

Article

How Artificial Intelligence-Assisted Colour Lighting Can Improve Learning: Evidence from Recent Classrooms Studies

José Quiles-Rodríguez ^{1,*} , Ramon Palau ¹  and Josep M. Mateo-Sanz ² ¹ Department of Pedagogy, Universitat Rovira i Virgili, 43007 Tarragona, Spain; ramon.palau@urv.cat² Departament d'Enginyeria Química, Universitat Rovira i Virgili, 43007 Tarragona, Spain; josepmaria.mateo@urv.cat

* Correspondence: jquirod512@g.educaand.es

Featured Application: A potential application of this study is the implementation of AI-assisted dynamic colour lighting systems in primary school classrooms to enhance learning, cognition and emotional well-being. By adjusting lighting conditions based on real-time student needs, this technology could improve attention, impulse control, creativity and fundamental skills like reading and mathematics. The findings suggest that specific coloured lighting (e.g., orange for motivation and purple for cognitive engagement) can be integrated into adaptive, cost-effective and sustainable educational environments, supporting teachers in optimizing classroom conditions for improved academic performance and student satisfaction.

Abstract: Numerous studies have explored the role of colour in classroom environments and its effects on learning, cognition and motivation. However, research on coloured lighting remains limited, with most studies focusing only on correlated colour temperature (CCT). Addressing this gap, our study examines various chromatic lighting conditions that enhance learning outcomes while allowing for dynamic applications in educational settings. Conducted over three academic years in six primary classrooms, this quasi-experimental study employed a pretest and a control group to assess the effects of three chromatic lighting scenarios (orange, green and purple) on cognitive processes, emotional responses and basic instrumental learning. Descriptive, variance and comparative analyses revealed conclusive evidence of coloured lighting's impact, though effects varied across different variables. The study highlights the potential of dynamic lighting approaches to support learning and suggests that AI-assisted lighting adjustments could aid teachers. The findings support the broader implementation of coloured lighting in primary classrooms, advocating for cost-effective, sustainable and adaptive solutions beyond conventional lighting. Such advancements are expected to enhance students' learning, cognition and motivation while providing greater flexibility in educational environments.

Keywords: colour lighting; cognition; emotional development; dynamic colour; learning environment; smart classroom; artificial intelligence



Academic Editor: Pedro Couto

Received: 27 February 2025

Revised: 22 March 2025

Accepted: 24 March 2025

Published: 26 March 2025

Citation: Quiles-Rodríguez, J.; Palau, R.; Mateo-Sanz, J.M. How Artificial Intelligence-Assisted Colour Lighting Can Improve Learning: Evidence from Recent Classrooms Studies. *Appl. Sci.* **2025**, *15*, 3657. <https://doi.org/10.3390/app15073657>

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland.

This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

The intricate impact of colour in educational settings has been a focal point of extensive academic research for many decades [1]; however, the shift towards a comprehensive examination of coloured lighting remains conspicuously under-researched in the academic corpus [1]. Coloured lighting denotes the intentional employment of various shades of lighting within educational spaces to regulate and enhance students' academic performance,

cognitive processing, emotional health and, as a result, their overall educational experience. In this sense, the study conducted by Quiles-Rodríguez et al. [1] functions as a systematic review of the existing literature regarding the effects of colour as it is traditionally perceived, which refers to its tangible presence in classrooms, leaving aside the potential ramifications towards coloured light. Through a meticulous and systematic analysis of the role of colour elements in educational contexts, both independently and in conjunction with other environmental variables, the authors conclude their examination by classifying the existing literature derived from a total of 35 academic articles into two main classifications: one that recognises the influence of colour on learners' cognitive processes and another that recognises its effect on emotional and social processes. This classification, together with the inclusion of fundamental instrumental learning (language and mathematical competence), will form the basis of this article, as will be developed in later sections.

Similarly, it is crucial to clarify that, while the relationship between CCT and brightness in relation to learning outcomes has been thoroughly examined in the existing literature [2], particularly with respect to its implications for academic performance, attention and concentration levels, as well as students' emotional and motivational states, we find that there is a significant paucity of exclusively educational sources investigating the explicit effects of coloured lighting [2]. It is essential to differentiate between these two distinct parameters—CCT and light colour—each of which has fundamentally different characteristics and is quantified using different units, namely kelvin for the former and nanometres for the latter. Researchers such as Suh et al. [3], Rajae-Joordens [4] and Kombeiz et al. [5] have been at the forefront of this emerging field of educational research on the colour of light as they have been among the few researchers to conduct experimental research on the direct influence of coloured lighting on learning, all three agreeing on its potential to influence learning, although they each approach it from a very different experimental situation and context. This incipient state of learning research contrasts with the breadth of research in other disciplines such as interior design [6], agricultural methodologies [7,8], medical fields [9] and even aerospace studies [10].

Research on the effect of environmental colour in educational settings often suffers from insufficient systematic and comprehensive methodologies [11]; this inadequacy also extends to the limited research focused specifically on coloured lighting [12]. For example, Von Castell et al. [13] state that the effects produced by ambient colour are so variable and erratic that deriving practical applications is a challenging task. In a related context, some researchers have suggested that visual disturbances and colour variations may negatively affect academic performance in educational settings [14]. Conversely, other scholars have made concerted efforts to improve the rigour and systematic nature of their research on environmental influences, including the role of colour, in the context of expansive longitudinal studies [15,16].

Current circumstances evoke increasing concern when we specifically examine students' cognitive processes, which can be delineated as a broad set of brain activities that transpire independently of socio-affective mechanisms, as identified in the existing literature [17]. While a multitude of research on environmental colour, traditionally perceived as such, such as those aggregated by Quiles-Rodríguez et al. [1], has established correlations between physical colour and cognitive performance, as shown by the in-depth studies of Mehta et al. [18] (colours such as red and blue have different incidences on cognitive tasks such as avoidance, concentration or creativity), Duyan et al. [19] (establishing the influence of classroom wall colour on attention), Tuszyńska-Bogucka et al. [20] (establishing the goodness of dim classroom colours for students' emotionally positive response) and Pourbagher et al. [21] (students' concentration is affected by classroom wall colour), there is a conspicuous deficiency in specific research on the tangible effects of coloured lighting

on cognitive processes. A sparse number of studies, exemplified by the research conducted by Kombeiz et al. [5] that examined the influence of coloured lighting on creativity within an academic environment at a German university, along with previous research conducted in primary education settings [11], have endeavoured to address this fundamental question. Of importance is the foundational work established by our predecessor, the research executed by Quiles-Rodriguez et al. [12], who conducted a comprehensive exploratory intervention in a primary school context with the aim of revealing the cognitive, academic and emotional consequences derived from the adoption of coloured lighting in classrooms, ultimately reaching substantial conclusions that act as a stimulus for further research.

However, when we explore the existing literature on CCT and its respective impacts on cognitive processes, we find that the body of research is notably more extensive and substantial. For example, Mogas-Recalde et al. [22] present a comprehensive review of 18 different studies that collectively investigate the complex interaction between CCT and various cognitive functions, concluding that academic performance, attention rate, work speed, productivity and accuracy depend on CCT, with a high rate (of LED light) in comparison to effect size light being the most appropriate, while Llinares et al. [23] analyse how CCT specifically influences attention and memory retention, where higher levels of CCT allow for the improvement of both variables. In addition, Hviid et al. [24] examine how CCT, together with ventilation, affects critical cognitive functions such as concentration, logical reasoning and processing speed, with cool values of CCT, together with high ventilation, being the optimal values. Despite some degree of overlap with the aims of our current study, these previous investigations do not focus on our specific variable of interest, which is coloured illumination.

A comparable situation arises when we direct our literature review towards the effects of environmental colour specifically on students' affective processes. We concur with the perspective articulated by Gross [25], who states that discussions about learning not only encompass skills, knowledge and abilities, but also extend to behaviours and values, thus inherently involving affective processes. In this regard, Mora [26] clarifies that the phenomenon of learning cannot occur in the absence of emotional involvement. Recognising this fundamental principle, the incorporation of environmental colour, traditionally interpreted in relation to various affective parameters, has been examined in relation to various affective variables, such as stress and anxiety [21,27] (the physical characteristics of the classroom should not be distracting or stimulating, with wall colour having up to a 10% impact on self-perceived stress), positive emotional response [20] (subdued colours bring better results), calm states [28–30] (the colour red is inappropriate for these states as well as for academic performance, although cheerful colours from early childhood, especially in classroom artwork, support an appropriate emotional state) and energy [31–33] (wall colour can even vary human physiological response, where colours such as red or blue can cause cerebral and cardiac arousal).

As noted above, it is now also evident that findings in this area do not show uniformity and consistency across studies [12].

In the realm of academic research on coloured lighting, despite its acknowledged limitations, it is pertinent to note that a considerable number of these investigations do consider affective responses as the primary dependent variable in their analyses. In particular, the remarkable research by Kombeiz et al. [5] explores the complex dynamics between approach motivation and the effects of red and blue light, concluding that both blue and red accent light increased strategic approach motivation compared to white accent light, while Rajae-Joordens [4] conducts a comprehensive examination of human psychological arousal and satisfaction levels in relation to the impacts of red, green and blue lighting, finding that red light was less pleasant and more arousing than green and blue light, as

measured subjectively, without finding clear psychophysiological effects. In addition, Suh et al. [3] provide valuable empirical data on students' mood, energy levels and overall satisfaction in relation to purple, green and orange-lit scenarios, suggesting that there is a possible relationship between students' increased energy level under green-filtered light and an increase in students' feelings of pleasure under purple-filtered light. Similarly, Quiles-Rodriguez et al. [34] show that orange light provides a higher energy level and that any coloured lighting studied (green, orange or violet) is more satisfying than white light. The findings articulated in these investigations have considerable relevance to the present research work, having profoundly influenced the formulation of a self-perception survey that reflects the methodologies adopted by these scholars.

