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Augmented Reality for Personal Hygiene Safety Skills among Children with Intellectual Disabilities: A Development and Effectiveness Study

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ABSTRACT

This study aimed to develop an augmented reality-based learning tool to teach personal hygiene safety skills to children with intellectual disabilities. The study employed a Research and Development (R&D) approach using the ADDIE instructional design model, followed by expert validation involving a media expert, a content expert, and a practitioner, and a Single Subject Research (SSR) A-B-A field trial with one child with an intellectual disability. The developed augmented reality incorporated interactive and safety-oriented learning features across three personal hygiene domains: toothbrushing, bathing, and hair washing. Validation results yielded scores of 84.2% from the media expert, 90.9% from the content expert, and 88.0% from the practitioner, with an overall validity score of 87.7%, categorized as very valid. The SSR A-B-A field trial showed a clear improvement in personal hygiene safety skills following the introduction of the AR media, with mean observation scores increasing from 14.00 (Baseline-1) to 24.88 (Intervention) and being maintained at 34.00 (Baseline-2), with 100% non-overlapping data (PND) between adjacent phases, indicating a highly effective intervention. The findings indicate that the AR is feasible for use in special education settings and has potential to support the development of personal hygiene safety skills among children with intellectual disabilities. These findings confirm that the developed AR learning media is highly valid and effective in improving personal hygiene safety skills in children with intellectual disabilities, suggesting its potential as an innovative instructional tool for special education practice.

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■ INTRODUCTION

Intellectual disability is a condition characterized by significant impairments in intellectual functioning and adaptive behavior, including conceptual, social, and practical skills. This condition emerges during an individual's developmental period before age 22, affecting adaptive behavior and making it difficult for children with intellectual disabilities to understand abstract concepts, such as processing information and applying knowledge in real-life situations (Schalock et al., 2021). According to a 2023 report by the World Health Organization and UNICEF, the prevalence of idiopathic intellectual disability among children aged 5–14 years is approximately 2.0%, with higher rates observed in low- and middle-income countries. Given the large number of children affected worldwide, there is a growing need for educational interventions that promote independence and adaptive functioning, particularly in daily living skills that directly influence health, safety, and quality of life.

The various limitations in adaptive skills experienced by children with intellectual disabilities indicate that personal hygiene and safety skills are a crucial aspect. However, they still receive relatively little attention in both practice and research. Children with intellectual disabilities generally experience impairments in intellectual functioning and adaptive behavior that affect their ability to remember, focus their attention, and carry out a series of steps in sequence. These conditions make it difficult for them to perform personal hygiene activities independently and safely, even though these skills are an important part of daily life.

The above explanation aligns with observations made in special education schools and inclusive schools, which indicate that children with intellectual disabilities face challenges in developing safe and independent personal hygiene skills. Children with

intellectual disabilities are not yet able to practice good hygiene habits or understand the safety procedures for using personal care items in the correct sequence. These findings indicate that safe personal hygiene skills among children with intellectual disabilities are at a low level and require further educational innovation.

Personal hygiene refers to a series of actions individuals take to maintain cleanliness and health to support physical and psychological well-being. Maintaining good personal hygiene plays a crucial role in improving health, as inadequate hygiene can accelerate the development of various diseases (Yoo & Song, 2021). Suboptimal personal hygiene can increase an individual's susceptibility to various health problems, such as skin diseases (e.g., scabies), infectious diseases, oral and dental health issues, and gastrointestinal disorders (Gupta et al., 2024). Consistent efforts to maintain personal cleanliness and health to support physical and psychological well-being can be considered good personal hygiene if one can maintain bodily cleanliness independently and consistently in accordance with applicable health standards.

Effective personal hygiene requires not only the ability to maintain bodily cleanliness, but also the ability to do so safely in order to avoid injury and various health risks. Safety skills are defined as a set of competencies that includes knowledge, practical skills, and behavioral readiness, enabling a person to identify sources of danger and take appropriate preventive measures to reduce or avoid risks that could harm them (Trevor et al., 2021). Personal hygiene and safety skills refer to an individual's ability to recognize the importance of personal hygiene and practice safe, appropriate, and independent hygiene behaviors to prevent illness, injury, and other health risks in daily life.

