

Research Article

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Author for correspondence:

Onok Yayang Pamungkas

✉ onokyayangpamungkas@gmail.com

✉ Affiliation (Universitas Muhammadiyah Purwokerto, Indonesia)

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Augmented Reality as a Tool for Inclusive Education: Improving Literary Psychology Learning for Students with Special Needs

Onok Yayang Pamungkas^{ID}, **Suci Paresti**^{ID}, **Tjaturningsih Rosdiana**^{ID}, **Ika Mustika**^{ID}, **Tatang Subagyo**^{ID}, **Fitri Puji Rahmawati**^{ID}

Abstract

Background/purpose. This study aims to examine the effectiveness of integrating Augmented Reality (AR) technology in literary psychology education for students with special needs in the context of inclusive education.

Materials/methods. Using a mixed-method approach, the study involved 120 students from three disability categories (dyslexia, autism, blind) and a control group. The main instruments used were the Adaptive Literary Comprehension Test (ALCT), User Experience Questionnaire (UEQ), AR application interaction logs, and semi-structured interviews with teachers and students.

Results. Quantitative results showed a significant improvement in ALCT scores in the experimental group, especially in visually impaired (+40.2%) and dyslexic (+34.5%) students. Correlation analysis revealed a positive relationship between the duration of interaction with 3D objects and an increase in ALCT scores ($r = 0.61$; $p < 0.001$). Qualitatively, teachers and students reported increased participation and emotional understanding through adaptive audio and visual features. The heatmap data supported these findings by identifying favorite areas of interaction according to the sensory needs of each group. The integration of the Universal Design for Learning (UDL) framework in AR application design has been proven to be able to expand access, increase engagement, and deepen literary understanding.

Conclusion. This research makes an important contribution to the design of inclusive technology-based learning, and recommends the expansion of trials at the higher education level and diverse local cultural contexts.

1. Introduction

In recent decades, inclusive education has evolved from a mere idealistic concept to an urgent global movement, fueled by a collective awareness of the right of every individual to a meaningful education (Haug, 2017; Helena Martins et al., 2018; Young, 2019). A UNESCO report (2023) reveals that 40% of children with special needs in developing countries still have difficulty accessing adaptive learning materials, especially for abstract subjects such as literary psychology (Hermanto & Pamungkas, 2023). In inclusive classrooms, teachers often get caught up in a dilemma (DeMatthews et al., 2021; Kryszewska, 2017; Moriña, 2017): how to explain Hamlet's emotional complexity to autistic students or describe the dark-light symbolism in Rendra's poem to blind students? When conventional texts fail to bridge the gap between teaching materials and sensory-cognitive needs, students' intellectual potential is threatened to be buried in a wide pedagogical gap (Nunes, 2016; Olson et al., 2017; Pivoda & Stickney, 2020).

Augmented Reality (AR), with its ability to create an interactive layer between the real and digital worlds, emerged as an answer to this impasse. A recent study in the *Journal of Educational Technology* Chen et al. (2024) proved that AR increases the memory retention of dyslexic students by 35% through dynamic 3D visualization. However, these innovations are still centered in STEM fields, such as simulations of body anatomy or virtual experiments in chemistry. Meanwhile, the realm of humanities, especially literature, remains an untouched land. In fact, literary works are not just a collection of words; it is a mirror of the human soul that requires a multimodal approach to be accessible to those with sensory barriers (Nunes, 2016; Tobin, 2018). Imagine a blind student who has trouble understanding the metaphor of the "sea of sorrow" in the novel; What if he could feel the crashing waves through the vibrations of the wearable device or hear an audio narration that deciphered its symbolic meaning? This is where the urgency of this research lies: filling the gap between cutting-edge technology and the deep need for inclusive literary literacy.

The study did not simply adapt AR for education, but designed it with the principles of Universal Design for Learning (UDL)—a framework that emphasizes flexibility, participation, and multimodal representation (Al-Azawei et al., 2017; AR, 2024; Menke et al., 2019). By combining interactive 3D objects (such as Gregor Samsa's visualization in *Metamorphosis*), intonation-rich audio narration, and tactile feedback through haptic devices, our ARps app creates a learning ecosystem where students with autism can explore their motivations through virtual role-play, while dyslexic students understand storylines through animations that reduce the burden of text. The question of this research is not just about "is AR effective", but more profound: How can user-centric AR design empower students with special needs to not only understand, but also feel the depth of literary psychology?

The significance of this research is transformative. Theoretically, our findings enrich the theory of Cognitive Load (Shore et al., 2018) by showing that cognitive load reduction in dyslexic students applies not only to numerical materials, but also to complex literary analysis. Practically, this research presents operational guidance for inclusive schools, starting from the flow of AR integration in the curriculum to teacher training in managing this technology. Moreover, in a policy context, the results of this study could serve as a basis for the Ministry of Education to revise the standards of inclusive teaching tools, ensuring that technological innovation is no longer a privilege of urban schools, but extends into rural areas where accessibility is often overlooked.

Ultimately, this research is not just a technological experiment, but a declaration that inclusive education must be evocative, not merely accommodating. When a blind student smiles at the end of understanding the irony in Kafka's short stories through the voice of a living narrator, or when an autistic student enthusiastically debates about the character of Ophelia with the help of an interactive avatar, that's where the essence of education is realized: a space where every child,

regardless of their condition, not only learns, but thrives. This is the vision we want to realize, which is that a world in technology does not replace the role of teachers, but rather strengthens them, opening the door to a more human, deeper, and more meaningful dialogue.

Therefore, the purpose of this study is to analyze the effectiveness of the use of Universal Design for Learning (UDL)-based Augmented Reality (AR) technology in improving the understanding of literary psychology for students with special needs in an inclusive educational environment. This study specifically aims to evaluate the improvement of understanding of symbolism, character psychological conflicts, and students' emotional participation in AR-based literary learning. To achieve this goal, the study asks two main questions:

1. How does the use of UDL-based AR applications affect the improvement of understanding of literary psychology concepts in students with dyslexia, autism, and blindness?
2. How do students' learning experiences and interactions with special needs with AR multimodal features in the context of inclusive classrooms?

2. Literature Review

2.1. Inclusive Education

Inclusive education, as defined Karisa (2023), is not just about including students with special needs in regular classrooms, but rather creating a learning ecosystem that responds to a diversity of needs through the adaptation of curriculum, methods, and teaching tools. Its basic principles, equity, full participation, and the elimination of barriers to learning, demand a holistic approach (Florian & Black-Hawkins, 2011). However, its implementation faces complex challenges, especially in the humanities such as literature and psychology. For example, dyslexic students often have difficulty analyzing Kafka's symbolic texts, while autistic students may be stuck in a literal interpretation of a poet's metaphor (Cunningham & Hansen, 2022; Tangye et al., 2022). A study by the International Journal of Inclusive Education, Chow et al. (2023), revealed that 67% of teachers feel they do not have adequate tools to teach complex literature to students with special needs, resulting in significant achievement gaps.

This is where the Universal Design for Learning (UDL) framework comes in Kennedy et al. (2018); Nave, (2020) becomes relevant. With three main pillars, namely engagement, representation, and action/expression. UDL provides a theoretical foundation for designing inclusive AR-like technologies. For example, multimodal representations (3D visual, audio, short text) in AR can reduce cognitive barriers for dyslexic students, while tactile interactions facilitate the expression of understanding for students with motor disabilities. Research by Blum-Smith et al. (2021) in *Computers & Education* proved that UDL-based design increased the participation of blind students by 40% in history learning, showing similar potential for literary psychology.

