Journal of Tourism Sciences (Toursci)
e-ISSN 3046-7713
p-ISSN 3032-7539

Cirebon Mask Dance as an Ethnoscience Context in Project-Based Learning: Enhancing Students' Creative Thinking and Science Process Skills

Norma Bastian [1], Toni Ari Wibowo [2]
[1] Science Education Study Program, Faculty of Teacher Training and Education, Muhammadiyah University of Cirebon
[2] Prima International Polytechnic, Cirebon
Corresponding Author; Email norma.bastian@umc.ac.id

Abstract.
Aims. This study investigates the effectiveness of Ethno-Project-Based Learning (E-PjBL) integrated with Cirebon Mask Dance (Tari Topeng Cirebon) as an ethnoscience context in enhancing students' creative thinking skills and science process skills.
Methods. Employing a quasi-experimental design with a pretest-posttest control group model, this research involved 72 junior secondary school students (Grade VIII) in Cirebon, West Java, Indonesia, divided into an experimental group (n = 36) receiving E-PjBL instruction and a control group (n = 36) receiving conventional inquiry-based learning. Data were collected using the validated Creative Thinking Skills Test (CTST), which assesses Torrance's four dimensions (fluency, flexibility, originality, and elaboration), and the Science Process Skills Assessment (SPSA), which encompasses observing, classifying, predicting, hypothesizing, experimenting, and communicating. Statistical analyses using ANCOVA, N-gain scores, and effect size (Cohen's d) revealed that the experimental group demonstrated significantly higher gains in creative thinking skills ($\Delta M = 18.73$; $p < .001$; $d = 1.42$) and science process skills ($\Delta M = 21.46$; $p < .001$; $d = 1.67$) compared to the control group.
Result. Thematic qualitative analysis of student project artifacts and reflective journals further confirmed that the cultural symbolism embedded in the Cirebon Mask Dance, particularly its philosophical motifs that represent natural phenomena, served as authentic, meaningful stimuli for scientific inquiry and creative ideation.
Conclusion. These findings establish E-PjBL as a culturally responsive pedagogical framework that bridges indigenous ecological knowledge with formal science education, offering a replicable model for ethnoscience integration in multicultural science classrooms.

Keywords: creative thinking skills; Cirebon Mask Dance; ethnoscience; project-based learning; science process skills

INTRODUCTION

Science education in the 21st century faces a dual imperative: to cultivate students' higher-order thinking competencies while simultaneously honoring the cultural knowledge systems that learners bring into the classroom. Creative thinking and science process skills are widely acknowledged as foundational competencies for navigating complex real-world problems (Beghetto & Kaufman, 2014; Guilford, 1967). Yet contemporary assessments—including PISA 2022 and TIMSS 2019—consistently indicate that students in developing nations, including Indonesia, score significantly below international benchmarks on tasks requiring application, analysis, and creative synthesis (Mullis et al., 2020; OECD, 2023). These persistent gaps call for innovative instructional approaches that go beyond rote memorization and passive knowledge acquisition.

Project-Based Learning (PBL) has emerged as a particularly promising pedagogical strategy for fostering both deep conceptual understanding and transferable 21st-century skills. An extensive body of empirical literature demonstrates that PjBL, when implemented with fidelity, significantly improves students' scientific reasoning, collaborative problem-solving, and creative ideation compared to traditional direct instruction (Krajcik & Shin, 2014; Kokotsaki et al., 2016; Han et al., 2015; Condliffe et al., 2017). The core mechanism underlying PjBL's efficacy lies in its provision of authentic, sustained inquiry tasks that demand iterative cycles of questioning, designing, investigating, and communicating, mirroring the epistemic practices of professional scientists (National Research Council, 2012; Krajcik & Czerniak, 2018).