Personal hygiene safety skills are essential for individuals with intellectual disabilities because they help protect them from various health risks. Cognitive limitations such as memory, attention, understanding instructions, and problem-solving abilities often make it difficult for individuals with intellectual disabilities to perform personal hygiene activities independently and consistently, increasing their vulnerability to activity-specific hazards. Incorrect toothbrushing technique can contribute to plaque accumulation, cavities, gingivitis, and periodontitis (Kim et al., 2024). In contrast, a safe technique using a soft-bristled brush, light pressure, and non-abrasive toothpaste minimizes this risk (Kumar et al., 2025). Handwashing with soap is highly effective in removing germs and reducing disease transmission (Hilton et al., 2025), yet excessive washing can damage the skin barrier and cause irritant contact dermatitis (Beiu et al., 2020), Bathing supports blood circulation, sleep quality, mood, and immune function (Luo et al., 2023), but water that is too hot can cause burns within seconds (Singer et al., 2021). A wet or soapy bathroom floor substantially increases the risk of slipping (Chatterjee et al., 2022).

Conventional learning strategies for teaching daily living skills to students with intellectual disabilities, including task analysis, prompting, and modeling, have proven effective in controlled settings (Stierle et al., 2023). Conventional methods have limitations, including their reliance on direct human assistance, limited opportunities for repeated independent practice, difficulties in generalizing skills to real-life contexts, and the fact that conventional learning materials often fail to accommodate the visual and interactive learning preferences characteristic of many children with intellectual disabilities (Baragash et al., 2020). These limitations point to the need for an innovative, technology-based approach that can provide a consistent, engaging, and repeatable learning experience.

Augmented reality is a form of virtual reality in which users continue to view their real-world surroundings through a transparent device while receiving additional digital information. Users of augmented reality experience an immersive, technology-mediated environment where the real world is overlaid with virtual information that is dynamically displayed and tailored to the user's context or location(Benassi et al., 2020). Augmented reality combines the real world with virtual objects displayed simultaneously within a single environment (Schmalstieg & Hollerer, 2016). This technology is interactive because users can directly interact with virtual objects. Objects displayed in augmented reality are three-dimensional and adapt to the environment's orientation, providing a more realistic visual experience.

Previous studies have demonstrated the potential of augmented reality to support learning among individuals with intellectual disabilities, particularly in academic instruction, vocational training, and general daily living skills. AR has been reported to increase learner engagement, provide visual support, and facilitate skill acquisition through interactive learning experiences (Baragash et al., 2020). However, most existing studies have focused on improving task performance

without explicitly addressing safety-related behaviors that are critical for independent functioning.

Intellectual disabilities often face not only difficulties in completing hygiene routines but also challenges in recognizing and avoiding potential hazards associated with these activities. Common risks include swallowing toothpaste, using excessively hot water during bathing, injuring themselves while trimming nails, and improper use of hygiene products. Despite the importance of these safety-related behaviors, few studies have explored AR as a medium for teaching personal hygiene safety skills specifically designed for children with intellectual disabilities. This study fills an important gap in the literature by developing an AR-based learning app that integrates real-time safety instructions, visual guides, and step-by-step instructional support for personal hygiene practices.

This study focused on developing an augmented reality application to enhance personal hygiene safety skills among children with mild to moderate intellectual disabilities. The application incorporates interactive visual guidance, step-by-step procedural instructions, and contextual safety information to support safe, independent hygiene practices. Guided by the ADDIE instructional design model, the study aimed to develop and validate the application as an effective and accessible educational tool for improving personal hygiene safety skills in children with intellectual disabilities. Specifically, this study addressed the following research questions: (1) How valid and feasible is the developed AR-based learning media, as assessed by media, content, and practitioner experts? (2) How effective is the AR-based learning media in improving personal hygiene safety skills among children with intellectual disabilities, as measured through a Single Subject Research (SSR) A-B-A field trial?

■ METHOD

Research Design and Procedures

This study employed Research and Development (R&D) methodology guided by the ADDIE instructional design model (Branch, 2009). ADDIE's built-in iterative evaluation cycle is particularly suited to safety-critical instructional media because it requires domain experts to verify content accuracy before learner exposure, preventing inaccurate safety information from being embedded in the deployed media. Table 1 presents the five ADDIE phases as implemented in this study.

