Volume 4, Issue 2 (2026) 149-159

EQUATOR SCIENCE JOURNAL (ESJ)
e-ISSN: 2988-3881
Journal homepage:
https://ejournal.edukhatulistiwa.com/index.php/ESJ

DIY Photometer-Based Citizen Science for Project-Based Environmental Physics Learning and Light Pollution Literacy

Cahyo Puji Asmoro[1,4*], Rani Nur Widiawati[2], Asep Akmal Fadia Nurhalim[2], Abdul Salam[2], Najmi Hiyan Fathinah[2], Judhistira Aria Utama[1,4], Dhani Herdiwijaya[3,4]
[1]Physics Study Program, Universitas Pendidikan Indonesia, Indonesia
[2]Physics Education Study Program, Universitas Pendidikan Indonesia, Indonesia
[3]Astronomy Study Program, Institut Teknologi Bandung, Indonesia
[4]University Center of Excellence for Astronomy Data Science and Light Pollution, Universitas Pendidikan Indonesia, Indonesia

Received: May 2, 2026 | Revised: June 10, 2026 | Accepted: June 25, 2026
First Available Online: June 30, 2026 | Publication Date: June 30, 2026
DOI: https://doi.org/10.61142/esj.v4i2.359

**Corresponding author:* cp.asmoro@upi.edu

***Keywords**:*
Bortle scale;
DIY photometer;
Environmental education;
Light pollution;
Nelm

ABSTRACT

Artificial light at night (ALAN) is a growing environmental crisis, yet integrating light pollution literacy into science curricula is often hindered by the prohibitive cost of commercial sensors. Addressing this gap, this study examines the DIY CJ'01 photometer as a low-cost, open-source tool for measuring night sky brightness and advancing environmental physics education. Fieldwork across 15 sub-districts in Cimahi City compared the CJ'01 against an industry-standard Sky Quality Meter (SQM). Results demonstrated strong instrumental agreement, yielding a minimal mean discrepancy of 0.16 mag/arcsec². Robust validation via Bland–Altman analysis (bias = −0.157; 95% LoA = −0.465 to 0.152), alongside RMSE (0.218), MAE (0.157), and an Intraclass Correlation Coefficient of 0.832, confirmed its high reliability. Beyond technical validation, embedding the CJ'01 within a Project-Based Learning (PjBL) framework successfully repositioned undergraduate students as active citizen scientists. This instructional design enabled students to translate raw photometric data into baseline sky-brightness maps for municipal use. Ultimately, this experiential approach operationalizes SDG 4.7's active environmental citizenship, proving that democratized instrumentation can simultaneously serve scientific monitoring and Education for Sustainable Development (ESD).

INTRODUCTION

Light pollution, defined as the excessive and misdirected use of artificial light at night, has become a significant yet often ignored environmental threat. As urban infrastructure expands, the natural darkness of the night sky is increasingly degraded, leading to far-reaching consequences for biodiversity, human health, and energy conservation (Horálek & Wallner, 2022; Longcore & Rich, 2004; Owens et al., 2020; Walker et al., 2020). Unlike other forms of pollution, light pollution is frequently perceived as a byproduct of progress, which complicates efforts to mitigate its effects (Cora et al., 2022; Faid et al., 2024; Hearnshaw, 2022; Kyba et al., 2023; Liu et al., 2022; Luginbuhl et al., 2014; Varela Perez, 2023). In Indonesia, the impact is particularly visible in urban centers like Cimahi City, where the proliferation of artificial lighting has substantially reduced celestial visibility (Asmoro, 2024).

In physics education, light pollution offers a concrete context for teaching atmospheric optics, photon detection, and radiative transfer — physical concepts that otherwise stay abstract for most secondary students (Bohren & Huffman, 2008). The pedagogical potential extends well beyond content knowledge. Project-Based Learning (PjBL) positions students as investigators working on real, consequential problems over an extended period, and has demonstrated consistent gains in scientific reasoning and conceptual transfer compared with conventional instruction (Krajcik & Blumenfeld, 2006; Thomas, 2000). Experiential Learning Theory provides a complementary account: meaningful learning requires cycling through concrete experience, reflective observation, abstract conceptualization, and active experimentation(Da, 1984). Field measurement with a self-built instrument hits all four stages in a single project. Environmental Literacy frameworks add a further dimension — effective environmental education must cultivate not just factual knowledge but also affective engagement and the disposition to act responsibly in the face of environmental problems (Hungerford & Volk, 1990; Orr, 1992). Citizen Science — the structured participation of non-professional learners in authentic data collection — connects these threads: it gives students genuine ownership of the inquiry process, a factor consistently associated with stronger environmental awareness and pro-environmental behavior (Bonney et al., 2014; Kyba et al., 2023; Muaziyah et al., 2023). Education for Sustainable Development (ESD), as framed in UNESCO's SDG 4.7, explicitly calls for competencies in participatory environmental action, making citizen-science photometry a natural fit for ESD objectives (United Nations Educational, 2017)). The persistent obstacle is cost. The Sky Quality Meter — still the field standard for sky brightness measurement — is financially out of reach for most Indonesian schools, which means the experiential learning pathway described above remains inaccessible to the students who would benefit most from it (Barentine, 2022; Cinzano, 2005; Putraga et al., 2022)

