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Enhancing Scientific Literacy and *Gotong Royong* through Culturally Responsive Problem-Based Learning with Gamification: A Classroom Action Research on Rotational Dynamics

Upik Laila Hanum[1),*], Arina Zaida Ilma[2)], Rusmining[3)], Sri Sundari[4)]

[1)]Physics Teacher, SMA Negeri 2 Ngaglik, Yogyakarta
[2)]Primary Teacher Education Department, Universitas Pendidikan Ganesha, Bali
[3)]Mathematics Education Department, Universitas Ahmad Dahlan, Yogyakarta
[4)]Physics Teacher, SMA Negeri 1 Banguntapan, Yogyakarta

*Coresponding Author: upik.laila35@guru.sma.belajar.id

ABSTRACT

This classroom action research investigates the effectiveness of an integrated learning model combining Problem-Based Learning (PBL), Culturally Responsive Teaching (CRT), and educational gamification to enhance scientific literacy and *gotong royong* skills among 31 Grade XI students at SMA Negeri 1 Banguntapan, Yogyakarta. Using the Kemmis & McTaggart framework across two cycles on rotational dynamics, the intervention incorporated local Indonesian cultural elements (spinning top/gasing) and global contexts (ballet dance) into student worksheets and innovative games ("Who's Fast, They Get It" in Cycle 1 and "Stop and Go Challenge" in Cycle 2) to accommodate kinesthetic learning styles and foster collaborative interdependence. Results showed moderate to significant improvements: scientific literacy scores rose from 55.16 (pre-cycle) to 89.78 (Cycle 2), with N-gain values of 0.35 (Cycle 1) and 0.44 (Cycle 2), while *gotong royong* skills increased from 75.32% to 79.57%, with the most notable gains in interpreting data and evidence scientifically, solidarity, and mutual encouragement. This study contributes a novel culturally grounded integrative model aligned with Indonesia's Merdeka Curriculum and Pancasila Student Profile, providing empirical evidence that contextual gamified PBL effectively develops both cognitive and affective competencies in physics education.

Kata Kunci: Problem-Based Learning, Culturally Responsive Teaching, Gamification, Scientific Literacy, *Gotong Royong*, Classroom Action Research, Rotational Dynamics

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INTRODUCTION

Scientific literacy has emerged as a critical issue in the global education landscape, particularly in developing countries such as Indonesia, where students continue to experience difficulties in applying scientific knowledge to real-world contexts. The OECD Programme for International Student Assessment (PISA) 2022 results underscore this challenge, with Indonesian students obtaining a science score of 383—substantially below the OECD average of 485—and ranking near the bottom among 81 participating countries and economies (OECD, 2023). This score represents one of the lowest performances since Indonesia's initial participation in PISA, indicating persistent weaknesses in key dimensions of scientific literacy, including explaining phenomena scientifically, interpreting data and evidence, and evaluating or designing scientific investigations.

Further analyses of the PISA 2022 dataset reveal that only a small proportion of Indonesian students achieve proficiency Level 2 or above, the minimum level required to meaningfully engage with scientific issues in everyday life (OECD, 2023). Socio-economic disparities further intensify this condition, suggesting that students from disadvantaged backgrounds are disproportionately affected. These findings imply an urgent need for innovative and equitable pedagogical interventions that move beyond rote learning and emphasize inquiry-based, contextual, and student-centered approaches to strengthen scientific literacy and reduce achievement gaps.

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In response to these challenges, Indonesia's Merdeka Curriculum emphasizes holistic cognitive development alongside character building through the Pancasila Student Profile, where *gotong royong*—mutual cooperation encompassing collaboration, empathy, caring, sharing, and shared responsibility—serves as a core 21st-century competency essential for social harmony and collective problem-solving (Evans, 2020; Kemendikbudristek, 2022). This dimension aligns with broader efforts to revive traditional Indonesian values in education, fostering pro-social behaviors that support both academic achievement and civic engagement.

Observations conducted at SMA Negeri 1 Banguntapan, Yogyakarta—an institution officially designated as culture-based and committed to integrating local values into daily school practices—indicate that physics instruction remains predominantly teacher-centered. Classroom activities are largely characterized by lectures, note-taking, and the use of uniform worksheets, which limit student interaction, active participation, and opportunities for meaningful engagement with physics concepts. This instructional approach contrasts with the school's cultural vision and constrains students' ability to develop higher order thinking and collaborative skills. Pre-cycle diagnostic assessments, including a scientific literacy pretest aligned with PISA competencies, revealed an average score of 55.16 (moderate category), with particularly low performance in interpreting data and evidence scientifically (35.48), indicating persistent difficulties in applying scientific knowledge to real-world contexts (OECD, 2023). Additionally, baseline peer assessments and teacher observations of gotong royong skills showed moderate levels (approximately 70–75% on indicators such as collaboration and sharing), but with notable weaknesses in mutual encouragement, solidarity, and equitable knowledge sharing, reflecting limited empirical manifestation of collaborative interdependence in group settings despite the school's cultural emphasis (Kemendikbudristek, 2022).

