International Journal of Functional Research in Science and Engineering
e-ISSN: 2814-0923
www.ijfrse.com

Facilitating Science Process Skills in Early Childhood Education Through Digital Simulation: A Quasi-Experimental Study

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Abstract

This study examined the effectiveness of digital simulation in facilitating science process skills among children in early childhood education. A quasi-experimental pretest-posttest control group design was employed with 120 children aged 4 to 6 years drawn from four early childhood centers. The experimental group ($n = 60$) engaged with curriculum-aligned digital simulation activities addressing observing, classifying, measuring, predicting, and communicating, while the control group ($n = 60$) received conventional hands-on instruction on the same content over eight weeks. Skills were assessed with the Early Science Process Skills Rating Scale (ESPSRS). Analysis of covariance (ANCOVA), controlling for pretest scores, revealed a significant difference in posttest composite scores favoring the experimental group, $F(1, 117) = 113.58$, $p < .001$, partial $\eta^2 = .49$, a large effect. Gains were most pronounced in observing and communicating, with more modest but significant gains in measuring and predicting. Findings suggest that well-designed digital simulations, integrated with teacher scaffolding and hands-on follow-up, can meaningfully strengthen foundational scientific reasoning in young children without displacing developmentally appropriate practice.

science process skills, digital simulation, early childhood education, technology-enhanced learning, quasi-experimental design

Background

Science process skills—the cognitive and psychomotor competencies underlying scientific inquiry, including observing, classifying, measuring, predicting, and communicating—form the foundation for later scientific literacy (Padilla, 1990). These skills develop through repeated, guided opportunities to interact with phenomena rather than as automatic byproducts of maturation (Eshach & Fried, 2005). Early childhood is a sensitive period for this development, given young children's natural curiosity about their physical environment (Gelman & Brenneman, 2004), yet many classrooms devote little structured time to science, and where it is taught, instruction often emphasizes passive fact transmission over the active, exploratory experiences process-skill development requires (Charlesworth & Lind, 2020).

Digital simulation—interactive, computer-based representations that let learners manipulate variables and observe outcomes in real time—has emerged as a candidate tool for addressing this gap, making otherwise inaccessible phenomena observable within a single session (Clements & Sarama, 2003; Plass et al., 2015). Critics caution that screen-based tools risk supplanting the concrete, multisensory manipulation early-learning theory considers indispensable unless integrated with teacher guidance (Plowman & Stephen, 2005). Vygotsky's (1978) sociocultural theory frames simulation as a mediating tool that extends a child's zone of proximal development, while Bandura's (1986) social cognitive theory suggests immediate visual feedback strengthens self-efficacy and sustains engagement—together implying simulation is best positioned as a complement to, not substitute for, guided hands-on instruction. Empirical evidence remains thin: Hsin and Wu (2011) found a scaffolded simulation improved kindergarteners' predictive reasoning, and Ihmeideh and Al-Maadadi (2018) reported gains in observation and classification, but existing studies often use small samples or lack an equivalent hands-on comparison group. This study addresses these gaps with a controlled, multi-site design measuring the full range of process skills typically emphasized in early science curricula.

Purpose and Research Questions

This study determined whether structured digital simulation activities are more effective than conventional hands-on instruction in developing science process skills among children aged 4 to 6. Specifically: (1) Is there a significant difference in overall science process skill scores between children receiving digital simulation instruction and those receiving conventional instruction, controlling for pretest performance? (2) Do effects differ across the five component skill domains—observing, classifying, measuring, predicting, and communicating? It was hypothesized that the digital simulation group would show significantly higher adjusted posttest composite and domain scores than the conventional instruction group.

Method

Research Design and Participants

This study used a quasi-experimental, nonequivalent control group design with pretest and posttest measures (Moore & Tananis, 2009); whole classrooms were randomly assigned to condition, with pretest scores serving as a covariate to adjust for baseline differences.

Participants were 120 children (62 boys, 58 girls) aged 4 to 6 years (M = 5.02, SD = 0.79) from four early childhood centers in southeastern Nigeria, with 60 assigned to each condition. Centers were comparable in socioeconomic catchment and prior science exposure, confirmed by nonsignificant pretest differences, $t(118) = 1.42$, $p = .158$ (Table 1). Parental consent and child assent were obtained, and the protocol was approved by the host institution's research ethics committee.

Table 1

Demographic Characteristics of Participants (N = 120)

Characteristic	**Category**	**n**	**%**
Age	4–5 years	92	76.7
	6 years	28	23.3
Sex	Male	62	51.7
	Female	58	48.3
Group	Experimental (simulation)	60	50.0
	Control (conventional)	60	50.0

Note. Percentages may not sum to 100 due to rounding.

Instrumentation

Science process skills were measured using the Early Science Process Skills Rating Scale (ESPSRS), a 45-item observation instrument adapted from Padilla's (1990) taxonomy and validated for children aged 4 to 7, with five subscales rated from 0 (not demonstrated) to 2 (independently demonstrated) across nine items each. For consistency with Table 2, subscale means are expressed on a 0–10 scale. Internal consistency was high (composite $\alpha = .89$; subscale αs = .78–.86), and blind double-rating of 25% of sessions yielded an intraclass correlation of .91.

