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The Effectiveness of 3D Recycled Educational Tools Based on Deep Learning Principles in Strengthening Pancasila Literacy: A Quasi-Experimental Study in an Inclusive Primary School

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Abstract. Inclusive primary schools in resource-constrained and geographically remote regions frequently depend on text-based, lecture-driven instruction that inadequately accommodates the behavioural and cognitive profiles of students with special educational needs (SEN), particularly hyperactivity. This study examined the effectiveness of 3D Recycled Educational Game Tools (*Alat Permainan Edukatif*, APE) grounded in Fullan's Deep Learning principles: Conscious, Meaningful, and Enjoyable for strengthening Pancasila literacy in an inclusive fourth-grade classroom at SD YPK Ebenhaezer Yamna, Sarmi Regency, Papua, Indonesia. The target population comprised fourth-grade pupils enrolled in inclusive primary schools across the Sarmi coastal district; from this population, two intact classes (N = 32) were drawn through total sampling and assigned to an experimental class (n = 16) taught with the 3D Recycled APE Pancasila Maze and a control class (n = 16) taught conventionally, under a non-equivalent control-group pretest–posttest design. Data were gathered using a validated 10-item Pancasila literacy test and a multidimensional behavioural-engagement observation checklist and analysed with the normalised gain (N-Gain), assumption tests (Shapiro–Wilk normality and Levene's homogeneity of variance), and an independent-samples t-test. The two classes were statistically equivalent at pre-test ($t(30) = -0.78$, $p = .444$). After the intervention, the experimental class markedly outperformed the control class ($t(30) = 5.492$, $p < .001$), with a very large effect size (Cohen's $d = 1.94$) and a moderate mean N-Gain (0.58) versus a low gain (0.22). The findings indicate that tactile, locally contextualised, game-structured media effectively bridge cognitive-behavioural barriers for SEN learners in remote inclusive classrooms.

Keywords: 3D Recycled Educational Tools; Deep Learning; Pancasila Literacy; Inclusive Education; Quasi-experiment

1. Introduction

Inclusive education rests on the principle that every learner, irrespective of cognitive profile, behavioural characteristics, socio-economic circumstance, or geographical location, is entitled to equitable, meaningful, and participatory learning experiences (Navas Bonilla et al., 2025). Across Southeast Asia, and especially within resource-constrained and geographically remote communities, a persistent distance separates this normative commitment from everyday instructional practice. The gap is neither incidental nor evenly distributed: it concentrates in schools that combine limited physical infrastructure, thinly resourced teacher preparation, and curricula that remain culturally distant from the lived worlds of the children they are meant to serve. Recent meta-analytic evidence indicates that game-based and interactive learning environments consistently yield positive effects on cognitive achievement, motivation, and affective engagement, suggesting that active instructional approaches may be particularly valuable in the diverse primary classrooms where transmissive teaching most conspicuously fails(Barz et al., 2024).

SD YPK Ebenhaezer Yamna, a C-accredited primary school in Sarmi Regency on the northern coast of Papua, exemplifies this predicament. Its pupils negotiate a double disadvantage. On one axis lie cognitive and behavioural challenges associated with heterogeneous learning profiles, including hyperactivity; on the other lie the pedagogical limitations of conventional Pancasila and Civic Education instruction, which typically privileges verbal recitation of the

five national principles over their enactment. Fiharsono et al. (2024) demonstrate that pupils in lowland-remote Papua confront compounded barriers spanning both the physical school environment and culturally decontextualised curricula, conditions that widen the distance between civic-education content and learners' everyday experience. For children who already struggle to sustain attention in lecture-based settings, a curriculum delivered through abstract verbal transmission is doubly inaccessible, and the risk of disengagement compounds across each successive lesson.

This predicament is not merely local; it intersects with a national policy horizon. Indonesia's contemporary education agenda increasingly foregrounds deep, values-oriented learning and the strengthening of the Profil Pelajar Pancasila, while the country's inclusive-education mandate obliges ordinary schools to accommodate learners with special educational needs within regular classrooms. Yet policy ambition and classroom capacity are unevenly matched. In remote coastal and lowland districts, the very schools asked to deliver inclusive, character-forming civic education are those least equipped with trained personnel, adaptive materials, or infrastructure. The result is a structural mismatch: an aspirational curriculum that presumes resources and pedagogical repertoires that many frontier schools simply do not possess. Designing interventions that are simultaneously low-cost, culturally grounded, and responsive to neurodiverse learners is therefore not a peripheral concern but a precondition for translating national policy into equitable practice.