Recently, the study of light pollution has become a significant trend in science education research, particularly within the framework of Education for Sustainable Development (ESD) and the Sustainable Development Goals (SDGs), which are continuously promoted and actively pursued worldwide (Nidiasari et al., 2026; Perdani et al., 2024; Putri & Rizaldi, 2024). Bibliometric reviews reveal a surge of studies on the multidimensional impacts of artificial light at night, reflecting growing global concern (Rodrigo-Comino et al., 2023). In education, research highlights increasing student awareness yet limited conceptual understanding(Hariyono & Suprapto, 2023),while physics pedagogy increasingly integrates light pollution to assess competencies such as problem-solving through instruments analyzed with modern psychometric models like the Rasch Model (Lutfiani et al., 2025). Beyond classrooms, outreach programs connect academic physics with community environmental literacy, underscoring the need to move from theory to practical, field-based engagement(Adkins et al., 2025).

Despite growing scholarly attention to both DIY photometry and science education, their systematic integration remains underexplored. Studies validating low-cost photometers — including earlier work on the CJ'01 — have concentrated on technical accuracy without embedding the instrument in a structured pedagogical framework (Asmoro, 2024; Asmoro et al., 2022; Hänel et al., 2018). On the education side, studies on environmental literacy in physics classrooms tend to rely on simulated data or pre-packaged laboratory exercises rather than instruments that students build and deploy in authentic field conditions (Hariyono & Suprapto, 2023; Lutfiani et al., 2025). The result is a gap at the intersection: we lack evidence on what happens when a rigorously validated DIY instrument is placed inside a Project-Based Learning environment and students assume the role of citizen scientists. This study addresses that gap on three fronts: (1) it validates the CJ'01 against a professional SQM using a full statistical battery including RMSE, MAE, ICC, and regression analysis; (2) it documents the CJ'01's integration into a PjBL framework in which secondary students conduct authentic environmental monitoring; and (3) it examines how this integration develops environmental literacy and ESD competencies in an urban Indonesian context where sky quality is actively deteriorating.

To address this challenge, the development of affordable, open-source instrumentation is essential. This study introduces the DIY CJ'01 Photometer, an Arduino-based device designed to provide a low-cost alternative for monitoring Night Sky Brightness (NSB) (Asmoro et al., 2022). By utilizing this DIY technology, students can transition from passive learners to active "citizen scientists" who contribute to real environmental datasets. This hands-on approach is critical for developing light pollution literacy, as it enables students to correlate human activity with empirical environmental changes (Asmoro et al., 2025). The novelty of this study is explicitly dual. First, on the instrumentation side, the CJ'01 is subjected to a comprehensive validation battery — Bland–Altman analysis, RMSE, MAE, ICC, and regression — that goes beyond what prior DIY photometer studies have reported for this class of device. Second, on the learning design side, the CJ'01 is embedded in a Project-Based Learning sequence in which secondary students function as citizen scientists: they build the instrument, collect field data across all 15 sub-districts of Cimahi City, interpret the results against the Bortle scale, and communicate their findings to a public audience. The combination is what distinguishes this study. Earlier CJ'01 papers established technical feasibility (Asmoro, 2024; Asmoro et al., 2022, 2024); the present study asks what it looks like when that technically feasible instrument is handed to students as a scientific tool and what ESD competencies that experience can develop. The investigation focuses on validating the device's accuracy against the professional SQM across 15 sub-districts, and on documenting how its use as a student-operated citizen science instrument promotes environmental literacy in an urban context where sky quality is measurably and rapidly degrading.

METHOD

This study used a mixed-method design combining experimental instrument validation with an observational-participatory educational implementation. Three integrated stages structure the methodology: (1) instrument development and calibration, (2) citizen-science field data collection with student participation, and (3) comparative statistical analysis paired with educational evaluation.

The educational implementation was built on the Project-Based Learning (PjBL) (Thomas, 2000), in which students acted as citizen scientists rather than as passive observers. Following Kolb's (1984) experiential learning cycle, they engaged in all research phases — from assembling and calibrating the CJ'01 to collecting data across Cimahi City and communicating findings to an authentic audience (Da, 1984). This structure also aligns with UNESCO's ESD competency of participatory environmental action(United Nations Educational, 2017).