Before data collection, ethical procedures were completed to protect the rights, safety, and privacy of the participating children with intellectual disabilities. Permission to conduct the study was first obtained from the participating special education schools. The researcher then provided parents or legal guardians with information about the study objectives, procedures, potential benefits and risks, confidentiality, voluntary participation, and the right to withdraw at any time without consequences. Written informed consent was obtained from the parents or legal guardians before interviews, observations, and subsequent research activities were conducted. Where appropriate, the children were also given a simple explanation of the activities, and their willingness to participate was respected.

Three clusters of safety errors were identified, forming the scope of the AR instruction (Table 2). A technology availability assessment confirmed that Android smartphones and tablets were available at the school and that students could independently

Table 1. ADDIE development phases

Phase	ADDIE Stage	Key Activity
1	Analysis	Learner profiling via teacher interviews and classroom observation. Identification of six hygiene safety error patterns
2	Design	Safety skill task analysis and AR storyboard design.
3	Development	AR app built in Assembler Edu, 3D assets built in blender and expert validation (media, content, practitioner)
4	Implementation	Field trial with the student using a Single Subject Research (SSR) A-B-A design, assessed via 12 observation indicators (4 per skill material) on a 0–3 scale.
5	Evaluation	Evaluation of application effectiveness based on the student's final personal hygiene safety skill achievement.

operate touchscreen devices at the level required for AR interaction. Three personal hygiene safety skill clusters were targeted, each decomposed into safety-critical behavioral steps.

Toothbrushing, bathing, and hair washing were identified as priority targets for augmented reality-based safety instruction for three reasons. First, these are daily activities that children with intellectual disabilities frequently perform as part of their routine. Second, each activity carries potential safety risks that can lead to injury, health complications, and improper hygiene practices if performed incorrectly. Third, a needs assessment conducted through interviews and observations showed that these three activities are among the most frequently observed areas and require further learning support.

The AR interaction modality was designed around three safety cue mechanisms, each mapped to specific safety error patterns identified in the analysis phase (Table 2). Storyboards for each of the three task sequences were developed in a structured manner, including conditions and audio narration text. AR Features and mechanisms were adopted from Sivrikaya & Çetin (2023), as presented in Table 2. The AR was field-tested with students through a Single Subject Research (SSR) A-B-A design involving students with intellectual disabilities.

Participants

Student characteristics were determined through structured interviews with five special education teachers in Indonesian. Direct classroom observations were conducted with 12 students with mild to moderate intellectual disabilities during hygiene activities.

Consistent with common practice in ADDIE-based research and development studies in special education technology, this study used one qualified validator per domain (media, material, and practitioner), selected based on relevant academic and professional expertise. This single-expert-per-domain approach reflects the formative, developmental purpose of this validation stage, which assessed product feasibility and appropriateness prior to field implementation.

The field testing involved one student with intellectual disabilities who met the predetermined inclusion criteria. The participant was 15 years old and had moderate intellectual disabilities. Prior to the intervention, the participant had basic experience using smartphones or tablets and could perform basic touchscreen operations. The subject could perform personal hygiene and understood self-care activities, yet could not recognize or avoid potential hazards and had not demonstrated an anticipatory response to dangerous situations. All participant data were anonymized and used solely for research purposes.

Instruments

Expert validation was conducted using a structured Likert-scale questionnaire, with each instrument tailored to the validator's specific evaluation domain. An educational technology

Table 2. AR features and mechanisms

AR Feature	Safety Behavior Targeted	Mechanism
Safety while bathing	Avoiding injury while bathing	Keeping soap away from the eyes
	Avoiding the risk of slipping	Being careful on wet floors
	Using bathing tools safely	Not playing with hazardous bathing equipment
Safety while Toothbrushing	Using toothpaste safely	Use a pea-sized amount of toothpaste
	Using the toothbrush correctly	Point the bristles toward your front teeth (not toward your throat)
	Brushing teeth safely	Brush gently to avoid hurting your gums
	Avoiding hazardous behavior	Do not swallow the toothpaste or mouthwash
Safety while washing hair	Protecting body parts	Avoiding water entering the eyes, nose, and mouth
	Shampooing correctly	Not scrubbing the scalp too hard
	Using supplies appropriately	Using an appropriate amount of shampoo
	Avoiding slipping from water drips	Using a towel after finishing shampooing

expert conducted media validation, while a special education expert carried out content validation. Practitioner validation involved a special education teacher with over five years of teaching experience. The validators assessed the developed application based on usability, content suitability, instructional quality, and practical application within the special education setting.