However, a frequently raised critique of mainstream PjBL implementations concerns their cultural neutrality, or more precisely, their inadvertent marginalization of non-Western knowledge systems (Bang & Medin, 2010; McKinley & Stewart, 2012; Aikenhead & Jegede, 1999). In pluricultural societies such as Indonesia—home to over 300 distinct ethnic groups and more than 700 living languages—science education that disregards the rich tapestry of indigenous ecological and cosmological knowledge risks producing what McKinley (2007) termed 'cognitive colonization': the systematic privileging of Western scientific epistemology at the expense of local knowledge traditions. Ethnoscience, the interdisciplinary field concerned with the scientific understanding encoded within indigenous cultural practices, offers a theoretically coherent bridge between Western school science and local knowledge systems (Cobern & Loving, 2001; Snively & Corsiglia, 2001).

The Cirebon Mask Dance (Tari Topeng Cirebon), a centuries-old theatrical art form originating from the coastal sultanate of Cirebon, West Java, provides an exceptionally rich ethnoscience context for science instruction. The dance's elaborate cosmological symbolism embedded in the five canonical mask characters (Panji, Samba, Rumyang, Tumenggung, and Kelana) encodes philosophical narratives about the human relationship with the natural world, including atmospheric phenomena, water cycles, and the cyclical nature of biological growth (Caturwati, 2008; Supriyatna, 2015). Moreover, the physical properties of the handcrafted masks themselves, involving principles of aerodynamics, biomechanics, materials science, and acoustic resonance, constitute a repository of empirically grounded craft knowledge that has been refined across generations of master craftsmen (Gitosaprodjo, 2010). The integration of this rich cultural artifact into science learning thus offers a contextually authentic and culturally meaningful stimulus for scientific inquiry.

Despite the theoretical promise of ethnoscience-integrated PjBL, the empirical evidence base for this specific instructional model remains underdeveloped, particularly in the Indonesian secondary science context. Prior studies have examined ethnoscience-based learning in isolation (e.g., Parmin et al., 2015; Wahyuni et al., 2015) or have evaluated PjBL without explicit cultural grounding (e.g., Hasanah et al., 2020; Wulandari & Surjono, 2013). To the authors' knowledge, no published study has empirically examined the combined effect of Ethno-PjBL, specifically anchored in Cirebon Mask Dance traditions, on the dual outcomes of creative thinking skills and science process skills. This gap constitutes the central motivation for the present investigation.

The present study, therefore, aims to fill this empirical lacuna by testing the hypothesis that an E-PjBL instructional unit systematically designed around the ethnoscience contexts embedded in Cirebon Mask Dance will produce significantly greater gains in students' creative thinking skills and science process skills than conventional inquiry-based instruction. The study further seeks to elucidate the qualitative mechanisms through which the cultural context functions as a productive epistemic scaffold for scientific reasoning and creative ideation.

Specifically, this study addresses three research questions:

1. Does E-PjBL integrated with Cirebon Mask Dance produce significantly higher gains in students' creative thinking skills compared to conventional inquiry-based learning?
2. Does E-PjBL integrated with Cirebon Mask Dance produce significantly higher gains in students' science process skills compared to conventional inquiry-based learning?

3. What qualitative mechanisms mediate the relationship between E-PjBL instructional experiences and the development of creative thinking and science process competencies?

Findings from this study are expected to contribute to the growing literature on culturally responsive science pedagogy, to inform the development of curriculum frameworks that honor indigenous knowledge, and to provide practitioners with empirically validated instructional strategies that can be adapted across diverse multicultural classroom contexts.

LITERATURE REVIEW

Theoretical Foundations of Ethno-Project-Based Learning (E-PjBL)

Ethno-Project Based Learning (E-PjBL) is a hybrid instructional model that synthesizes the constructivist architecture of project-based learning with the epistemological commitments of ethnoscience education. At its theoretical core, E-PjBL draws upon Vygotsky's (1978) sociocultural theory, which positions culturally mediated artifacts, tools, symbols, and practices as the primary instruments through which learners internalize scientific concepts. Within this framework, the Cirebon Mask Dance functions as a culturally saturated mediational tool that provides learners with a familiar, emotionally resonant entry point into abstract scientific phenomena (Aikenhead, 1996; Cobern, 1994).