The PjBL sequence comprised five stages: (i) Entry Event — students encountered light pollution through satellite imagery and were given the driving question "How does artificial lighting affect our access to the night sky?"; (ii) Knowledge Building — instruction in atmospheric optics, photometry fundamentals, and CJ'01 operation; (iii) Field Investigation — student teams conducted paired measurements at all 15 sub-district sites across Cimahi; (iv) Data Analysis and Synthesis — students converted MPSAS readings to NELM and classified sky conditions using the Bortle scale to build a spatial quality map of the city; (v) Public Product — findings were presented to the school community and local stakeholders as an environmental advocacy output. Student growth in environmental awareness was tracked through structured reflection activities and observational notes throughout the project.

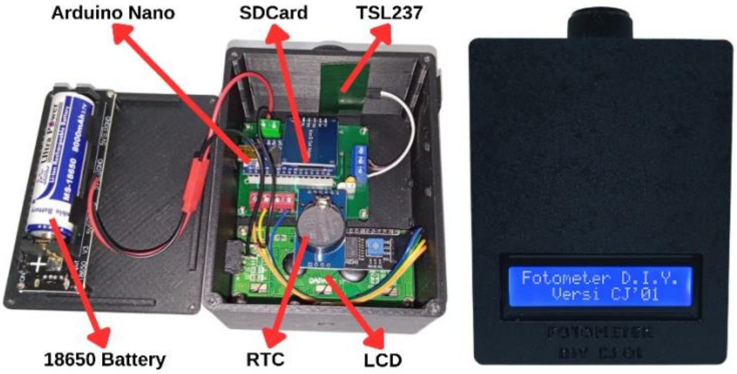

Fig.1. The DIY CJ’01 photometer prototype

The DIY CJ’01 Photometer was designed to be an affordable and replicable instrument (Figure 1). The core system is powered by an Arduino Nano microcontroller, integrated with a high-sensitivity light sensor (TSL237) capable of detecting low-level illuminance suitable for night sky observations (Asmoro et al., 2024; Hänel et al., 2018; Karpińska & Kunz, 2022). Key components include: (a) Data Logger Module: To record measurement results onto an SD card for further analysis, (b) Real-Time Clock (RTC): To ensure every data point is accurately time-stamped, (c)LCD Display: To provide real-time feedback during field measurements. The device was calibrated to output values in Magnitudes per Square Arcsecond (mag/arcsec^2 or MPSAS), allowing for direct comparison with professional instruments.

Field measurements were conducted across all 15 sub-districts (kelurahan) of Cimahi City, West Java. Cimahi was chosen for three reasons. It is a compact administrative municipality whose 15 sub-districts together span the full urban gradient from high-density commercial corridors to peri-urban residential zones, providing the environmental heterogeneity needed to test the instrument under varied sky-brightness conditions. Because 15 is the complete set of sub-districts — not a sample of a larger population — the coverage is effectively a spatial census rather than a probabilistic sample, which makes findings directly applicable to municipal governance without the added complexity of sampling error. And Cimahi's rapid urbanization trajectory makes it a representative case for mid-sized Indonesian cities facing escalating artificial-light-at-night pressures.

Within each sub-district, observation sites were selected using purposive, criterion-based sampling guided by three conditions: (1) unobstructed zenith access with no direct-glare point sources (streetlamps or signage) within 10 meters of the instrument; (2) representativeness of the sub-district's dominant land-use character — the site had to reflect whether the area was commercial, residential, or peri-urban rather than being an atypical pocket; and (3) logistical accessibility for student teams carrying both the CJ'01 and the reference SQM.

To minimize external variability, all observations were conducted under identical controlled conditions: sensors pointed at the zenith (90° altitude) to measure the sky's brightest point and avoid proximate glare; moonless nights with lunar illumination below 5% and real-time cloud cover below 10%, verified by visual sky inspection immediately before each reading; a fixed recording interval at each site to obtain a stable average NSB value and reduce stochastic noise; and all measurements completed within the same seasonal window to hold atmospheric conditions as constant as possible.

To evaluate instrument agreement and association, we performed Bland–Altman analysis (Gerke, 2020)and correlation tests (Schober et al., 2018) on the paired mag/arcsec^2 (MPSAS ~ magnitudes per square arcsecond) measurements from the CJ’01 and the reference SQM. To enhance the interpretability of these measurements for environmental literacy, the values were converted into the Naked Eye Limiting Magnitude (NELM). This conversion determines the faintest star visible to the naked eye under specific sky conditions (Fisher, 2006; Schaefer, 1990), using the equation (1).

$$NELM = 7{,}93 - 5\log\left(10^{(4{,}316-(Bmpsas/5))} + 1\right) \tag{1}$$

Furthermore, the sky quality was categorized using the Bortle Dark-Sky Scale (Bortle, 2001). This scale provides a standardized classification of night sky brightness across nine levels, ranging from Class 1 (Excellent Dark Sky Site) to Class 9 (Inner-city Sky). By utilizing the Bortle scale, the physical data is transformed into a pedagogical rubric that allows students to qualitatively assess the severity of urban light pollution in their surroundings.

