

Exploring the emergence of scientific ethics in inquiry-based renewable energy learning: a case study in elementary school

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Abstract: *This study explores the emergence of scientific ethics through inquiry-based renewable energy learning among fifth-grade elementary students. While inquiry-based learning (IBL) is widely recognized for improving scientific literacy and conceptual understanding, its role in fostering scientific ethical values at the elementary level remains underexplored. Using a qualitative case study design at SDN Ciptomulyo 1 Malang City, data were collected through participant observation, in-depth interviews, and documentation, and analyzed thematically. The findings indicate that inquiry activities involving experiments with mini solar panels and windmills fostered honesty in data recording, responsibility in conducting procedures, openness to empirical evidence, collaborative engagement, and critical reflection on experimental outcomes. These ethical dispositions emerged through structured investigation and teacher-facilitated discussion. The study highlights that inquiry-based renewable energy instruction not only enhances conceptual mastery but also supports the development of scientific character in elementary science education.*

Keywords: *inquiry learning, scientific ethics, renewable energy, science, elementary school*

Introduction

Elementary science education serves as a foundational stage for cultivating not only students' conceptual understanding but also their scientific dispositions and ethical awareness. At the primary level, science learning is expected to develop habits of evidence-based reasoning, intellectual honesty, responsibility, and openness to alternative explanations. These dimensions align with the broader framework of scientific literacy, which integrates cognitive competence with epistemic and ethical orientations toward knowledge construction (Urdanivia Alarcón et al., 2023). Thus, science education in elementary schools should not be limited to mastering content but must also nurture scientific character through meaningful engagement with empirical phenomena.

Inquiry-Based Learning (IBL) has been widely acknowledged as a pedagogical approach capable of fostering authentic scientific practices. Grounded in constructivist learning theory, IBL positions students as active investigators who formulate questions, design procedures, collect data, interpret evidence, and construct explanations (Kotsis, 2024). Research indicates that inquiry-oriented laboratories enhance scientific literacy and argumentation skills because students participate in processes resembling real scientific investigation (Eymür & Çetin, 2024). Through structured inquiry, learners engage in reasoning processes that require justification of claims based on empirical evidence, thereby strengthening epistemic cognition and reflective thinking.

Beyond cognitive development, inquiry-based science learning has been associated with the cultivation of scientific attitudes. Studies have shown that guided inquiry can improve students' responsibility, collaboration, and critical thinking skills (Hamid et al., 2023; Widowati et al., 2023). These findings suggest that inquiry learning environments provide social and intellectual contexts where students practice disciplined observation and cooperative problem-solving. However, much of the existing literature conceptualizes these outcomes as "scientific attitudes" without deeply examining their ethical dimensions, such as integrity in reporting data, accountability in experimentation, and openness to discrepant results.

Scientific ethics, distinct from general scientific attitudes, refers to the moral and epistemic commitments embedded within scientific practice. It encompasses honesty in data collection and reporting, respect for empirical evidence, transparency in procedures, and responsibility toward collaborative work. In educational contexts, scientific ethics represent the internalization of values that regulate how knowledge is produced and validated. While prior research has examined epistemic cognition and scientific literacy (Hasanah, 2024), limited empirical studies have explicitly explored how ethical dispositions emerge during inquiry processes at the elementary level.

Renewable energy learning provides a particularly relevant context for examining the formation of scientific ethics. Topics such as solar panels and wind turbines involve observable variations in experimental outcomes influenced by environmental conditions, procedural accuracy, and measurement techniques. These variations naturally require students to interpret inconsistent data, negotiate explanations within groups, and reflect on procedural limitations. Such conditions create opportunities for practicing honesty, openness to evidence, and collaborative responsibility. Without explicit ethical reflection, however, inquiry activities risk becoming merely technical exercises rather than morally meaningful scientific engagements.

Despite the recognized potential of inquiry-based learning, there remains a research gap concerning how scientific ethical values emerge within renewable energy instruction in elementary schools. Previous studies have predominantly focused on learning outcomes, conceptual mastery, or critical thinking (Jannah et al., 2024; Eymür & Demirel, 2024), leaving the ethical dimension of inquiry underexamined. Furthermore, the integration of sustainability-related science topics with character-oriented inquiry practices has not been sufficiently investigated through qualitative exploration. Understanding this intersection is essential for advancing science education that aligns with both cognitive and character development goals.