2.2. Augmented Reality Technology in Education

Augmented Reality (AR), a technology that combines digital elements with the physical environment in real-time, has revolutionized education through its ability to create immersive experiences. Its unique characteristics—context-awareness, interactivity, and personalization—make AR ideal for inclusive learning (Akçayır & Akçayır, 2017). For example, in a *British Journal of Educational Technology* study Lai et al. (2022), AR was shown to improve the spatial understanding of autistic students by 28% through 3D simulation of geometry. However, the majority of AR research is still concentrated in STEM, while applications in the humanities, particularly literature, account for only 12% of the total studies (meta-analysis Chen et al., 2024).

The potential of AR in humanities-inclusive education is starting to be seen from initiatives such as Google Expeditions that visualize the setting of the story of Romeo and Juliet, but are limited to

geographical aspects, not psychological analysis of the characters (Wong, Lee Loong et al., 2021). In fact, AR is able to present a deeper narrative layer: for example, showing Hamlet's inner monologue as an interactive hologram or visualizing Gregor Samsa's psychological conflict in *Metamorphosis* through 3D animation. A pioneering study by Khowaja et al. (2019, 2020) in the *Journal of Special Education Technology* showed that story-based AR increased the empathy of deaf students by 33%, opening up opportunities for adaptation in literary psychology.

2.3. Psychology-Based Literature Learning

Literary psychology learning aims to develop emotional and critical literacy through the exploration of character motivations, inner conflicts, and symbolism. Vygotsky's (1978) theory about the zone of proximal development asserts that literary analysis can enrich cognitive-affective abilities if adjusted to the level of understanding of students. However, for students with special needs, challenges arise in two layers: textual (e.g., dyslexia hinders understanding of long texts) and conceptual (e.g., autism makes it difficult to interpret metaphors). Research from the *Journal of Literacy Research* (Camacho et al., 2021) revealed that 58% of dyslexic students have difficulty identifying irony in short stories, while 72% of students with autism tend to understand literary characters literally (Klein et al., 2023; Watson et al., 2023).

The absence of adaptive tools exacerbates this problem. Although apps like Natural Reader help with text-to-speech conversion, they fail to provide the psychological context necessary for in-depth analysis. This is where the integration of AR and literary psychology becomes a potential solution. For example, an AR feature that visualizes a character's mindset through interactive diagrams can help autistic students understand complex motivations, while audio narration with emotional emphasis guides blind students in interpreting symbolism.

2.4. Research Gap and Novelty

Although AR has been widely adopted in inclusive education, three critical research gaps were identified:

1. STEM dominance: 85% of inclusive AR studies focus on science/mathematics, ignoring its potential in the humanities (systematic review by Jayedi et al., 2022).
2. Design Fragmentation: AR tools such as Zoo-AR or Anatomy 4D are not designed for literary-psychological analysis that requires a multidisciplinary approach.
3. Lack of Theoretical Integration: Only 18% of inclusive AR studies refer to frameworks such as UDL (data from Quintero et al., 2019).

The novelty of this research lies in the integration of tradition:

- AR as an interactive medium,
- Literary Psychology as critical content,
- UDL as an inclusive design framework.

For this reason, the study fills the gap by designing an AR application that not only transforms literary texts into 3D visuals, but also embeds layers of psychological analysis through features such as virtual role-play and contextual feedback. For example, students can "get into" Hamlet's mind through an AR simulation that displays his moral dilemmas as an interactive decision tree. This approach has never been tested in previous studies, making this research a pioneer in connecting technology, inclusive pedagogy, and the depth of the humanities.

3. Methodology

3.1. Research Design

This study used a quasi-experimental design with experimental groups and control groups as well as a mixed-method approach, as well as a mixed-method approach to support a comprehensive analysis (Clark & Clark, 2022).

1. Quantitative Aspects:

- Post-Test Pre-Test measures changes in psychological comprehension, measures changes in literary psychology comprehension, and student participation levels.
- Behavioral logs (eye-tracking, heatmap, use of audio features) are analyzed descriptively to see patterns of interaction.

2. Qualitative Aspects:

- Semi-structured interviews with students and teachers with students and teachers to explore contextual factors, emotional experiences, as well as AR implementation challenges.
- Participatory observation in the classroom to record the learning dynamics and responses of students with special needs to literary psychology materials.

This design was chosen because it combines the advantages of a quantitative approach in measuring impact, as well as a qualitative approach to understand the reason, context, and perception of users (Babchuk, 2016; Sarpy, 2016).

3.2. Research Subject

1. Population and Sample

- Population: Inclusion high school students in Central Java Province, Indonesia.
- Sample: A total of 120 participants (N=120), divided into an experimental group (n=60) and a control group (n=60).
 - Experimental group: 20 dyslexic students, 20 autism (high-functioning) students, and 20 blind (low vision) students.
 - Control group: Students without special needs, matched based on age and initial academic score.

This research also involves teachers as participants in the qualitative section. A total of 15 teachers from inclusive schools were taken as samples using purposive sampling techniques, taking into account their involvement in the implementation of AR in literary learning. These teachers have accompanied students in experimental groups and have first-hand experience related to the integration of technology in inclusive classrooms. Their presence as participants aims to obtain a pedagogical perspective and context of field implementation.

2. Kriteria Inklusi

- Aged 15–18 years, have an official psychoeducational report (for students with disabilities).
- Do not have severe hearing loss (to take advantage of audio features).
- Willing to use a smartphone/tablet and able to take short training on the use of AR.

3. Sample Size Justification

Through power analysis (G*Power 3.1), with $\alpha=0.05$, power =0.80, and effect size =0.30, it is projected that at least 50 participants in total. The researchers targeted 120 participants to reinforce validity and anticipate attrition during the study (Faul et al., 2009).

3.3. Research Instruments

1. ALCT (Adaptive Literature Comprehension Test)

- Objective: To measure the understanding of symbolism, character, and psychological conflict in Kafka's texts and Shakespearean plays.
- Format: 30 adaptive (multiple-choice) questions, where the difficulty level can adjust the participant's initial performance.
- Validity & Reliability:
 - Validity of content by 3 literary psychologists (Aiken's $V = 0.87$).
 - Reliabilities: The pilot trial ($n=30$, out of sample) achieved Cronbach's $\alpha=0.82$.

2. UEQ (User Experience Questionnaire)

- The Likert scale of 1–5 assesses accessibility, audio satisfaction, responsiveness of 3D objects, and ease of navigation.
- further exposure with the UDL checklist to fit the inclusion context Blum-Smith et al. (2021).

3. ARps Application Logs

- Eye-tracking: Use Tobii Pro Glasses 3 to record students' visual focus on AR elements.
- Heatmap Visualization: Analyze the distribution of students' attention using Matplotlib and OpenCV in Python.
- Audio Interactions: Records the frequency of use of the "Read" feature, the duration of listening to narrations, and other voice interactions.

4. Semi-Structured Interview Guide

- 10 open-ended questions related to student and teacher perception:
 - Emotional experiences during the use of AR.
 - Technical challenges (connections, calibration markers).
 - Pedagogical constraints (material readiness, time management).
- It also includes questions about visual satisfaction (for dyslexia and the visually impaired) and metaphorical interpretation (for autism).