Diagnostic assessments further reveal that a substantial proportion of students (40%) demonstrate a kinesthetic learning style, indicating a preference for hands-on experiences, physical involvement, and movement-based learning activities. However, the prevailing conventional instructional methods do not adequately accommodate these preferences, exacerbating students' disengagement and limiting conceptual understanding (Ilma et al., 2022; Mustaqim et al., 2025; Wahab & Nuraeni, 2020). This trend aligns with findings from broader Indonesian high school contexts, where kinesthetic learning styles frequently dominate or rank highly among students, emphasizing the need for experiential and interactive pedagogical approaches (Angelia & Wadison, 2023; Karataş & Yalin, 2021). Students also express a strong preference for innovative, group-based learning strategies that not only support comprehension of complex physics topics but also foster social interaction and collaborative competencies, highlighting the empirical urgency to address both cognitive gaps in scientific literacy and affective shortcomings in gotong royong through targeted interventions.

Problem-Based Learning (PBL) has been widely recognized as an effective pedagogical approach for promoting scientific literacy, actively engaging students in solving authentic, real-world problems that demand inquiry, critical reasoning, evidence-based decision-making, and higher-order thinking. Empirical studies and meta-analyses demonstrate that PBL yields medium to large effect sizes on science learning outcomes, particularly when integrated with STEM elements, by stimulating questioning, data interpretation, argumentation, and transferable skills beyond rote memorization (Aripin et al., 2025; Suciana & Sausan, 2023; Wijnia et al., 2024). Moreover, PBL inherently supports collaborative competence, making it ideal for addressing both cognitive and affective domains in education.

Culturally Responsive Teaching (CRT) plays a vital role in enhancing inclusivity and relevance by incorporating students' cultural backgrounds, local knowledge, and lived experiences into the curriculum, thereby boosting engagement, motivation, intrinsic ownership, and conceptual understanding—especially among diverse learners in multicultural settings like Indonesia. By bridging the "relevance gap" between abstract scientific concepts and community contexts, CRT promotes equity, reduces alienation, and facilitates deeper application of knowledge (Anyichie et al., 2023; Liu et al., 2025; Pinneo & Benton, 2024). In ethnoscience contexts, CRT leverages indigenous artifacts and traditions to contextualize science, fostering cultural preservation alongside scientific inquiry.

Educational games and gamification further complement these strategies by providing interactive, scaffolded environments that heighten intrinsic motivation, facilitate repeated problem-solving practice, and encourage structured collaboration through elements like points, badges, leaderboards, and challenges. Recent meta-analyses confirm positive moderate effects on STEM achievement, engagement, and 21st-century skills,

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including communication, coordination, and pro-social behaviors closely aligned with *gotong royong* (Pan et al., 2025; Wang et al., 2022). Well-designed collaborative games create interdependence, leading to improved collective responsibility, peer support, and long-term retention.

To conceptualize the interrelationships among the key variables in this study, Problem-Based Learning (PBL) directly enhances scientific literacy by engaging students in authentic, inquiry-driven problem-solving that develops competencies in explaining phenomena scientifically, interpreting data and evidence, and evaluating or designing investigations, with empirical evidence from recent meta-analyses showing moderate to large positive effects on science learning outcomes in high school contexts (Aripin et al., 2025; Suciana & Sausan, 2023). Culturally Responsive Teaching (CRT) strengthens cultural relevance and student engagement by integrating local knowledge, traditions, and lived experiences—such as Javanese artifacts—into the curriculum, thereby bridging abstract concepts with students' backgrounds, reducing alienation, and promoting deeper conceptual understanding and motivation, particularly in diverse or multicultural science education settings (Anyichie et al., 2023; Pinneo & Benton, 2024). Gamification complements these approaches by incorporating game elements (e.g., challenges, points, interdependence) that foster collaboration, mutual support, and pro-social behaviors aligned with gotong royong, as recent studies indicate positive effects on social skills, cooperation, and collective responsibility in STEM learning environments (Pan et al., 2025; Wang et al., 2022). The integration of these three elements creates synergistic effects: PBL provides the inquiry structure for scientific literacy gains, CRT ensures cultural relevance and equity, and gamification amplifies collaborative interdependence to empirically strengthen gotong royong as a measurable outcome.

Although prior research has demonstrated the effectiveness of combining PBL with gamification or CRT in isolation, yielding improvements in scientific literacy, motivation, engagement, and social interaction in various science context (Rahmawati & Agustina, 2025; Safira & Agustina, 2024; Sukmawati et al., 2025), these studies typically addressed only two components at a time. For instance, PBL integrated with CRT has enhanced science learning outcomes and problem-solving skills in junior high settings by incorporating cultural relevance, but without gamification elements to boost collaboration and motivation (Mawaddah et al., 2024; Rahmawati & Agustina, 2025). Similarly, gamification combined with PBL has improved problem-solving, academic performance, and engagement in mathematics or STEM subjects, yet often without explicit cultural responsiveness or focus on Indonesian sociocultural values (Rojas et al., 2025). In ethnoscience approaches, limited studies have explored traditional Javanese artifacts like the gasing (spinning top) to contextualize rotational dynamics concepts (moment of inertia, angular momentum, torque, and conservation laws), accommodating kinesthetic preferences and fostering perseverance, but these remain exploratory or isolated without integration into full PBL frameworks or gamified collaboration (Elviana et al., 2024; Jusmaniar et al., 2024). Notably, few—if any—studies have fully integrated all three elements—PBL, CRT (with local artifacts like gasing and global analogies like ballet), and gamification—within Indonesia's sociocultural framework, particularly for abstract senior high school physics topics such as rotational dynamics. Moreover, no prior work has explicitly targeted simultaneous enhancement of scientific literacy (addressing PISA weaknesses) and gotong royong skills (as a measurable Pancasila competency) through kinesthetic, interdependent gamified tasks in a culture-based school context. This integration represents the novelty of the present study: a synergistic, three-component model grounded in ethnoscience pedagogy that bridges cognitive gains in scientific literacy with affective development of collaborative interdependence, offering a replicable, contextually aligned approach for Indonesian physics classrooms under the Merdeka Curriculum.