Student performance across each skill material was assessed using an observation instrument comprising 12 indicators, rated on a 0–3 scale (yielding a maximum possible score of 36), capturing observable behavioral responses and cooperation with the AR stimuli across the baseline (A1), intervention (B), and follow-up baseline (A2) phases. The Evaluation phase assessed the application's effectiveness from the perspective of student engagement and enjoyment during use, measured using an observation checklist completed by the teacher.

Data Analysis

Interview and observation data were analyzed using thematic analysis to identify the most frequent, most dangerous, and least addressed patterns of hygiene safety errors.

■ RESULTS AND DISCUSSION

This study developed an augmented reality educational media product specifically designed to teach personal hygiene safety skills to students with intellectual disabilities. This media emphasizes learning content focused on safe, proper, and independent personal hygiene practices, including bathing, toothbrushing, and washing hair. The media's design and development are based on an analysis of students' needs and a review of personal hygiene safety skill materials aligned with the cognitive functions and adaptive behaviors of students with intellectual disabilities. The primary principle guiding the development of the media is safety-oriented learning, which involves presenting the material in an educational, contextual, structured, and easily understandable manner, tailored to the students' abilities. Through this approach, the media is designed to help students with intellectual disabilities apply safe personal hygiene procedures and enhance their independence in performing daily self-care activities.

This section serves as the application's main navigation interface. It provides access to three personal hygiene safety skills: toothbrushing, bathing, and hair washing. Each skill is presented with visual illustrations and color-coded icons to facilitate understanding, engagement, and independent navigation among students with intellectual disabilities. The Augmented reality feature demonstrates personal hygiene procedures step by step through a series of sequential slides. Each step includes corresponding audio instructions to help students understand the safe actions to take at each stage, supporting the development of personal hygiene safety skills and reducing the risk of injury or inappropriate behavior during personal hygiene activities.

Media and Content Validation

The suitability of media is evaluated through a validation process involving media experts and subject matter experts. The validation instrument assesses various aspects, including the user interface, functionality, technological aspects, reliability, and the media's contribution to the effectiveness of the learning process.

Validators were selected based on their academic qualifications and professional experience in special education, educational

Figure 1. Augmented reality media interface visualization

Table 3. Expert validation results by dimension

Validator	Dimension	Score Obtained	Score Maximum	Percentage
Media Expert	System usability	31	35	84.2%
Media Expert	Learner's basic psychological needs	49	60	
Material Expert	Curriculum	10	10	90.9%
Material Expert	Material concept	26	30	
Material Expert	Presentation quality	14	15	
Practitioner	Effectiveness	23	25	88.0%
Practitioner	Usefulness	25	30	
Practitioner	Enjoyment	15	15	
Practitioner	Ease of use	12	15	
Practitioner	Attitude (future use)	11	15	
Overall Average				**87.7%**

technology, and developing interactive digital media. The assessment used a five-point rating scale with the following score categories: 5 = highly appropriate, 4 = appropriate, 3 = somewhat appropriate, 2 = less appropriate, and 1 = inappropriate. The validation results were then analyzed to determine the suitability of the developed media and to serve as a basis for revising and refining the product before its implementation in the pilot phase.

The validation instrument used in this study was developed based on a literature review and an evaluation framework relevant to developing technology-based learning media. The media validation instrument is based on the evaluation framework for the educational impact of extended reality adopted by Lampropoulos & Chen (2025). The material validation instruments were developed based on the aspects of learning material quality assessment adopted by Daryanes et al. (2023), and the practitioner validation instrument adopted by Yeni et al (2020). The validation results by dimension are presented in Table 3.

The media expert evaluation yielded a validity score of 84.2% (very appropriate), reflecting strong performance across the system usability and learner psychological needs dimensions. High scores on instructional clarity and enjoyment indicate that the AR interface successfully presents safety-oriented hygiene content in a manner that is both comprehensible and engaging. In contrast, the social interaction dimension obtained the lowest scores among all indicators, suggesting that the application is designed primarily as an individual, self-paced learning experience rather than a collaborative one. This aligns with the single-user interaction model adopted in the current design, which prioritizes independent, step-by-step guidance over peer- or teacher-mediated activities. This finding indicates a direction for future development: incorporating collaborative or teacher-assisted features so the media can also support the development of social interaction skills alongside personal hygiene safety skills.