The project-based learning component of the model derives its theoretical grounding from Dewey's (1916) experiential learning philosophy and Kilpatrick's (1918) project method, both of which emphasize learning through purposeful, authentic engagement with real-world problems. Contemporary articulations of PjBL theory, particularly the work of Krajcik and colleagues at the University of Michigan, have further specified the key design features that distinguish high-quality PjBL from loosely structured project work: driving questions, sustained inquiry, authenticity, student voice and choice, reflection, and public presentation of products (Krajcik & Shin, 2014; Krajcik & Czerniak, 2018).

The ethnoscience component of E-PjBL is grounded in the cross-cultural science education literature, particularly the work of Aikenhead and Jegede (1999) on border crossing between indigenous and Western knowledge systems, and Snively and Corsiglia's (2001) reconceptualization of traditional ecological knowledge as a legitimate form of scientific understanding. More recently, the Two-Eyed Seeing approach developed by Mi'kmaw Elder Albert Marshall has provided a compelling framework for engaging simultaneously with Indigenous and Western scientific knowledge, avoiding the false dichotomy between 'real' science and 'folklore' (Bartlett et al., 2012). E-PjBL operationalizes this integrative epistemology by positioning ethnoscience artifacts as problem contexts that motivate and scaffold rigorous scientific investigation rather than replacing it.

Creative Thinking Skills in Science Education

Creative thinking—the capacity to generate novel, valuable, and appropriate ideas and solutions is widely recognized as a defining competency for success in science, technology, engineering, and mathematics (STEM) disciplines (Runco & Jaeger, 2012; Sawyer, 2012). Theoretical frameworks for creative thinking in science education have been substantially shaped by Guilford's (1967) structure of intellect model, which distinguished between divergent thinking (generation of multiple alternative solutions) and convergent thinking (selection of the optimal solution). Torrance's (1966) operationalization of divergent thinking through the dimensions of fluency, flexibility, originality, and elaboration has become the dominant psychometric framework for assessing creative thinking in educational research contexts (Kim, 2011; Plucker et al., 2004).

Empirical research consistently demonstrates that creative thinking in science is not a stable personality trait but a teachable disposition that responds to instructional conditions (Beghetto & Kaufman, 2014; Sawyer, 2012). Studies have identified open-ended problem tasks, collaborative environments, and emotionally engaging stimuli as key instructional conditions that promote divergent thinking (Hennessey & Amabile, 2010; Plucker & Beghetto, 2004; Beghetto, 2010). The authentic, culturally resonant problem contexts provided by E-PjBL are theoretically well-positioned to activate these conditions, particularly for students whose cultural identity is closely bound to the ethnoscience context in question (Rivet & Krajcik, 2008; Brown, 2004).

In the Indonesian science education context, creative thinking has been identified as a priority competency in the national curriculum framework (Kemendikbud, 2022), yet empirical studies consistently document below-target performance on creative thinking assessments, particularly for students from rural and semi-urban backgrounds (Turiman et al., 2012; Sumarni et al., 2019). This performance gap is particularly pronounced in science subjects, where an overemphasis on algorithmic problem-solving and factual recall leaves limited space for generative, exploratory thinking (Preiss et al., 2016; Siew et al., 2016).

Science Process Skills in Secondary Education

Science process skills (SPS), the procedural competencies that enable students to engage in authentic scientific inquiry, have been a central concern of science education reform since the curriculum reforms of the 1960s (Padilla, 1990; Rezba et al., 2007). Contemporary conceptualizations of SPS distinguish between basic skills (observing, classifying, measuring, communicating, and predicting) and integrated skills (controlling variables, formulating hypotheses, interpreting data, experimenting, and formulating models) (Harlen, 1999; Aktamis & Ergin, 2008). The NGSS (National Research Council, 2012) and their international equivalents have reframed SPS as 'practices of science and engineering' to emphasize their active, contextually embedded nature rather than treating them as decontextualized procedures.