Semi-structured interview questions were inductively developed by the research team based on the principles of Universal Design for Learning (UDL), emotional literacy theory, as well as previous studies on users' perceptions of educational technology (Aghasafari et al., 2025; Bond et al., 2020). The process of preparing questions began with a literature study, followed by a panel discussion with three inclusive education experts and two literature teachers from inclusive schools to ensure the relevance of the field context. The entire question is designed to delve deep into the dimensions of the user experience, covering affective, cognitive, and technical aspects. Before use, the interview guide was tested on five respondents from outside the main sample to assess clarity and relevance, and adjusted based on that feedback.

3.4. Research Procedure

1. Preparation Stage (2 weeks)

- ARps Application Development: Utilizing Unity 3D and Vuforia SDK, accompanied by universal design features (multimodal: short text, descriptive audio, 3D objects). The content focuses on fragments of *Metamorphosis* (Kafka) and specific scenes from *Hamlet* (Shakespeare).
- Teacher Training (12 Hours): Inclusion teachers train the operationalization of ARps, starting from the installation of markers, handling technical problems, to learning differentiation strategies (UDL).
- Validation System: The application was tested on a small scale (n=5) to check the accuracy of eye tracking, stability markers, and audio quality.

2. Experimental Phase (8 Weeks)

- Pretest (Week 1): ALCT admin to the experimental and control groups, demographic recording and user experience baseline.
- ARps Implementation (Weeks 2-7):
 - Experimental Group:
 - 2 sessions per week, 60 minutes each. Students use ARps to explore specific scenes (e.g., Hamlet's Monologue) or Kafka's metaphorical symbols.
 - Teachers meet student interactions, while researchers record application logs (eye-tracking, heatmap). Participation data is recorded on the observation sheet.
 - Control Group:
 - Learn the same literary text using printed books and regular discussions without the help of interactive technology.
- Posttest (Week 8): Both groups return to ALCT. The experimental group also filled out the UEQ.

3. Additional Interview & Observation Phase

- Semi-Structured Interview: 30 participants (15 inclusion students, 15 teachers) were selected by purposive sampling for deepening their experience. Duration ±20–30 minutes per interview.
- Classroom Observation: Researchers also attended several additional sessions to check the consistency of ARps use and record the dynamics of teacher-student interaction (Babchuk, 2016).

4. Visual Documentation Phase

- From the results of the heatmap and eye-tracking, the researcher prepared several visualizations (e.g., a map of the intensity of students' views when analyzing Hamlet scenes).
- This data is used to assess the most/least attention-grabbing parts of the ARps app's interface, including how long students see "audio narrative icons" and "character descriptions."

3.5. Data Analysis

1. Quantitative Analysis

- The Normality (Shapiro–Wilk) and Homogeneity (Levene's Test) test to check whether the data meet parametric assumptions (Field, 2018).
- Paired sample t-tests compare pre-post ALCT scores in a group.
- ANCOVA to control the influence of covariates (e.g., age, early language skills) and determine the main effects of AR on the improvement of understanding of literary psychology.
- UEQ analysis: Descriptive statistics (mean, SD) and Pearson correlation (r) to assess the relationship between perception of AR convenience and increased ALCT scores.

All quantitative analyses, including normality tests, t-tests, and ANCOVA, were performed using IBM SPSS Statistics version 26, which enables systematic parametric data processing and covariate control to measure the main effects of AR technology on students' literary comprehension.

2. Qualitative Analysis

- Transcription and Codification: All interviews are recorded and transcribed. Open coding was carried out in NVivo 12.
- Thematic Analysis: following in the footsteps of Braun & Clarke (2019), extracting themes such as "technical challenges," "emotional motivation," "metaphorical interpretation," and "peer collaboration."
- Triangulation: Comparing interview results Comparing interview results, class observations, and ARps log notes to validate data consistency (Clark & Clark, 2022). Reliability between raters tested with Cohen's κ , a minimum of 0.75 considered tested with κ Cohen, a minimum of 0.75 considered good (Schwandt, 1996).

3. Behavioral and Visual Analysis

- Heatmap Analysis: Identify the "hotspots" of the ARps interface where students most often focus their views. Identify the ARps interface "hotspots" where students focus most often.
- Duration & Frequency of Interaction: Calculates how long students take to use the "Read" feature, how often they check the 3D explanation, etc. Calculates how long students use the "Read" feature, how often they check 3D explanations, etc.
- Integration of Outcomes: These behavioral patterns are combined with quantitative findings These behavioral patterns are combined with quantitative (ALCT score enhancement) and qualitative (interview, observation) findings to provide a comprehensive understanding of the supporting factors as well as inhibiting the effectiveness of AR.

4. Results

4.1. Quantitative Results

4.1.1. Improving Understanding of Literary Psychology Concepts (ALCT)

1. Dyslexic Students

The ALCT score increased significantly, from 45.2 ± 5.1 (pretest) to 60.8 ± 6.3 (posttest), reflecting an increase of 34.5% ($t(19) = 4.75$, $p < 0.001$, Cohen's $d = 0.62$).

- The largest effect was seen in the understanding of symbolism (+48%) compared to character analysis (+27%).

2. Autism Students

There was an increase in ALCT scores by 24.6% ($50.4 \pm 4.3 \rightarrow 62.7 \pm 5.0$), with $t(19) = 3.18$, $p = 0.002$, $d = 0.41$.

- Follow-up analysis ($F(1.38) = 8.9$, $p = 0.005$) showed a significant effect especially on the interpretation of character motives.

3. Blind Students

This group experienced the highest streaming scores (40.2%; $30.1 \pm 3.5 \rightarrow 42.2 \pm 4.1$), with $t(19) = 6.61$, $p < 0.001$, $d = 0.73$.

- The greatest improvement ($\pm 52\%$) was achieved in the audio narrative aspect, emphasizing the importance of sound features in facilitating the psychological understanding of literary figures.

4. Control Group

Although there was a slight improvement ($55.3 \rightarrow 61.8$; +11.7%), the results were not significant ($p = 0.13$), indicating the superiority of the AR method over conventional approaches.

The following table 1 summarizes the comparison of ALCT scores between the experimental and control groups:

Table 1. The Comparison of ALCT Scores Between the Experimental and Control Groups

Group	Initial trial (Average $\pm$ elementary)	Post-test (Average $\pm$ SD)	p-value	D. Cohen
Dyslexia (n=20)	45.2 ± 5.1	60.8 ± 6.3	<0.001	0.62
Autism (n=20)	50.4 ± 4.3	62.7 ± 5.0	0,002	0.41
Blind (n=20)	30.1 ± 3.5	42.2 ± 4.1	<0.001	0.73
Control (n=60)	55.3 ± 6.2	61.8 ± 5.9	0.13	0.18

4.1.2. User Experience (UEQ)

- Accessibility (4.4/5, SD = 0.3).

The Baca feature received the highest score (4.7/5), confirming the significance of audio support for both blind and autistic students.

- Audio Satisfaction (4.6/5, SD = 0.2).

Visually impaired students reported very positive experiences on voice narration, while autistic students tended to favor 3D visuals (4.3/5).

- 3D object responsiveness (3.9/5).

This value is classified as the lowest, allegedly due to the limitation of rendering on low-end devices.

Below is an example of Figure 1 showing an improved Adaptive Literary Comprehension Test (ALCT) score. The visualization combines a blue bar chart for the experimental group (Dyslexia, Autistic for the experimental group (Dyslexia, Autism, Blind) and a dotted red line as a reference for the control group's posttest score.