In addition, it is essential to recognise that compelling results have emerged in fields often perceived as peripheral to education, namely in the medical and astronautical disciplines, in relation to the effects of coloured light on human emotional states. In particular, research in the medical field has shown that exposure to blue light can increase parasympathetic activity, thereby promoting a sense of calmness, while red light has been associated with a reduction in such activity [9]. Similarly, insights from astronautics highlight the advantageous effects of multicolour lighting, which has been shown to mitigate negative emotions and anxiety among individuals inhabiting a simulated environment for seven days [10]. This body of evidence is corroborated by contemporary studies indicating that the emotional effects of coloured light diverge significantly from those associated with traditionally coloured objects [35], a differentiation that carries implications for educational differentiation, particularly with regard to the origins and characteristics of various colour sources.

Shifting our attention to what has previously been characterised as fundamental instrumental learning, and considering the multifaceted dimensions of learning, it becomes imperative to conceptualise it as an integral synthesis of skills, values, behaviours, knowledge and abilities that individuals acquire or adapt over time. Language competence, in particular, stands as one of the most crucial and universal learning processes for human beings and as a foundational element of any educational framework, to the extent that Spanish Organic Law 3/2020 [36] recognises it as instrumental learning, due to its importance in facilitating the acquisition of other competences. It is not uncommon to find a multitude of academic articles that explicitly correlate colour, traditionally interpreted, with improved language skills [16,28,30], among other contributions that indicate that factors of colour stimulation level and complexity are important in patterns of reading and writing progress, or that the number of pupils who improved their language performance is an important contribution of classroom transformation to the learning process. In contrast, it is rather difficult to find references that clearly link the notion of coloured light to learners' language proficiency. The only noteworthy exception is the research by Suh et al. [3], who, albeit in somewhat ambiguous terms, propose the possibility of improved academic performance under different coloured lighting conditions in educational settings. As pointed out by Mogas-Recalde et al. [22], the impact of CCT on students' academic performance has been corroborated by their research results, showing that higher CCT in classrooms and from LED technology increases alertness and academic performance. More specifically, Quiles-Rodriguez et al. [37] claim that, when students are subjected to certain scenarios involving coloured light, there is a significant improvement in their language proficiency, while certain alternative scenarios may in fact result in a decrease in proficiency levels.

Similarly, it is undisputed that mathematical competence represents another cornerstone of our education system, alongside linguistic competence, as set out in Organic Law 3/2020 [36]. A considerable amount of the academic literature explores the complex interaction between conventional understanding of colour and mathematical competence,

as research by scholars such as Vidal Rojas et al. [28], Barrett et al. [16] and Gilavand [30] demonstrate, expressing themselves in similar terms to those indicated above for language skills, and even more strongly in terms of the major impact of classroom design on mathematical progress [16]. However, a marked deficiency persists in the effort to establish a direct correlation between mathematical competence itself and the concept of coloured light. A review of the existing literature reveals only a limited number of studies, namely those by Suh et al. [3] and Quiles-Rodríguez et al. [38], which can be considered direct precedents in this area, albeit with notable divergences in their methodologies and conclusions. The research conducted by Suh et al. [3] tends to address only superficially the potential benefits that coloured light can provide in improving academic performance, while the research conducted by Quiles-Rodríguez et al. [38] offers a comprehensive analysis regarding the distinctive influence of coloured light on the development of mathematical competence.

Other scholars, especially in relation to CCT, explicitly state that the patterns of brain oscillatory activity that occur during mathematical study increase significantly as a function of the specific CCT employed [35]. Furthermore, Jee et al. [39] emphasise that not only mathematical computation, but the broader spectrum of learning is profoundly affected by CCT. Choi et al. [40] (establishing the positive effect of 6500 K lighting on academic performance), Lekan-Kehinde et al. [41] (supporting that higher CCT exposure leads to greater improvement in children's task switching performance) and Mogas-Recalde et al. [22] (attaching particular importance to the use of high CCT for good academic performance), come to similar conclusions, although without direct reference to mathematics, and highlight the correlation between colour temperature and academic performance from a holistic point of view. On the other hand, in addition to the ideas provided by the aforementioned researchers, it is essential to recognise the presence of a contingent that defends the advantages of natural lighting, which has been shown to exert a notably positive influence on students' educational results, as corroborated by the research results of Plympton et al. [42]. Accordingly, Mogas-Recalde et al. [22] propose that the ideal learning atmosphere can be achieved through a judicious amalgamation of natural and artificial light, thus establishing the most favourable conditions for optimal learning and academic performance.

It is worth noting that Mogas-Recalde et al. [22] also advocate the integration of 'dynamic lighting' in the framework of smart classrooms by stating that the results clearly indicate that dynamic lighting is necessary to accommodate different activities in the classroom, a suggestion that finds support in the views of Poldma [6] and Suh et al. [3], who directly address coloured lighting and state that the actual experience of the interior space and its illumination is dynamic rather than limiting their analysis to CCT alone. This concept of dynamic lighting, as articulated by the aforementioned scholars, is not only vital in smart classrooms, but also lays the groundwork for substantial advances in their management through the use of artificial intelligence (AI), thus enabling the personalisation and adaptability of pedagogical and learning experiences [43].

In the following sections, we will show the materials and methodologies used in the experimental framework which includes three experimental situations addressed as a whole. We will present the results obtained for each variable through a triadic analysis (descriptive, variance and comparative) that will ultimately lead to definitive conclusions after the mandatory discourse.

2. Materials and Methods

2.1. Statement of the Problem: Objectives, Questions and Hypotheses

Based on existing knowledge, our research aims to achieve the following general objectives:

- GO1. To investigate the impact of colour lighting on learning processes within primary school settings.

- GO2. To investigate the effectiveness of 'Dynamic Colour' in primary school settings and its impact on learning processes.

Therefore, the particular aims articulated in the format of distinct objectives are as follows:

- SO1. To evidence the impact of colour lighting on pupils' cognitive processes in primary school settings.
- SO2. To evidence the impact of colour lighting on pupils' basic instrumental learning in primary school settings.
- SO3. To evidence the impact of colour lighting on pupils' affective processes in primary school settings.
- SO4. To examine the advantages and disadvantages associated with the implementation of 'dynamic colour' in primary schools.
- SO5. To examine the possibility of using artificial intelligence to assist teaching decisions on dynamic lighting.

In view of this, and taking into account previous research that assessed the impact of various coloured lighting conditions on student learning, we endeavoured to delve deeper into the basic cognitive, affective and instrumental mechanisms influenced by exposure to coloured lighting, employing an experimental framework that will be detailed in subsequent sections and which, if anything, aims to broaden the experimental sample by pooling data from several experimental situations. This approach aims to mitigate the limited robustness of the initial exploratory research predecessor in the literature [12], attributable especially to its exploratory nature and inadequate counterbalanced design, while improving consistency, reliability and validity and thus facilitating the derivation of more rigorous conclusions. Consequently, the specific objectives articulated are specified through the following research questions:

- RQ1. How does the use of coloured light influence cognitive processes of primary school pupils?
- RQ2. How does the use of coloured light influence basic instrumental learning of primary school pupils?
- RQ3. How does the use of coloured light influence affective processes of primary school pupils?
- RQ4. What are the advantages and disadvantages associated with the application of 'dynamic colour' in primary education settings?
- RQ5. Is it possible to use artificial intelligence to assist teaching decisions on dynamic lighting?

Since hypotheses function as conjectural resolutions of the research [44], it is imperative that they be subjected to empirical examination [45]. Accordingly, the hypotheses put forward in this research are articulated as follows:

- H1. The use of colour lighting in primary schools' environments promotes the development of pupils' cognitive processes.
- H2. The implementation of coloured lighting in primary education classrooms facilitates an enhancement in the attainment of basic instrumental learning among pupils.
- H3. The implementation of colour lighting in primary schools facilitates an improvement in pupils' self-assessment of emotional processes.
- H4. The implementation of 'dynamic colour' lighting in primary educational environments offers the advantage of the flexibility of coloured lighting to adapt to the requirements of various activities.
- H5. Artificial intelligence can be a good assistant for teaching decisions about dynamic lighting.

2.2. Methodology

This research integrates a total of three quasi-experimental frameworks (Figure 1), two of which incorporate a control group, systematically employing a pretest, two of them similar to the Campbell et al. [46] classification as an ‘equivalent materials design’ and the other with an incomplete counterbalanced design. Over three distinct intervals, and across several educational institutions (spanning both rural and urban settings), four assessments were conducted within each institution for each dependent variable and its respective dimensions: an initial pretest followed by three post-test assessments following the implementation of coloured light scenarios. These coloured light scenarios function as the dependent variable, using shades that align with the examinees as outlined by Suh et al. [3]. The ‘daylight’ conditions and coloured light scenarios can be quantified in later sections and, in all cases, are realised by using LED bulbs in the colours recommended by Suh et al. [3], which correlate with the shades typically observed in the natural environment.

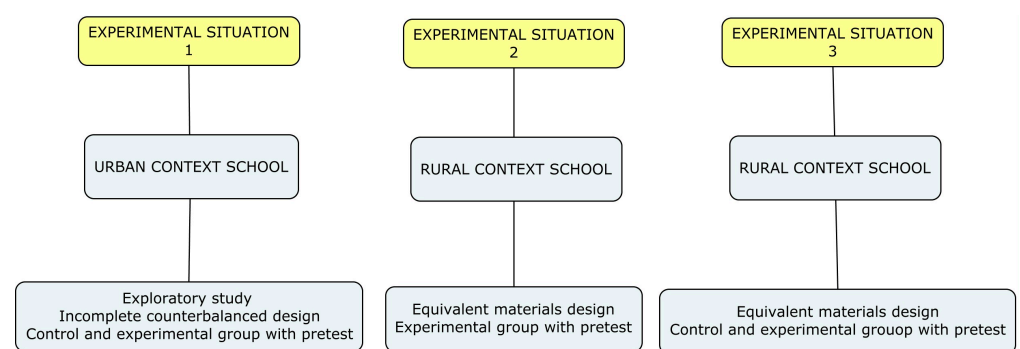


Figure 1. Overview of experimental situations, looking at the three partial experimental situations from which the total data of this study are obtained.