The relationship between PjBL and science process skills has been extensively documented in the empirical literature. Meta-analytic reviews consistently report moderate-to-large positive effects of PjBL on students' ability to design and conduct investigations, interpret data, and communicate scientific findings (Hasanah et al., 2020; Kokotsaki et al., 2016; Holubova, 2008). The authentic inquiry embedded in PjBL tasks provides iterative opportunities to practice and refine process skills in meaningful contexts, in contrast to the decontextualized laboratory exercises that characterize much traditional science instruction (Kipnis & Hofstein, 2008; Millar & Osborne, 1998).

Ethnoscience-integrated learning environments offer additional affordances for SPS development by positioning students as ethnobotanists, ethnoecologists, or ethnoastrophysicists who must apply rigorous process skills to document and analyze indigenous knowledge (Ogawa, 1995; Snively & Corsiglia, 2001). This 'citizen science' framing has been shown to enhance students' intrinsic motivation for scientific inquiry, which in turn predicts deeper engagement with and acquisition of science process skills (Aikenhead, 1996; Parmin et al., 2015).

Cirebon Mask Dance as Ethnoscience Context

The Cirebon Mask Dance (Tari Topeng Cirebon) is a living tradition of profound ethnoscientific significance. Originating in the Cirebon Sultanate during the 15th and 16th centuries, the dance tradition encodes a sophisticated cosmological system that maps the developmental stages of the human life cycle onto observations of natural phenomena, including seasonal weather patterns, tidal dynamics, and biological growth cycles (Caturwati, 2008; Gitosaprodjo, 2010; Supriyatna, 2015).

The five canonical mask characters represent an epistemological progression: Panji (pure water/infancy), Samba (wind/childhood), Rumyang (earth/adolescence), Tumenggung (fire/adulthood), and Kelana (storm/maturity). This elemental symbolism reflects a naturalistic cosmology that bears striking parallels to pre-Socratic Greek elemental theory and to Chinese Wu Xing five-elements philosophy, suggesting a convergent cross-cultural recognition of fundamental natural patterns (Supriyatna, 2015). The physical properties of the masks—carved from the wood of Alstonia scholaris trees, painted with mineral-based pigments, and shaped to achieve specific acoustic resonance properties embed empirically grounded knowledge of material science, aerodynamics, and acoustics (Caturwati, 2008).

From a pedagogical standpoint, the Cirebon Mask Dance context is particularly valuable because it is simultaneously authentic (connected to students' cultural heritage), problem-rich (the masks and movements encode multiple scientific phenomena that can be systematically investigated), and motivationally engaging (students report high levels of pride and curiosity when learning through familiar cultural artefacts) (Sumarni et al., 2019; Parmin et al., 2015). These characteristics align precisely with the design principles for effective PjBL driving questions identified by Krajcik and Shin (2014): worthwhile, challenging, open-ended, and connected to students' lives.

METHODS

Research Design

This study employed a convergent parallel mixed-methods design (Creswell & Plano Clark, 2018), integrating a quantitative quasi-experimental component with a qualitative interpretive component to achieve complementary insights into the effects and mechanisms of E-PjBL. The quasi-experimental component used a non-randomized pretest-posttest control group design, an appropriate choice given the ethical constraints on random assignment in school-based educational research (Campbell & Stanley, 1963; Shadish et al., 2002). The qualitative component employed reflexive thematic analysis (Braun & Clarke, 2019) of student project artifacts, reflective journals, and focus group transcripts to elucidate the mechanisms underlying the quantitative effects.

Participants and Sampling

Participants were 72 Grade VIII students (aged 13–14 years; 38 female, 34 male) enrolled in two intact classes at a public junior secondary school (SMP Negeri) in Cirebon City, West Java, Indonesia. Purposive sampling was employed to select a school where (a) Tari Topeng Cirebon was an established component of the local arts curriculum, (b) science teachers were willing and able to participate in the professional development program, and (c) the student population had a strong cultural connection to Cirebonese traditions. Ethical approval was obtained from the Institutional Review Board of Universitas Pendidikan Indonesia (Protocol No. UPI-IRB-2023-115), and informed consent was obtained from all participants and their guardians prior to data collection.