Material validation produced the highest score among the three validators at 90.9% (very appropriate). This strong result indicates that the hygiene safety content embedded in the application is conceptually accurate, appropriately structured, and well-aligned with the competency indicators and learning objectives established for students with intellectual disabilities. The practitioner validation score of 88.0% (very appropriate) reflects strong endorsement from the perspective of classroom implementation. High scores on the effectiveness and enjoyment dimensions indicate that teachers working with students with intellectual disabilities perceive the AR application as a practical, engaging, and contextually appropriate instructional tool.

Effectiveness Testing

A study on the effectiveness of augmented reality media was conducted on a child with an intellectual disability to determine the media's effectiveness in improving personal hygiene safety skills. Before the learning session, the subject was observed to assess their baseline abilities. Next, the subject participated in a learning session using AR media and was then observed again after the session to measure improvements in personal hygiene safety skills.

The results of personal hygiene safety skills scores by skill indicator (Figure 1) indicate a clear pattern of improvement following the introduction of the AR-based learning media. During the Baseline-1 (A1) phase, the subject's scores were low and stable, ranging from 12 to 15 (M = 14.00), with a trend

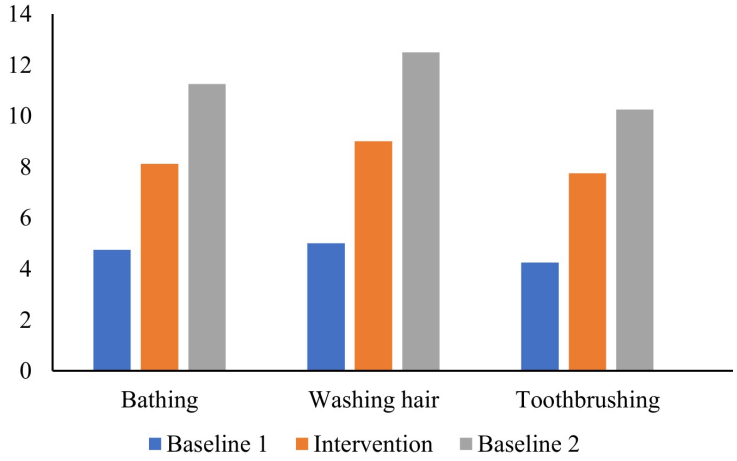

Figure 1. Personal hygiene safety skills scores by skill indicator

stability of 100%, reflecting the subject's initial ability prior to intervention (Kazdin, 2021).

Following the introduction of AR media in the Intervention (B) phase, scores increased consistently from 18 to 31 (M = 24.88), showing a marked upward trend; the lower trend stability of the B phase (50%) reflects the expected variability of an active skill-acquisition process rather than a plateaued level. During the Baseline-2 (A2) phase, after the AR media was withdrawn, scores remained high and stable, ranging from 33 to 35 (M = 34.00, stability = 100%), indicating that the improvement in personal hygiene safety skill was maintained even without continued use of the AR media. The following graph shows the results of the SSR trial in children with intellectual disabilities.

Figure 2 integrates observation scores, within-phase trend and stability analysis, and between-phase level-change and overlap analysis into a single graph. Scores remained low and stable during Baseline-1 (A1), increased consistently throughout the Intervention (B) phase, and were maintained at a higher level during Baseline-2 (A2), indicating a positive and sustained effect of the AR intervention. The shaded band in each phase represents the stability envelope (mean level ± 15%), the dashed horizontal line marks the mean level, and the orange line shows the trend estimated using the split-middle method; the steep, less-stable trend line in the B phase, contrasted with the flatter, tightly-banded trend lines in A1 and A2, visually confirms the shift from an unstable, skill-acquisition phase to a stable, higher-performing phase. The orange arrows mark the magnitude of level change at each phase transition (+3 from A1 to B, +4 from B to A2), and the annotated callouts indicated both transitions had zero overlap between adjacent phases (PND = 100%).