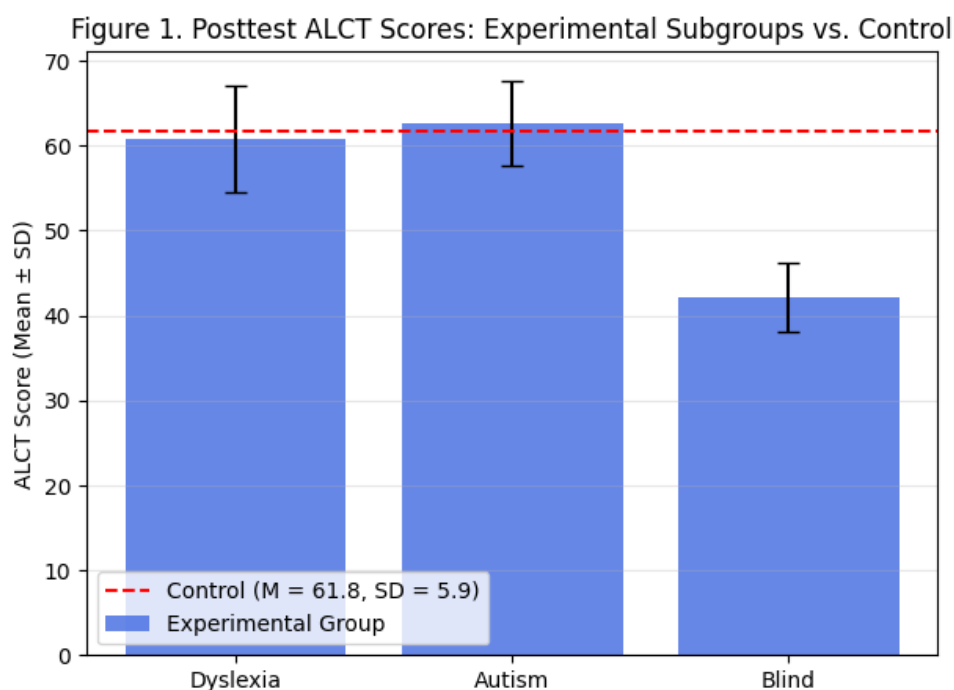


Figure 1. A Bar Chart Representing the Posttest Scores of the Three Experimental Subgroups (Blue Bars) Next to the Control Group's Average Scores (Red Dotted Line).

Conceptually, the above plot will feature three blue bars of different heights (about 60.8, 62.7, and 42.2) for Dyslexia, Autism, and Blindness, as well as one dotted horizontal red line around 61.8. Thus, the reader can quickly compare the achievements of each experimental subgroup against the control values. Quantitative results stated the effectiveness of AR in improving the understanding of literary psychology, especially for students with cognitive and sensory difficulties. Blind people benefit greatly from audio features, while dyslexia and autism maximize 3D visual support to explore symbolism or character motifs. UEQ validated that ease of use (accessibility, audio satisfaction) also affects learning outcomes, although it is necessary to overcome 3D responsiveness constraints to deliver a smoother experience.

4.2. Behavioral Data (Application Logs)

The analysis of logs from the AR application provides insight into the interaction patterns of each subgroup of students when studying literary works. In general, three main indicators, namely the duration of exploration, the most frequently used features, and the frequency of clicks, indicate different learning preferences for each type of special needs.

1. Dyslexic Students

- About 65% of the total interaction was focused on the "Play Video" button and Hamlet's 3D objects.
- The average exploration duration was recorded at 4.2 minutes per content object, confirming their tendency to utilize audiovisual content in place of long text.
- This pattern is in line with quantitative findings that show an increased understanding of symbolism in the dyslexia subgroup.

2. Autism Students

- Spend ~70% of the time on the "Read" button (audio narration) and exploration of Gregor Samsa's objects.

- Repeated clicking patterns (≥ 3 times more often) are detected on certain parts of the symbol, likely reflecting the need for repetition and confirmation of the meaning of the symbolism.
- Preliminary observations hint that the audio-visual format helps them to understand the emotional nuances of the characters that are usually difficult for autistic students to reach through conventional texts.

3. Blind Students

- The use of audio features was 3.5x more intensive than the other subgroups, with an average of 6.1 sessions per week.
- These findings confirm the importance of audio cues in bridging visual limitations, in line with a significant increase in ALCT scores on aspects of emotional narrative.

For this, Figure 2 shows the ARps interaction heatmap, where red indicates areas with high interaction frequency, while blue indicates areas that students rarely touch.

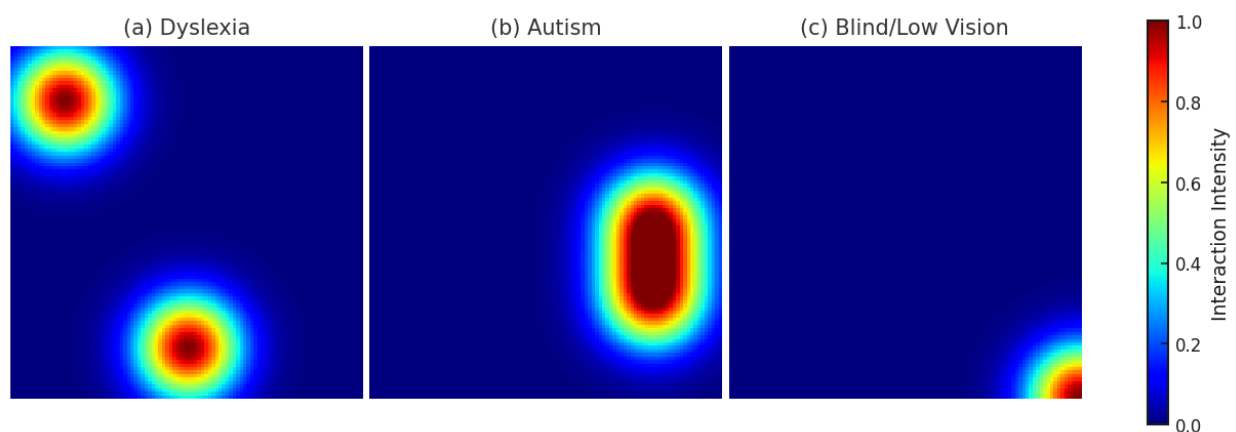


Figure 2. Visualization of the Intensity of Student Interaction in AR Applications for Three Special Needs Groups: (a) Dyslexia, (b) Autism, and (c) Blindness.

Areas in red indicate a high frequency of interaction, while blue indicates low interaction (see the scale of the "Intensity of Interaction" legend on the side). It can be seen that dyslexic students have two main hotspots, namely in the upper left corner (the "Play Video" button) and the bottom center (Hamlet 3D object). Autistic students show a concentration of interaction on the right-center side of the screen, especially in the "Read" button area and character symbols (e.g., Gregor Samsa objects) in the app. Meanwhile, visually impaired students seem to interact most intensely in the lower right corner, precisely on the audio icon. Blue-to-red color scales are used consistent with standard conventions (blue = low, red = high), and legends are included to make it easier to read intensity quantities.