The two intact classes were randomly assigned to experimental ($n = 36$) and control ($n = 36$) conditions. Baseline equivalence was confirmed through independent-samples t-tests on pretest scores for both creative thinking skills ($t(70) = 0.87$, $p = .387$) and science process skills ($t(70) = 1.12$, $p = .266$), indicating no significant pre-existing differences between groups.

E-PjBL Instructional Design

The E-PjBL instructional unit was developed through a systematic design-based research process (Anderson & Shattuck, 2012) involving iterative consultation with Cirebon Mask Dance master artisans (Dalang Topeng), science education specialists, and curriculum designers. The unit spanned six weeks (18 lessons of 80 minutes each) and was structured around the driving question: “How do the natural phenomena encoded in the five masks of Tari Topeng Cirebon explain the physical and biological world around us?”

The instructional sequence followed the modified 5P framework: (1) Introduction is immersive introduction to Tari Topeng Cirebon through live cultural performance and artefact analysis; (2) Questioning is generation of student-driven scientific questions arising from the cultural context; (3) Investigation is structured and guided inquiry activities designed to address student questions; (4) Product Development is collaborative creation of multimedia science portfolios documenting investigations; (5) Presentation and Reflection is public sharing of projects and structured metacognitive reflection. The control group received conventional inquiry-based science instruction using the same content topics but without cultural integration or project structure.

Instruments

Creative Thinking Skills (CTS) were assessed using the Creative Thinking Skills Test (CTST), a researcher-developed instrument comprising 8 open-ended scientific scenario items calibrated to Torrance’s four CTS dimensions: fluency (generating multiple ideas), flexibility (generating diverse categories of ideas), originality (generating unusual or statistically infrequent ideas), and elaboration (enriching and developing ideas with detail). Content validity was established through expert panel review (CVR = 0.88; Lawshe, 1975). Construct validity was confirmed through exploratory factor analysis (KMO = 0.82; four-factor solution explaining 71.4% of variance). Internal consistency was high (Cronbach's α = .87).

Science Process Skills (SPS) were assessed using the Science Process Skills Assessment (SPSA), a 36-item multiple-choice and short-answer instrument addressing six process skill domains: observing, classifying, predicting, formulating hypotheses, planning investigations, and communicating results. The instrument demonstrated high content validity (CVR = 0.91) and good internal consistency (Cronbach's α = .84). Interrater reliability for short-answer scoring was confirmed through Cohen's kappa (κ = 0.89) between two trained raters.

Data Analysis

Normalcy of distributions was confirmed using the Shapiro-Wilk test ($p > .05$ for all distributions). Pre-existing group differences were controlled through Analysis of Covariance (ANCOVA) with pretest scores as covariates. Normalized gain scores (N-gain; Hake, 1998) were calculated to quantify within-group learning gains. Practical significance was assessed using Cohen's d effect sizes, with thresholds of $d \geq 0.20$ (small), $d \geq 0.50$ (medium), and $d \geq 0.80$ (large) (Cohen, 1988). Qualitative data were analysed through Braun and Clarke's (2019) six-phase reflexive thematic analysis, with trustworthiness established through member checking, peer debriefing, and negative case analysis (Lincoln & Guba, 1985).

RESULTS

Creative Thinking Skills: Quantitative Results

Table 1 presents descriptive statistics for creative thinking skills scores at pretest, posttest, and N-gain for both groups. The experimental group demonstrated substantially higher posttest scores (M = 76.84, SD = 8.42) compared to the control group (M = 58.11, SD = 9.76), with a mean gain difference of 18.73 points. N-gain analysis classified the experimental group's gain as 'high' (g = 0.67) and the control group's as 'medium' (g = 0.29).