Therefore, this classroom action research proposes and examines a novel integrative model combining Problem-Based Learning (PBL), Culturally Responsive Teaching (CRT)—incorporating local cultural elements like the Javanese spinning top (gasing) and global references such as ballet dance for illustrating angular momentum conservation—and gamification to simultaneously enhance scientific literacy and gotong royong skills among senior high school students. While previous studies have measured cognitive outcomes like scientific literacy or critical thinking through PBL and CRT integrations in science or mathematics education (Mawaddah et al., 2024; Rahmawati & Agustina, 2025), gotong royong—as a core dimension of the Pancasila Student Profile emphasizing mutual cooperation, empathy, sharing, and collective responsibility—has rarely been treated as a quantifiable, empirically measured variable in physics learning contexts, particularly in senior high school settings. Existing research on PBL or CRT in Indonesian science education has primarily focused on cognitive gains, motivation, or general collaboration, with limited attention to assessing gotong royong as a distinct,

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observable outcome through structured instruments like peer assessments or observations (Smith, 2012). Furthermore, the integration of gamification to amplify interdependent, pro-social behaviors aligned with gotong royong remains underexplored in abstract physics topics such as rotational dynamics. By addressing these gaps, this study not only aligns with the Merdeka Curriculum's emphasis on holistic cognitive and character development but also contributes theoretically to ethnoscience-grounded inquiry-based learning and provides practical, measurable strategies for engaging kinesthetic learners in Indonesian physics classrooms, with potential scalability across STEM subjects.

METHOD

Research Approach

This study employed a classroom action research (CAR) approach to systematically improve teaching practices and student outcomes in a real classroom setting. CAR is particularly suitable for Indonesian high school physics education, where teachers often face challenges like low scientific literacy and limited student engagement (Fernandez, 2017). The model adopted was based on the Kemmis & McTaggart framework (Kemmis et al., 1998, 2014), which consists of four interconnected stages: planning, action, observation, and reflection. This cyclical process allows educators to iteratively test interventions, reflect on results, and refine strategies, fostering reflective practice and professional growth (Kemmis et al., 2014). Unlike traditional research, Kemmis & McTaggart's model emphasizes collaborative and emancipatory action, empowering teachers to address local issues such as kinesthetic learning mismatches in physics classrooms (Ilma et al., 2022). In Indonesian contexts, this framework has proven effective for enhancing physics learning, as seen in studies improving conceptual understanding through inquiry-based cycles (Fayanto et al., 2023).

Subject

The study was conducted at SMA Negeri 1 Banguntapan, Yogyakarta, a public senior high school designated as culture-based, integrating local Javanese values like *gotong royong* into the curriculum (Aditya, 2023). This setting was chosen for its alignment with the Merdeka Curriculum, which prioritizes Pancasila Student Profile competencies (Kemendikbudristek, 2022). Participants were 31 students from Grade XI Science Program (19 females, 12 males, aged 16–17), selected purposively as they represented typical challenges in rotational dynamics learning. The class was heterogeneous in academic ability and learning styles, with 40% kinesthetic learners based on pre-cycle diagnostics (Wahab & Nuraeni, 2020). Ethical considerations were paramount: informed consent was obtained from students, parents, and the school principal, emphasizing voluntary participation, no academic penalties for withdrawal, and data anonymity . Benefits included improved learning without extra burden, aligning with CAR's emancipatory ethos (Kemmis et al., 2014).

Research Design

The four stages form a spiral: Planning involves identifying problems (e.g., low scientific literacy from pre-cycle diagnostics) and designing interventions (e.g., gamified PBL with cultural elements). Action implements the plan in class. Observation collects data on outcomes using multiple instruments. Reflection analyzes findings to inform the next cycle. This iterative nature ensures continuous improvement, with each cycle building on the previous one (Kemmis et al., 2014). Figure 1 illustrates the procedure, showing how reflection loops back to revised planning.

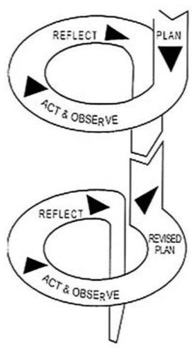

Figure 1. CAR Procedure Based on Kemmis & McTaggart Model (Kemmis et al., 2014)

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Data Collection

Data were collected using triangulated test and non-test instruments to ensure validity and reliability. Triangulation involved multiple sources—quantitative tests, qualitative reflections, and peer observations—to cross-verify findings and minimize bias (Mears et al., 2025; Muzari et al., 2022). Scientific literacy was measured via a pre- and post-test adapted from PISA 2018 competencies (Schleicher, 2019), with 20 items across three indicators: (1) explaining phenomena scientifically (e.g., "Explain why a spinning top slows down"); (2) interpreting data and evidence (e.g., analyzing graphs of angular velocity); (3) evaluating and designing investigations (e.g., critiquing an experiment on torque). The instrument was validated by two physics experts (content validity index = 0.85) and demonstrated good internal consistency (Cronbach's alpha = 0.82), indicating that the instrument was sufficiently valid and reliable to produce trustworthy data for subsequent analysis. *Gotong royong* skills were assessed through: (1) peer assessment via Google Forms (10 items on collaboration, e.g., "My group shared ideas equally"); (2) teacher observation sheets with 15 items (10 collaboration, 4 caring, 1 sharing) from Kemendikbudristek, (2022), validated with Cronbach's alpha 0.85 and 0.79 respectively. Qualitative data included student reflection journals (e.g., "How did group games help your understanding?") and observer notes.

