

LIGHT POLLUTION IN SLOVENIAN CURRICULA: OPPORTUNITIES FOR INTEGRATION IN PHYSICS TEACHER EDUCATION

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Abstract

This study examines how light pollution is represented in Slovenian STEM curricula and explores its pedagogical potential for integration into teaching, with a particular focus on physics teacher education. Using qualitative document analysis, we examined selected primary and secondary school curricula to identify both explicit and implicit references to light pollution and related topics. The results show that light pollution is rarely addressed explicitly, with direct references mainly in secondary school physics. However, it is implicitly present across multiple subjects, including physics, biology, geography, and natural sciences, through themes related to light, energy use, ecosystems, and environmental impacts. The analysis shows that existing curricula provide multiple entry points for integrating light pollution into teaching without requiring major structural changes. In addition, we examined two pilot activities implemented within a higher education physics teacher education program through reflective analysis. The findings highlight the pedagogical potential of light pollution as a context for inquiry-oriented and field-based learning, supporting connections between physics concepts and real-world environmental issues. They emphasize the role of teacher education in translating implicit curricular opportunities into classroom practice. Light pollution thereby emerges as a relevant context for integrative and sustainability-oriented STEM learning, particularly within teacher education.

Keywords: *Light pollution, curriculum analysis, physics teacher education, sustainability, STEM education.*

1. Introduction

Environmental challenges such as climate change, biodiversity loss, and pollution require not only scientific knowledge but also the ability to understand complex, interconnected systems. Education therefore plays a crucial role in preparing young people to engage with sustainability-related issues. Within this context, STEM education has been recognized as an important framework for developing competences such as critical thinking, systems thinking, and problem solving (Bybee, 2013).

One environmental issue that has received increasing attention in recent years is light pollution. Light pollution refers to excessive or misdirected artificial light at night (ALAN), which has increased significantly over recent decades. This growth has led to the disruption of natural light-dark cycles and night-time environments. Studies have shown that ALAN affects ecosystems, biodiversity, and human health, while also influencing energy consumption and constraining astronomical observations (Falchi et al., 2016; Gaston et al., 2015; Kyba et al., 2017). Despite its growing environmental relevance, light pollution is still rarely included in formal education. At the same time, it represents a particularly suitable context for integrative learning. In physics, it is linked to light propagation, energy use, optical phenomena, and astronomical observations. It also relates to ecological processes and the behavior of nocturnal organisms in biology, while in geography it can be studied through spatial patterns of urbanization and environmental change.

In Slovenia, sustainability and environmental issues are integrated across several STEM subjects. National curricula emphasize interdisciplinary approaches and environmental responsibility as one of the key educational goals. In this study, we aim to analyze how light pollution is represented in Slovenian curricula and identify opportunities to integrate this topic into teaching. Furthermore, we explore how it can be incorporated into physics teacher education programs as a context of inquiry-based and interdisciplinary learning. The study addresses the following research questions:

- RQ1: To what extent is light pollution represented in Slovenian curricula at primary and secondary levels?
RQ2: What opportunities exist for integrating light pollution into STEM teaching?

RQ3: What is the pedagogical potential of using light pollution as a context for inquiry-based learning in physics teacher education?

2. Methodology

We employ document analysis to examine the extent to which light pollution is represented in official Slovenian curricula. Document analysis is widely used in educational research to analyze curriculum content and thematic coverage (Bowen, 2009).

The analysis focused on eight official curricula from the Slovenian national education system, published as part of the 2025 curriculum reform. The selected documents include five primary school subjects (Nature and Technology, Natural Sciences, Physics, Biology, Geography) and three secondary school subjects (Physics, Biology, Geography). The selection was guided by relevance to content areas where light pollution could be meaningfully integrated. The curricula were analyzed using a qualitative content analysis to identify explicit and implicit representations of light pollution. Explicit representation was defined as the direct occurrence of the term “light pollution” in curriculum objectives, content descriptions, or learning outcomes. Implicit representation was identified through related thematic content, including references to properties and use of light and illumination, energy consumption and efficiency, ecosystems and biodiversity, circadian rhythms and physiological processes, environmental pollution and human impacts, urbanization and spatial patterns affecting the night environment.

In addition to curriculum analysis, this study explores the pedagogical potential of integrating light pollution into physics teacher education. The two pilot activities consisted of (1) a laboratory-based investigation of artificial light sources and their physical properties, and (2) a field-based exploration of light pollution in outdoor environments. Pre-service teachers analyzed characteristics such as light intensity and spectral properties and related them to environmental impacts. In the field component, students conducted measurements using a sky quality meter (SQM), as well as a spectrometer to analyze the street lighting spectrum. The activities were implemented within a physics teacher education program at the University of Maribor and were designed to model inquiry-based and context-based teaching approaches (Pedaste et al., 2015). Their evaluation is based on reflective analysis by the instructor, focusing on the extent to which activities supported connections between theoretical physics concepts and real-world contexts, as well as their potential for supporting inquiry-based learning, and their applicability in school teaching. Student responses to guided reflection questions served as a supplementary data source for this evaluation.