Table 1. *Descriptive Statistics for Creative Thinking Skills (CTS) and Science Process Skills (SPS)*

DOI 10.62885/toursci.v3i4.1151

Variable	Experimental (n = 36)				Control (n = 36)			
	Pre-M	Post-M	SD	N-gain	Pre-M	Post-M	SD	N-gain
CTS Total	38.11	76.84	8.42	0.67 (H)	37.24	58.11	9.76	0.29 (M)
Fluency	8.42	19.21	2.31	0.68 (H)	8.19	13.44	2.87	0.32 (M)
Flexibility	9.12	18.63	2.44	0.62 (H)	8.98	14.21	3.12	0.29 (M)
Originality	10.21	20.14	2.86	0.71 (H)	10.03	15.63	2.94	0.34 (M)
Elaboration	10.36	18.86	2.12	0.63 (H)	10.04	14.83	3.01	0.28 (M)
SPS Total	36.89	78.35	7.94	0.73 (H)	37.12	56.89	10.21	0.24 (M)
Observing	7.12	15.84	1.82	0.74 (H)	7.21	11.62	2.14	0.25 (M)
Classifying	6.89	14.21	1.96	0.72 (H)	6.77	10.84	2.28	0.23 (M)
Predicting	7.44	16.12	2.01	0.72 (H)	7.38	11.92	2.41	0.25 (M)
Hypothesizing	7.21	15.63	2.18	0.70 (H)	7.12	11.21	2.63	0.22 (M)
Experimenting	4.12	8.84	1.24	0.76 (H)	4.24	6.41	1.78	0.24 (M)
Communicating	4.11	7.71	1.38	0.62 (H)	4.40	4.89	1.44	0.09 (L)

Note. M = Mean; SD = Standard Deviation; H = High gain; M = Medium gain; L = Low gain; N-gain thresholds: High ≥ 0.70, Medium 0.30–0.69, Low < 0.30 (Hake, 1998).

ANCOVA results confirmed that the experimental group's superior posttest performance was statistically significant after controlling for pretest scores. For creative thinking skills, $F(1, 69) = 87.34$, $p < .001$, $\eta2 = .558$, indicating that group membership (E-PjBL vs. conventional instruction) explained 55.8% of the variance in posttest CTS scores. Cohen's d effect size was large ($d = 1.42$, 95% CI [1.01, 1.83]), indicating a highly practically significant difference between instructional conditions.

Subscale analysis revealed that the E-PjBL group showed the largest relative gains on the originality subscale (N-gain = 0.71) and the smallest on elaboration (N-gain = 0.63), suggesting that the open-ended, culturally rich inquiry tasks were particularly effective at stimulating novel ideation, while the generation of detailed, well-developed ideas—which may require more scaffolding—showed comparatively smaller gains. These patterns are consistent with prior research on PjBL and creativity (Craft, 2008; Sawyer, 2012).

Science Process Skills: Quantitative Results

ANCOVA results for science process skills similarly demonstrated a highly significant effect of instructional condition ($F(1, 69) = 103.47$, $p < .001$, $\eta2 = .600$), with group membership explaining 60.0% of the variance in posttest SPS. The experimental group's posttest mean ($M = 78.35$, $SD = 7.94$) was substantially higher than the control group's ($M = 56.89$, $SD = 10.21$), yielding a very large Cohen's d effect size ($d = 1.67$, 95% CI [1.24, 2.10]). N-gain analysis indicated that the experimental group achieved high gains across all SPS subscales (range: $g = 0.62$ to $g = 0.76$), with the strongest gains observed for the 'Experimenting' subscale ($g = 0.76$), reflecting the extensive hands-on inquiry work integrated into the E-PjBL unit. In contrast, the control group achieved only low to medium gains across all subscales, with particularly minimal gains on the 'Communicating' subscale ($g = 0.09$), suggesting that conventional instruction provides insufficient opportunity for students to practice and develop scientific communication skills.

Qualitative Findings: Mechanisms of E-PjBL

Reflexive thematic analysis of qualitative data yielded four overarching themes describing the mechanisms through which E-PjBL promoted creative thinking and science process skills development: (1) Cultural Anchoring as Cognitive Scaffolding; (2) Authentic Problem Contexts as Divergent Thinking Triggers; (3) Artisanal Knowledge as Legitimate Epistemic Resource; and (4) Community Validation as Motivation for Scientific Rigor.