Therefore, this study aims to explore the emergence of scientific ethics in inquiry-based renewable energy learning among fifth-grade elementary students. Using a qualitative case study approach, this research seeks to provide an in-depth understanding of how ethical values such as honesty, responsibility, openness to evidence, collaboration, and critical reflection are enacted and interpreted within classroom inquiry practices. By linking inquiry pedagogy, scientific ethics, and renewable energy instruction, this study contributes to

strengthening the theoretical and practical integration of character formation within elementary science education.

Method

This study employed a qualitative approach with a case study design to explore the emergence of scientific ethics in inquiry-based renewable energy learning. A case study was selected to enable an in-depth investigation of classroom interactions, contextual dynamics, and students' ethical meaning-making processes within a real educational setting. The research was conducted at SDN Ciptomulyo 1 Malang City during the second semester of the 2024/2025 academic year over a period of four weeks.

Participants consisted of one fifth-grade science teacher and 28 fifth-grade students who were actively involved in inquiry-based renewable energy instruction. Participants were selected using purposive sampling to ensure that the classroom had implemented structured inquiry activities involving experimentation with mini solar panels and wind turbines. The teacher had more than five years of teaching experience and had previously applied inquiry strategies in science instruction.

Data were collected through participant observation, semi-structured in-depth interviews, and document analysis. Classroom observations were conducted during four inquiry sessions focusing on experimental design, data collection, group discussion, and reflection. Field notes documented instances related to honesty in reporting data, responsibility in procedures, openness to differing results, collaboration, and critical questioning. Semi-structured interviews were conducted with the teacher and six selected students representing diverse levels of participation to explore their perceptions of scientific processes and ethical values. Documents analyzed included lesson plans, student worksheets, experimental reports, and classroom photographs.

Data analysis followed a thematic analysis procedure. First, all observation notes and interview transcripts were transcribed verbatim. Second, open coding was conducted to identify meaningful units related to scientific ethical behaviors. Third, codes were grouped into broader categories reflecting dimensions of scientific ethics, such as honesty, responsibility, openness to evidence, collaboration, and critical reflection. Finally, themes were refined and interpreted through iterative comparison across data sources. The analysis process was conducted systematically to ensure consistency between raw data, codes, categories, and emerging themes.

To ensure trustworthiness, several validation strategies were applied. Method triangulation was conducted by comparing findings from observations, interviews, and documentation. Source triangulation involved cross-checking perspectives between the teacher and students. Member checking was performed by sharing preliminary interpretations with the teacher to confirm the accuracy of representations. Additionally, an audit trail consisting of field notes, coding sheets, and analytic memos was maintained to enhance transparency and dependability.

The researcher acted as a non-participant observer during classroom activities and ensured minimal interference in instructional processes. Ethical clearance was obtained from the school principal, and informed consent was secured from parents and participants. All participant identities were anonymized using initials, and data were stored securely to maintain confidentiality.

Results and Discussion

The analysis identified five major themes representing the emergence of scientific ethics during inquiry-based renewable energy learning: (1) honesty in data recording, (2) responsibility in experimental procedures, (3) openness to empirical evidence, (4) collaborative accountability, and (5) critical scientific reflection. These themes emerged consistently across observation data, interviews, and classroom documentation.

1. Honesty in Data Recording

Observations during solar panel and wind turbine experiments revealed that students recorded experimental results based on actual measurements, even when outcomes differed from expectations. For instance, one group reported that their windmill rotation was slower than other groups due to weaker airflow near the classroom wall. Instead of adjusting results to match peers' findings, students documented variations and discussed possible causes. During interviews, a student stated, "If the light is dim, we must write it as dim, even if others get brighter results." This indicates the internalization of honesty as an epistemic commitment rather than compliance with teacher instruction.

This finding aligns with research emphasizing that authentic inquiry contexts strengthen integrity in scientific reporting (Widowati et al., 2023). However, the present study extends prior findings by demonstrating that ethical honesty emerges specifically when students encounter discrepant empirical outcomes, particularly in renewable energy experiments where environmental variables influence results.