As noted in the introduction, the impact of classroom lighting (with respect to CCT and brightness) on academic performance, attention and emotional–motivational states is one of the most frequently addressed topics in academic discourse [2]. This observation is valid not only with respect to lighting as an isolated variable, but also with respect to colour as it is conventionally perceived as a physical element of the classroom environment [1]. Although it is not feasible to examine these aspects exhaustively, we consider attention (along with its intrinsic connection to the regulation of impulsivity) to be paramount; this assessment is based on its established importance within the scientific community and the increased attention it currently receives in historical and socio-cultural contexts, particularly in relation to minors [47]. Furthermore, we consider creativity to be of particular importance, especially as it is valued by educational policies in the western world, which emphasise cognitive processes derived from Bloom’s taxonomy as fundamental for optimal academic performance [36,48]. Similarly, the fundamental instrumental learning processes highlighted in the legislation, mainly mathematical and linguistic skills [36], together with emotions frequently highlighted in the previous literature [3], are incorporated to form our dependent variables.

Accordingly, we have assessed the following dependent variables, which we briefly summarise in Figure 2:

- V1. Cognitive Processes: The present investigation will evaluate three of its dimensions (figurative creativity, attentional focus and regulation of impulsivity). Figurative creativity will be measured using four indicators: originality, elaboration, fluency and flexibility.

- V2. Instrumental learning: Two of its dimensions will be examined (written linguistic competence and mathematical competence). The score for written linguistic competence is derived from two indicators: written expression and written comprehension.
- V3. Affective processes: Three of its facets will be analysed (level of satisfaction, energy level and feeling). The third facet is nominal; however, it will be converted into a numerical format for the purpose of statistical analysis.

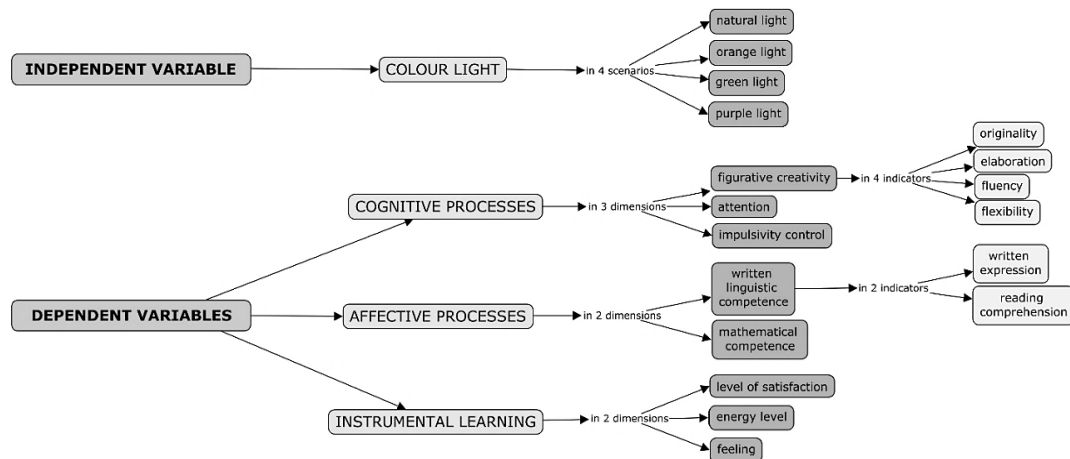


Figure 2. Complete summary of variables (dependent and independent) and their constituent dimensions that make up the study.

The instruments used for data collection have remained uniform throughout the three experimental situations and are as follows:

- For the variable ‘cognitive processes’: Torrance’s creativity assessment documented by Artiles Hernández et al. [49], which encompasses four indicators (originality, elaboration, fluency and flexibility), in conjunction with Faces’ assessment of attention, according to Thurstone et al. [50], which presents the regulation of the attention network and impulsivity. Both assessments distinctly classify the dependent variables as quantitative ratio variables, wherein net attention can range from 0 to 60, impulsivity control can vary from 0 to 100, and figurative creativity can extend from 0 to approximately 300.
- For the ‘instrumental learning’ variable: Andalusian regionally standardised assessments in language (restricted to the dimensions of written expression and comprehension) and mathematics, although modified to align with the expected duration of the tests [51–56], were used. The level of the mathematical competence test was maintained at a maximum of 13 points, while the linguistic competence test allowed a total of 34 points, 22 of which corresponded to written expression and 12 to written comprehension.
- For the variable ‘affective processes’: A questionnaire integrating the foundational study by Suh et al. [3], composed of three self-perception questions (two Likert-scaled out of a score of ten and one nominal), was used. For the statistical coding of the final question, we used the conversion criteria outlined in Table 1.

The research framework, as noted above, adheres closely to the ‘equivalent materials design’ articulated by Campbell et al. [46] in two of the experimental contexts, thus ensuring a high degree of internal validity despite certain limitations in external validity, as acknowledged in the authors’ theoretical framework. In contrast, the initial context, exploratory research characterised by an incomplete counterbalanced design (as mentioned above), demonstrates reduced rigour, although the measures outlined below were similarly applied. To improve this validity, efforts were made to mitigate extraneous variables, although it

was recognised that complete isolation of such variables was unfeasible, particularly in the standardised classroom environment where the assessments were administered:

- To mitigate the influence of weather factors on the lighting conditions, we mitigated their effects while ensuring that students did not experience a sense of confinement resulting from the absence of natural light.
- To increase the sample size (which was limited in the initial counterbalanced structure), we administered tests to all participants in the experimental cohort on a daily basis in experimental conditions 2 and 3, thus foregoing the counterbalanced approach.
- The introduction of coloured lighting took place one month before the start of data collection in each experimental situation, thus integrating it into the usual activities of the educators in the classroom on a daily basis at the choice of the educators themselves. In this way, the students became accustomed to the exposure to coloured light, so that after one month the experimental tests were approached as normally as possible. In this way, we were able to alleviate possible biases of the ‘Hawthorne’ motivation effect.
- To reduce the learning effect, according to Chacón-Moscoso et al. [35], the experimental situations were approached by scheduling the data collection of the different light scenarios with a spacing of two weeks, trying to reduce the students’ memory of the tests. In addition, to avoid any alteration of students’ behavioural and emotional responses, the purpose of the study was not disclosed, and all activities were framed within the usual classroom practices.
- To further minimise recall biases, in experimental conditions 2 and 3, the sequence of the ‘coloured light’ scenarios was modified.

Table 1. Coding to number of sentiments collected.

Assigned Score	Sentiment Expressed by Students
1	empty, pressured, anxious, disappointed, disillusioned, bad, fatal, painful, anger
2	uncomfortable, discouraged, bored, scared, a little bit bad, overwhelmed, tired, weird, cannot see, strange, blind, confused, asleep, sad, bad taste
3	equal, normal, nothing, regular, calm, hard-working, quiet, relaxed, peaceful, prepared, average, medium
4	kind, easy-going, nice, comfortable, motivated, excited/sentimental, content, joyful, happy, proud, inspired, nervous/hyperactive, environmental, cheerful, confident, beautiful, nature, interested, fun
5	very good, happy, great, excellent, thrilled, very happy, energetic, excited, hardworking, impacted, very comfortable, imaginative

2.3. Sample and Context of the Study: Experimental Situation

The subjects of the study were 129 fifth and sixth grade primary school students from three publicly funded schools located in Andalusia (Spain). Among them, two schools are located in rural areas where agriculture is the dominant economic activity and have a medium socio-economic index, while the third school is urban and heavily dependent on the tourism sector, having a medium–high socio-economic index. Of the total cohort of 129 pupils, 63 constituted the different experimental groups (although there is no exact correspondence with the ‘n’ value as the first design was incomplete counterbalanced as mentioned above), and 66 constituted the two experimental groups in experimental situations 1 and 3. This non-probabilistic sample was constituted by intact class groups,

thus preserving the established organisational structure of the school. Participants were between 10 and 12 years old.