The intervention spanned pre-cycle (baseline assessment) and two cycles (each 90 minutes, one week apart). Cycle 1 focused on moment of force and inertia: Planning identified kinesthetic gaps; Action used gasing videos and "Who's Fast, They Get It" game in heterogeneous groups; Observation collected test/peer data; Reflection revealed uneven sharing. Cycle 2 addressed angular momentum: Revised plan incorporated ballet dance and "Stop and Go Challenge"; Action emphasized interdependence; Observation showed gains; Reflection confirmed improved collaboration.

To provide clarity on the gamification mechanics, the "Who's Fast, They Get It" game in Cycle 1 involved groups competing to complete the culturally responsive LKPD as quickly and accurately as possible. Once a group finished the core tasks (e.g., problem identification, data collection via virtual simulations of gasing, hypothesis formulation, and conclusions), they earned priority access to select and answer bonus analytical questions related to rotational dynamics. This structure encouraged speed and precision while reinforcing group interdependence, as success depended on collaborative contributions to avoid errors.

In Cycle 2, the "Stop and Go Challenge"—inspired by the MasterChef television program—featured four applicative questions on angular momentum and conservation laws, drawn randomly for individual group members in a turn-based format. The game began with the teacher announcing "Go," prompting participants to solve their assigned question while receiving verbal encouragement from teammates. A student could halt the round by raising their hand and declaring "Stop" if confident in their answer; the teacher then verified it. Correct answers awarded maximum points to the group and ended the round, while incorrect ones incurred penalties (e.g., a 30-second delay or loss of turn), ensuring thorough individual mastery, equitable knowledge sharing, and enhanced *gotong royong* through solidarity and mutual support.

Data Analysis

Data analysis used descriptive statistics and normalized gain (N-gain) to quantify effectiveness (Meltzer, 2002). N-gain measures learning improvement relative to potential:

$$N - gain = \frac{posttest\ score - pretest\ score}{ideal\ score - pretest\ score} \tag{1}$$

Table 1. N-Gain Category (Hake, 1999)

N-gain score	Category
N-gain ≥ 0,7	High
0,3 ≤ N-gain < 0,7	Middle
N-gain < 0,3	Low
N-gain score	Category

Gotong royong data were analyzed as percentages per indicator. Qualitative reflections underwent thematic analysis (Braun & Clarke, 2019) to identify patterns like "increased confidence in groups." Triangulation confirmed consistency: test gains aligned with observation of active participation. This rigorous method ensured

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reliable, valid insights, contributing to Indonesian physics education by demonstrating CAR's practicality for curriculum alignment (Fayanto et al., 2023).

RESULTS AND DISCUSSION

Results

This classroom action research was conducted over three phases—pre-cycle, Cycle 1, and Cycle 2—with 31 students from Grade XI MIPA 1 at SMA Negeri 1 Banguntapan, Yogyakarta. The pre-cycle phase aimed to diagnose existing classroom conditions, student learning styles, and baseline scientific literacy levels. Observations during regular lessons showed that physics instruction was predominantly teacher-centered: the teacher explained concepts verbally while writing on the board, and students copied notes into pre-prepared physics worksheets. Although these worksheets ensured uniformity in content delivery, they did not accommodate diverse student needs, leading to disengagement manifested in behaviors such as playing with gadgets, drowsiness, or complete withdrawal from participation. A non-cognitive diagnostic assessment revealed significant variation in learning styles, with 40% of students identified as kinesthetic learners who prefer physical involvement and hands-on experiences, followed by visual (approximately 35%) and auditory learners (25%). The distribution of learning styles is presented in Figure 2. This finding highlighted a mismatch between teaching methods and student preferences, as kinesthetic learners were underserved by passive note-taking.

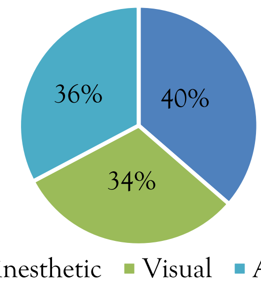

Figure 2. Student's learning style

The pre-cycle scientific literacy test, consisting of items aligned with PISA competencies (explaining phenomena scientifically, interpreting data and evidence, and evaluating/designing investigations), produced an average score of 55.16 (moderate category). Breakdown by indicator showed particular weakness in interpreting data and evidence scientifically (35.48), moderate performance in explaining phenomena (62.90), and relatively better results in evaluation/design (67.10). Detailed results across phases are shown in Table 2. Complementary semi-structured interviews with eight representative students confirmed that physics was perceived as difficult due to its abstract nature and formula density, yet students expressed interest when learning involved interaction. They unanimously favored group-based activities, noting that such formats reduced hesitation in asking questions and simultaneously honed social skills.