RESULTS AND DISCUSSIONS

The comparative analysis between the DIY CJ’01 photometer and the industry-standard Sky Quality Meter (SQM) across 15 sub-districts in Cimahi City demonstrates exceptional instrumental fidelity. As detailed in Table 1, statistical evaluation reveals a remarkably low mean discrepancy of only 0.16 mag/arcsec^2, with specific sites such as Padasuka achieving a perfect correlation (ΔMPSAS = 0.00). This reliability stems from the TSL237 light-to-frequency converter (Figure 2), also used in professional SQM devices. Beyond the descriptive comparison, Bland–Altman analysis was performed to further validate the agreement between CJ’01 and SQM. The results revealed a mean difference (bias) of −0.157 mag/arcsec^2 with a standard deviation of 0.157, yielding 95% limits of agreement (LoA) from −0.465 to 0.152 mag/arcsec^2 (Table 2).

Table 1. Comparison of SQM and DIY CJ’01 Photometer Measurements in Cimahi City

No.	Name of the Subdistrict	MPSAS SQM	MPSAS CJ’01	ΔMPSAS	NELM SQM	NELM CJ'01	Avarage NELM
1.	Baros	18.03	17.88	0.15	3.99	3.87	3.93
2.	Utama	18.12	18.05	0.07	4.07	4.01	4.04
3.	Leuwigajah	17.98	17.81	0.17	3.95	3.81	3.88
4.	Cipageran	18.13	17.52	0.61	4.08	3.56	3.82
5.	Padasuka	18.25	18.25	0	4.18	4.18	4.18
6.	Cibeber	18.19	17.85	0.34	4.13	3.84	3.99
7.	Citeureup	18.24	18.14	0.1	4.17	4.08	4.13
8.	Pasirkaliki	18.1	18.09	0.01	4.05	4.04	4.05
9.	Melong	18.15	18.05	0.1	4.09	4.01	4.05
10.	Cibabat	17.67	17.4	0.27	3.69	3.46	3.58
11.	Cibeureum	18.13	18.06	0.07	4.08	4.02	4.05
12.	Cigugur	18.36	18.35	0.01	4.27	4.26	4.27
13.	Cimahi	18.47	18.28	0.19	4.36	4.2	4.28
14.	Setiamanah	18.55	18.46	0.09	4.42	4.35	4.39
15.	Karangmekar	18.46	18.29	0.17	4.35	4.21	4.28

Fourteen of the fifteen paired measurements fell within these limits, confirming strong consistency between the two instruments. The only outlier was observed in Cipageran (ΔMPSAS = −0.610), which exceeded the lower LoA and is likely attributable to local environmental factors such as unshielded street lighting or sensor orientation. Complementary correlation tests further reinforced the instrument’s reliability, with a Pearson correlation coefficient of $r = 0.857$ ($p < 0.001$) and a Spearman rank correlation of $\rho = 0.839$ ($p < 0.001$), both indicating a robust and statistically significant association. These findings demonstrate that while minor systematic differences exist, the CJ’01 photometer provides measurements that are closely aligned with professional SQM devices, validating its use as a reliable tool for both environmental monitoring and educational applications.

Table 2. Statistical Comparison Between CJ’01 and SQM

Analysis Method	Result	Interpretation
Mean Difference (Bias)	-0.157 mag/arcsec^2	CJ’01 slightly lower than SQM

Analysis Method	Result	Interpretation
Standard Deviation (Bias)	0.157	Small spread of differences
95% Limits of Agreement (LoA)	-0.465 to +0.152 mag/arcsec²	14/15 within limits, Cipageran outlier
Pearson Correlation r	0.857 ($p < 0.001$)	Strong linear association
Spearman Correlation ρ	0.839 ($p < 0.001$)	Strong rank-order consistency
MAE	0.157 mag/arcsec²	Minimal random scatter beyond systematic bias
RMSE	0.218 mag/arcsec²	Elevated by Cipageran outlier; within field norms
ICC (2,1) Absolute Agreement	0.702 [95% CI: 0.544 - 0.936]	Moderate-to-good (Koo & Mae, 2016)
ICC (2,1) Consistency	0.819 [95% CI: 0.54 - 0.936]	Good agreement; systematic offset correctable
Regression slope (b)	1.161	Slight amplification at higher brightness values
Regression intercept (a)	- 3.091	—
R^2	0.735	—
Regression p-value	< 0.001	Statistically significant