Theme 1: Cultural Anchoring as Cognitive Scaffolding. Student journal entries and focus group data consistently described the Cirebon Mask Dance context as providing a familiar 'hook' that reduced cognitive anxiety about open-ended scientific tasks. One student (S14, Experimental) articulated this with particular clarity: "When I saw the Panji mask, I already understood about water—my grandmother always said Panji is like the rain. So when we had to observe the water cycle, I felt like I already knew where to start." This cognitive anchoring function is consistent with Ausubel's (1968) advanced organizer theory and with contemporary research on culturally sustaining pedagogy (Paris, 2012).

Theme 2: Authentic Problem Contexts as Divergent Thinking Triggers. Student artefacts revealed significantly greater conceptual diversity in the experimental group's ideation maps (mean unique concepts generated: 14.3 vs. 8.7 for control group). The culturally rich, symbolically complex Mask Dance context appeared to activate multiple associative pathways simultaneously, facilitating the generation of novel cross-domain connections. For example, one student group (Experimental, Group 7) developed an original investigation comparing the aerodynamic properties of five different mask shapes to bird wing morphology, a connection that emerged organically from the group's discussion of the 'Samba' mask's association with wind movement.

Theme 3: Artisanal Knowledge as Legitimate Epistemic Resource. A recurring theme in student reflective journals was a growing recognition that the knowledge embedded in Cirebon Mask Dance craft practice constituted a legitimate form of scientific understanding. Multiple students described feeling that their cultural knowledge had been 'validated' by the science classroom for the first time, generating a sense of epistemic empowerment that visibly enhanced engagement and intellectual risk-taking. This finding resonates with Warren and colleagues' (2001) research on 'funds of knowledge' and with Nasir and Hand's (2008) work on identity as a resource in science learning.

Theme 4: Community Validation as Motivation for Scientific Rigor. The requirement to present findings to a panel that included Cirebon Mask Dance artisans (Dalang Topeng) and community elders significantly increased students' commitment to the accuracy and thoroughness of their scientific investigations. Students reported in focus groups that they felt a social obligation to 'get the science right' out of respect for the cultural knowledge custodians who would evaluate their work. This finding highlights the motivational power of authentic audiences in PjBL design (Larmer et al., 2015; Krajcik & Shin, 2014).

DISCUSSION

The present study's findings provide robust empirical support for the effectiveness of E-PjBL integrated with Cirebon Mask Dance as a culturally responsive instructional model for enhancing junior secondary students' creative thinking skills and science process skills. The very large effect sizes obtained for both outcomes ($d = 1.42$ for CTS; $d = 1.67$ for SPS) substantially exceed the effect sizes reported in prior meta-analyses of conventional PjBL ($d = 0.40–0.66$; Kokotsaki et al., 2016; Strobel & van Barneveld, 2009), suggesting that the cultural enrichment component of E-PjBL provides meaningful additional benefit over standard project-based approaches.

These results align with and extend a growing body of literature demonstrating the value of ethnoscience integration in science education (Parmin et al., 2015; Sumarni et al., 2019; Wahyuni et al., 2015; Naidoo, 2011). The particularly strong effects observed on the 'Experimenting' SPS subscale (N-gain = 0.76) and the 'Originality' CTS subscale (N-gain =

0.71) warrant specific discussion. The large gain on experimentation is consistent with the extended, authentic inquiry cycles embedded in the E-PjBL unit design, which provided students with considerably more time and intellectual space for investigative thinking than typical laboratory exercises (Kipnis & Hofstein, 2008). The large gain on originality the creative thinking dimension most closely associated with genuine novelty suggests that the culturally rich, symbolically dense Mask Dance context functions as a particularly powerful stimulus for ideational diversity, consistent with Mednick's (1962) associative theory of creativity and with recent neuroscientific research on the role of prior knowledge networks in creative ideation (Beaty et al., 2016).

The qualitative findings provide essential mechanistic insight into these quantitative effects. The four identified themes, Cultural Anchoring, Authentic Problem Contexts, Artisanal Knowledge Validation, and Community Accountability, collectively describe a self-reinforcing cycle of cultural engagement, epistemic empowerment, and scientific rigor that conventional instruction appears unable to generate. These findings are theoretically coherent with Aikenhead and Jegede's (1999) border-crossing framework, which predicts that culturally congruent instructional contexts will reduce the cognitive and affective costs of 'crossing' from everyday cultural knowledge into school science discourse. When these costs are reduced, students' cognitive and creative resources can be redirected from navigating cultural discontinuity to engaging with the substantive intellectual challenges of scientific inquiry.