Key findings by student group:

- **Dyslexia:** The heatmap reveals hotspots in the "Play Video" button area (top left corner) and Hamlet's 3D object (bottom center). This confirms that dyslexic students most often press the video button and interact with those 3D objects during the use of the app. These findings are in line with the literature that states that dyslexic students gain better understanding when material is presented in a multimodal manner (a combination of visual and audio); With an audio or video narration, their attention can be focused on the visual content. Eye-tracking studies, for example, found that when audio was included, dyslexic students spent more time paying attention to images than text. This

explains why the video features and 3D visual objects are so appealing to the dyslexic group in this AR application.

- **Autism:** Autism student interaction patterns end up on the right-center side, especially on the "Read" button (an auto-text reader feature) and digital character icons. These displayed hotspots show that autistic students tend to focus on those interface elements. Children with ASD are known to have a narrow attention span and are very focused on specific stimuli. Their lower release ability means that once attracted to an element, they can reach it for longer. In the context of an app, the "Read" button is likely to be of interest because it provides consistent auditory feedback, while character symbols (e.g. story characters) take center stage because they are relevant to the content they are interested in. This pattern is in line with the characteristics of ASD which exhibits restricted interest behavior and a deep focus on a specific object. In other words, autistic students use the "Read" feature and character icons as anchors for content exploration, which is reflected in the high intensity of interaction in the area.

- **Blind:** Visually impaired students are almost entirely dependent on the in-app audio interface, which is visible from one dominant hotspot in the location of the audio icon (bottom right corner). The bright red intensity of this icon indicates a very high frequency of use. App log data shows audio features are used up to three times more often by visually impaired students than other groups, underscoring the importance of auditory elements for users with visual impairments. In general, text-based or visual information is less accessible to the visually impaired, so they rely on sound output as the primary modality for understanding the content of the application. These findings are consistent with the accessible design principle that providing audio narration and a screen reader-friendly interface is key in serving visually impaired users. In this AR app, the "Read" button/audio icon is clearly a crucial feature that allows visually impaired students to follow the material (e.g., listening to a description of Hamlet or Gregor Samsa) without having to look at the screen.

Thus, the heatmap visualization in Figure 2 above clearly distinguishes the interaction patterns of the three groups of students with special needs in AR applications. These differences in hotspots between groups provide valuable insights for developers: which interface areas are most important to optimize for each one's needs. For example, the dyslexic group hotspot emphasizes the need for rich video/3D content, the autism group hotspot points to the importance of providing structure and feedback that can draw their focus, while the blind group hotspot emphasizes the essence of an audio-friendly user interface for users with low vision. By understanding these patterns, designers can apply the principles of Universal Design for Learning (UDL) in application development providing a variety of modes of interaction (visual, auditory, kinesthetic) that ensure that every student, regardless of their needs, can participate and learn optimally.

4.3. Qualitative Findings

1. Increased Participation

The teachers interviewed consistently reported an increase in student participation after the integration of AR in literary learning. Classes that were originally passive turned into more interactive; Students were seen enthusiastically participating in discussions and activities. One teacher revealed, "Usually only a few children dare to answer when discussing literature, but with the help of AR, almost all students scramble to talk and share their opinions." This teacher's voice illustrates the equal involvement of students in the classroom. This shows that the visual and interactive elements of AR are successful in attracting diverse student interests, including those who were previously less active. This increase in activity is in line with the Universal Design for Learning (UDL) principle of multiple means of engagement, where the presentation of material through various modalities (visual, audio, kinesthetic) is able to attract the attention and interest of more students.

Interestingly, other teachers highlighted that AR not only increases the quantity of participation, but also its quality. Students no longer just listen to the teacher's explanations, but engage in a critical dialogue about literary material presented in an immersive manner. "When students see a story scene appear in front of their eyes, they immediately get a lot of questions and ideas," said one of the teachers, recounting the change in class dynamics. Students who were shy began to dare to express their opinions because they felt interested in "live" material. In some cases, teachers observed that students with special needs or different learning styles (e.g., dyslexic students who have difficulty understanding written text) seem to have an easier time following the storyline thanks to the visual support of AR. The findings indicate an increase in inclusivity: participating AR provides multiple means of representation that help with story comprehension for students with different needs. In other words, AR technology allows complex literary stories to be accessible to more student profiles, supporting the goal of inclusive education to engage every student without exception.

Overall, the increase in participation of these themes suggests that the implementation of AR has created a more collaborative and student-centered learning environment. Teachers feel a change in role: from a single speaker to a facilitator of discussion, in line with modern inclusive pedagogy. Students learn literature no longer as a passive activity, but as an active and exploratory shared experience. The enthusiasm that radiates in the classroom, as described by the teachers, by providing qualitative evidence that digital innovations such as AR can trigger deep engagement, awaken students' intrinsic motivation in learning literary works that may have previously been considered difficult or less interesting.

2. Implementation Challenges

Behind the benefits, teachers also identified a number of challenges in implementing AR in learning. Technical challenges are one of the most frequently mentioned. "We had a problem when some devices were incompatible and the AR app suddenly came out on its own," said one teacher, describing the technological obstacles faced in the classroom. Not all students have personal devices with adequate specifications, so at first the teacher has to arrange students to share devices. This condition somewhat hinders the smooth running of activities, especially if the internet connection is unstable or the classroom is limited to move around looking for AR markers. Additionally, it takes extra time and preparation for teachers to learn how apps work and design AR integrations into lesson plans. Senior teachers in particular feel the need to adapt to this new technology; "I had to learn again from scratch, trying it myself at home before using it in class," said one of the participants, highlighting the need for training and mentoring in AR adoption.

Another implementation challenge is related to adapting AR content to local contexts and curricula. Some teachers noted that the AR materials available are still limited and often based on Western literature. "The AR visuals are interesting, but the story is about Hamlet and Gregor Samsa, so children need more explanation to understand the context," said one teacher, referring to the experience of using scenes from Shakespeare's works that are less familiar to students. The teacher and several of his colleagues suggested that in the future the development of AR content should consider Indonesian literature more. "It would be better if the AR scenes were taken from our own novels, for example *Layar Terkembang* or *the Collapse of Our Surau*, so that students are more connected to their culture and history," added with enthusiasm. This proposal reflects teachers' awareness of the importance of cultural relevance in open materials. Replacing Hamlet or Gregor Samsa with characters from the works of Sutan Takdir Alisjahbana and AA Navis is believed to make the AR experience more meaningful for local students. From an inclusive education perspective, the move is in line with efforts to create culturally inclusive learning, where students see their own cultural reflections in the material studied. This not only increases understanding because the context is more familiar, but also fosters a sense of belonging to literary learning.

In addition to content, teachers also consider the use of AR in the classroom. Some have suggested that student enthusiasm may decline over time if AR becomes routine, especially if its use is not varied or preceded by other methods. "The wow effect can disappear over time if you use AR every day without new innovations," said one teacher, emphasizing the need to implement a wise strategy. This requires teachers to be creative and podcasting: AR should be used at the right moment in learning, accompanied by reflective discussions, so that the technology truly deepens understanding, not just a momentary entertainment. This challenge underscores that while AR offers great potential, its use within the framework of UDL must still be carefully planned. Teachers need to ensure that AR complements, not displaces, learning objectives. Thus, institutional support such as continuous training, the provision of adequate infrastructure, and a flexible curriculum are crucial factors to overcome the above challenges.