Table 2. Pre-cycle, Cycle 1 and Cycle 2 of scientific literacy result

Indicator	Score		
	Pre-cylce	Cycle 1	Cycle 2
Explaining phenomena scientifically	68.55	75.81	88.71
Interpretating data and evidence scientifically	35.48	74.19	90.32
Evaluating and designing scientific investigations	51.61	62.90	90.32
Mean	55.16	62.90	89.78

Cycle 1 targeted the subtopics of moment of force (torque) and moment of inertia. The intervention began with problem orientation through a video demonstration of the traditional spinning top (gasing), selected for its cultural familiarity in Javanese communities and direct relevance to rotational concepts. Students were divided into eight heterogeneous groups based on pre-cycle literacy scores to ensure balanced collaboration. Activities centered on culturally responsive student worksheets (LKPD) that guided PBL steps: problem identification, data collection via virtual laboratory simulations, hypothesis formulation, and conclusion drawing. Gamification was introduced through the "Who's Fast, They Get It" game, where the quickest group to complete core tasks earned bonus analytical questions, fostering competition tempered by group interdependence.

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Post-Cycle 1 assessments showed clear progress. Scientific literacy rose to 70.97 (high category), yielding an N-gain of 0.35 (moderate) and increasing conceptual understanding from approximately 40% to 61.83% of students (Table 2). The normalized gain scores for both cycles are illustrated in Figure 3. The most significant indicator gains occurred in interpreting data (from 35.48 to 68.71) and evaluation/design. *Gotong royong* skills, measured by peer assessment and observer sheets, averaged 75.32%, with strong performance in task division and collaboration (above 80%) but room for improvement in sharing knowledge and mutual encouragement (around 65–70%). A complete breakdown of *gotong royong* indicators across phases is provided in Table 3. Reflections and observer notes indicated high enthusiasm for the gasing-based activities, though some students requested games that balanced group success with individual accountability.

Table 3. Pre-cycle, Cycle 1 and Cycle 2 of "*Gotong Royong*" skills result from peer assessment

Indicator	Score	
	Cycle 1	Cycle 2
Collaboration	75.81	88.71
Caring	74.19	90.32
Sharing	62.90	90.32
Mean	62.90	89.78

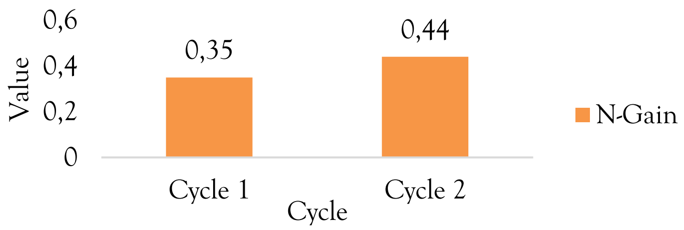

Figure 3. N-Gain Score of Scientific Literacy

Building on Cycle 1 reflections, Cycle 2 focused on angular momentum, conservation laws, and rotational kinetic energy. Cultural responsiveness was enhanced by incorporating global elements through ballet dance videos, illustrating angular momentum conservation when dancers pull in their arms. The gamification innovation—"Stop and Go Challenge"—required group members to answer unpredictable questions in turns, with peers providing encouragement and penalties for errors, ensuring comprehensive material mastery. This format directly addressed previous shortcomings in knowledge sharing.

Cycle 2 results demonstrated further consolidation. Scientific literacy achieved 89.78 (high category), with an N-gain of 0.44 (moderate) and conceptual understanding reaching 79.03%. Dramatic improvement was evident in data interpretation (90.32), while explaining phenomena and evaluation also exceeded 85% (Table 2). *Gotong royong* scores increased to 79.57%, with the largest gains in mutual encouragement (+12%), solidarity (+9%), and sharing (+8%) (Table 3). Qualitative data from reflections revealed students appreciating the model's interactivity, time management demands, and socialization opportunities. However, minor persistent issues included occasional misconceptions (reduced but present in ~21% of responses) and uneven participation in some groups.

Discussion

The observed improvements in both scientific literacy and *gotong royong* skills can be attributed to the synergistic interplay of PBL, CRT, and gamification, each addressing specific deficiencies identified in the pre-cycle phase. First, regarding scientific literacy, the moderate yet consistent N-gain across cycles (0.35 to 0.44) aligns with meta-analytic findings on PBL's impact in secondary science education (Aripin et al., 2025; Suciana & Sausan, 2023). The most substantial leap in interpreting data and evidence scientifically—from 35.48 in pre-cycle to 90.32 in Cycle 2—stems from the model's emphasis on kinesthetic and contextual experiences. Traditional lecturing rarely provides opportunities for students to generate, manipulate, or critique data firsthand; in contrast, virtual laboratory simulations with gasing and ballet contexts allowed students to observe real-time variations in torque or angular velocity, articulate predictions, and confront discrepancies collaboratively. This process mirrors the inquiry cycle advocated by Bybee (2013) and Hmelo-Silver et al. (2019), where active data engagement reduces cognitive load for abstract topics like rotational dynamics. The cultural

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anchoring via CRT further amplified relevance: gasing as a familiar childhood artifact lowered affective barriers, making physics "feel Indonesian" and reducing the alienation often reported in PISA underperformance analyses (OECD, 2023).

Gamification played a pivotal role in sustaining engagement and promoting equitable contribution. The "Who's Fast, They Get It" game in Cycle 1 incentivized efficiency while maintaining group accountability, whereas the "Stop and Go Challenge" in Cycle 2 enforced comprehensive understanding by randomizing individual responsibility—directly addressing Cycle 1 reflections on uneven knowledge sharing. These mechanics created positive interdependence, a core element of effective collaborative learning (Lin & Wang, 2023; Pan et al., 2025), resulting in measurable *gotong royong* gains. The 5.64% overall increase, though modest given the short duration, was qualitatively significant: observer notes documented shifts from task-focused individualism to proactive peer support, aligning with Pancasila Student Profile dimensions (Kemendikbudristek, 2022).