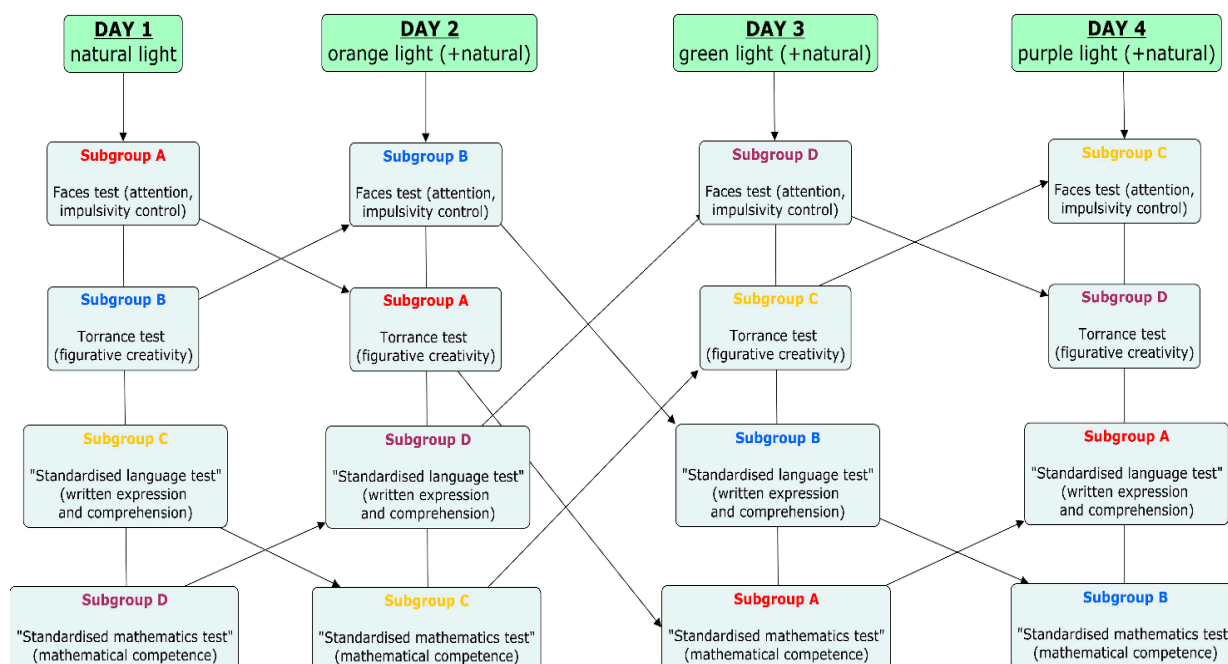
They were not informed of the research objectives and considered the study as a normal classroom engagement. The experimental group was represented by the classroom in which the necessary technological modifications for coloured lighting had been introduced. Every experimental classroom was equipped with coloured LED spotlights, and the light intensity was evaluated using the ‘evo lightspectrum pro’ application. Daily post-test measurements were taken in the absence of the pupils. For each scenario, multiple measurements—one per table—were recorded using a smart device for data documentation. Three parameters were evaluated for each measurement: luminance (lx), CCT in Kelvin (K) and wavelength of light (nm). The mean values for each colour scenario are shown in Table 2 for the experimental cohort and in Table 3 for the control cohort. An overview of the whole experimental procedure is illustrated in Figure 3. In this figure, we observe the incomplete counterbalanced design of the experimental group in experimental situation 1 in which the affective self-perception surveys that were carried out at the beginning of each and every one of the rest of the tests have not been added, as the self-perceived affectivity was integrated in each test. The design of the control group corresponds exactly to the one shown here, but only with the natural light scenario. The choice of the natural light scenario (actually a mixture of natural outdoor and artificial white indoor) as a control and pretest corresponds to what is usual in the previous literature, especially in the case of our reference Suh et al. [3], who contrasts the effects of coloured lighting scenarios with the pre-existing artificial white light. Likewise, it was very interesting to combine such artificial white light with the strictly natural outdoor light, as several authors such as Mogas-Recalde et al. [22] propose the ideal combination of both lights (outdoor–indoor) as the most favourable for optimal learning conditions. Contrasting the coloured light scenarios with this previously advocated ideal lighting scenario was crucial for us.

Table 2. Experimental group light measurements (total class average for each scenario and value).

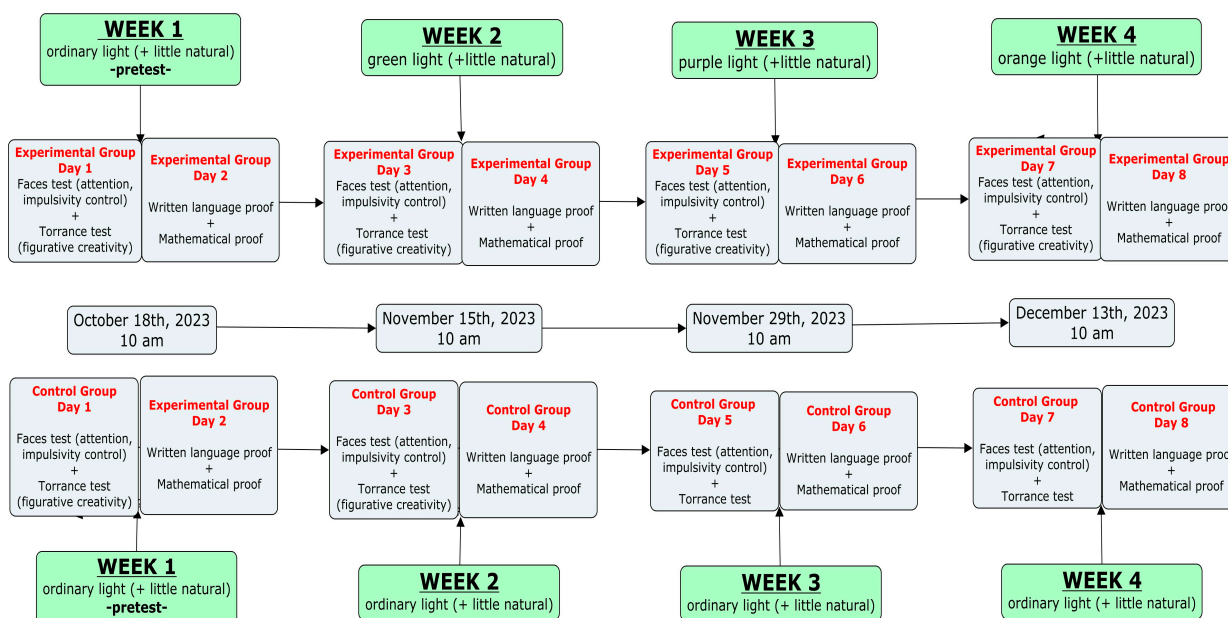
	Natural Light	Green Light	Purple Light	Orange Light
Experimental situation 1	1009 lx	1691 lx	1437 lx	1375 lx
	5100 K	5037 K	5150 K	4658 K
	Wavelength: peak values at 460 nm and 700 nm	Wavelength: medium and equal density between 460 nm and 650 nm	Wavelength: peak values at 360 nm and 800 nm	Wavelength: peak values at 720 nm
	1692 lx	2083 lx	1893 lx	1851 lx
	3453 K	4047 K	4133 K	3171 K
	Wavelength: peak values at 460 nm and 700 nm	Wavelength: medium and equal density between 460 nm and 650 nm	Wavelength: peak values at 360 nm and 800 nm	Wavelength: peak values at 680 nm
Experimental situation 2	1196 lx	1679 lx	1389 lx	1016 lx
	5385 K	5589 K	5438 K	4064 K
	Wavelength: maximum values at 460 nm and 700 nm	Wavelength: medium and equal density between 460 nm and 600 nm	Wavelength: maximum values at 360 nm and 800 nm	Wavelength: maximum values in 720 nm

Table 2. Cont.

	Natural Light	Green Light	Purple Light	Orange Light
	980 lx	907 lx	846 lx	775 lx
	3963 K	4239 K	4004 K	3502 K
Experimental situation 3	Wavelength: maximum values in 660 nm	Wavelength: maximum values in 520 nm	Wavelength: maximum values in 360 nm	Wavelength: maximum values in 720 nm



(a)



(b)

Figure 3. (a) Experimental design of the experimental group in experimental situation 1, being an incomplete counterbalanced design; (b) experimental design of the experimental and control group in experimental situation 3, being quasi-experimental with control and pretest.

Table 3. Control group light measurements (total class average for each scenario and value).

		Natural Light	Natural Light 2	Natural Light 3	Natural Light 4
Experimental situation 1	Cloudy day	821 lx			
		5005 K			
	Wavelength: peak values at 460 nm and 700 nm				
	Clear day	1842 lx			
3208 K					
				Wavelength: peak values at 460 nm and 700 nm	
Experimental situation 3	976 lx		992 lx	1008 lx	975 lx
	4004 K		3901 K	4010 K	3953 K
	Wavelength: maximum values in 670 nm		Wavelength: maximum values in 660 nm	Wavelength: maximum values in 650 nm	Wavelength: maximum values in 660 nm

Regarding the design of experimental situation 3, we indicate the same for the affective self-perception surveys (they are not included in the scheme because they were integrated in all the rest of the tests). The scheme of experimental situation 2 does not appear in the figure because it corresponds to the same design as experimental situation 3, with the following differences: experimental situation 2 takes place on other dates and in a different educational context, it has no control group, and the order of application of colours is natural-orange-green-purple.

2.4. Ethical Considerations

To carry out the research with minors, explicit and informed consent was obtained from the guardians. They were provided with a comprehensive information document describing all facets of the study, in accordance with both European and national regulations (General Data Protection Regulation 679, [57]; Organic Law 3, [58]). This protocol was submitted to the People, Society and Environment Research Ethics Committee (CEIPSA) of the Rovira i Virgili University, which subsequently gave its approval.

3. Results

Examining each of the three different experimental settings independently facilitates statistical analysis of the data derived from the non-parametric nature of the data set, as evidenced by the non-normality indicated by the Shapiro–Wilk test for most variables, compounded by sample sizes of 20 or less in each specific experimental setting, together with the absence of homogeneity of variance (as assessed by Levene’s test). However, by aggregating data from the three experimental contexts to obtain a global perspective on the overall influence of coloured light conditions, statistical procedures could allow for a parametric analysis; however, this approach would hinder meaningful discourse with previous research (we insist that these are those constitutive of this more agglomerative research and which we clearly indicated were non-parametric at the beginning of this paragraph), as it would divert us from obtaining results in fully non-parametric settings. Consequently, we opted to restate the findings using non-parametric statistical methodologies. Accordingly, each dependent variable and its respective dimensions will be delineated in subsections organised as efficiently as possible, thus optimising space by reducing the need for supplementary tables and figures. For each variable, we will present descriptive statistics, an analysis of variance in relation to the various coloured light conditions (using a Kruskal–Wallis test, ANOVA, and standard post hoc test, including Dunn’s post hoc p, and adding the Bonferroni adjustment and the effect size by Cohe’s d), along with a comparative

analysis between the experimental and control cohorts using the Mann–Whitney U test (in cases where there was a control group in the experimental conditions).

Furthermore, a concluding subsection encapsulates the extreme values—both maximum and minimum—of all variables along with their respective dimensions, in addition to their mean and median values, thereby offering a concise overview.