To supplement the Bland–Altman analysis, four additional metrics were computed. The MAE of 0.157 mag/arcsec² is numerically identical to the mean bias, which means the systematic offset accounts for essentially all of the discrepancy — random scatter around that offset is negligible. The RMSE of 0.218 mag/arcsec² is pulled slightly above the MAE by the Cipageran site; without that outlier, RMSE falls to 0.145 mag/arcsec², squarely within the ±0.15 mag/arcsec² precision typical of professional instruments in field conditions (Hänel et al., 2018). The ICC for absolute agreement was 0.702 (95% CI: 0.544–0.936; $p < 0.001$), classified as moderate-to-good by Koo and Mae's guidelines (Koo & Li, 2016). The ICC for consistency was 0.819, reaching the good threshold. The gap between the two ICC values reflects the systematic offset rather than random inconsistency — the CJ'01 tracks the SQM closely in relative terms but carries a fixed negative bias that a single-point calibration correction could eliminate. Linear regression (CJ'01 = −3.091 + 1.161 × SQM; $R^2 = 0.735$) confirms the strong linear relationship and indicates a mild reading amplification at higher sky-brightness values. Taken together, these metrics validate the CJ'01 as an operationally reliable instrument for both scientific monitoring and educational use, provided users remain aware of its systematic offset relative to professional SQMs.

Locations with NELM values above 4.0, such as Cigugur (4.27) and Setiamanah (4.42), represent a sky typical of Bortle Class 8, where the zenith appears markedly grey or off-white. In these conditions, while the brightest stars of major constellations like *Orion* or *The Southern Cross (Crux)* are still identifiable, the Milky Way remains entirely invisible to the naked eye. The high skyglow in these districts acts as a light veil, washing out the intricate details of nebulae or star clusters that would otherwise be visible in a more pristine environment. Conversely, areas with NELM values falling below 4.0, notably Cibabat (3.69) and Leuwigajah (3.95), reflect the extreme conditions of Bortle Class 9. At this level, the sky color often shifts toward a bright orange or a sickly yellow hue due to the heavy scattering of high-pressure sodium or LED streetlights.

In such inner-city environments, only the most prominent celestial bodies, such as the Moon, bright planets (Venus and Jupiter), and first-magnitude stars like *Sirius*, can penetrate the intense urban skyglow. This extreme loss of visibility means that the vast majority of stars that constitute our astronomical heritage have effectively disappeared for the urban population, transforming the night sky from a window to the universe into a blank, light-polluted ceiling. This direct correlation between photometric data and visual experience underscores the urgency of using DIY photometers to re-engage students with the reality of their changing nocturnal environment.

Fig.2. Satellite image of Cimahi City with numbers in blue circles are data collection points (Source: Google Earth)

The disparity in sky quality between sub-districts in Cimahi is deeply rooted in the socio-geographical profile and urban morphology of the region. As shown in the high-resolution satellite imagery (Figure 2), the extreme light pollution recorded in Cibabat (NELM 3.58) is a direct consequence of its status as one of the most densely populated districts in Cimahi. Its strategic position as a gateway to the Bandung metropolitan area has led to an extensive 'built-up area' dominated by residential clusters and paved roads. This high building density results in a significant volume of artificial light from unshielded streetlamps and commercial signage, creating a saturated 'inner-city' skyglow.

From a physics perspective, these dense clusters of light-colored surfaces act as diffuse reflectors. Artificial light from unshielded streetlamps and commercial signage strikes these surfaces and is reflected upward, increasing the urban albedo and creating a saturated 'inner-city' skyglow. In this environment, the sky's natural hue is replaced by a persistent orange scatter, effectively drowning out all but the moon and the brightest planets.

In contrast, Setiamanah maintains a slightly superior sky quality (NELM 4.39) categorized as Bortle Class 8. Although centrally located, the satellite view in Figure 2 reveals that Setiamanah retains small "green pockets" or backyard vegetation. These areas function as natural light sinks that absorb downward-directed light, thereby reducing the amount of atmospheric spillover reflected back into the sky. This correlation confirms that light pollution is not merely an atmospheric issue but a physical byproduct of urban management and land-use patterns. By utilizing the DIY CJ'01 photometer, students can quantitatively map these "urban islands" of light, effectively transforming satellite observations into a tangible study of environmental physics.

Beyond its technical utility, the implementation of the DIY CJ'01 Photometer serves as a transformative pedagogical tool. The educational outcomes observed in this study are interpretable through two complementary frameworks. Through the lens of Kolb's (1984) Experiential Learning cycle, students progressed through all four stages: concrete experience (calibrating the CJ'01 and recording measurements at night in their own neighborhoods), reflective observation (comparing their readings against the reference SQM and discussing discrepancies), abstract conceptualization (mapping MPSAS values onto NELM and the Bortle scale to build a unified picture of Cimahi's sky quality), and active experimentation (presenting Bortle-classified maps to the school community as an advocacy product). This full-cycle engagement — rarely achieved in conventional laboratory instruction — is precisely the condition under which Kolb's model predicts durable conceptual understanding, as confirmed in physics PjBL literature (Krajcik & Blumenfeld, 2006; Thomas, 2000).