3. Results and discussion

3.1. Representation of light pollution in the curriculum

The document analysis shows that light pollution is rarely addressed explicitly in Slovenian curricula (Table 1). Among the analyzed curricula, explicit references appear only in secondary school physics, where students are expected to “describe light pollution” and “discuss possible mitigation measures”. In other curricula, at both primary and secondary levels, the topic is not directly mentioned but is embedded implicitly within broader environmental and sustainability-related themes. This reflects a broader tendency for sustainability-related issues to be present at a conceptual level but to lack explicit curricular framing, which may limit their visibility and systematic treatment in classroom practice (UNESCO, 2017; Sterling, 2004).

Table 1. Summarized document analysis results.

<i>Subject</i>	<i>Education level</i>	<i>Representation</i>	<i>Potential entry points</i>
<i>Nature and Technology</i>	Primary school	implicit	environmental impacts of artificial light
<i>Natural Sciences</i>	Primary school	implicit	ecosystems, biodiversity
<i>Physics</i>	Primary school	implicit	properties of light and illumination
<i>Biology</i>	Primary school	implicit	ecosystems, organism–environment interactions
<i>Geography</i>	Primary school	implicit	human impacts on environment
<i>Physics</i>	Secondary school	explicit	energy efficiency, lighting design
<i>Biology</i>	Secondary school	implicit	circadian rhythms, biodiversity, ecological impacts
<i>Geography</i>	Secondary school	implicit	spatial patterns of light pollution

Despite the absence of explicit curricular references, these thematic connections indicate that light pollution is inherently compatible with existing learning objectives. The topic aligns particularly well with sustainability education, as it integrates ecological, technological, and societal dimensions. Moreover, it allows for the inclusion of less visible forms of environmental degradation, complementing more commonly discussed issues such as air, water, and soil pollution. Such implicit topics are recognized as important for developing environmental and sustainability literacy, particularly when linked to real-world problems (Wiek et al., 2011).

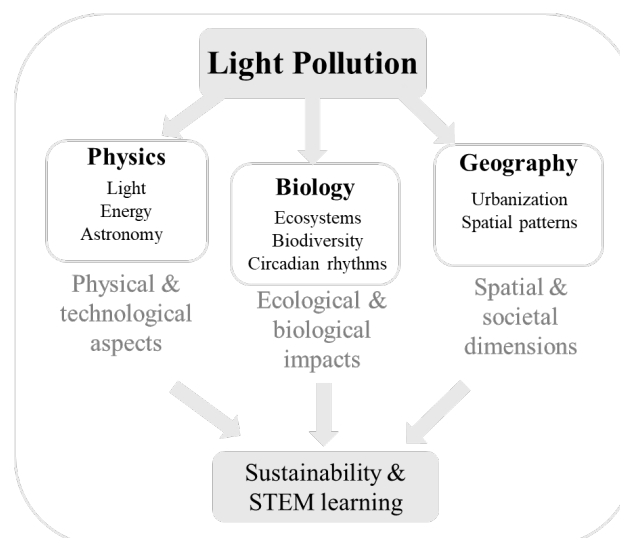
3.2. Opportunities across analyzed curricula

Our findings show that existing curricular topics provide multiple entry points for integrating light pollution in teaching. These opportunities reflect the cross-disciplinary character of complex socio-scientific issues. Across curricula, three main thematic entry points can be identified, emerging from the qualitative content analysis: (1) Physical and technological aspects of light and energy use, (2) Ecological and biological impacts, and (3) Spatial and societal dimensions.

In physics and technology-related subjects, light pollution can be connected to fundamental concepts such as the properties of light, light sources, illumination, and energy efficiency. These topics provide a natural foundation for introducing ALAN as a consequence of technological development and energy use. In biology and natural sciences, light pollution can be addressed within themes related to ecosystems, biodiversity, and organism-environment interactions. ALAN can be conceptualized as an anthropogenic environmental factor that alters natural conditions, influencing species behavior, reproduction, and survival. In addition, topics such as circadian rhythms provide a direct link between physical environmental changes and physiological processes. These connections are strongly supported by existing research on artificial light at night (Gaston et al., 2013; Gaston et al., 2015). Geography offers opportunities to address light pollution through its spatial distribution and its relation to urbanization, land use, and environmental change. The use of spatial data, maps, and satellite imagery allows light pollution to be analyzed as a measurable environmental phenomenon, thereby linking local observations with global patterns (Kyba et al., 2015; Falchi et al., 2016). This perspective also supports discussions on sustainable development and responsible resource use.