A significance threshold (α) of 0.05 was consistently employed to determine the relevance of the findings. Statistical evaluations were conducted utilizing Jasp, version 0.18.3.

3.1. Cognitive Processes

3.1.1. Descriptive Analysis

The parameters examined included net attention (A-E), impulsivity control index (ICI) and figurative creativity. Descriptive statistics for the experimental cohort are presented in Table 4, while Table 5 contains the data for the control cohort. For the experimental group, the aggregated data from the three experimental conditions have been categorised according to the different coloured light scenarios. Similarly, for the two existing control groups, the data were organised in a comparable way in relation to the two applicable experimental conditions. All tables present the sample size ('n') for each dimension assessed in the various lighting scenarios. Each lighting scenario is associated with a different day, as outlined in the methodological framework.

Table 4. Descriptive values of net attention, impulsivity control and figurative creativity in the different experimental coloured light scenarios.

Cognitive Variables and Dimensions	Natural Light	Orange Light	Green Light	Purple Light
Net attention (A-E) (level over 60)	median 35.500 mean 35.857 n = 42	median 43.000 mean 41.442 n = 43	median 40.000 mean 41.310 n = 42	median 44.000 mean 44.881 n = 42
Impulsivity control (ICI) (level over 100)	median 90.100 mean 89.379 n = 42	median 92.900 mean 88.407 n = 43	median 90.200 mean 89.105 n = 42	median 94.750 mean 91.974 n = 42
Figurative creativity	median 171.000 mean 173.000 n = 41	median 204.000 mean 198.857 n = 42	median 207.000 mean 202.095 n = 42	median 211.000 mean 200.829 n = 42

Table 5. Descriptive values of net attention, impulsivity control and figurative creativity in the different control light scenarios.

Cognitive Variables and Dimensions	Natural Light	Natural2 Light	Natural3 Light	Natural4 Light
Net attention (A-E) (level over 60)	median 37.000 mean 38.355 n = 31	median 38.000 mean 40.194 n = 31	median 42.500 mean 40.700 n = 30	median 48.000 mean 45.552 n = 29
Impulsivity control (ICI) (level over 100)	median 93.300 mean 87.406 n = 31	median 92.400 mean 89.716 n = 31	median 94.900 mean 90.470 n = 30	median 96.200 mean 90.400 n = 29
Figurative creativity	median 131.000 mean 125.633 n = 30	median 136.500 mean 140.906 n = 32	median 161.000 mean 162.667 n = 30	median 144.000 mean 159.806 n = 31

The experimental group shows elevated A-E and ICI values in almost all coloured light scenarios, in contrast to the daylight condition. When juxtaposed with the results of the control group on a daily basis, the experimental group’s net attention is significantly lower in the daylight condition; conversely, it is higher in the orange and purple scenarios compared to the control group’s daylight condition. This trend does not extend to the ICI,

where the experimental group’s values remain systematically lower, with the exception of the median of the purple scenario, which exceeds that of the control group. In terms of figurative creativity (and most of its component dimensions), the experimental group also shows high values in all colour scenario assessments relative to the natural condition. Compared to the results of the control group, all metrics of the experimental group exceed those recorded by the control group.

3.1.2. Variance Analysis

Examination of variance within the experimental cohort, using the Kruskal–Wallis test, yields $p < 0.05$ for both net attention and figurative creativity (see Table 6). In the subsequent post hoc analysis, we employed a conventional approach incorporating Cohen’s d and Bonferroni’s p , together with Dunn’s post hoc analysis presenting p -values (see Table 7), which similarly show p -values < 0.05 that are consistent with ‘ d ’ values equal to or greater than 0.5. These remarkable p -values and d -values indicate convincing trends. Figure 4 presents graphical representations of the analysis of variance for the dimensions that make up the ‘cognitive processes’ variable, in order to provide an illustrative visual approximation.

Table 6. Analysis of variance on net attention, impulsivity control and figurative creativity in different coloured light scenarios of experimental group.

Kruskal–Wallis Test	Net Attention (Level over 60)			Impulsivity Control (Level over 100)			Figurative Creativity		
	statics	df	p	statics	df	p	statics	df	p
Coloured light scenarios	17.694	3	<0.001	2.820	3	0.420	8.077	3	0.044

Table 7. Conover post hoc on the variance of net attention, impulsivity control and figurative creativity in different coloured light scenarios.

Post Hoc Comparisons		Net Attention (Level over 60)			Impulsivity Control (Level over 100)			Figurative Creativity		
		Cohen’s d	p_{bonf}	Dunn’s Post Hoc p	Cohen’s d	p_{bonf}	Dunn’s Post Hoc p	Cohen’s d	p_{bonf}	Dunn’s Post Hoc p
Natural	Orange	−0.602	0.037	0.006	0.093	1.000	0.852	−0.449	0.256	0.027
	Green	−0.587	0.047	0.012	0.026	1.000	0.894	−0.505	0.137	0.022
	Purple	−0.972	<0.001	<0.001	−0.247	1.000	0.173	−0.483	0.182	0.014
Orange	Green	0.014	1.000	0.839	−0.066	1.000	0.749	−0.056	1.000	0.941
	Purple	−0.370	0.538	0.155	−0.340	0.715	0.236	−0.034	1.000	0.807
Green	Purple	−0.385	0.479	0.106	−0.273	1.000	0.135	0.022	1.000	0.864

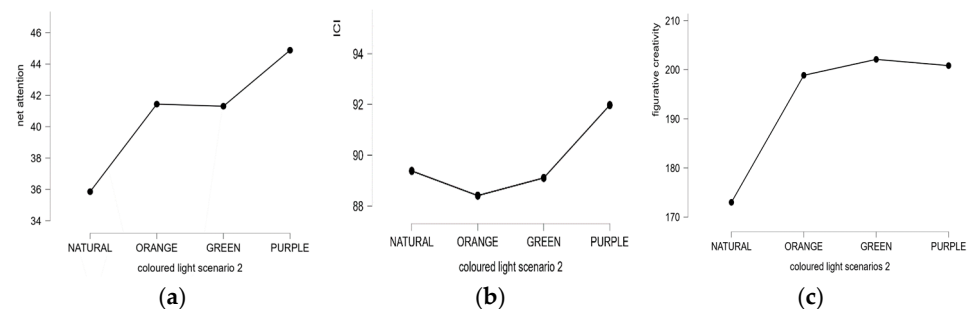


Figure 4. (a) Plot of variance in the net attention variable for the four different coloured light scenarios; (b) plot of variance in the impulsivity control variable for the four different coloured light scenarios; (c) plot of variance in the figurative creativity variable for the four different coloured light scenarios.

3.1.3. Comparative Analysis

With each passing day, both the Student’s *t*-test (applicable under normal distribution conditions) and the Mann–Whitney test were used to make non-parametric comparisons between the experimental and control cohorts in the two experimental settings in which these control groups were present (Table 8). This methodological approach increases the precision of the observations derived from the previous analyses. In contrast to those earlier assessments, the *p*-values now appear to lack generalisability, with a few notable exceptions, and this is similarly observed for the effect sizes, which do not become large in any of the Mann–Whitney comparisons as seen in Table 8. Thus, in terms of net attention, all conditions appear advantageous for the experimental group (except the final orange light scenario and the initial natural condition), while the situation is different for ‘impulsivity control’, where only the two natural light conditions and the first purple scenario are beneficial for this experimental group. As far as figurative creativity is concerned, it is evident that most of the scenarios also favour the experimental group.

Table 8. Comparison of net attention, impulsivity control and figurative creativity between experimental and control groups on all experimental days where control group exists.

Independent Samples <i>t</i> -Test and Mann–Whitney	Test	Net Attention (Level over 60)				Impulsivity Control (Level over 100)				Figurative Creativity			
		Statistic	df	<i>p</i>	Effect Size	Statistic	df	<i>p</i>	Effect Size	Statistic	df	<i>p</i>	Effect Size
Day 1A	Student	−1.786	14	0.096	−0.963	0.308	14	0.763	0.166	2.450	13	0.029	1.342
Natural light	M-W	14.000		0.140	−0.491			0.954	0.036	41.000		0.055	0.640
Day 2A	Student	0.537	14	0.600	0.290	−0.109	14	0.914	−0.059	1.568	14	0.139	0.905
Orange light	M-W	29.000		0.909	0.055	27.500		1.000	0.000	34.000		0.262	0.417
Day 3A	Student	0.525	14	0.608	0.283	−0.117	14	0.909	−0.063	2.185	14	0.046	1.179
Green light	M-W	31.500		0.692	0.145	25.000		0.819	−0.091	37.000		0.308	0.345
Day 4A	Student	0.718	12	0.487	0.400	1.536	12	0.150 ^a	0.857	−0.064	13	0.950	−0.037
Purple light	M-W	27.500		0.546	0.222	32.500		0.200 ^a	0.444	23.500		0.896	0.068
Day 1B	Student	0.301	36	0.765	0.098	0.608	36	0.547	0.198	1.093	36	0.282	0.355
Natural light	M-W	198.00		0.608	0.100	181.000		0.988	0.006	209.500		0.396	0.164
Day 2B	Student	0.720	37	0.476	0.231	−0.415	37	0.681	−0.133	1.248	37	0.220	0.400
Green light	M-W	218.000		0.438	0.147	160.000		0.406	−0.158	220.000		0.407	0.158
Day 3B	Student	0.226	34	0.822	0.076	0.531	34	0.599	0.177	−4.315	34	<0.001	−1.441
Purple light	M-W	163.500		0.962	0.012	156.000		0.873	−0.034	51.000		<0.001	−0.684
Day 4B	Student	−0.404	37	0.688	−0.130	−0.826	37	0.414	−0.265	0.326	37	0.746	0.104
Orange light	M-W	172.500		0.632	−0.092	158.000		0.371	−0.168	201.500		0.757	0.061

Note. For the Student *t*-test, effect size is given by Cohen’s *d*. For the Mann–Whitney test, effect size is given by the rank biserial correlation. ^a Levene’s test is significant (*p* < 0.05), suggesting a violation of the equal variance assumption.