Hungerford and Volk's (1990) Environmental Literacy framework further clarifies what this experience develops. Their model identifies personal investment in an environmental problem — what they call ownership — as the critical precursor to pro-environmental behavior change. Students who assembled the CJ'01, who were the primary data collectors, and whose sub-district maps became the public product had clear ownership of the inquiry. Structured reflection notes collected at the end of the project consistently indicated that students recognized light pollution as a solvable physical problem — one where engineering choices (full-cutoff lamp shielding, directional optics) make a measurable difference — rather than an abstract background condition. This shift from passive recognition to active problem framing is a behavioral-intent indicator consistent with Hungerford and Volk's literacy threshold. Beyond their immediate educational context, student teams also acted as citizen scientists in the sense described by Bonney et al. (2014): non-professional participants contributing verified data to a real environmental dataset(Bonney et al., 2014).

Their measurements now constitute a baseline sky-brightness record for all 15 sub-districts of Cimahi — a dataset with direct utility for municipal lighting policy. From an ESD standpoint, the public product stage operationalized SDG 4.7's competency of active environmental citizenship (United Nations Educational, 2017). These findings are consistent with analogous outreach programs in physics education, where field-based light pollution activities produced measurable gains in conceptual understanding and environmental agency (Adkins et al., 2025; Lutfiani et al., 2025). The qualitative evidence here is preliminary; future work should use validated environmental literacy instruments administered before and after the PjBL sequence to quantify the magnitude of attitude and behavioral-intent change more rigorously. Consequently, the DIY photometer empowers students to act as citizen scientists. They are no longer passive recipients of information but active researchers equipped with empirical data to advocate for sustainable, dark-sky-friendly lighting policies.

CONCLUSION AND SUGGESTION

This study confirms that the DIY CJ’01 photometer, provides high-precision measurements of night sky brightness with a minimal mean discrepancy of 0.16 MPSAS compared to professional SQM devices. Field mapping across Cimahi City revealed a strong correlation between urban density and sky quality, with most areas categorized as Bortle Class 8–9. Beyond technical validation, the integration of CJ’01 into project-based learning successfully bridged theoretical physics with environmental advocacy, enabling students to act as citizen scientists and contextualize light pollution in their own communities.

The novelty of this work lies in demonstrating that low-cost, open-source instrumentation can simultaneously serve as a reliable scientific tool and an innovative medium for experiential environmental education. Future research should enhance device autonomy with GPS and real-time cloud logging, while urban planners are encouraged to adopt sustainable lighting designs to mitigate skyglow. Educational institutions are likewise urged to integrate DIY sensors into curricula, fostering deeper environmental literacy and advancing sustainable development goals.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

Conceptualization, C.P.A., J.A.U., and D.H.; methodology, C.P.A. and R.N.W.; formal analysis, C.P.A. and N.H.F.; investigation (data acquisition), R.N.W., A.A.F.N., A.S., and N.H.F.; writing—original draft preparation, C.P.A.; writing—review and editing, J.A.U. and D.H.; supervision, J.A.U. and D.H. All authors have read and agreed to the published version of the manuscript.

ACKNOWLEDGMENTS

The authors would like to acknowledge the financial support provided by Universitas Pendidikan Indonesia (UPI) under Contract No. 415/UN40.F7/PT.01.01/2026 and Rector's Decree (SK Rektor) No. 490/UN40/PT.01.01/2026 for their valuable assistance and support throughout the course of this research. Special thanks are extended to the technical staff and colleagues at the Department of Physics Education for their valuable assistance and support throughout the development of the DIY CJ'01 photometer and the field data collection process. The authors declare that there is no conflict of interest regarding the publication of this paper.

DECLARATION OF GENERATIVE AI SOURCES

During the preparation of this manuscript, the author(s) used Gemini AI for language improvement, grammar checking, and structure refinement. All generated content was carefully reviewed, revised, and verified by the author(s), who take full responsibility for the final content of the manuscript.