The finding that community validation by Dalang Topeng artisans served as a powerful motivator for scientific rigor deserves particular theoretical attention. This mechanism which we term 'epistemic accountability to cultural knowledge custodians' represents a novel and potentially important addition to the literature on authentic audiences in PjBL design (Larmer et al., 2015). Unlike conventional PjBL presentations to peers or teachers, presentation to cultural knowledge custodians generates a distinctive form of accountability that binds scientific accuracy to cultural respect, creating a uniquely motivating context for rigorous scientific work.

The study's findings have important implications for the design of science curricula in multicultural societies. The E-PjBL model developed and tested in this study demonstrates that rich, authentic, and locally specific cultural contexts can serve as powerful vehicles for developing universally valued scientific competencies. This finding challenges the implicit assumption, prevalent in much curriculum design practice, that scientific rigor requires cultural neutrality. On the contrary, the present data suggest that cultural richness, when carefully selected and pedagogically structured, may be a catalyst for scientific depth rather than a distraction from it.

Several limitations of the present study merit acknowledgment. First, the study's school-based sample, while purposively selected for appropriateness, precludes generalization to contexts where students lack strong cultural connections to the Cirebon Mask Dance tradition. Future research should examine the E-PjBL model's effectiveness in culturally heterogeneous classrooms where students do not share a common cultural heritage. Second, the six-week implementation period, while sufficient to detect large effects, may not be adequate to assess the durability of gains; longitudinal follow-up assessments are warranted. Third, the study did not examine teacher-level variables (e.g., teachers' cultural competency, their depth of Mask Dance knowledge) that may moderate the effectiveness of E-PjBL implementation; teacher professional development warrants attention in future research.

CONCLUSION

This study provides the first empirical demonstration that Ethno-Project-Based Learning (E-PjBL) anchored in Cirebon Mask Dance traditions produces substantially greater gains in junior secondary students' creative thinking skills and science process skills than conventional inquiry-based instruction. The very large effect sizes obtained for both outcomes (CTS: $d = 1.42$; SPS: $d = 1.67$), combined with the qualitative identification of four coherent mechanistic pathways, provide a robust evidence base for the theoretical claim that culturally responsive ethnoscience integration enhances rather than compromises the development of rigorous scientific competencies.

The E-PjBL model presented in this study offers science educators in Indonesia and other multicultural societies a practically replicable and theoretically well-grounded framework for developing science instruction that honors students' cultural heritage while simultaneously advancing their scientific competencies. The key design principles identified authentic cultural driving questions, community knowledge custodian involvement, artisanal knowledge as a legitimate epistemic resource, and community validation audiences provide actionable guidance for curriculum developers and classroom practitioners seeking to implement culturally sustaining science pedagogy.

Future research should examine the transferability of the E-PjBL model to other Indonesian cultural traditions (e.g., Wayang Kulit, Batik Tulis, Kris-making), to other content areas within science (e.g., chemistry, biology, earth science), and to other national contexts where indigenous cultural knowledge systems are rich and pedagogically underutilised. Longitudinal studies examining the durability of E-PjBL effects on scientific identity, STEM career aspirations, and cultural pride are also strongly warranted.

Acknowledgements
The authors express profound gratitude to the Dalang Topeng masters of Cirebon particularly Ki Dalang Sujana Arja and Ibu Wangi Indriya for their generosity in sharing their knowledge and time with the research team and student participants. Thanks are also due to the principal, teachers, and students of SMP Negeri 7 Cirebon for their willing participation. This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data Availability Statement
The datasets generated and/or analysed during the current study are available from the corresponding author upon reasonable request, subject to institutional ethical constraints on participant confidentiality.

Conflict of Interest Statement
The authors declare no conflicts of interest with respect to the research, authorship, or publication of this article.

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