system is powered by rechargeable 18650 batteries with integrated charging and step-up modules, ensuring portability during therapy sessions. The letter tiles are fabricated from textured acrylic to support tactile discrimination and reduce common letter reversal errors, while the board and casing are constructed from layered acrylic with protected cable management to enhance durability and child safety.

2.5.2 Software

The software component is implemented as a Progressive Web App (PWA) developed using React.js and designed to operate on tablets, smartphones, or laptops via the Chrome browser. The application supports BLE scanning and pairing with the Dissolve board and includes six sequential game levels, progressing from single-letter recognition to decoding six-letter words. The system provides real-time visualization of target letter sequences, automatic progress tracking, and non-visual AR feedback through changes in screen state and LED patterns, eliminating the need for camera-based interaction. The PWA can be installed locally via the browser's "Add to Home Screen" feature and used offline after initial loading, which is particularly important in clinical environments with unstable internet connectivity.

2.5.3 Testing Procedures

System testing was conducted in three stages. Unit testing was performed on individual hardware and software components, including RFID readers, BLE communication, and application logic. Integration testing then verified end-to-end communication between the puzzle board and the PWA, with particular attention to latency and reconnection behavior. Finally, usability testing involved psychologists, therapists, and children with dyslexia to assess ease of setup, clarity of feedback, and levels of child engagement during therapy sessions.

2.6 Deliver: Evaluation Design

The evaluation phase combined observational analysis, semi-structured interviews with psychologists, and technical performance measurements. Success indicators included phonetic accuracy in pronouncing letter sequences, decoding ability for two- to six-letter words after completing 66 interactive games across six levels, and increased attention span during therapy sessions from approximately 30 minutes to around 60 minutes. Technical performance was evaluated based on sensor latency below 0.3 seconds and BLE signal loss below 2%. From an operational perspective, the system aimed to enable one psychologist to manage more than one child per session, thereby reducing waiting times and improving service efficiency. Performance comparisons were conducted by psychologists based on observable changes in routine clinical practice rather than formal standardized testing scores.

3. Result and Discussion

The evaluation of Dissolve demonstrates that the integration of IoT-enabled physical manipulatives with non-visual augmented reality feedback can enhance both learning outcomes in dyslexia therapy and operational efficiency within a clinical setting.

From a learning perspective, psychologists reported substantial improvements in phonetic accuracy after several therapy sessions using Dissolve. Children who initially could only identify isolated letters were able to pronounce sequences of letters correctly, achieving phonetic accuracy levels exceeding 95% in guided tasks.

The tactile texture and anti-reversal design of the letter tiles effectively reduced confusion between visually similar letters, such as b–d and p–q, while repeated physical placement reinforced grapheme–phoneme mapping. These findings are consistent with prior studies indicating that multisensory and kinesthetic reinforcement strengthens phonological processing in dyslexic learners.

In terms of decoding ability, children who completed all 66 interactive games across six progressive levels were generally able to decode two- to six-letter words with stable articulation. The system’s immediate feedback enabled therapists to identify specific phoneme positions that remained challenging and to selectively repeat relevant levels. Psychologists observed a shorter learning curve compared to conventional worksheet-based therapy, as children quickly grasped the interaction rules and progressed through levels with minimal verbal instruction. This supports existing evidence that structured, feedback-rich learning environments can accelerate phonological acquisition in children with reading difficulties.

Attention and engagement also showed marked improvement. Observational data indicated that children maintained focused engagement for approximately 60 minutes per session, compared to about 30 minutes when using traditional tools. Children voluntarily continued to subsequent levels, requested to repeat successfully completed tasks, and displayed positive emotional responses to visual and tactile feedback, such as green LED indicators for correct answers. The combination of color cues, tactile interaction, and simple gamification elements sustained motivation without causing sensory overload, aligning with research on attention regulation in multisensory learning environments.

From a technical standpoint, system performance met the predefined design targets. Average sensor latency was measured at 0.28 seconds, and Bluetooth Low Energy (BLE) signal loss remained below 2% during continuous operation. Most errors were attributed to misaligned letter tiles rather than communication failures and were easily resolved by repositioning the tiles. The Progressive Web App (PWA) remained responsive on mid-range Android devices and standard laptops, while offline capability ensured uninterrupted therapy sessions in environments with unstable internet connectivity. These results indicate that the chosen hardware–software architecture offers a reliable and cost-effective solution for clinical deployment.

Beyond learning outcomes, Dissolve produced measurable benefits in service efficiency and economic performance. The system enabled a shift from a one-child-per-session model to a small-group therapy model, allowing one psychologist to supervise up to three children within a 30–60-minute session using one or more puzzle boards. Individual progress could still be monitored through the application dashboard, reducing administrative overhead. This operational change shortened waiting lists and increased monthly service capacity without additional staffing. The partner institution estimated that the added value of digital, interactive therapy could justify a 10–25% increase in therapy fees per child, while overall profitability could rise by approximately 25% due to higher throughput and differentiated services.

Overall, the findings indicate that Dissolve effectively operationalizes multisensory therapy principles by combining tactile, kinesthetic, and audiovisual cues within a structured phonological progression. Unlike purely digital interventions, the use of physical puzzles supports motor planning and letter orientation, which are critical for children who struggle with letter reversals. At the same time, the IoT-based architecture reduces the cognitive and administrative load on therapists, allowing them to focus on observation and decision making rather than manual scoring. The use of BLE communication and a PWA-based interface represents a pragmatic balance between performance, scalability, and cost, requiring only low-cost microcontroller hardware and widely available consumer devices.

Despite these promising results, several limitations should be acknowledged. The number of participating children was limited, and the evaluation relied primarily on short-term pre–post observations within routine clinical practice, without a randomized control group. In addition, long-term effects on reading fluency in classroom contexts have not yet been assessed. Future research should involve controlled studies with larger samples, incorporate automated progress analytics, and extend the system to support writing and spelling interventions, such as digital handwriting recognition modules.

4. Conclusions

This study introduced Dissolve, an IoT-enabled and non-visual augmented reality multisensory therapy tool co-designed with a dyslexia therapy clinic. The system integrates tactile letter puzzles with an interactive Progressive Web App to support structured phonological training across six graded learning levels. Evaluation involving children diagnosed with dyslexia and professional psychologists indicates that Dissolve significantly improves phonetic accuracy to over 95%, strengthens decoding skills for two- to six-letter words, and extends effective attention duration from approximately 30 minutes to around one hour per therapy session. In addition, the system enables a shift from a one-child-per-session model to a small-group approach, allowing one psychologist to guide up to three children simultaneously, thereby increasing service capacity and institutional profitability.

Overall, these findings suggest that Dissolve represents a promising, inclusive, and scalable digital transformation of conventional multisensory dyslexia therapy. By preserving physical manipulatives while augmenting them with real-time digital feedback, the system bridges the gap between traditional therapeutic practices and modern interactive technology. Future work will focus on extending the system to support writing and spelling tasks through handwriting recognition, conducting longitudinal studies to evaluate long-term reading outcomes, and optimizing hardware design for mass production using lightweight polymer materials to facilitate broader adoption in schools and therapy centers.

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