3.1.4. Summary to Support the Conclusions

An examination of the means of all dimensions related to the variable indicates that the best results were observed in the green and violet experimental conditions, while one of the metrics was recorded in the natural light environment of the control group (a similar pattern is observed when evaluating the medians). All minimum scores were obtained in natural light conditions (in both the control and experimental groups). Both the dimensions of net attention and figurative creativity show generalisable *p*-values, which favour coloured lighting conditions, while impulse control, despite achieving optimal results in violet light, shows lower results in orange and green lighting compared to natural experimental lighting (this finding is not generalisable). The larger effect sizes in terms of attention and figurative creativity further favour the coloured lighting conditions. The comparative

analysis indicates that, despite the internal variability present between the different control and experimental groups, the impact of specific coloured lighting conditions has the potential to ameliorate adverse initial situations for the experimental group (specifically with regard to the dimensions of attention and impulse control). Considering these results, supported by remarkable n-values, and paying attention to the dimension of impulse control, sufficient information can be drawn for what will be the first of the conclusions in Section 5 of this study.

3.2. Instrumental Learning

3.2.1. Descriptive Analysis

The dimensions examined pertain to written language proficiency (indicators of written expression and comprehension) and mathematical competence (assessed as a collective whole). Descriptive results are presented in Table 9 for the experimental cohort and in Table 10 for the control cohort. Each table encompasses the 'n' value for each dimension scrutinised across various lit conditions, pooling values from all experimental contexts.

Table 9. Descriptive values of reading comprehension, written expression and mathematical competence in the different experimental coloured light scenarios.

Cognitive Variables and Dimensions	Natural Light	Orange Light	Green Light	Purple Light
Reading comprehension (level over 22)	median 17.000 mean 16.488 n = 43	median 18.000 mean 17.951 n = 41	median 18.500 mean 17.762 n = 42	median 18.000 mean 17.267 n = 45
Written expression (level over 12)	median 7.000 mean 6.268 n = 41	median 10.000 mean 9.634 n = 43	median 10.000 mean 8.786 n = 42	median 10.000 mean 9.233 n = 43
Mathematical competence (level over 13)	median 8.000 mean 7.765 n = 44	median 10.000 mean 9.377 n = 43	median 9.500 mean 9.351 n = 42	median 10.000 mean 9.405 n = 42

Table 10. Descriptive values of reading comprehension, written expression and mathematical competence in the different control light scenarios.

Cognitive Variables and Dimensions	Natural Light	Natural2 Light	Natural3 Light	Natural4 Light
Reading comprehension (level over 22)	median 20.000 mean 19.567 n = 30	median 20.000 mean 19.750 n = 32	median 21.000 mean 19.281 n = 32	median 19.000 mean 18.438 n = 32
Written expression (level over 12)	median 9.000 mean 8.000 n = 30	median 8.000 mean 8.063 n = 32	median 9.000 mean 8.750 n = 32	median 8.000 mean 7.871 n = 31
Mathematical competence (level over 13)	median 8.335 mean 8.275 n = 32	median 9.000 mean 8.849 n = 32	median 9.000 mean 8.729 n = 31	median 9.250 mean 9.034 n = 32

The experimental cohort's readings in reading comprehension outperform those in natural light across all coloured light conditions. A similar trend is observed in written production, with the variation being markedly more significant. In daily comparisons between the experimental and control groups, reading comprehension is markedly higher in the control group from the outset, a trend that persists even in the coloured light conditions, although the disparities between the two groups decrease, especially in the

purple light setting. As for written production, the differences observed between the two groups vary according to the specific scenarios.

In terms of mathematical competence, the experimental group shows a score that improves with the transition from daylight to orange, and this improvement is consistently observed in the green and purple scenarios. Daily comparisons with the control group show fluctuations, as noted above for written production.

3.2.2. Variance Analysis

The variability within the experimental cohort, assessed using the Kruskal–Wallis test designed for non-parametric data sets, reveals that both written competence and numerical competence present statistically significant results (see Table 11). Accordingly, post hoc analyses (using standard with Bonferroni and Dunn adjustments, as shown in Table 12) reveal *p*-values of less than 0.05 for written proficiency when comparing the natural environment to all coloured lighting conditions; this trend is similarly observed for numeracy, which also demonstrates substantial effect size metrics, large in those cases where the value reaches $d = 0.8$. Figure 5 illustrates graphical representations of the analysis of variance relating to the components that constitute the ‘instrumental learning’ variable, thus providing a more complete visual interpretation.

Table 11. Analysis of variance on reading comprehension, written expression and mathematical competence in different coloured light scenarios of experimental group.

Kruskal–Wallis Test	Reading Comprehension (Level over 22)			Written Expression (Level over 12)			Mathematical Competence (Level over 13)		
	statics	df	<i>p</i>	statics	df	<i>P</i>	statics	df	<i>p</i>
Coloured light scenarios	2.003	3	0.572	33.024	3	<0.001	14.221	3	0.003

Table 12. Conover post hoc on the variance of reading comprehension, written expression and mathematical competence in different coloured light scenarios.

Post Hoc Comparisons		Reading Comprehension (Level over 22)			Written Expression (Level over 12)			Mathematical Competence (Level over 13)		
		Cohen’s <i>d</i>	<i>p</i> bonf	Dunn’s Post Hoc <i>p</i>	Cohen’s <i>d</i>	<i>p</i> bonf	Dunn’s Post Hoc <i>p</i>	Cohen’s <i>d</i>	<i>p</i> bonf	Dunn’s Post Hoc <i>p</i>
Natural	Orange	−0.369	0.558	0.217	−1.298	<0.001	<0.001	−0.666	0.013	0.003
	Green	−0.321	0.844	0.238	−0.971	<0.001	<0.001	−0.655	0.017	0.003
	Purple	−0.196	1.000	0.526	−1.143	<0.001	<0.001	−0.678	0.012	0.001
Orange	Green	0.048	1.000	0.950	0.327	0.829	0.149	0.011	1.000	1.000
	Purple	0.173	1.000	0.534	0.155	1.000	0.487	−0.012	1.000	0.770
Green	Purple	0.125	1.000	0.574	−0.172	1.000	0.446	−0.022	1.000	0.772

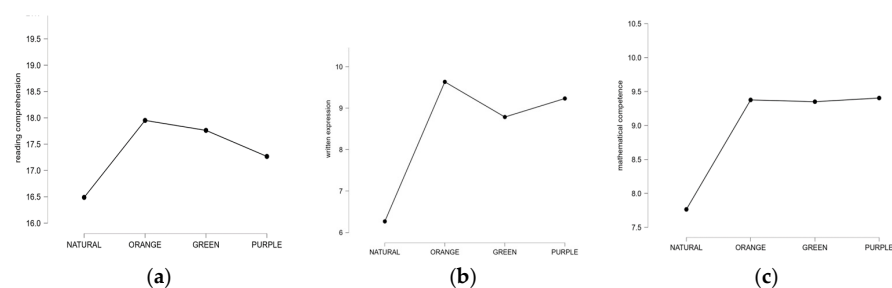


Figure 5. (a) Plot of variance in the reading comprehension variable for the four different coloured light scenarios; (b) plot of variance in the written expression variable for the four different coloured light scenarios; (c) plot of variance in the mathematical competence variable for the four different coloured light scenarios.

3.2.3. Comparative Analysis

Table 13 presents the outcomes of the *t*-test and the Mann–Whitney test (inclusive of effect size), utilizing daily parallelism between the experimental and control cohorts. The results indicate that only reading comprehension $p = 0.022$ (Mann–Whitney), with an effect size of -0.436 (medium effect size) and written expression of $p = 0.033$, are statistically significant, which aligns with the findings previously discussed in earlier analyses.

Table 13. Comparison of reading comprehension, written expression and mathematical competence between experimental and control groups on all experimental days where control groups exist.

Independent Samples <i>t</i> -Test and Mann–Whitney	Test	Reading Comprehension (Level over 22)				Written Expression (Level over 12)				Mathematical Competence (Level over 13)			
		Statistic	df	<i>p</i>	Effect Size	Statistic	df	<i>P</i>	Effect Size	Statistic	df	<i>p</i>	Effect Size
Day 1A	Student	−2.127	13	0.053 _a	−1.165	0.233	13	0.819	0.128	−0.663	16	0.517	−0.331
Natural light	M-W	15.000		0.235 _a	−0.400	28.500		0.710	0.140	28.500		0.509	−0.208
Day 2A	Student	−2.088	14	0.056 _a	−1.206	0.000	14	1.000	0.000	0.075	14	0.941	0.578
Orange light	M-W	12.500		0.161 _a	−0.479	23.500		1.000	−0.021	24.000		1.000	0.331
Day 3A	Student	−2.063	15	0.057 _a	−1.098	−1.359	15	0.194	−0.723	−0.643	14	0.531	−0.347
Green light	M-W	22.000		0.406 _a	−0.267	20.000		0.311	−0.333	19.000		0.356	−0.309
Day 4A	Student	0.494	16	0.628	0.247	0.668	14	0.515	0.360	−2.794	13	0.015	−1.804
Purple light	M-W	39.500		0.774	0.097	33.000		0.568	0.200	4.000		0.050	−0.778
Day 1B	Student	−2.658	36	0.012	−0.864	−2.187	35	0.035	−0.722	−1.717	36	0.095	−0.558
Natural light	M-W	101.500		0.022	−0.436	100.000		0.033	−0.412	123.500		0.097	−0.314
Day 2B	Student	−1.461	37	0.152	−0.468	1.233	37	0.225	0.395	−0.959	37	0.344	−0.307
Green light	M-W	157.000		0.358	−0.174	217.000		0.451	0.142	153.500		0.306	−0.192
Day 3B	Student	−1.705	37	0.097	−0.546	−0.090	37	0.928	−0.029	0.088	37	0.930	0.028
Purple light	M-W	126.500		0.075	−0.334	207.000		0.640	0.089	194.500		0.910	0.024
Day 4B	Student	−0.539	37	0.593	−0.173	1.245	37	0.221	0.399	−0.326	37	0.746	−0.104
Orange light	M-W	174.000		0.661	−0.084	247.000		0.108	0.300	183.000		0.853	−0.037

Note. For the Student *t*-test, effect size is given by Cohen’s *d*. For the Mann–Whitney test, effect size is given by the rank biserial correlation. _a Levene’s test is significant ($p < 0.05$), suggesting a violation of the equal variance assumption.