The within-condition analysis (Table 4) demonstrates a clear change in the subject's performance across the three research phases. During the Baseline-1 (A1) phase, the subject

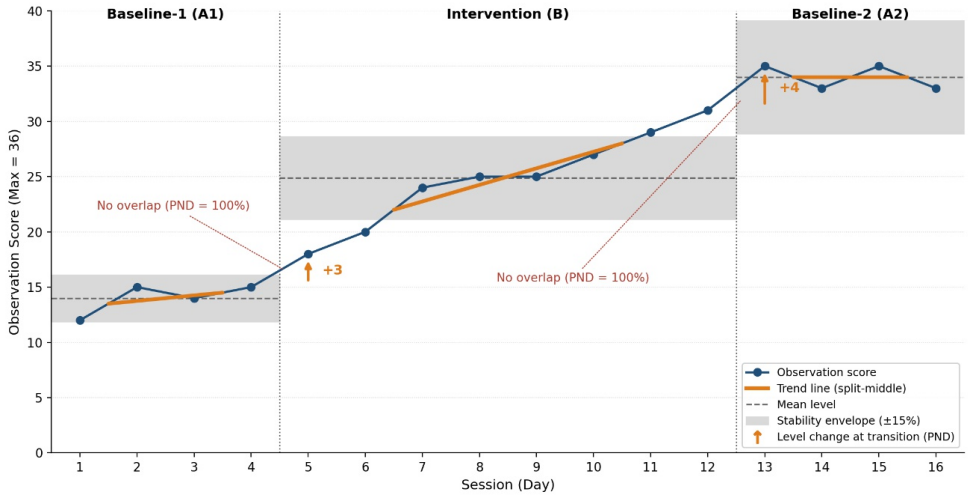

Figure 2. Ssr a–b–a results: observation scores, split-middle trend, stability envelope, and data overlap (pnd).

Table 4. Summary of visual analysis within and between conditions

Component	A1	B	A2	A1 vs B	B vs A2
Condition length	4 sessions	8 sessions	4 sessions	–	–
Trend direction	(+) Increasing	(+) Increasing	(=) Flat/stable	(+)→(+): positive effect	(+)→(=): effect maintained
Trend stability	100% (Stable)	50% (Variable)	100% (Stable)	Stable → Variable	Variable → Stable
Level range	12–15	18–31	33–35	–	–
Level change (within)	(+3): 12→15	(+13): 18→31	(+2): 33→35	–	–
Level change (between)	–	–	–	(+3): 15→18	(+4): 31→35
Data overlap (PND)	–	–	–	0% overlap (100% PND)	0% overlap (100% PND)

demonstrated a relatively low level of personal hygiene safety skill, although performance showed a mild upward tendency across the four observations. The overall pattern was stable, suggesting that the subject's initial performance had not changed substantially before the AR media was introduced. Following the introduction of the AR media in the Intervention (B) phase, the subject's performance increased progressively, showing a markedly upward trend. Although the data were less stable during this phase, the pattern reflected ongoing skill acquisition, with the subject's performance improving across successive intervention sessions. After the AR media was withdrawn in the Baseline-2 (A2) phase, performance remained substantially higher than during the initial baseline.

The data also became stable again, indicating that the improved performance was maintained after the intervention was discontinued. Overall, the within-condition pattern shows progressive improvement from a low, relatively stable level in A1 to increasing performance during B, followed by a stable and substantially higher level in A2. This pattern suggests that introducing the AR media was associated with improvement and subsequent maintenance of the subject's personal hygiene safety skills. The between-condition analysis (Table 4) showed a clear intervention effect across adjacent phases. From A1 to B, the level increased immediately by 3 points (15 to 18), indicating a prompt positive response to the AR media. From B to A2, the level increased by a further 4 points (31 to 35), suggesting that the improvement was maintained after the intervention was withdrawn. Both phase transitions showed 0% overlap (100% PND), indicating that all intervention data exceeded baseline performance. According to Scruggs & Mastropieri (1998), a PND of 90% or higher represents a highly effective intervention.

Supplementary Effect-Size Analysis: Controlling for Baseline Trend (Tau-U)

Table 4 reports a mild upward tendency during Baseline-1 (A1; +3 points, from 12 to 15, across four sessions). Because the AR intervention was introduced immediately after this fourth session, the observed A1 to B gain is potentially confounded with maturation, the possibility that the subject's scores would have continued rising even without the AR media.