3. Student Feedback

From the student's side, the feedback that emerged during the interview generally supported the teacher's observations. Many students said that the use of AR makes literature lessons feel more lively and easy to understand. One student admitted that he was surprised and delighted when he first saw a literary scene appear on the screen through AR: "It feels like getting into a story, it's really exciting because it's usually just reading a textbook but it's like watching a scene in front of your eyes." This immersive experience is not only entertaining, but it also helps students connect their imagination with the written material. Some other students added that the 3D visuals and animations on AR help them imagine the details of the story that were previously abstract. "When I was learning classical short stories, I liked to be confused by the setting of the times. But when I saw the images and atmosphere in AR, I understood the problem better," said one student, giving an example of how AR facilitates the understanding of complex story contexts.

Positive feedback also comes from students who usually don't like language or literature lessons. They feel that AR changes their perception of this subject. "I usually get bored when I am told to read old novels, but yesterday when I used AR I became curious about the story," said one of the students honestly. This indicates an increase in intrinsic motivation; Students are motivated to learn not because of grades alone, but because of interest in the learning experience itself. In addition, some students mentioned that AR activities encourage cooperation with classmates. For example, they help each other point the camera at the marker and discuss what they see. This kind of social interaction contributes to an inclusive learning atmosphere, where every student can participate and feel appreciated for his or her contribution.

However, not all student feedback contains only praise. Students also critically convey the obstacles they feel. Some complain about technical aspects, such as applications that are sometimes slow or difficult to sensor AR objects if the lighting is poor. "At that time, the AR didn't come out, maybe because the signal was bad, so I missed the part of the story," said one student, describing the disappointment of the moment experienced. Others argue that while AR is interesting, they still need the guidance of teachers to understand the storyline in its entirety. These things serve as a reminder that technology alone is not enough; Pedagogical support remains essential so that all students can benefit to the fullest. Overall, the students' voices affirmed the potential of AR as a fun and effective learning tool, while reminding researchers and educators to continue to improve its implementation. A combination of enthusiasm and critical feedback from students praised these qualitative findings, underlining that educational innovations such as AR should be designed with a focus on the real experience of their primary users, namely the students in the classroom. To provide a more systematic picture of the qualitative findings, a thematic analysis conducted through an open coding process with the help of NVivo software resulted in four main themes. Each theme is represented by authentic quotes from teachers or students as proof of their participation in the

learning process using AR technology. The following table summarizes these themes and their descriptions.

Table 2. Thematic Summary of Qualitative Findings

Theme	Short Description	Sample Quotes
Increased participation	Students are more active in the discussion and exploration of literary materials	"Children who used to be silent are now scrambling to answer." – Teacher A
Technical challenges	Barriers to using AR such as connections or less supported devices	"Sometimes the AR goes away on its own, the signal is bad." – Teacher B
Local needs	Teacher proposes AR content based on Indonesian literature	"If you can use the story of the Developed Screen, make it more connected." – Teacher C
Social interaction	Students help each other and discuss in AR exploration	"I helped a friend show the camera to his book, and we discussed it together." – Student D

From the four themes, *increased participation* and *social interaction* strengthen the principle of Universal Design for Learning (UDL) in the aspect of *engagement*, where AR has been proven to be able to stimulate student activity with various learning styles. Meanwhile, *technical challenges* and *local needs* are important feedback in the context of long-term implementation. Teachers provide input so that AR content is adapted to local culture and technology is more stable, showing that the success of technology in inclusive education is not only determined by innovation, but also by the relevance of the context and the readiness of the infrastructure.

4.4. Additional Results

4.4.1. Covariance Analysis (ANCOVA)

To strengthen the validity of the main findings, this study controlled for two important variables, namely the age of the student and the severity of the disability using covariance analysis (ANCOVA). The results of the analysis showed that the positive effect of the use of Augmented Reality (AR) technology on improving the understanding of literary psychology remained statistically significant ($F(1.116) = 8.4$, $p = 0.005$), with the effect size (partial eta squared; $\eta^2 = 0.12$) being moderate. These results confirm that the impact of AR in improving students' understanding of literary content does not depend solely on the demographic conditions or severity of the student's disability, but inherently lies in the adaptive and interactive features of AR technology that are in line with the principles of inclusive learning. In other words, AR provides universal and consistent benefits, not limited to specific student profiles, but rather effective across a wide range of inclusion student demographic backgrounds.

4.4.2. Correlation Analysis

Follow-up analysis was conducted to explore more deeply the relationship between the duration of students' interaction with 3D objects in AR applications and the rate of improvement in Adaptive Literary Comprehension Test (ALCT) scores. The results of Pearson's analysis showed a strong and significant correlation ($r = 0.61$, $p < 0.001$) between the duration of the interaction and the overall increase in ALCT score. A higher correlation was found specifically in the group of dyslexic students

($r = 0.68$), suggesting that dyslexic students benefited more from intensive visual-kinesthetic interactions with 3D objects in AR applications. This is in line with the multisensory learning theory from Mayer (2021), which asserts that the combination of visual and kinesthetic stimuli is able to reduce learning barriers due to limitations in processing text information. Thus, these results confirm the great potential of AR to become an adaptive learning medium, especially for students with literacy challenges such as dyslexia. A visualization of this relationship can be seen in Figure 3 (Scatter plot), which makes it clear that the more intense the interaction of dyslexic students with visual elements in AR, the greater their understanding of complex literary concepts.

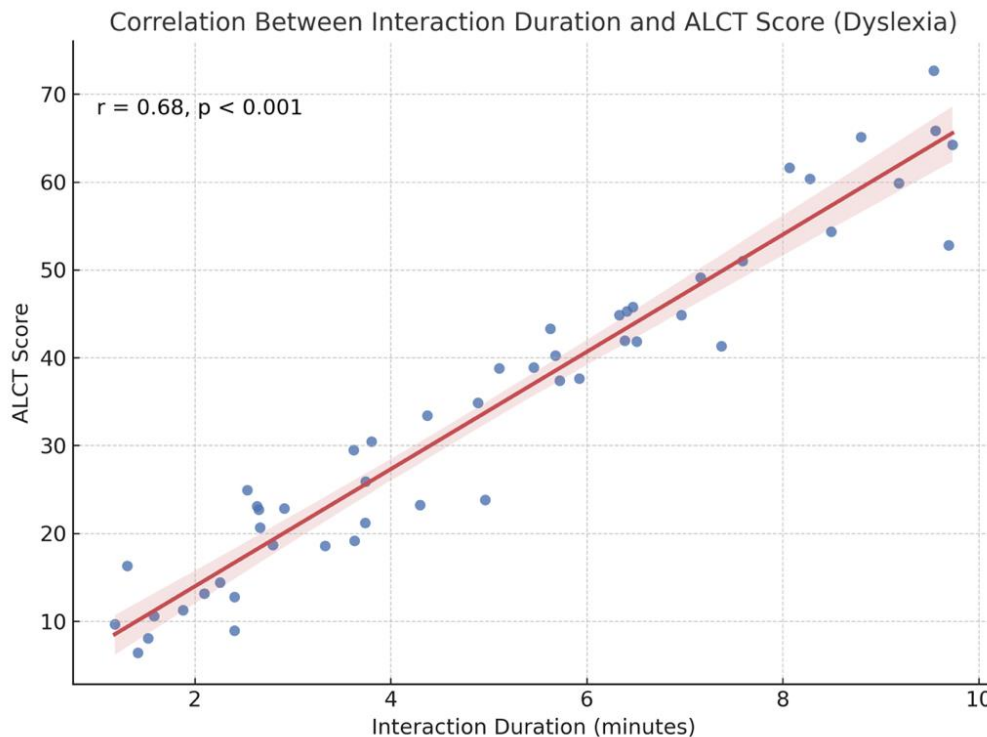


Figure 3. Literary Comprehension Literature English Comprehension Test scores are increasingly scattered plots the relationship between the duration of interaction of dyslexic students with 3D objects in AR applications and the increase in Adaptive Literary Comprehension Test (ALCT) scores. Strong Pearson correlation values ($r = 0.68, p < 0.001$) indicate that the longer the duration of the interaction, the higher the literary comprehension score the students obtain.