Compared to related Indonesian studies, this model's outcomes are competitive. Safira & Agustina (2024) reported high-category scientific literacy using PBL-CRT without gamification, while Rahmawati & Agustina (2025) achieved similar affective gains in junior high settings. The present study advances these by demonstrating a three-component integration in senior high physics—a more abstract domain—and by explicitly targeting kinesthetic learners, a subgroup often overlooked in conventional classrooms. Nevertheless, the moderate rather than high N-gain values warrant closer examination in light of contextual constraints and comparative literature. The overall N-gain range of 0.35–0.44 falls within the moderate category defined by Hake (1999), which is consistent with many PBL interventions in secondary physics, where abstract topics often yield incremental rather than transformative gains in short-term implementations (Hmelo-Silver et al., 2019). The two-week duration, encompassing only two cycles, likely limited deeper internalization of concepts, as extended exposure is frequently cited as necessary for shifting entrenched misconceptions in rotational dynamics (Bybee, 2013). For instance, the persistence of a small proportion of students (approximately 21%) exhibiting incomplete conceptual understanding in Cycle 2 may reflect insufficient time for repeated inquiry cycles or inadequate prior scaffolding in translational-to-rotational analogies. Future implementations could incorporate pre-intervention diagnostic remediation or extend to four or more cycles to push N-gain toward the high category observed in longer PBL studies (Suciana & Sausan, 2023).

The pronounced success in the data interpretation indicator deserves particular attention, as it addresses a core weakness in Indonesian PISA performance (OECD, 2023). The integration of kinesthetic and visual elements—manipulating virtual gasing parameters and observing ballet dancers' arm movements—provided concrete, multisensory experiences that traditional instruction lacks. This aligns with learning style theory, where kinesthetic learners benefit disproportionately from physical and interactive modalities (Karataş & Yalin, 2021; Wahab & Nuraeni, 2020). Moreover, the cultural relevance of gasing as a Javanese artifact and ballet as a global performance art created dual pathways to meaning-making: local familiarity reduced cognitive dissonance, while the global example broadened perspectives, embodying the inclusive ethos of culture-based schools. Such dual anchoring exemplifies effective CRT application, which prior meta-analyses show enhances achievement among diverse learners by fostering ownership and reducing the "relevance gap" (Anyichie et al., 2023; Pinneo & Benton, 2024).

Regarding *gotong royong*, the steady 5.64% improvement, though modest in absolute terms, represents meaningful behavioral change within a brief intervention. The shift toward greater mutual encouragement and solidarity reflects the deliberate design of interdependence in the gamified tasks. In the "Stop and Go Challenge," random assignment of questions compelled every member to prepare thoroughly, while peer vocal support during "Go" phases reinforced empathy and collective success—mechanisms directly drawn from collaborative game research (Pan et al., 2025). This outcome supports the Pancasila Student Profile framework (Kemendikbudristek, 2022), demonstrating that structured gamification can operationalize abstract social values in subject-specific lessons. Compared to conventional group work in Indonesian classrooms, which often suffers from free-riding or dominance by high performers (Mustaqim et al., 2025), the present model's explicit rewards for sharing and encouragement mitigated such issues, though not entirely eliminated them.

Several limitations temper the interpretation of these findings and highlight directions for refinement. First, the small sample size (n=31) from a single urban public school restricts generalizability to rural, private, or larger cohorts. Second, the researcher's dual role as teacher and primary facilitator, despite peer observation,

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introduces potential desirability bias in student responses and reflections. Third, the short timeframe may have amplified novelty effects—initial excitement from games and cultural elements—rather than reflecting sustainable change (Wijnia et al., 2024). Finally, while instruments were expert-validated and reliable, the *gotong royong* measures relied heavily on self- and peer-reporting, which can be influenced by social desirability.

Theoretically, this study enriches the discourse on inquiry-based and culturally responsive pedagogies by offering an empirically tested three-component model tailored to Indonesia's educational priorities. It extends PBL theory by illustrating how cultural artifacts can serve as authentic problems, moving beyond Western-centric examples toward ethnoscience integration. Practically, it provides physics educators with a transferable blueprint: LKPD templates embedding local culture, scalable games accommodating kinesthetic preferences, and reflective cycles for continuous adaptation. Curriculum developers under the Merdeka framework can draw on these findings to embed similar integrations across STEM subjects, strengthening both scientific literacy targets and character education outcomes.

In summary, the integrated PBL-CRT-gamification model proved effective in yielding moderate yet meaningful gains in scientific literacy and *gotong royong* within a constrained classroom action research context. By grounding abstract physics in culturally resonant, interactive experiences, the approach not only elevated cognitive performance—particularly in data interpretation—but also cultivated collaborative dispositions essential for 21st-century learning. These results underscore the value of contextually sensitive innovations in addressing Indonesia's PISA challenges while nurturing national values.