3.2.4. Summary to Support the Conclusions

When assessing mean and median values, the dimensions of written expression and mathematical competence show higher values in coloured lighting conditions, while reading comprehension does not follow this trend. All minimum values are observed in daylight conditions (both in the experimental and control groups). The analysis of variance also reveals highly significant values for the two dimensions mentioned initially, together with a considerable effect size. In contrast, this is not the case for reading comprehension, although it does show high results in the orange light scenario. The comparative analysis clarifies the favourable initial situation of the control group, which is altered by the effect of the coloured light on the mentioned dimensions that are most significantly affected, while reading comprehension remains virtually unchanged. Therefore, despite the complexities associated with reading comprehension, and taking into account the significant *n*-values

involved, we are again in possession of important data to support the second conclusion of Section 5 of this study.

3.3. Affective Processes

3.3.1. Descriptive Analysis

Our research methodology has incorporated the dimensions of energy level, preference and emotional response as integral elements of the affective process variable. An examination of Table 14 for the experimental cohorts and Table 15 for the control cohorts reveals that the experimental group has high values in all affective dimensions when contrasting coloured and natural light scenarios. The maximum energy value is recorded with a mean of 8.634 points (median of 9.375) in the orange light condition (compared to the natural minimum of 7.537/7.625), the maximum preference value is observed with a mean of 8.500 (median of 9.000) also within the orange condition (versus the natural minimum of 7.771/8.000), and the most pronounced expression of emotional response is again reflected in the orange condition (mean of 3.942 and median of 4.000). The daily comparison with the control group indicates minimal but consistent distinctions. On the first day, all values of the control group exceed those of the experimental group (with both groups located in natural light), while in most coloured light scenarios, the experimental group generally shows marginally higher values.

Table 14. Descriptive values of energy, satisfaction and feeling self-perceived in the different experimental coloured light scenarios.

Cognitive Variables and Dimensions	Natural Light	Orange Light	Green Light	Purple Light
Energy	median 7.625 mean 7.537 n = 60	median 9.375 mean 8.634 n = 56	median 8.500 mean 8.124 n = 59	median 9.000 mean 8.430 n = 57
Satisfaction	median 8.000 mean 7.771 n = 60	median 9.000 mean 8.500 n = 56	median 9.000 mean 8.460 n = 59	median 9.000 mean 8.421 n = 57
Feeling	median 3.875 mean 3.549 n = 60	median 4.000 mean 3.942 n = 59	median 4.000 mean 3.768 n = 59	median 4.000 mean 3.934 n = 57

Table 15. Descriptive values of energy, satisfaction and feeling self-perceived in the different control coloured light scenarios.

Cognitive Variables and Dimensions	Natural Light	Natural2 Light	Natural3 Light	Natural4 Light
Energy	median 8.000 mean 7.806 n = 63	median 8.000 mean 7.534 n = 67	median 8.500 mean 8.138 n = 65	median 8.625 mean 8.102 n = 64
Satisfaction	median 8.000 mean 7.853 n = 63	median 8.000 mean 7.437 n = 67	median 8.000 mean 7.904 n = 65	median 8.000 mean 7.898 n = 64
Feeling	median 4.000 mean 3.593 n = 63	median 3.500 mean 3.531 n = 65	median 4.000 mean 3.821 n = 63	median 4.000 mean 3.722 n = 62

3.3.2. Variance Analysis

The Kruskal–Wallis test indicates that the dimensions of affective processes investigated are statistically significant for both energy and emotions (see Table 16). This

preliminary identification is further elaborated in Table 17 by applying dual post hoc analyses (standard and Dunn’s), although there is a paucity of substantial effect size values (only on one occasion does it reach the average value of $d = 0.5$). Figure 6 presents graphical representations of the analysis of variance for the dimensions of the variable ‘affective processes’.

Table 16. Analysis of variance on energy, satisfaction and feeling self-perceived in different coloured light scenarios of experimental group.

Kruskal–Wallis Test	Energy			Satisfaction			Feeling		
	Factor	statics	df	p	statics	df	p	statics	df
Coloured light scenarios	14.790	3	0.002	6.713	3	0.082	11.475	3	0.009

Table 17. Conover post hoc on the variance of energy, satisfaction and feeling self-perceived in different coloured light scenarios.

Post Hoc Comparisons		Energy			Satisfaction			Feeling		
		Cohen’s d	pbonf	Dunn’s Post Hoc p	Cohen’s d	pbonf	Dunn’s Post Hoc p	Cohen’s d	pbonf	Dunn’s Post Hoc p
Natural	Orange	−0.581	0.012	<0.001	−0.410	0.169	0.035	−0.465	0.079	0.003
	Green	−0.311	0.547	0.128	−0.388	0.212	0.065	−0.260	0.949	0.062
	Purple	−0.473	0.067	0.002	−0.366	0.294	0.023	−0.456	0.087	0.004
Orange	Green	0.270	0.894	0.070	0.022	1.000	0.773	0.205	1.000	0.254
	Purple	0.108	1.000	0.874	0.044	1.000	0.881	0.009	1.000	0.881
Green	Purple	−0.162	1.000	0.097	0.022	1.000	0.659	−0.196	1.000	0.320

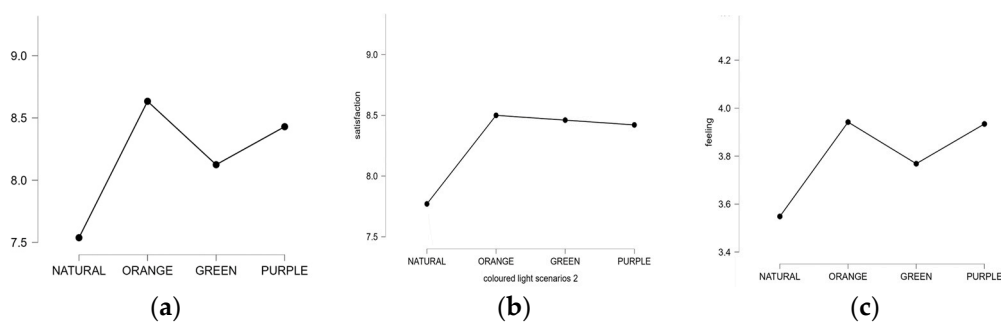


Figure 6. (a) Plot of the variance of the self-perceived energy variable for the four different coloured light scenarios. (b) Plot of the variance of the self-perceived satisfaction variable for the four different coloured light scenarios. (c) Plot of the variance of the self-perceived sensation variable for the four different coloured light scenarios.

3.3.3. Comparative Analysis

In the usual t -test and Mann–Whitney test, we observed only one significant value, corresponding to a satisfaction of $p = 0.022$. Table 18 shows the details of all the day-to-day comparisons.

Table 18. Comparison of energy, satisfaction and feeling self-perceived between experimental and control groups on all experimental days where control group exists.

Independent Samples <i>t</i> -Test and Mann–Whitney	Test	Satisfaction			Energy			Feeling				
		Statistic	df	<i>p</i>	Effect Size	Statistic	df	<i>p</i>	Effect Size	Statistic	df	<i>p</i>
Day 1A Natural light	Student	−0.582		0.563	−0.155	−1.101	0.563	−0.293	0.598		0.552	0.159
	M-W	404.000	62	0.497	−0.105	401.500	62	0.497	−0.111	491.500	62	0.543
Day 2A Orange light	Student	−0.901		0.371	−0.255	−0.688	0.494	−0.195	−1.502		0.138	−0.427
	M-W	360.000	62	0.548	−0.099	359.000	62	0.538	−0.101	284.000	60	0.103
Day 3A Green light	Student	−0.604		0.548	−0.162	1.294	0.200	0.348	−0.118		0.906	−0.032
	M-W	419.500	63	0.666	−0.068	538.000	63	0.207	0.196	403.000	61	0.668
Day 4A Purple light	Student	−0.165		0.870	−0.046	−0.302	0.764	−0.084	−0.215		0.831	−0.061
	M-W	389.000	60	0.919	−0.018	367.000	60	0.653	−0.073	360.000	58	0.760
Day 1B Natural light	Student	−2.397		0.022	−0.768	−1.662	0.105	−0.532	−1.251		0.219	−0.401
	M-W	127.000	37	0.076	−0.332	128.000	37	0.083	−0.326	144.000	37	0.192
Day 2B Green light	Student	0.584		0.563	0.187	0.944	0.351	0.302	−0.262		0.794	−0.084
	M-W	201.000	37	0.765	0.058	226.000	37	0.315	0.189	173.000	37	0.640
Day 3B Purple light	Student	0.445		0.659	0.143	0.536	0.595	0.172	0.052		0.959	0.017
	M-W	237.000	37	0.168	0.247	230.000	37	0.245	0.211	198.500	37	0.818
Day 4B Orange light	Student	1.292		0.204	0.414	1.504	0.141	0.482	1.088		0.284	0.325
	M-W	233.500	37	0.220	0.229	234.500	37	0.209	0.234	222.000	37	0.369

Note. For the Student *t*-test, effect size is given by Cohen’s *d*. For the Mann–Whitney test, effect size is given by the rank biserial correlation.