1.1. Problem Statement

The theoretical inadequacy of text-centred civic instruction for this population is well established. In a systematic review of constructivist instructional evidence, Arega and Hunde (2025) confirm that primary-school children build deeper and more durable conceptual understanding when learning actively engages them in manipulating objects connected to familiar environments. Behavioural barriers compound the difficulty: learners with attention-deficit/hyperactivity disorder (ADHD) and related hyperactivity profiles require structured, physically engaging, goal-directed tasks to sustain attention and regulate behaviour (Lee et al., 2025). Contemporary reviews reinforce this point, noting that highly structured, executive-function-oriented activities are precisely what students with special educational needs require to focus and to minimise distraction (Gunnars, 2024).

The neurocognitive basis of this requirement is increasingly clear. Núñez et al. (2024) report that executive-function capacities inhibitory control, cognitive flexibility, and working memory are significantly more impaired in SEN learners than in neurotypical peers, and that activity-based interventions targeting these capacities produce meaningful academic gains. Complementary clinical evidence shows that movement and touch are not merely motivational adjuncts but functional mechanisms: Zheng et al. (2025) demonstrate meta-analytically that physical activity significantly alleviates core ADHD symptoms, while Robertz et al. (2024) show that structured tactile stimulation measurably reduces hyperactivity, impulsivity, and inattention in young people with ADHD. Taken together, these findings imply that instruction for hyperactive learners should be redesigned around embodied, tactile, and goal-structured activity rather than verbal transmission, yet such redesign remains rare in remote inclusive classrooms, where teaching materials are scarce and professional support is intermittent.

1.2. Related Research

A growing body of quantitative synthesis supports embodied and game-based approaches. In a meta-analysis of 46 studies, Liu et al. (2025) report a significant overall advantage of embodied learning on academic performance, with effects that are larger at the primary-school level. Alotaibi (2024) documents significant positive effects of game-based learning on cognitive development ($g = 0.46$), motivation ($g = 0.40$), and engagement ($g = 0.44$) in early childhood and primary education, while Li et al. (2023) find that the addition of game elements substantially strengthens both learner drive and achievement. These results converge with Zeng et al. (2024), whose comprehensive meta-analysis of studies published between 2008 and 2023 reports a moderately positive overall effect of gamification on academic

performance (Hedges' g = 0.782). Analog and tangible games appear to offer a distinctive advantage: Sousa et al. (2023) show that board and tabletop formats generate physical interactions frequently absent from digital media, fostering intense peer collaboration and direct hands-on engagement, and contemporary reviews confirm that gamified environments sustain intrinsic motivation and participation in ways well suited to accommodating diverse learner needs (Lampropoulos & Kinshuk, 2024).

Despite this convergence, two limitations recur across the school-based literature. First, most prior studies rely on single-group pretest–posttest designs that lack a comparison condition and therefore cannot isolate the medium's causal contribution. Wang et al. (2026) illustrate a critical methodological advancement by extending the evidence base of game-based learning into formal quasi-experimental designs within elementary education, complete with the inclusion of control groups. Second, few studies engage learners with special educational needs in remote, culturally specific settings; the evidence base remains dominated by well-resourced, urban, and neurotypical samples. Di Fuccio et al. (2025) show experimentally that materials engaging visual, tactile, and kinaesthetic channels simultaneously produce significantly greater retention than single-channel approaches, but such multisensory designs have rarely been tested where they may matter most among SEN children in under-resourced schools. The present study addresses both gaps. Its novelty lies in coupling a controlled comparative design with an explicit focus on SEN learners inside a remote Papua inclusive primary school, using instructional media handcrafted from locally sourced coastal waste.

1.3. Research Objectives and Hypotheses

Within Fullan's Deep Learning framework, this study introduced 3D Recycled Educational Game Tools (APE) fashioned from locally sourced Sarmi coastal waste. Three objectives were pursued: (1) to determine whether pupils taught with 3D Recycled APE media attain significantly higher Pancasila literacy than those taught conventionally; (2) to quantify the magnitude of improvement in each class through N-Gain and effect size; and (3) to examine the learning and behavioural response of hyperactive learners as a confirmatory case embedded within the design. Two statistical hypotheses were tested. The null hypothesis (H0) states that there is no significant difference in post-test Pancasila literacy between the experimental and control classes; the alternative hypothesis (H1) states that the experimental class achieves significantly higher post-test scores than the control class.

2. Theoretical Framework

2.1. Deep Learning Principles

Fullan et al. (2018) articulate Deep Learning as a pedagogical framework built on three interconnected qualities: Conscious learning that is purposeful and reflective; Meaningful learning that connects to learners' real-world contexts and values; and enjoyable learning that sustains intrinsic motivation and positive affect. Each quality carries a distinct pedagogical implication for Pancasila education in an inclusive coastal classroom, and each was deliberately operationalised in the design of the intervention rather than treated as a general aspiration.