Ideal data collection would continue baseline until three data points are obtained that are stable and do not show a particular trend in a row before the intervention begins, in accordance with standard SSR visual analysis guidelines. However, in this study, the timing of the intervention was constrained by the school semester schedule and ethical considerations regarding the avoidance of unnecessarily prolonging the untreated baseline phase once a consistent response pattern began to emerge (Parker et al., 2011; Tarlow, 2017)

The trend in phase A1 was considered minor (a 3-point increase, or an average of 1 point per session, within the 12–15 range on a 36-point scale) compared with the 13-point increase observed in phase B. Rather than relying solely on visual analysis to rule out such confounding factors, we quantitatively re-examined the magnitude of the intervention effect using Tau-U, a rank nonparametric effect size measure for single-case designs that statistically controls for pre-existing baseline trends before estimating the contrast between phases A and B. For each transition, calculations were performed for Tau-U without correction (which only removes overlap between phases) and Tau-BC with baseline trend correction (which also eliminates the influence of monotonic trends in the baseline phase prior to effect estimation), as well as the unbiased standard error, 95% confidence interval, and two-tailed z-test p-value. Table 5

Table 5. Tau-U and baseline trend corrected Tau-C (Tau-BC) for each phase transition

Transition	Tau-U (uncorrected)	Tau-BC (trend-corrected)	SE	p	95% CI
A1 → B	0.906	0.969	0.050	< .001	[0.281, 0.999]
B → A2	0.156	−0.500	0.500	.317	[−0.852, 0.204]

summarizes the results.

For the A1 to B transition, the uncorrected Tau-U was already large (0.906). After statistically removing the mild upward trend present in A1, the baseline-trend-corrected effect size increased slightly to Tau-BC. Because Tau-BC did not shrink toward zero once the A1 trend was partialed out, and if anything increased, the intervention effect cannot be attributed to the pre-existing maturation trend in the baseline; the AR intervention was associated with a genuine, statistically significant level and trend shift beyond what the A1 trajectory would have predicted on its own. This addresses the concern that introducing the intervention before A1 reached a flat, stable trend could have inflated the apparent treatment effect; correcting for that very trend did not weaken the effect, but strengthened it.

For the B to A2 transition, the uncorrected Tau-U was comparatively small (0.156), and the trend-corrected Tau-BC was negative and non-significant. This pattern is expected rather than concerning, because the B phase itself already carried a steep improving trend (18 to 31); Tau-BC evaluates whether A2 scores exceeded what a continuation of that already rising B-phase trend would have predicted. The A2 scores (range 33–35) remained at or above this projected trajectory rather than falling below it, indicating that gains achieved during the Intervention phase were fully maintained, not reversed, after AR was withdrawn; the non-significant Tau-BC here reflects a stable maintenance plateau near the upper end of the 36-point scale rather than a loss of treatment effect, consistent with the 100% trend stability and 0% overlap already reported for A2 in Table 4.

Expert validation results showed that the developed application achieved a high level of feasibility, with an overall validity score of 87.7%, indicating that the media is suitable for use in special education settings. The SSR A-B-A field trial further demonstrated that the application was effective in improving the subject's personal hygiene safety skill, with observation scores rising from a mean of 14.00 during the initial baseline to 24.88 during the intervention phase and being maintained at 34.00 after the AR media was withdrawn, with 100% non-overlapping data between adjacent phases. The findings suggest that AR technology has considerable potential to support the learning characteristics of children with intellectual disabilities by providing concrete, structured, and engaging learning experiences. In addition, integrating safety cues, preventive guidance, and real-time warnings represents a distinctive contribution to the development of technology-assisted instruction for adaptive and daily living skills.

A notable contribution of this study is integrating safety-oriented instructional features within an Augmented Reality environment. Previous studies have generally focused on using AR to improve engagement, task completion, and general daily living skills among individuals with intellectual disabilities (Abdullah et al., 2024; Guarnieri et al., 2025; Wu & Tsai, 2023). In contrast, the present application explicitly incorporates safety cues, warning systems, and preventive guidance designed to help learners recognize and avoid potential hazards during personal hygiene activities. Field observations during the Intervention and Baseline 2 phases supported this hazard-responsive interpretation: the subject brushed with visibly lighter, more controlled pressure rather than repeating the on-screen motion outright, and held onto the wall while moving across the wet bathroom floor, a precautionary action not explicitly modeled in the AR sequence, suggesting a generalized response to slip risk rather than simple imitation. This safety-centered approach expands the role of AR from merely supporting task performance to promoting safer and more independent daily functioning.