2. Responsibility in Experimental Procedures

Scientific responsibility was evident in how students distributed roles, managed materials, and followed experimental steps systematically. Groups assigned members to measure light exposure, adjust equipment position, and document findings. When errors occurred, such as incorrect placement of the solar panel students repeated the procedure without teacher coercion. This reflects procedural accountability.

Consistent with guided inquiry literature (Hamid et al., 2023), responsibility here was not merely task completion but ownership of the investigative process. Renewable energy experiments required careful handling of equipment, reinforcing procedural discipline. This suggests that material-based inquiry contexts strengthen responsibility through tangible interaction with scientific tools.

3. Openness to Empirical Evidence

Openness to evidence emerged when students compared cross-group data and reconsidered initial hypotheses. In several sessions, groups obtained different illumination levels from identical mini solar panels. Rather than rejecting conflicting data, students

debated potential causes such as angle of light exposure and obstruction from classroom objects. A student reflected, “Maybe our panel was not facing the light directly.”

This behavior demonstrates epistemic openness a willingness to revise explanations based on empirical discrepancies. Previous studies (Braund & Hames, 2022) discuss pupil agency in inquiry; however, this study highlights that renewable energy contexts naturally generate variable outcomes, making them particularly conducive to fostering openness toward scientific uncertainty.

4. Collaborative Accountability

Collaboration was not limited to cooperation but extended to collective accountability. During discussions, students negotiated procedural decisions and corrected peers who attempted shortcuts. For example, when one member suggested estimating light intensity without measurement, another insisted on rechecking using the tool. This indicates shared responsibility for data validity.

Inquiry-based environments are known to enhance scientific communication (Eymür & Demirel, 2024), yet this study reveals that collaboration becomes ethically meaningful when students perceive accuracy as a shared obligation. The renewable energy context, involving visible and measurable phenomena, strengthened this collective scientific norm.

5. Critical Scientific Reflection

Critical reflection emerged when students questioned inconsistencies and evaluated possible sources of error. Students did not merely accept results but asked why certain windmills rotated faster or why light output differed. These questions prompted procedural re-evaluation and refinement.

While prior research links inquiry to critical thinking development (Kotsis, 2024), this study demonstrates that critical questioning also reflects ethical engagement with evidence. Students showed concern for accuracy and validity, indicating an emerging scientific conscience embedded in reasoning processes.

Overall, the findings suggest that inquiry-based renewable energy learning fosters scientific ethics through structured engagement with variable empirical phenomena. The combination of hands-on experimentation, group negotiation, and teacher-facilitated reflection creates conditions where ethical dispositions become embedded in epistemic practices.

Unlike prior studies that focus primarily on cognitive gains, this research demonstrates that ethical formation occurs through interaction with real-world variability inherent in renewable energy experiments. Environmental unpredictability becomes a pedagogical catalyst for honesty, responsibility, and openness. Thus, renewable energy instruction serves not only as a conceptual topic but as an ethical learning space.

The findings reinforce constructivist and epistemic cognition theories, suggesting that ethical values in science are constructed through participatory engagement rather than direct moral instruction. Teachers play a mediating role in guiding reflection, ensuring that inquiry remains ethically meaningful rather than procedurally mechanical.

Conclusion

This study reveals that inquiry-based renewable energy learning creates meaningful conditions for the emergence of scientific ethics among fifth-grade elementary students. Through hands-on experimentation with mini solar panels and wind turbines, students demonstrated ethical dispositions reflected in honesty in recording data, responsibility in conducting procedures, openness to empirical differences, collaborative accountability, and critical reflection on experimental outcomes. These values emerged organically through engagement with variable scientific phenomena, peer interaction, and guided classroom reflection rather than through explicit moral instruction. The findings suggest that renewable energy inquiry contexts function not only as platforms for conceptual understanding but also as epistemic spaces where scientific character is constructed through authentic investigative practices. Therefore, integrating structured inquiry with sustainability-related science topics contributes to strengthening the alignment between cognitive development and ethical formation in elementary science education.

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