Overall, these entry points show that light pollution is compatible with existing curricular structures without requiring major modifications (Figure 1). Instead, it can be integrated by extending already defined learning objectives towards real-world environmental contexts. This aligns with the treatment of socio-scientific issues in STEM education, which typically cut across disciplinary boundaries and support the development of systems thinking (Wiek et al., 2011). However, the implicit nature of these connections also suggests a potential limitation. Without explicit curricular framing, the inclusion of light pollution in classroom practice depends largely on teacher awareness and initiative. This further underlines the importance of teacher education in supporting the identification and implementation of such topics. As a result, the extent to which these opportunities are realized may vary considerably in practice. This highlights the importance of teacher education in supporting the identification and implementation of such topics (Darling-Hammond et al., 2006; Van Poeck et al., 2012; Klemenčič et al., 2023).

Figure 1. Conceptual framework for integrating light pollution across disciplines, highlighting physical, ecological, and spatial aspects and their connection to sustainability-oriented STEM learning.



3.3. Implications for teacher education

The following analysis is based on reflective evaluation by the instructor and is intended as exploratory insight rather than empirical evidence.

In the winter semester of the 2025/2026 academic year, we implemented two pilot activities within a higher education physics teacher education program. The first activity focused on analyzing properties of artificial light sources, while the second extended this work into outdoor environments through field investigations of light pollution using SQM. Our aim was to connect physics content knowledge with environmental contexts and to provide future teachers with initial ideas for classroom implementation.

Both activities highlighted the cross-disciplinary nature of light pollution, linking physics (light properties and measurement), biology (effects on organisms and circadian rhythms), and technology (lighting design and mitigation measures such as shielding). The relevance of light pollution for astronomical observations further extends the topic beyond disciplinary boundaries. The activities also show that investigating light pollution does not depend exclusively on specialized equipment. While digital sensors such as SQMs enable quantitative measurements, simpler observational approaches, such as estimating sky brightness by counting visible stars, can also be applied. This increases the accessibility of the topic and supports its implementation in school contexts with limited resources. From a learning perspective, the activities illustrate how abstract physics concepts can be connected to real-world issues related to energy use and environmental impact. The combination of laboratory and field-based work introduces an applied, decision-making aspect and supported engagement with data and evidence-based reasoning (OECD, 2019). At the same time, several practical limitations need to be considered. Field-based investigation is highly dependent on environmental conditions, including weather, cloud cover, and moonlight, which can affect measurement reliability. In addition, organizing and conducting measurements, often in the evening or at night, poses time, logistical and safety challenges, particularly in school settings, where supervision and appropriate locations outside school premises must be ensured.

From a teacher education perspective, the activities illustrate how light pollution function as both a scientific topic and a pedagogical resource. They also supported reflection on how similar approaches could be adapted for different educational levels, contributing to the development of pedagogical content knowledge (Shulman, 1986; Klemenčič et al., 2023).

Student reflections further support these observations. Participants emphasized the importance of environmental conditions and demonstrated an understanding of key measurement principles, such as consistent sensor positioning and the influence of external factors on data reliability. They also recognized the didactical potential of the activities, suggesting their implementation with pupils, while highlighting the need for simplification, careful organization, and guided reflection when adapting them to school contexts.

Overall, these observations demonstrate that inquiry-based and field-oriented approaches offer a meaningful pathway for integrating light pollution into physics teacher education (Pedaste et al., 2015), highlighting its pedagogical potential. Related pilot implementations are also described in recent conference contribution on digitally supported fieldwork (Repnik et al., 2026).

4. Conclusions

Light pollution is rarely addressed explicitly in Slovenian curricula, with direct references identified only in secondary school physics (RQ1). Nevertheless, it is consistently embedded across all analyzed subjects through related thematic areas. This indicates that existing curricula provide meaningful entry points for integrating light pollution into teaching without requiring major changes (RQ2).

The analysis further shows that light pollution is particularly suitable as an interdisciplinary context that connects physical, ecological, and spatial perspectives, thereby supporting integrative and sustainability-oriented STEM learning. However, its largely implicit presence also means that its inclusion in classroom practice depends on teacher awareness and initiative.

The pilot activities in physics teacher education highlight the pedagogical potential of light pollution as a context for inquiry-based learning (RQ3). They demonstrate how abstract physics concepts can be meaningfully connected to real-world environmental issues while supporting the development of analytical thinking, data literacy, and sustainability competences. In this context, teacher education emerges as a key factor in enabling the use of existing curricular opportunities and their translation into classroom practice.

Finally, it should be noted that the findings are based on document analysis and reflective evaluation of pilot activities, which limit their generalizability. Future research should include empirical classroom studies to further examine how light pollution is implemented in practice and how it supports student learning across different educational levels.

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