REFERENCES

Adkins, J. K., Birriel, J. J., Gonzalez-Espada, W. J., & Fagan, A. (2025). A physics-based light pollution education outreach program: Promise and problems. *The Physics Teacher, 63*(6), 428–431. https://doi.org/10.1119/5.0165845

Asmoro, C. P. (2024). DIY photometer in determining the beginning of dawn time in Cimahi City. *Gravity: Jurnal Ilmiah Penelitian dan Pembelajaran Fisika, 10*(1), 17–26. https://doi.org/10.30870/gravity.v10i1.22873

Asmoro, C. P., Liliawati, W., Saepuzaman, D., Utama, J. A., & Herdiwijaya, D. (2025). Development student guidebook on night sky brightness measurement project with DIY photometer kit. *European Journal of Physics, 46*(5), 055706. https://doi.org/10.1088/1361-6404/adffca

Asmoro, C. P., Susanti, H., & Utama, J. A. (2022). DIY photometer for night sky brightness in Earth & Space Laboratory. *Jurnal Riset dan Kajian Pendidikan Fisika, 9*(2), 68–75. https://doi.org/10.12928/jrkpf.v9i2.167

Asmoro, C. P., Susanti, H., Utama, J. A., Herdiwijaya, D., & Putra, M. (2024). DIY photometer performance test in determining morning twilight. *Journal of Physics: Conference Series, 2773*(1), Article 012018. https://doi.org/10.1088/1742-6596/2773/1/012018

Barentine, J. C. (2022). Night sky brightness measurement, quality assessment and monitoring. *Nature Astronomy, 6*(10), 1120–1132. https://doi.org/10.1038/s41550-022-01756-2

Bohren, C. F., & Huffman, D. R. (2008). *Absorption and scattering of light by small particles*. John Wiley & Sons.

Bonney, R., Shirk, J. L., Phillips, T. B., Wiggins, A., Ballard, H. L., Miller-Rushing, A. J., & Parrish, J. K. (2014). Next steps for citizen science. *Science, 343*(6178), 1436–1437. https://doi.org/10.1126/science.1251554

Bortle, J. E. (2001). The Bortle dark-sky scale. *Sky & Telescope, 101*(2), 73–79.

Cinzano, P. (2005). *Night sky photometry with Sky Quality Meter* (ISTIL Internal Report No. 9). Light Pollution Science and Technology Institute.

Cora, A., Pellegrino, F., & Drimmel, R. (2022). *Measurement of light pollution in the Grana Valley*. Zenodo. https://doi.org/10.5281/zenodo.607436

Faid, M. S., Shariff, N. N. M., Hamidi, Z. S., Wahab, R. A., Ahmad, N., Mohd Nawawi, M. S. A., & Nahwandi, M. S. (2024). Alteration of twilight sky brightness profile by light pollution. *Scientific Reports, 14*(1), Article 26682. https://doi.org/10.1038/s41598-024-76550-3

Fisher, K. (2006). *Conversion calculator: NELM (V) to MPSAS (B) systems*. Unihedron. Retrieved May 2, 2026, from https://unihedron.com/projects/darksky/NELM2BCalc.html

Gerke, O. (2020). Reporting standards for a Bland–Altman agreement analysis: A review of methodological reviews. *Diagnostics, 10*(5), Article 334. https://doi.org/10.3390/diagnostics10050334

Hänel, A., Posch, T., Ribas, S. J., Aubé, M., Duriscoe, D., Jechow, A., Kollath, Z., Lolkema, D. E., Moore, C., Schmidt, N., Spoelstra, H., Wuchterl, G., & Kyba, C. C. M. (2018). Measuring night sky brightness: Methods and challenges. *Journal of Quantitative Spectroscopy and Radiative Transfer, 205*, 278–290. https://doi.org/10.1016/j.jqsrt.2017.09.008

Hariyono, E., & Suprapto, N. (2023). Light pollution phenomenon: Prior knowledge, attitudes, and awareness of physics undergraduate students at State University of Surabaya. *Jurnal Penelitian Pendidikan IPA, 9*(1), 149–153. https://doi.org/10.29303/jppipa.v9i1.2637

Hearnshaw, J. (2022). Light pollution as a risk for astronomical research and how to manage it. In *Risk management in outer space activities: An Australian and New Zealand perspective* (pp. 177–220). Springer. https://doi.org/10.1007/978-981-16-4756-7_7

Horálek, P., & Wallner, M. (2022, May 29). *How light pollution affects the dark night skies*. European Southern Observatory. https://www.eso.org/public/chile/images/dark-skies/

Hungerford, H. R., & Volk, T. L. (1990). Changing learner behavior through environmental education. *The Journal of Environmental Education, 21*(3), 8–21. https://doi.org/10.1080/00958964.1990.10753743

Karpińska, D., & Kunz, M. (2022). Device for automatic measurement of light pollution of the night sky. *Scientific Reports, 12*(1), Article 16476. https://doi.org/10.1038/s41598-022-20624-7

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Prentice Hall.