Conscious learning is enacted whenever a pupil deliberately selects the maze pathway that represents a particular sila, for instance, tracing the route that corresponds to sila ke-5, keadilan sosial bagi seluruh rakyat Indonesia. The act of choosing, rather than being told, demands purposeful moral reasoning and positions the learner as an agent rather than a recipient of civic content. Meaningful learning becomes tangible when abstract civic principles such as gotong royong, the essence of the sila ke-3 (the third principle of Pancasila), are not merely recited but physically enacted, as students guide one another through the maze, take turns, and negotiate shared paths. This design resonates with Awaliya and Utami (2024), who document that the gotong royong character is most durably strengthened through active group participation demanding solidarity and shared decision-making, precisely the conditions the maze format created. Enjoyable learning completes the triad by lowering affective barriers; the game structure transforms a civics lesson from obligatory

recitation into voluntary exploration, a shift particularly consequential for SEN learners who may associate formal instruction with frustration and failure (Reeve et al., 2025).

The distinction that gives the framework its analytical bite is the contrast between deep and surface learning. Surface learning treats civic principles as discrete facts to be memorised and reproduced on demand; deep learning treats them as competencies to be understood, applied, and internalised through sustained, connected experience. In the conventional PKn lesson, a pupil may correctly recite the five sila yet fail to enact any of them; under a Deep Learning design, recitation is replaced by decision, negotiation, and reflection, so that the value is not only known but practised. This shift is precisely what a values-laden subject such as Pancasila education requires, since its ultimate objective is dispositional rather than merely informational: the formation of citizens who reason morally and act cooperatively, not learners who can list principles.

Considered together, these three principles do more than frame the intervention; they map onto Pancasila's own internal logic of conscious citizenship, social solidarity, and equitable participation. This alignment echoes the national effort to strengthen the Profil Pelajar Pancasila by shifting the emphasis from memorizing concepts to practicing values in daily school life (Rahmat & Suparjana, 2023). The intervention thus positions Deep Learning not as a generic engagement strategy but as a structural translation of civic values into embodied action.

2.2. Embodied and Multisensory Learning

Embodied learning theory holds that cognition is grounded in bodily experience and in physical interaction with the environment rather than in the manipulation of abstract symbols alone (Liu et al., 2025). Recent embodied-cognition research demonstrates that learning activities requiring direct physical interaction with instructional materials strengthen conceptual understanding by integrating sensory, motor, and cognitive processes into a single, unified experience (Lin et al., 2024). The pedagogical payoff is not merely affective; it is mnemonic and conceptual. Di Fuccio et al. (2025) provide experimental confirmation that children who learn through multisensory materials engaging visual, tactile, and kinaesthetic channels simultaneously retain significantly more information than peers taught through single-modality instruction. Yeung and Ng (2023) similarly show that object manipulation and touch-based interaction promote deeper cognitive processing and stronger memory retention than passive reception. For a civic curriculum traditionally delivered through words, these findings suggest a concrete redesign principle: encode each abstract value in a manipulable object and a navigable spatial structure, so that the learner's hands and movement, not only their ears, carry the meaning.

2.3. Inclusive Education and SEN Learners

For pupils with ADHD and hyperactivity profiles, conventional transmissive pedagogy is particularly ill-suited: executive-function impairments systematically disadvantage these learners in lecture-based settings, where sustained attention and inhibitory control are prerequisites for access (Núñez et al., 2024). Converging evidence indicates that tactile stimulation and structured physical activity are not peripheral comforts but genuine therapeutic mechanisms. Robertz et al. (2024) find that structured tactile input reduces hyperactivity, impulsivity, and inattention; Zheng et al. (2025) show meta-analytically that physical activity alleviates core ADHD symptomatology; and Piller et al. (2025), in a systematic review spanning 2015–2024, report strong evidence for deep-pressure and sensory-based interventions on functional outcomes in children and youth. An inclusive pedagogy that embeds movement and touch into ordinary academic tasks therefore addresses the neurology of these learners directly, rather than treating their behaviour as a disciplinary problem to be suppressed. It is this convergence between what embodied learning offers all children and what SEN learners specifically require that motivates the design of the present intervention.