CONCLUSION

This classroom action research successfully demonstrates that the integrated model of Problem-Based Learning (PBL), Culturally Responsive Teaching (CRT), and gamification effectively enhances scientific literacy and *gotong royong* skills among senior high school students in the context of rotational dynamics physics learning, thereby achieving the study's primary objectives. Implemented through two iterative cycles with 31 Grade XI students at SMA Negeri 1 Banguntapan, Yogyakarta, the intervention—featuring culturally relevant contexts such as the traditional Javanese spinning top (gasing) and ballet dance, combined with kinesthetic-oriented games—yielded moderate yet consistent improvements: scientific literacy scores rose from 55.16 in the pre-cycle to 89.78 in Cycle 2 (N-gain 0.35–0.44), with the most significant gains in interpreting data and evidence scientifically, while *gotong royong* skills increased from 75.32 to 79.57%, particularly in mutual encouragement and sharing. These findings affirm that grounding abstract physics concepts in local cultural elements and interactive gamification not only accommodates kinesthetic learning preferences but also fosters collaborative interdependence, aligning directly with the Merdeka Curriculum's emphasis on cognitive proficiency and the Pancasila Student Profile's character dimensions. The core novelty of this study lies in its three-component integration within an Indonesian ethnoscience framework, offering a replicable approach that simultaneously addresses national concerns over low PISA science performance and the need for meaningful social skill development in teacher-centered classrooms. Despite limitations related to sample size and intervention duration, the model provides a promising foundation for future pedagogical innovations in culture-based schools.

Daftar Pustaka

Angelia, T. J., & Wadison, E. (2023). A study of students learning modalities at english education program at muhammadiyah university of Bengkulu. *Teaching English and Language Learning English Journal*, *3*(1), 20–26. https://doi.org/https://doi.org/10.36085/telle.v3i1.5572

Anyichie, A. C., Butler, D. L., & Nashon, S. M. (2023). Exploring teacher practices for enhancing student engagement in culturally diverse classrooms. *Journal of Pedagogical Research*, *7*(5), 183–207. https://doi.org/10.33902/JPR.202322739

Aripin, N., Mufit, F., Lufri, Andromeda, & Festiyed. (2025). The role of problem-based learning in developing Science literacy and 21st-century skills in high school students. *Fermatif: Jurnal Ilmiah Pendidikan MIPA*, *15*(148), 269–284. https://doi.org/10.30998/formatif.v15i1.27799

Braun, V., & Clarke, V. (2019). Reflecting on reflexive thematic analysis. *Qualitative Research in Sport, Exercise*

ISSN: 2088-0294 | e-ISSN: 2621-9166
https://doi.org/10.37630/jpm.v16i1.4052

and Health, *11*(4), 589–597.

Bybee, R. W. (2013). *The Case for STEM Education: Challenges and Opportunities.* National Science Teachers Association, NSTA Press.

Elviana, T., Liliawati, W., & Sriyati, S. (2024). Exploration the Ethnoscience of Gasing Game from Malay Riau Culture and its Potential for Physics Learning. *Journal of Science Education Research*, *8*(2), 120–132. https://doi.org/10.21831/jser.v8i2.75081

Evans, C. (2020). Measuring student success skills: A review of the literature on collaboration. In *National Center for the Improvement of Educational Assessment*. National Center for the Improvement of Educational Assessment. www.nciea.org

Fayanto, S., Erniwati, & Sabilu, M. (2023). Analysis of the inquiry learning model with ICT support for science learning: a literature review. *Proceedings Series of Educational Studies*, *3*.

Fernandez, F. B. (2017). Action research in the physics classroom: The impact of authentic, inquiry based learning or instruction on the learning of thermal physics. *Asia-Pacific Science Education*, *3*(1), 1–20. https://doi.org/10.1186/s41029-017-0014-z

Hake, R. R. (1999). *Analyzing Change/Gain Scores*. Dept of Physics Indiana University.

Hmelo-Silver, C. E., Bridges, S. M., & Mckeown, J. M. (2019). Facilitating Problem - Based Learning Epistemology of PBL Facilitation. In *The Wiley Handbook of Problem-Based Learning* (pp. 297–319). John Wiley & Sons, Inc.

Ilma, A. Z., Jumadi, J., & Narumsari, M. C. (2022). Teacher's perceptions of essential learning models to improve students' science learning achievement in secondary schools. *Jurnal Pendidikan Sains Indonesia*, *10*(2), 403–423. https://doi.org/10.24815/jpsi.v10i2.23881

Jusmaniar, J., Riani, I., Anderson, E. C., Lee, M. C., & Oktavia, S. W. (2024). Gasing Game: Ethnoscientific Exploration of Circular Motion in Physics Learning on the Coast of East Sumatra to Build the Character of Perseverance. *Schrödinger: Journal of Physics Education*, *5*(1), 1–9. https://doi.org/10.37251/sjpe.v5i1.902

Karataş, E., & Yalin, H. İ. (2021). The impact of matching learning-teaching styles on students' academic achievement. *Eurasian Journal of Educational Research*, *2021*(92), 377–402. https://doi.org/https://doi.org/10.14689/ejer.2021.92.19

Kemendikbudristek. (2022). Dimensi, elemen, dan subelemen profil pelajar pancasila pada kurikulum merdeka. In *Kemendikbudristek*. Badan Standar, Kurikulum dan Asesmen Pendidikan Kementerian Pendidikan, Kebudayaan, Riset dan Teknologi Republik Indonesia.

Kemmis, S., McTaggart, R., & Nixon, R. (1998). Action Research Planner Book. In *Springer Science+Bussiness Media Singapore*.

Kemmis, S., McTaggart, R., & Nixon, R. (2014). *The Action Research Planner*. Springer.