Intervention and Comparison Condition

The experimental group completed twenty-four 30-minute sessions over eight weeks using tablet-based simulations covering states of matter, plant growth, simple machines, weather, and floating and sinking, each session structured around teacher orientation (5 min), guided paired exploration with picture-based recording (15 min), and group discussion (10 min); teachers received eight hours of prior scaffolding training. The control group covered identical topics, session count, and time allocation using conventional hands-on materials (real plants, objects of varying density, pulley and lever models, thermometers), holding instructional time and structure constant across conditions.

Procedure and Data Analysis

Both groups completed the ESPSRS pretest the week before and posttest the week after the intervention, rated by the same trained, condition-blind observers. A one-way ANCOVA on posttest composite scores, with pretest scores as the covariate, addressed Research Question 1, with assumption checks confirming linearity, homogeneity of regression slopes, and homogeneity of variance. Separate subscale ANCOVAs addressed Research Question 2, all at $\alpha = .05$.

Results

Descriptive statistics for the experimental group are presented in Table 2. Both groups improved from pretest to posttest across all subscales; however, the experimental group's gains were consistently larger.

Table 2

Descriptive Statistics for Science Process Skill Scores, Experimental Group (n = 60)

Skill Domain	Pretest M	Pretest SD	Posttest M	Posttest SD
Observing	5.42	1.18	8.71	0.94
Classifying	4.87	1.32	7.96	1.05
Measuring	4.15	1.41	7.38	1.20
Predicting	3.98	1.29	7.02	1.16
Communicating	5.10	1.24	7.85	0.98
Composite score	4.70	0.97	7.78	0.83

Note. Scores are standardized to a 0–10 scale for each subscale and the composite. M = mean; SD = standard deviation.

For the control group, composite scores rose from a pretest mean of 4.63 (SD = 1.02) to a posttest mean of 6.21 (SD = 1.10), a smaller gain than in the experimental group. The ANCOVA revealed a significant effect of group, $F(1, 117) = 113.58$, $p < .001$, partial $\eta^2 = .49$, a large effect indicating instruction type accounted for roughly 49% of posttest variance after adjusting for baseline. The covariate was also significant, $F(1, 117) = 22.41$, $p < .001$, partial $\eta^2 = .16$ (Table 3).

Table 3

Summary of Analysis of Covariance (ANCOVA) for Posttest Composite Science Process Skill Scores

Source	**SS**	**df**	**MS**	**F**	**p**	**η²p**
Pretest (covariate)	18.62	1	18.62	22.41	< .001	.162
Group	94.37	1	94.37	113.58	< .001	.494
Error	97.14	117	0.83	—	—	—
Total	210.13	119	—	—	—	—

Note. SS = sum of squares; MS = mean square; η²p = partial eta squared.

Subscale-level ANCOVAs showed the experimental group significantly outperformed the control group on all five subscales: observing, $F(1, 117) = 96.32$, $p < .001$, partial $\eta^2 = .45$; classifying, $F(1, 117) = 71.84$, $p < .001$, partial $\eta^2 = .38$; measuring, $F(1, 117) = 42.17$, $p < .001$, partial $\eta^2 = .27$; predicting, $F(1, 117) = 38.05$, $p < .001$, partial $\eta^2 = .25$; and communicating, $F(1, 117) = 83.61$, $p < .001$, partial $\eta^2 = .42$. Effect sizes were largest for observing and communicating and comparatively smaller, though still meaningful, for measuring and predicting.

Discussion

This study examined whether digital simulation, relative to content-matched conventional instruction, more effectively facilitates science process skill development in early childhood. Results support the hypothesis: the digital simulation group showed significantly greater composite gains, with a large effect size, and outperformed the comparison group on every subscale, extending Hsin and Wu (2011) and Ihmeideh and Al-Maadadi (2018) within a design holding instructional time and structure constant across conditions.

Gains were largest for observing and communicating, which benefit from vivid visual representations and built-in verbal sharing, and more modest, though still substantial, for measuring and predicting, skills that depend more on embodied engagement with real materials. This pattern aligns with concerns that digital tools cannot fully substitute for concrete manipulation (Plowman & Stephen, 2005), suggesting simulation is best conceptualized as a complement to, rather than a replacement for, hands-on experience for psychomotor-heavy skills. Some of the composite effect may also reflect novelty of tablet use in these centers; longer-term follow-up would clarify durability.

Findings suggest educators can strengthen children's scientific reasoning by embedding well-designed simulations within teacher orientation, guided exploration, and discussion, with adequate teacher scaffolding training, pairing simulation with hands-on follow-up for measuring and predicting. Limitations include reliance on intact classrooms rather than individual random assignment, a single-region sample, and an eight-week duration precluding conclusions about durability; future research should include delayed follow-up and examine which design features moderate effectiveness.

Conclusion

Structured digital simulation activities, embedded within teacher-guided instruction, produced significantly greater gains in early childhood science process skills than content-matched conventional instruction, with the largest advantages in observing and communicating. These results support digital simulation as a valuable complement to, rather than a replacement for, concrete hands-on exploration, with pedagogical integration and teacher preparation essential to realizing its benefits.

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