3. Method

3.1. Research Design

A non-equivalent control-group pretest–posttest framework was implemented, following the quasi-experimental tradition described by Campbell and Stanley (1966) and Creswell (2018). Quasi-experimentation was appropriate because the random assignment of individual pupils would have disrupted established classes in a small school; intact classes were therefore used, and equivalence was established statistically at pre-test rather than by randomisation. The design compared an experimental class taught with 3D Recycled APE media against a control class taught through conventional lecture-based instruction, with both classes assessed immediately before and after the intervention. It is represented notationally as E: O1 X O2 for the experimental group and C: O3 – O4 for the control group, where O denotes an observation (test) and X the intervention. To limit threats to internal validity, both classes followed the same Pancasila content, the same instructional duration, and the same assessment instruments; only the mode of delivery differed. The study received ethical approval from the relevant university's Research Ethics Committee, and informed parental consent was obtained for every participating child.

3.2. Population and Sample

The target population of this study comprised fourth-grade pupils enrolled in inclusive primary schools within the Sarmi coastal district of Papua Province, Indonesia, schools that share the defining features of C-accreditation, limited instructional resources, and mixed classrooms in which SEN and neurotypical learners are educated together. The accessible population consisted of the fourth-grade cohort at SD YPK Ebenhaezer Yamna, the inclusive primary school at which the intervention was conducted. Because the school maintains only two parallel fourth-grade classes, total (saturated) sampling of intact classes was adopted rather than probability sampling: every eligible pupil in both classes was included, yielding a census of the accessible population and eliminating volunteer self-selection within it.

Class IV-A was designated the experimental group (n = 16) and Class IV-B the control group (n = 16), for a total of 32 participants. The assignment of classes to conditions was made prior to any testing and was not based on prior achievement. The two classes were demographically comparable in age, language background, and coastal-community origin. The experimental class included one pupil with a formally noted hyperactivity profile (coded TR) and three pupils with low baselines (pre-test ≤ 30); the control class included one pupil with a comparable hyperactivity profile (coded RS) and one low-baseline pupil. This near-symmetry in the distribution of hyperactive learners across conditions was not engineered, but it proved analytically valuable, permitting a within-study comparison (TR versus RS) of two similarly diagnosed children exposed to different instructional modalities. Baseline equivalence of the two groups was subsequently confirmed statistically (see Section 4.1), supporting the interpretability of the post-test contrast despite the absence of randomisation.

3.3. The Intervention: The 3D Recycled APE "Pancasila Maze"

The instructional medium consisted of a three-dimensional educational game, constructed entirely from locally sourced coastal waste from Sarmi, including reclaimed timber, metal bolts, processed shells, and dried leaves. The device took the form of a navigable maze whose branching pathways each terminated in a station representing one of the five sila of Pancasila; principal symbols were encoded in tactile shell-and-leaf markers so that each value could be seen, touched, and physically reached. Pupils moved a shell token through the maze, naming and reasoning about the corresponding sila at each junction, both individually and in small collaborative groups.

The maze was designed to operationalise the three Deep Learning qualities concurrently. Consciousness was engaged at each decision point, where a pupil had to choose a path and justify why it corresponded to a given principle; meaning was engaged by rendering an abstract value as a physical route with a culturally familiar marker; and enjoyment was engaged by the game structure itself, which reframed assessment-like tasks as play. Each of

the six sessions followed a consistent rhythm: a brief orientation, guided individual navigation, small-group collaborative navigation, and a short reflective debrief so that pupils accumulated repeated, structured exposure to the same civic content across the two-week window. The maze was expert-validated prior to implementation to confirm that its structure faithfully represented the five principles and was developmentally appropriate for fourth-grade learners. In the control class, the identical Pancasila content was delivered through the school's customary lecture-and-textbook method, without manipulatives, over the same number of sessions and the same total instructional time.

3.4. Data Collection Instruments

Two instruments were used. The first was a 10-item Pancasila literacy test covering all five Pancasila principles, constructed from a content blueprint that mapped items to principles and administered identically at pre-test and post-test. The test yielded a content validity index of CVI = 0.91 and acceptable internal-consistency reliability (Cronbach's α = 0.82). The second instrument was a multidimensional behavioral-engagement observation checklist that captured cognitive, emotional, and behavioral engagement indicators. This tool was adapted from the engagement framework of Reeve et al. (2025) and was completed by the classroom teacher and the researcher during each session. The checklist provided the behavioural evidence used to interpret the hyperactive-learner case reported in Section 4.5.

3.5. Validity and Reliability

Content validity of the literacy test was established through expert review, producing a content validity index of 0.91. Internal-consistency reliability was acceptable (Cronbach's α = 0.82). The 3D Pancasila Maze itself was expert-validated before implementation to ensure conceptual fidelity and developmental suitability. For the observation checklist, inter-rater reliability was supported through joint training of the classroom teacher and the researcher prior to the intervention, so that both raters applied the engagement indicators consistently.