Lin, Y. L., & Wang, W. T. (2023). Analysis of the social interaction of perceived problem-based learning performance in internship courses. *Journal of Computer Assisted Learning*, *39*(1), 194–209. https://doi.org/https://doi.org/10.1111/jcal.12739

Liu, W., Jamaludin, K. A., & Hamzah, M. I. (2025). Systematic review of culturally responsive teaching and implications for technical communication education. *Multidisciplinary Reviews*, *8*(4). https://doi.org/10.31893/multirev.2025117

Mawaddah, I., Wahyono, H., Andayani, E. S., & Sumarsono, H. (2024). The effect of STEAM approach to economics media based on Bima local wisdom in elementary schools. *Journal of Ecohumanism*, *3*(7), 1396–1411. https://doi.org/10.62754/joe.v3i7.4300

Mears, M., Dash, L., Galloway, R., Karpenko, C., Labrosse, N., Mason, V., & Quinn, M. (2025). Mixed-Methods Study of First-Year Physics Students: Soft Barriers to Coding. *Journal of Science Education and Technology*, *34*(2), 420–435. https://doi.org/10.1007/s10956-025-10198-0

ISSN: 2088-0294 | e-ISSN: 2621-9166
https://doi.org/10.37630/jpm.v16i1.4052

Meltzer, D. E. (2002). The relationship between mathematics preparation and conceptual learning gains in physics: A possible "hidden variable" in diagnostic pretest scores. *American Journal of Physics*, *70*(12), 1259–1268. https://doi.org/10.1119/1.1514215

Mustaqim, B., Akhyar, M., Joyoatmojo, S., & Akhyar, M. (2025). A study of problem-based flipped learning of Indonesian vocational high school students. *Journal of Teaching and Learning Physics*, *19*(2), 80–97. https://doi.org/https://doi.org/10.22329/jtl.v19i2.9292

Muzari, T., Nevers Shava, G., & Shonhiwa, S. (2022). Qualitative Research Paradigm, a Key Research Design for Educational Researchers, Processes and Procedures: A Theoretical Overview. *Indiana Journal of Humanities and Social Sciences*, *2*(1), 14–20. https://indianapublications.com/Journals/IJHSS

OECD. (2023). Equity in education in PISA 2022. In *PISA 2022 Results (Volume I): The State of Learning and Equity in education* (Vol. 1). https://www.oecd-ilibrary.org/education/pisa-2022-results-volume-i_03c74bdd-en

Pan, Y., Shao, X., & Shakibaei, G. (2025). *Influence of digital game-based learning on social collaboration , problem-solving skills , and motivation : An integrative approach of expectancy-value theory and flow theory*. 90(March), 1–15.

Pinneo, L., & Benton, A. L. (2024). Culturally responsive elementary science teaching: a meta-analysis of current science teaching studies and implications. *Cultural Studies of Science Education*, *19*(4), 553–572. https://doi.org/10.1007/s11422-024-10222-6

Rahmawati, L., & Agustina, L. (2025). Application of problem based learning (PBL) learning model based on culturally responsive teaching (CRT) to the science learning outcomes of students in grade VII junior high school. *Assimilation: Indonesian Journal of Biology Education*, *8*(1), 109–120.

Rojas, M. O., Chiluiza, K., Valcke, M., & Mendoza, C. B. (2025). How gamification boosts learning in STEM higher education : a mixed methods study. *International Journal of STEM Education*, 1–14. https://doi.org/10.1186/s40594-024-00521-3

Safira, G., & Agustina, L. (2024). Students ' science literacy skills through the application of problem- based learning (PBL) learning model based on culturally responsive Teaching (CRT). *Bioeduscience*, *8*(3), 327–333. https://doi.org/https://doi.org/10.22236/jbes/14619

Schleicher, A. (2019). *PISA 2018 Insights and Interpretations: Vol. I*. OECD Publishing. https://doi.org/10.1787/5f07c754-en

Smith, G. D. (2012). Taxonomy and History. In *The Laboratory Rabbit, Guinea Pig, Hamster, and Other Rodents* (pp. 747–752). https://doi.org/10.1016/B978-0-12-380920-9.00026-2

Suciana, D., & Sausan, I. (2023). A meta-analysis study : The effect of problem based learning integrated with STEM on learning outcomes. *European Journal of Education and Pedagogy*, *4*(2), 133–138. https://doi.org/10.24018/ejedu.2023.4.2.619

Sukmawati, F., Qodr, T. S., & Rutambuka, T. (2025). Integrating digital games into project-based learning to enhance student achievement in STEM education. *IJORER : International Journal of Recent Educational Research*, 6(2), 294–315. https://doi.org/10.46245/ijorer.v6i2.744

Wahab, I., & Nuraeni, N. (2020). The analysis of students' learning style. *Seltics*, 3(1), 41–46. https://doi.org/https://doi.org/10.46918/seltics.v3i1.509

Wang, L. H., Chen, B., Hwang, G. J., Guan, J. Q., & Wang, Y. Q. (2022). Effects of digital game-based STEM education on students' learning achievement: a meta-analysis. *International Journal of STEM Education*, *9*(1). https://doi.org/10.1186/s40594-022-00344-0

Wijnia, L., Noordzij, G., Arends, L. R., Rikers, R. M. J. P., & Loyens, S. M. M. (2024). The effects of problem-based, project-based, and case-based learning on students' motivation: A meta-analysis. In *Educational Psychology Review* (Vol. 36, Issue 1). Springer US. https://doi.org/10.1007/s10648-024-09864-3