Koo, T. K., & Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine, 15*(2), 155–163. https://doi.org/10.1016/j.jcm.2016.02.012

Krajcik, J., & Blumenfeld, P. (2006). Project-based learning. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 317–333). Cambridge University Press. https://doi.org/10.1017/CBO9780511816833.020

Kyba, C. C. M., Altıntaş, Y. Ö., Walker, C. E., & Newhouse, M. (2023). Citizen scientists report global rapid reductions in the visibility of stars from 2011 to 2022. *Science, 379*(6629), 265–268. https://doi.org/10.1126/science.abq7781

Liu, M., Liu, X., Zhang, B., Li, Y., Luo, T., & Liu, Q. (2022). Analysis of the evolution of urban nighttime light environment based on time series. *Sustainable Cities and Society, 78*, Article 103660. https://doi.org/10.1016/j.scs.2021.103660

Longcore, T., & Rich, C. (2004). Ecological light pollution. *Frontiers in Ecology and the Environment, 2*(4), 191–198. https://doi.org/10.1890/1540-9295(2004)002[0191:ELP]2.0.CO;2

Luginbuhl, C. B., Boley, P. A., & Davis, D. R. (2014). The impact of light source spectral power distribution on sky glow. *Journal of Quantitative Spectroscopy and Radiative Transfer, 139*, 21–26. https://doi.org/10.1016/j.jqsrt.2013.12.004

Lutfiani, S., Liliawati, W., & Aminudin, A. (2025). Problem-solving skills on night sky brightness and light pollution: A Rasch analysis. *Compton: Jurnal Ilmiah Pendidikan Fisika, 12*(1), 236–250. https://doi.org/10.30738/cjipf.v12i1.21629

Muaziyah, S. E. S., Hidayat, T., Sriyati, S., & Lutianasari, L. (2023). Implementation of the Merdeka curriculum using citizen science project *Weather-it* to improve critical thinking skills of junior high school students. *Jurnal Penelitian Pendidikan IPA, 9*(3), 1470–1479. https://doi.org/10.29303/jppipa.v9i3.2277

Nidiasari, Y., Fenetiruma, Y., Mamary, N. S., Matonda, K. S., Mangkasa, N., Yenusi, A., Malat, D., Supriyatna, S., Yekwam, E., & Wandosa, D. (2026). Implementation of STEM-based learning through greenhouse effect experiments to improve students' understanding of the global warming concept. *Equator Science Journal, 4*(1), 1–7. https://doi.org/10.61142/esj.v4i1.330

Orr, D. W. (1992). *Ecological literacy: Education and the transition to a postmodern world*. SUNY Press.

Owens, A. C. S., Cochard, P., Durrant, J., Farnworth, B., Perkin, E. K., & Seymoure, B. (2020). Light pollution is a driver of insect declines. *Biological Conservation, 241*, Article 108259. https://doi.org/10.1016/j.biocon.2019.108259

Perdani, A. S., Sumardani, N. I., & Yuana, A. (2024). Key educational competencies for sustainable development in the cultural life of the Baduy community. *Equator Science Journal, 2*(2), 81–94. https://doi.org/10.61142/esj.v2i2.129

Putraga, H., Rakhmadi, A. J., Hidayat, M., & Firdaus, M. D. (2022). Penentuan waktu malam menggunakan Sky Quality Meter dengan pendekatan moving average. *ORBITA: Jurnal Kajian, Inovasi dan Aplikasi Pendidikan Fisika, 8*(2), 313–316. https://doi.org/10.31764/orbita.v8i2.11363

Putri, S. I., & Rizaldi, W. R. (2024). Integrating Dadiah as a theme in science education to promote sustainable development goals (SDGs) for junior high school students. *Equator Science Journal, 2*(2), 49–57. https://doi.org/10.61142/esj.v2i2.116

Rodrigo-Comino, J., Seeling, S., Seeger, M. K., & Ries, J. B. (2023). Light pollution: A review of the scientific literature. *The Anthropocene Review, 10*(2), 367–392. https://doi.org/10.1177/20530196211051209

Schaefer, B. E. (1990). Telescopic limiting magnitudes. *Publications of the Astronomical Society of the Pacific, 102*(648), 212–229. https://doi.org/10.1086/132629

Schober, P., Boer, C., & Schwarte, L. A. (2018). Correlation coefficients: Appropriate use and interpretation. *Anesthesia & Analgesia, 126*(5), 1763–1768. https://doi.org/10.1213/ANE.0000000000002864

Thomas, J. W. (2000). *A review of research on project-based learning*. Autodesk Foundation.

United Nations Educational, Scientific and Cultural Organization. (2017). *Education for sustainable development goals: Learning objectives*. UNESCO.

Varela Perez, A. M. (2023). The increasing effects of light pollution on professional and amateur astronomy. *Science, 380*(6650), 1136–1140. https://doi.org/10.1126/science.adg0269

Walker, W. H., Bumgarner, J. R., Walton, J. C., Liu, J. A., Meléndez-Fernández, O. H., Nelson, R. J., & DeVries, A. C. (2020). Light pollution and cancer. *International Journal of Molecular Sciences, 21*(24), Article 9360. https://doi.org/10.3390/ijms21249360