3.6. Research Procedure

The study proceeded in four stages. In the Preparation stage, pupils were profiled, local materials were mapped, and the pre-test was administered to both classes. In the Development stage, the 3D APE Pancasila Maze was designed and expert-validated using locally sourced Sarmi coastal waste reclaimed timber, metal bolts, processed shells, and dried leaves. In the Implementation stage, the experimental class engaged with the maze across six structured sessions over two weeks, while the control class received the same content through conventional instruction over the same period. In the Evaluation stage, the post-test was administered, and the behavioural-observation records were scored. Holding content, duration, and assessment constant across conditions ensured that any post-test divergence could reasonably be attributed to the mode of delivery.

3.7. Data Analysis

Analyses were conducted in IBM SPSS Statistics 26 at α = .05. For every participant, the normalised gain was computed as N-Gain = (Post-test − Pre-test) / (Maximum − Pre-test), with interpretive bands of high ≥ 0.70, moderate 0.30–0.69, and low < 0.30 (Hake, 1999) Before hypothesis testing, the distributional assumptions were verified: normality was assessed with the Shapiro-Wilk procedure and homogeneity of variance with Levene's test. The principal hypothesis was tested with an independent-samples t-test on post-test scores, and the magnitude of the effect was quantified with Cohen's d. Baseline equivalence was examined with an independent-samples t-test on pre-test scores.

4. Findings

4.1. Baseline Equivalence at Pre-test

Table 1 reports descriptive statistics for both classes. The pre-test independent-samples t-test detected no significant difference between the experimental class ($M = 39.06$, $SD = 8.41$) and the control class ($M = 41.56$, $SD = 9.78$), $t(30) = -0.78$, $p = .444$. The two groups therefore began

from statistically equivalent levels of Pancasila literacy, a precondition that licenses attributing any subsequent divergence to the intervention rather than to pre-existing differences. Figure 1 visualises the pre-test and post-test means for both classes, showing closely matched starting points and a pronounced post-test divergence favouring the experimental class.

Table 1. Descriptive Statistics of Pre-test and Post-test Scores by Class (N = 32)

Class	n	Pre-test M ± SD	Post-test M ± SD	Avg. N-Gain	Category
Experimental (3D Recycled APE)	16	39.06 ± 8.41	74.69 ± 8.46	0.58	Moderate
Control (Conventional)	16	41.56 ± 9.78	54.06 ± 12.41	0.22	Low
Mean diff. (post-test)	—	—	20.62	—	—

Note. N-Gain: high ≥ 0.70; moderate 0.30–0.69; low < 0.30 (Hake, 1999).

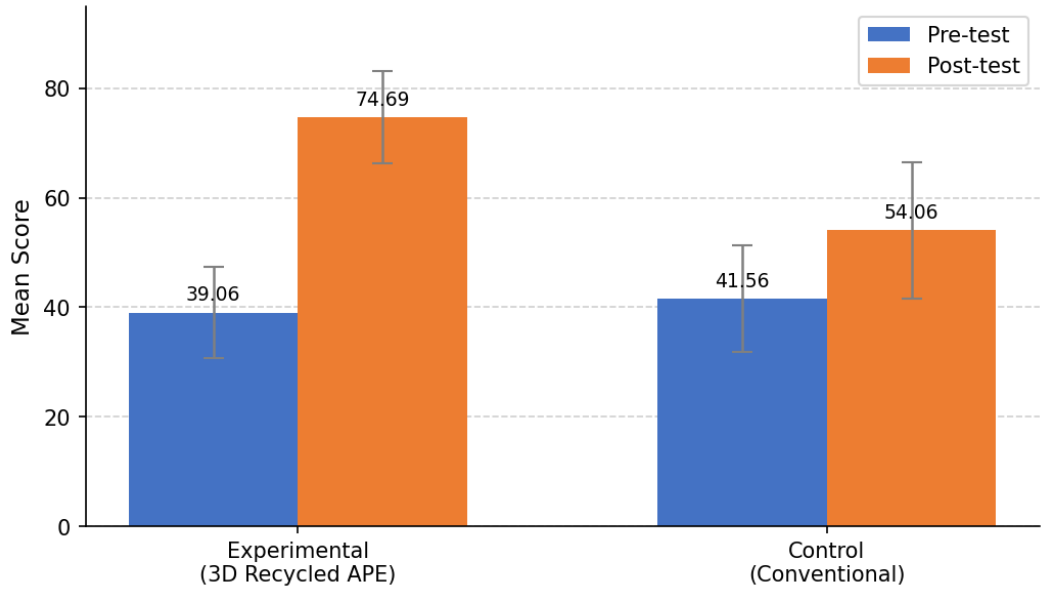

Figure 1. Comparison of Pre-test and Post-test Mean Pancasila Literacy Scores between the Experimental and Control Classes (error bars = SD).