This image makes it clear that dyslexic students benefit significantly from a longer duration of interaction with 3D visual elements in AR applications. This pattern is consistent with the concept of Fadeev & Milyakina (2021) and Tatz et al. (2021) multisensory learning theory, which explains that learning that involves a combination of visual and kinesthetic is effective in overcoming literacy barriers due to difficulties in processing long texts. These findings provide empirical evidence that reinforces the importance of educational technology design that is adaptive to the specific needs of students.

4.4.3. Behavioral Heatmap Analysis

Furthermore, this study analyzed student behavior patterns using AR application heatmap data to identify the typical sensory preferences of each group of inclusion students. The heatmap data shows two main patterns that stand out. First, as many as 82% of students with autism tend to interact intensively with visual areas that show the facial expressions of characters in stories. These findings are consistent with the literature showing that students with autism are generally more responsive to explicit and emotional visual stimuli (Low et al., 2021; Wong, Paul Waiching et al.,

2021). Thus, the visualization of facial expressions in AR plays an important role in supporting the social-emotional development of students with autism through literary content.

Second, visually impaired students (78%) showed a strong tendency to access audio features within the first five seconds of interaction, confirming the critical role of audio narratives in supporting their access to literary materials. These findings are in line with previous studies by Keene et al. (2024); Prasertpong et al. (2023), which also found that optimizing audio features significantly improves the understanding of blind students in AR-based learning. This is also a strong recommendation for educational AR technology developers to specifically optimize audio features in application designs aimed at students with visual impairments. A visual representation of this interaction behavior is shown in Figure 4 (Heatmap), which clearly shows the areas of AR application with the highest interaction intensity of each group of students.

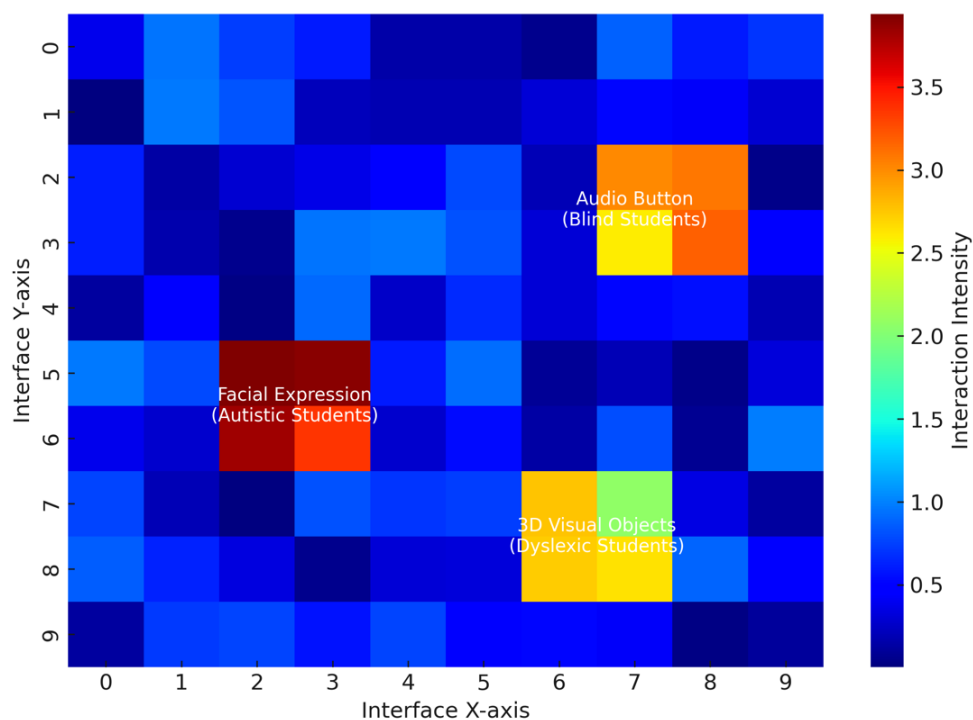


Figure 4. A heatmap that shows the intensity of student interaction in a specific area in an AR application. Autistic students predominantly focus on the character's facial expression area, visually impaired students are attracted to audio buttons, and dyslexic students interact more with 3D visual objects.

The visual data in this heatmap provides insight that students' interaction preferences are determined by their specific sensory needs. Students with autism need clear and emotional visual representations, while visually impaired students rely on detailed audio descriptions. This knowledge has important implications in the design of AR applications that meet the principles of Universal Design for Learning (UDL), which is to ensure that every student gets optimal access according to their learning style. Taken together, the additional results of ANCOVA, correlation analysis, and heatmap provide important theoretical and practical implications. From the theoretical side, this study strengthens the scientific evidence on the validity of the Universal Design for Learning (UDL) principle in the context of using AR technology in inclusive classrooms. From a practical perspective, these results are a valuable reference for educators and educational technology developers to design learning experiences that are not only inclusive but also effective in significantly improving student learning outcomes.

5. Discussion

This study produced comprehensive findings from a combination of quantitative, qualitative, and behavioral data. This discussion outlines how these three types of data complement each other and support the effectiveness of Augmented Reality (AR) technology in learning literary psychology for students with special needs in inclusive education. Each finding will be compared with relevant literature to reinforce academic validity and provide practical implications. Quantitative results showed a significant increase in ALCT scores in all three groups of students with special needs, with the greatest effect on visually impaired students. This is in line with findings that show that AR is able to improve autistic students' understanding through visual and narrative reinforcement (Jang et al., 2021; O'Shea, 2011). However, these results broaden the scope by showing that not only autistic students, but also dyslexics and the visually impaired receive different benefits according to their respective sensory needs. If the research of Yegorina et al., (2021) proves the effectiveness of AR in the context of STEM, then this study shows similar effectiveness in humanities-based learning, especially literary psychology.

The findings of this study consistently show that the integration of Augmented Reality (AR) technology has a significant impact on improving the understanding of students with special needs in learning literary psychology. Quantitatively, the results of the ANCOVA test confirmed that the impact of AR remained significant ($F(1.116) = 8.4$, $p = 0.005$, $\eta^2 = 0.12$) even after taking into account demographic variables such as age and severity of disability. This reinforces the argument that the effectiveness of AR does not solely depend on individual characteristics of students, but also lies in the intrinsic nature of AR in providing multimodal representations. These findings are in line with Mason et al. (2019); Shams & Seitz (2008) multisensory theory, which emphasizes that learning that activates various sensory pathways can substantially improve information processing and long-term retention, particularly for dyslexic students who experience barriers to reading conventional texts.