The improvement observed in this study is consistent with the conceptualization of personal hygiene as a functional self-care skill central to an individual's daily living standards (Stewart et al., 2022), and of safety skills as the capacity to recognize, avoid, and respond appropriately to potentially harmful situations (Basahel, 2021; Miltenberger & Novotny, 2022). For children with intellectual disabilities, these two domains are closely linked, since safety skills such as understanding risk, following safety rules, and adopting

preventive behavior are prerequisites for performing hygiene routines independently and safely. The sustained gains observed during the Baseline-2 phase therefore suggest that the AR media supported not only task completion but also the acquisition of adaptive, safety-oriented self-care behavior consistent with these definitions.

A plausible mechanism for this sustained gain relates to how the AR media manages cognitive demand for a learner profile characterized by difficulty with abstract reasoning, memory retention, and multi-step instructions. Rather than requiring the subject to hold verbal, step-by-step instructions in working memory, the AR media externalized each safety step as a concrete, sequential audio-visual cue presented at the point of action, which reduces the amount of information the subject needed to process and retain at any one time. This concrete, multisensory presentation is consistent with the documented cognitive and psychomotor characteristics of children with intellectual disabilities, who tend to rely more heavily on direct visual and procedural demonstration than on abstract verbal instruction to acquire new skills. Once the subject had internalized these safety cues through repeated audio-visual exposure during the Intervention phase, the behavior could be reproduced independently even after the external AR support was withdrawn, which accounts for the stable, high-level performance observed during Baseline-2. This mechanism aligns with cognitive load theory, which posits that learning is impaired when working memory is overloaded by extraneous demands; by presenting each safety step as a discrete, concrete audio-visual cue rather than a verbally held instruction (Sweller et al., 1998), the AR media reduces extraneous cognitive load and frees working memory capacity for the germane processing needed to internalize the safety behavior

Augmented reality allows users to interact with digital content presented in real time and integrated into their physical surroundings (Arena et al., 2022), a characteristic that underlies the high validity scores and the consistent skill improvement observed during the SSR A-B-A field trial. This outcome suggests that the AR-based media is well aligned with the learning characteristics of children with intellectual disabilities, who typically experience difficulty with abstract reasoning, memory retention, and following complex instructions (Dobosiewicz et al., 2020).

The media developed has been proven to be valid and suitable for use; however, this study has several limitations that should be noted: the field trial used a Single Subject Research (SSR) design involving a small number of participants, so the app's effectiveness in improving personal hygiene skills has not yet been established across a larger and more diverse sample of children with intellectual disabilities. The app is currently limited to Android devices, so it requires further development to be compatible with other technology platforms. Further research is recommended to test the app's effectiveness by involving a larger number of students, and future studies could examine the long-term impact of AR use on skill retention.

■ CONCLUSION

This study set out to answer two questions: how valid the developed AR learning media is, and how effective it is in improving personal hygiene safety skills among children with intellectual disabilities. Both questions are answered affirmatively. Expert validation confirmed that the media, developed using the ADDIE instructional design model and integrating interactive three-dimensional visualizations, audio-guided instructions, and safety-oriented features across toothbrushing, bathing, and hair washing, is highly valid for use in special education settings. The SSR A-B-A field trial further confirmed that the media is effective, producing a clear and sustained improvement in the subject's personal hygiene safety skill.

For classroom practice, these findings suggest that special education teachers can introduce the AR media as a structured, repeatable supplement to direct instruction when teaching toothbrushing, bathing, and hair-washing safety, rather than as a replacement for teacher-led modeling. Given that the intervention phase showed a more variable, actively-learning pattern before stabilizing, teachers are encouraged to allow sufficient repeated practice sessions with the AR media before withdrawing support, and to pair AR sessions with brief teacher-guided discussion of the safety cues shown, so that gains are more likely to be consolidated into independent, lasting skill mastery. Taken together, these findings position the AR media not as a stand-alone replacement for direct instruction, but as a pedagogically grounded supplement whose benefits depend on how deliberately it is paired with teacher-guided practice.

■ DECLARATION OF GENERATIVE AI USAGE IN THE WRITING PROCESS

During the drafting of this manuscript, the

authors used ChatGPT (OpenAI) to refine sentence structure, improve English grammar and academic language, and assist with translation. Following the use of this tool, the authors reviewed and revised the content as necessary and accept full responsibility for the final content of the article.

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