4.2. Assumption (Prerequisite) Testing

Table 2 reports the assumption tests that precede parametric analysis. The Shapiro–Wilk procedure confirmed normality for all four score distributions (all $p > .05$), and Levene's test confirmed homogeneity of variance between the two post-test distributions, $F(1, 30) = 1.16$, $p = .287$. With both assumptions satisfied, the pooled independent-samples t-test was justified.

Table 2. Results of Prerequisite Tests (Normality and Homogeneity of Variance)

Test	Data	Statistic	Decision
Shapiro–Wilk	Pre-test, Experimental	W = 0.94, p = 0.281	Normal
Shapiro–Wilk	Pre-test, Control	W = 0.97, p = 0.859	Normal
Shapiro–Wilk	Post-test, Experimental	W = 0.96, p = 0.714	Normal
Shapiro–Wilk	Post-test, Control	W = 0.95, p = 0.480	Normal

Test	Data	Statistic	Decision
Levene	Post-test (Exp. vs Control)	F = 1.16, p = 0.287	Homogeneous

Note. p > 0.05 indicates the assumption is met.

4.3. Principal Hypothesis Test (Post-test Comparison)

The independent-samples t-test on post-test scores, reported in Table 3, was highly significant: the experimental class (M = 74.69, SD = 8.46) significantly outperformed the control class (M = 54.06, SD = 12.41), t(30) = 5.492, p < .001, with a mean difference of 20.62 points (95% CI [12.96, 28.29]) and a very large effect size (Cohen's d = 1.94). The null hypothesis (H0) is therefore rejected, and the alternative hypothesis (H1) accepted: pupils taught with the 3D Recycled APE media achieved significantly higher Pancasila literacy than those taught conventionally.

Table 3. Independent-Samples t-Test on Post-test Pancasila Literacy Scores

Comparison	t	df	p	Mean diff.	95% CI	Cohen's d
Experimental vs Control (post-test)	5.492	30	< 0.001	20.62	12.96–28.29	1.94

Note. Equal variances assumed (Levene's p = 0.287). Cohen's d = 1.94 = very large effect.

4.4. Normalised-Gain Analysis

Complementing the between-groups test, the normalised gain quantifies the improvement realised within each class relative to the room available for growth. The experimental class achieved a moderate mean N-Gain of 0.58, more than double the low mean gain of 0.22 recorded in the control class. Table 4 summarises the N-Gain distribution. The disparity indicates not only that the experimental class scored higher at post-test but that its pupils converted a substantially larger share of their available learning potential into measured gains consistent with the interpretation that the medium, rather than differential starting points, drove the improvement.

Table 4. Summary of N-Gain Scores in Experimental and Control Classes

Class	N	Minimum	Maximum	Mean N-Gain	Category
Experimental (3D Tools)	16	0.50	1.00	0.58	Moderate
Control (Conventional)	16	0.00	0.55	0.22	Low

Note. N-Gain interpretive bands follow Hake (1999): high ≥ 0.70; moderate 0.30–0.69; low < 0.30.

4.5. Behavioural Engagement and the Hyperactive-Learner Case (TR versus RS)

The near-symmetric placement of two similarly diagnosed hyperactive pupils across the two conditions afforded a quasi-experimental dissociation of media effect from diagnosis. Although TR (experimental) and RS (control) carried the same hyperactivity designation, their trajectories diverged sharply: TR advanced from 20 to 80 (N-Gain = 0.75), whereas RS advanced only from 35 to 50 (N-Gain = 0.23). The behavioural-engagement records add texture to this contrast. In Session 1, TR struggled to remain seated and repeatedly left the task before completion, recording some of the lowest emotional and cognitive-engagement scores in the experimental class. During Session 3, TR independently traced the maze pathways using a shell token and correctly named each *sila* at every junction, a change that the classroom teacher specifically highlighted on the observation checklist. By Session 6, TR completed the maze twice, corrected a peer's placement of the sila ke-2 symbol, and

remained on task for the full session. RS, receiving conventional instruction, was afforded no comparable tactile or goal-directed channel and showed only marginal change. This within-study contrast localises the active ingredient of the intervention in its embodied, tactile, and goal-structured affordances rather than in content exposure alone.