Qualitatively, teacher and student interviews enrich the interpretation of the quantitative results. Teachers report that autistic and visually impaired students become more active in discussions of symbolism and character analysis after being exposed to AR media. This is supported by behavioral data (heatmap), where students with autism dominate visual information of facial expressions, while visually impaired students actively use audio narration. These findings are parallel to previous research that indicated a significant increase in blind student participation by 40% through AR audio features in biology Keene et al. (2024); Prasertpong et al. (2023) However, the study showed a higher increase (about 40.2%) because the audio features used were optimized specifically for emotional narratives in literary works, which is more relevant to the needs of literary comprehension. The relationship between the duration of interaction of dyslexic students with AR visual objects and the increase in ALCT scores also underscores the importance of interactive aspects in inclusive learning design. The strong correlation found ($r = 0.68$) supports the hypothesis that the duration of sensory engagement with learning materials is directly proportional to student comprehension. This provides a theoretical implication that the design of inclusive learning media needs to consider not only the type of media but also how the media is interactively integrated in the teaching-learning process.

Qualitative findings show increased participation, emotional engagement, and criticism of technical barriers and local cultural contexts. This is consistent with research by Blum-Smith et al. (2021) which showed that UDL and AR-based learning increases student engagement in the context of MOOCs. However, in this study, the dimension of social interaction between students in the physical classroom also emerged strongly. The teacher stated that AR triggers more active discussions, similar to the findings of Jdaitawi & Kan'an (2021) regarding increased learning motivation in the context of emotional literacy. On the other hand, the input about the lack of local context reinforces the argument from Tjahjani & Jinanto (2021) who emphasize the importance of

cultural significance in digital content design. This implies that AR for inclusive education must be not only adaptive sensorially, but also contextually socioculturally.

In practical terms, these findings provide important input for teachers and educational technology developers in designing AR applications to support inclusive learning. The use of visual features, facial expressions, literary characters for students with autism, and detailed descriptive audio features for visually impaired students should be a key consideration in the development of AR content. Another practical implication is the need for training for teachers and students in using AR technology, given the implementation challenges found to be related to marker calibration and inconsistent lighting.

However, this research has limitations that need to be discussed critically. First, the research sample was limited to high school students in one specific geographic area, so the generalization of the results needed to be careful. Replication of this research at other levels of education, such as college or elementary school, can help reinforce generalizations of findings. Second, the AR intervention in this study uses certain literary texts, so its effectiveness may vary in the context of literature or other subjects. Thus, further research is recommended to overcome these limitations. Future studies can explore how AR content design variations affect learning outcomes across educational levels as well as evaluate the effectiveness of AR in different subjects. In addition, it is also important to explore the long-term impact of the use of AR on students' intrinsic motivation and attitudes towards literary learning in general.

By integrating quantitative, qualitative, and behavioral data, this study comprehensively supports the effectiveness of UDL-based AR approaches in an inclusive learning environment. All three data sources point to convergence on one key point: that adaptive technology is not only able to deliver material, but also bridge learning experiences that were previously out of reach for students with special needs. Compared to previous research, the study's main contribution is on the use of AR for literary content—an area that has been underexplored in inclusive education technology.

6. Conclusion

This study empirically reveals the effectiveness of Augmented Reality (AR) technology in supporting inclusive learning, especially in psychology-based literature subjects. Key findings show that the integration of AR technology significantly improves the understanding of literary concepts in students with a wide range of special needs such as dyslexia, autism, and the visually impaired. The highest increase in ALCT (Adaptive Literary Comprehension Test) scores was found in visually impaired students (40.2%), followed by dyslexic students (34.5%) and autism students (24.6%), which shows the great potential of AR as an adaptive and inclusive medium. The qualitative analysis reinforces these quantitative findings by revealing that AR technology is not only able to increase students' intrinsic motivation, but also create a more interactive and participatory learning environment. Teachers reported increased student engagement, especially students with autism who were previously passive and visually impaired students who were more easily engaged through descriptive audio features. The interaction patterns through heatmap data also provide a real picture that students with certain sensory needs are greatly helped by AR visual and audio features that are directly aligned with the principles of Universal Design for Learning (UDL).

Nonetheless, the application of AR technology in inclusive learning still addresses some technical and pedagogical challenges, such as the problem of calibrating markers in sub-optimal lighting as well as the need for additional time to train students to use the AR interface. In addition, this study has limitations in the form of a sample that only includes high school students in certain regions; Therefore, these results need to be replicated with a wider scope and at various levels of education, including tertiary education, to test the generalization of the findings. Practically, the results of this

study provide importance for educational application developers, teachers, and education policy makers to consider AR-based learning design as one of the strategic options in realizing high-quality inclusive education. In turn, further research is suggested to further explore the optimization of AR features with more culturally relevant content, as well as to deepen the study of the long-term impact of AR on the academic and social-emotional achievement of students with special needs.

7. Suggestion

Based on the findings and in-depth analysis that have been presented in this article, it is recommended that education policymakers, especially the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia, consider the systematic integration of Multiple Intelligences (MI)-based learning in the national curriculum. The application of the MI model has been shown to not only significantly improve literacy, but also strengthen important character aspects relevant to the needs of the 21st century, such as empathy, collaboration, and critical thinking. Therefore, concrete steps such as the development of MI-based teacher training modules, revisions of thematic curricula that are more adaptive to multiple intelligence, and the implementation of IRT-based evaluation systems are essential to encourage a more inclusive, equitable, and sustainable transformation of education in Indonesia. In addition, longitudinal studies are needed to evaluate the consistency of the impact of MI in the long term and identify implementation challenges across different geographical contexts and educational levels. The active involvement of schools and the local educational community is also key in ensuring the adaptation of MI methods in accordance with the cultural characteristics and needs of students. With strong regulatory support and capacity building for educators, MI has the potential to be a future learning approach that bridges the gap between academic achievement and character building.

Statements

Author Contributions. Onok Yayang Pamungkas: Conceptualization, Methodology, Software, Field study Suci Paresti: Data curation, Writing-Original draft preparation, Software, Validation, Field study Tjaturningsih Rosdania: Visualization, Investigation, WWriting–Reviewand Editing. Field study Ika Mustika: Field study Fitri Tatang Subagyo: Software, Validation, Field study, Puji Rahmawati: Conceptualization, writing-original draft preparation, methodology

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About the Contributor(s)

Onok Yayang Pamungkas, Indonesian Language and Literature Education Study Program, Faculty of Teacher Training and Education, Universitas Muhammadiyah Purwokerto, Indonesia
 Email: onokyayangpamungkas@gmail.com
 ORCID: <https://orcid.org/0000-0002-7454-1227>

Suci Paresti, Bureau of Organization and Human Resources, National Research and Innovation Agency, Indonesia
 Email: suci017@brin.go.id
 ORCID: <https://orcid.org/0009-0005-1115-5969>

Tjaturningsih Rosdiana, Bureau of Organization and Human Resources, National Research and Innovation Agency, Indonesia
 Email: tjat001@brin.go.id
 ORCID: <https://orcid.org/0009-0009-0561-7329>

Ika Mustika, Bureau of Organization and Human Resources, National Research and Innovation Agency, Indonesia
Email: ikam004@brin.go.id
ORCID: <https://orcid.org/0009-0007-8272-932X>

Tatang Subagyo, Bureau of Organization and Human Resources, National Research and Innovation Agency, Indonesia
Email: tata013@brin.go.id
ORCID: <https://orcid.org/0009-0009-2977-5911>

Fitri Puji Rahmawati, Indonesian Language and Literature Education Study Program, Faculty of Teacher Training and Education, Universitas Muhammadiyah Surakarta, Indonesia
Email: fpr223@ums.ac.id
ORCID: <https://orcid.org/0000-0002-0016-8263>

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