5. Discussion

The results provide controlled, comparative evidence that 3D Recycled APE media grounded in Deep Learning principles constitute an effective instructional solution for resource-constrained, inclusive primary schools in remote Papua. Because the two classes were statistically equivalent at pre-test ($p = .444$) and satisfied the normality and homogeneity assumptions (Levene's $p = .287$), the highly significant post-test difference ($t(30) = 5.492$, $p < .001$) and very large effect (Cohen's $d = 1.94$) can be attributed to the intervention with reasonable confidence. The convergence of evidence points to four interlocking mechanisms: multisensory encoding, executive-function engagement, embodied–tactile regulation, and constructivist cultural contextualisation.

The multisensory architecture of the medium is central to its effectiveness. This finding aligns with reviews showing that tactile interaction and object manipulation enhance learning by promoting deeper cognitive processing and stronger memory retention, particularly when learners actively engage with physical materials rather than passively receiving information (Yeung & Ng, 2023). Di Fuccio et al. (2025) confirm experimentally that children recall significantly more when learning engages visual, tactile, and kinaesthetic channels simultaneously. Within the Pancasila Maze, shells and dried leaves function as simultaneous visual–tactile encoders of principal symbols, while maze navigation adds a spatial-kinaesthetic reasoning component. The medium thus distributes the cognitive load of an abstract civic concept across several perceptual channels, each providing a redundant route to the same idea, an arrangement that benefits all learners and disproportionately benefits those for whom a single verbal channel is a bottleneck. Figure 2 shows the locally sourced Sarmi coastal waste used in construction, and Figure 3 illustrates the completed Pancasila Maze together with pupils engaging with it during intervention sessions.

Figure 2. Local coastal waste materials (shells) collected from Sarmi Beach for 3D APE construction. All materials were ethically sourced from public coastal areas in Sarmi Regency.

Figure 3. (Top left) The 3D Pancasila Maze APE crafted from Sarmi coastal waste. (Top right & bottom) Students engaging with the APE during intervention sessions. Parental consent was obtained; faces are partially obscured to protect confidentiality.

The comparison between TR and RS offers a near-experimental dissociation of media effect from diagnosis and warrants particular emphasis. Their divergent trajectories (N-Gain 0.75 versus 0.23) reflect a mechanism that the clinical literature now identifies clearly. Fang et al. (2024) Report meta-analytically that cognitively engaging physical activity produces significant improvements in executive functioning, behavioural regulation, and attention control among children with ADHD, supporting the interpretation that the physical, goal-directed nature of the maze contributed to TR's substantial gains. Zheng et al. (2025) show that structured physical activity reduces core ADHD symptoms; Robertz et al. (2024) demonstrate that tactile stimulation lowers hyperactivity, impulsivity, and inattention; and Piller et al. (2025) confirm strong evidence for sensory-based input on functional outcomes. RS, by contrast, received no such sensory affordance: conventional lecture-based instruction withheld the very regulatory channel that TR's neurology required. The substantial N-Gain disparity underscores the necessity of aligning instructional modality with the neurological profile of SEN learners, rather than evaluating content acquisition in isolation from the conditions under which these children can actually attend.

The locally sourced Sarmi materials deserve more than passing mention; they may represent the study's most transferable design principle. The shells, reclaimed timber, and dried leaves embedded in the maze are not generic recyclables. They are objects that Sarmi's coastal children encounter daily, carry home, and associate with familiar adult practices of fishing, building, and gathering along the shore. This ecological familiarity is pedagogically active. Driving educational change in remote coastal areas depends heavily on mobilising local resources to compensate for infrastructural scarcity (Indra Putra et al., 2025). Fiharsono et al. (2024) document that pupils in lowland-remote Papua face compounded barriers when

curricula are culturally decontextualised from their environments; conversely, when materials draw on locally resonant objects, they narrow the psychic distance between abstract content and lived meaning. In this sense, the maze embodies the Indonesian principle of kearifan lokal (local wisdom), anchoring formal civic knowledge within the ecological and cultural knowledge children already bring to the classroom. Arega and Hunde (2025) confirm that constructivist approaches that ground learning in familiar socio-cultural and environmental contexts yield significantly superior outcomes, and the present study extends that finding to an inclusive, remote Papua primary school setting. The results likewise support emerging evidence that interventions are more effective when they simultaneously integrate contextual relevance, active participation, and meaningful experience, enabling pupils to connect academic concepts with everyday realities while sustaining motivation (Barz et al., 2024; Lampropoulos & Kinshuk, 2024)

Theoretically, these findings substantiate the claim that Deep Learning's three qualities are not interchangeable engagement tactics but structurally distinct levers: consciousness recruits moral reasoning, meaning recruits cultural memory, and enjoyment lowers the affective threshold to participation. Each lever, moreover, targets a different point of failure in the conventional lesson: the absence of agency, the absence of relevance, and the presence of aversion, which helps explain why the combined intervention produced an effect of unusual magnitude rather than the modest gains typical of single-component manipulations. The four mechanisms identified above are best understood as mutually reinforcing rather than additive: multisensory encoding gives executive function something concrete to act upon, tactile regulation makes sustained engagement possible, and cultural contextualisation supplies the motivation that keeps a hyperactive learner returning to the task.

Practically, the study demonstrates that a high-impact inclusive intervention need not depend on digital infrastructure or commercial materials; it can be built from waste that the community already possesses. In terms of policy, this reframes the challenge of inclusive education reform in frontier districts: the binding constraint is often not funding for imported technology, but rather the design imagination and teacher capacity required to convert locally abundant materials into rigorous, values-aligned pedagogy. Interventions of this kind are therefore plausibly scalable across the many Indonesian schools whose circumstances resemble those of SD YPK Ebenhaezer Yamna, provided that scaling is accompanied by adequate teacher preparation. Equipping teachers with adaptive skills through ongoing professional training is a key condition for managing such interventions effectively (Pratama & Muna, 2025). Where local governments seek to scale this model across schools, adopting robust, implementation-informed strategies is essential so that the core pedagogical benefits are preserved as the intervention moves into new settings (Ryan et al., 2024).

Methodologically, the very large effect size should be read with appropriate caution: intact-class designs and small samples can inflate estimates, and the confirmatory single-case contrast, while illuminating, cannot by itself establish population-level generality. The convergence of the between-groups test, the within-class N-Gain analysis, and the behavioural record nonetheless renders the substantive conclusion robust, even as the precise magnitude awaits replication. Accordingly, the reliance on intact classes and a single-school sample limits external validity, and the effect, while encouraging, should be confirmed in larger, multi-site trials with longer follow-up before strong generalisation is warranted.

6. Conclusion

This quasi-experimental study set out to answer three questions concerning the effect of 3D Recycled Educational Game Tools grounded in Deep Learning principles on Pancasila literacy in an inclusive fourth-grade classroom at SD YPK Ebenhaezer Yamna, Sarmi, Papua. In response to the first question, the experimental class, which began from a baseline statistically equivalent to that of the control class ($t(30) = -0.78$, $p = .444$), significantly outperformed the control class at post-test ($t(30) = 5.492$, $p < .001$); the null hypothesis was therefore rejected and the alternative accepted. In response to the second question, the magnitude of the advantage was substantial: a very large effect size (Cohen's $d = 1.94$) accompanied a

moderate mean normalised gain (0.58) in the experimental class against a low gain (0.22) in the control class. In response to the third question, the hyperactive learner taught with the media advanced from 20 to 80 (N-Gain = 0.75), while the comparably diagnosed learner taught conventionally improved only marginally, isolating the tactile, kinaesthetic, and goal-directed affordances of the medium as the decisive pedagogical ingredient. Taken together, the findings establish that locally contextualised, embodied, and game-structured media significantly strengthen Pancasila literacy and behavioural engagement for SEN learners in a remote inclusive primary school, and that the effect is attributable to the mode of delivery rather than to differences in content or in the pupils' starting points.

Limitations

The study is limited by its single-school, two-class design within a specific remote-Papua context. The use of intact, non-randomly assigned classes introduces potential selection bias, and the small sample (N = 32) may inflate effect-size estimates. The six-session intervention window does not permit conclusions about long-term retention, and reliance on a single school constrains the generalisability of the findings to other inclusive settings.

Recommendations

Teachers in inclusive and remote primary schools are encouraged to shift toward adaptive, manipulative media built from locally available materials and to strengthen their adaptive teaching skills through ongoing professional training, which is a key condition for managing such interventions effectively. Local governments should invest in sustained teacher professional development in inclusive pedagogy and, where they seek to scale this model across schools, should adopt robust implementation strategies so that the core pedagogical benefits are preserved in new settings. Future research should employ larger, multi-site samples, randomised controlled trials where feasible, and longitudinal follow-up of SEN learners in remote Indonesian contexts, in order to test the durability and transferability of the effects reported here.

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Conflict of Interest Statement

The author(s) declare(s) that there is no conflict of interest.

Declaration of Generative AI and AI-assisted Technologies

The author(s) declare that no generative AI or AI-assisted technologies were used to produce the intellectual content, analysis, or interpretation reported in this manuscript. Any language-editing assistance was reviewed and verified by the author(s), who take full responsibility for the content of the publication.

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