3.3.4. Summary to Support the Conclusions

It should be noted that the *n*-values exceed those associated with the two summaries contributing to the above conclusions and that coloured lighting conditions, especially in the orange spectrum, yield higher results in the data. The variance within the experimental group corroborates this finding, indicating the generalisability and magnitude of the effects in relation to self-reported energy levels and emotional states. Furthermore, the comparative analysis facilitates the observation that the unfavourable initial conditions for the experimental group (now in all dimensions) can be improved in the different coloured light environments.

3.4. Extreme Values of the Dependent Variables

Table 19 succinctly delineates the primary descriptive statistics for each variable and dimension. The observed maximum and minimum values suggest that the scenarios featuring lighter hues, specifically orange, and intermittently green or violet, consistently produce the most elevated values. Conversely, the lowest values are invariably associated with one of the daylight scenarios within the control group.

Table 19. Maximum and minimum descriptive values of dimensions and variables.

Extreme Values of the Dependent Variables (Dimensions Included)				
	Maximum Value		Minimum Value	
	Mean	Median	Mean	Median
Net Attention (level over 60)	45.552 Natural light4	48.000 Natural light4	35.857 Natural light1	35.500 Natural light1
Impulsivity Control (level over 100)	(control group) 91.974 Purple light (experimental group)	(control group) 96.200 Natural light4 (control group)	(experimental group) 87.406 Natural light1 (control group)	(experimental group) 90.100 Natural light (experimental group)
Figurative Creativity	202.095 Green light (experimental group)	211.000 Purple light (experimental group)	125.633 Natural light1 (control group)	131.000 Natural light1 (control group)
Reading comprehension (level over 22)	19.750 Natural light2 (control group)	21.000 Natural light3 (control group)	16.488 Natural light (experimental group)	17.000 Natural light (experimental group)
Written expression (level over 12)	9.634 Orange light (experimental group)	10.000 Orange-green-purple light (experimental group)	6.268 Natural light (experimental group)	7.000 Natural light (experimental group)
Mathematical competence (level over 13)	9.405 Purple light (experimental group)	10.000 Orange-purple light (experimental group)	7.765 Natural light (experimental group)	8.000 Natural light (experimental group)
Energy	8.634 Orange light (experimental group)	9.375 Orange light (experimental group)	7.534 Natural light2 (control group)	7.625 Natural light (experimental group)
Satisfaction	8.500 Orange light (experimental group)	9.000 Orange-green-purple light (experimental group)	7.437 Natural light2 (control group)	8.000 All natural light (experimental and control groups)
Feeling	3.942 Orange light (experimental group)	4.000 Orange-green-purple light (experimental group) Natural light 1-3-4 (control group)	3.549 Natural light (experimental group)	3.500 Natural light2 (control group)

4. Discussion

The information derived from the current research, which aggregates findings from three experimental conditions described above in relation to coloured light scenarios, yields remarkable implications that facilitate considerable generalisations. In approaching this section systematically, we begin with net attention, considered as a crucial dimension of the variable ‘cognitive processes’. In this regard, the existing literature reveals multiple avenues for discourse. Mogas-Recalde et al. [22], in their analysis of CCT, underline the fundamental role of illumination in attention. At the same time, Hviid et al. [24] state that exposure to cold light improves concentration, while Llinares et al. [23] conclude that high CCT values positively influence attention. Focusing specifically on coloured lighting, Quiles-Rodríguez et al. [12] propose that a dynamic, coloured lighting system can improve the attention of primary school pupils, with the violet phase producing the most favourable results. In a subsequent investigation by the same authors [59], violet light re-emerges as the optimal condition for improving attention. The current study corroborates these findings.

Thus, all scenarios with coloured light in the experimental group show superior results compared to the natural scenario, although the control group shows generally high values (indicating a clearly superior baseline for the control group compared to the experimental group). Particularly noteworthy is the variance of less than 0.001, which translates into posterior analyses favouring coloured light across its entire spectrum, especially in the violet scenario, which shows a remarkably high effect size (0.972).

With respect to impulsivity control, there is a notable paucity of the literature, and only Quiles-Rodríguez et al. [12,59] have made previous contributions. In their initial paper, the authors identified that the violet scenario once again manifested the most convincing values in relation to impulsivity control, a finding they reiterated in their subsequent publication. Based on the current data, we can validate these claims; however, unlike the findings related to attention, the Kruskal–Wallis test of variance does not support broad generalisations, as it does not yield significant p -values, nor do the subsequent post hoc or comparative analysis tests, so we cannot be conclusive on this issue.

In consolidating the facets of the variable ‘cognitive processes’ in the dimension of figurative creativity, we indicate that this has been examined in studies such as those conducted by Kombeiz et al. [5], who concluded that creative tasks are optimally executed under red and blue lighting. In contrast, Quiles-Rodríguez et al. [12] postulated that green light emerged as the most advantageous for enhancing students’ figurative creativity; however, in subsequent research, the same researchers reported more favourable results associated with orange light [59]. Our findings now corroborate the pre-eminence of the green environment when assessing mean descriptive values, although the medians show a slightly altered result favouring the purple environment. In any case, the variance metrics are noteworthy (especially when juxtaposed with the natural pretest), as they are significant at their p -value, so the greater effect size aligns with the green condition in the post hoc analysis (although it is only moderate). Comparative evaluation with the two control groups that participated in different experimental contexts also reveals data supporting both the green and violet conditions.

In the instrumental learning variable, the few references found in the academic literature speak of it as ‘academic performance’ without being very precise. For example, Mogas-Recalde et al. [22] state that the impact of lighting on academic performance has been demonstrated, particularly in relation to CCT. Similarly, research by Jee et al. [39], Choi et al. [40] and Lekan-Kehinde et al. [41] concur on the significant influence of this CCT on academic performance, as already advanced and detailed in the first section of this article. Directly as coloured light, Suh et al. [3] claim that the use of coloured lighting in educational settings has the potential to improve academic performance.

More specifically, when addressing the aspect of mathematical competence, a detailed comparison can be made with the research conducted by Quiles-Rodríguez et al. [12], which emphasises the effects of coloured lighting in educational settings. Their findings indicate that orange and green-lit scenarios yield superior results in terms of mathematical competence compared to alternative lighting conditions, highlighting a bit the green light scenario. In a subsequent study by the same authors [38], the results were divergent and identified violet light as the most conducive; although green light remained notably beneficial, their values were overtaken by the first. More recent data continue to suggest that violet light is the most effective for mathematical competence, and although it yields comparable results to other coloured lighting options, it is still clearly superior to natural lighting. Consequently, a variance value of $p = 0.003$ was obtained, which reinforced the distinction with respect to natural lighting in the subsequent analysis. In this context, the comparative evaluation yields limited significant results inconclusive.

When focusing our attention on reading comprehension and written expression, the studies of Quiles-Rodríguez et al. [12,37] emerge as the main and most directly relevant research sources. In their initial study [12], while all coloured lighting scenarios showed higher values compared to the natural pretest for reading comprehension, violet light proved to be the most effective, and this lighting condition, together with orange, achieved optimal results for written expression. In the subsequent publication [37], orange light reaffirms its position as the most favourable colour for both dimensions of written language competence. The data presented in Section 3 of this article indicate that the orange lighting scenario continues to reflect superior values. An analysis of variance reveals the significance of written expression ($p \leq 0.001$), while comprehension shows a less pronounced significance, a finding corroborated by subsequent tests indicating that the orange scenario shows the largest effect at 1.298. The comparative analysis does not yield particularly remarkable results in this context.

The last variable examined, affective processes, is explicitly derived from research by Suh et al. [3], which is later corroborated by Quiles-Rodríguez et al. [12,34,60]. A parallel discourse can be established with Rajae-Joorden [4], who postulates a higher perception of pleasure in environments illuminated by green or blue light compared to red light, while Mogas-Recalde et al. [22] argue more generally that optimal lighting in classrooms increases visual pleasure. Notably, in the initial study [3], the highest levels of pleasure are achieved with violet lighting, while the second study [12] identifies green lighting as the most pleasurable, subsequently returning to violet in the third study [34] and orange in the fourth [60]. The comprehensive data now presented clearly argues for orange lighting as the optimal enhancer of student satisfaction, although the variance remains statistically insignificant and yields comparable values across all coloured lighting conditions. In the *ex post* analyses, generalisable *p*-values are obtained, especially in the comparisons between orange–natural and violet–natural, and both show interesting effect sizes, indicating that these coloured light environments are preferred over natural light.

As far as energy values are concerned, the scope for further discussion is considerably limited. While there is extensive research on the influence of chromatic energy in its traditional context [31–33], as detailed in the introduction to the article, there is considerably less focus on coloured lighting. Furthermore, as articulated by Lee et al. [35], colour effects are not directly comparable when derived from physical sources and light sources. In relation to the latter, Kombeiz and Steidle [5] state that blue light incites approach behaviour, while red light does not; however, neither of these light sources is incorporated in our experimental conditions. Suh et al. [3] show that peak energy levels are obtained by green light, while Quiles-Rodríguez et al. [12] find energy peaks under violet illumination, followed later by Quiles-Rodríguez et al. [34,60], who observe peak values under orange illumination among students, in contrast to the energy findings. Our current synthesis of results corroborates the facilitation of energy levels by orange lighting, which is particularly noteworthy given that the variance reaches a value of $p = 0.002$, resulting in a *post hoc* analysis that again reveals significant findings in the comparisons between natural orange and natural violet, along with a large effect size. The comparative analyses do not yield particularly remarkable values.

Although Suh et al. [3] incorporate feelings in their self-perception survey, the findings derived from this section are not quantitatively examined in their publication. This omission may be due to the challenges associated with quantifying such feelings to facilitate the establishment of correlations. While there are few educational studies that make comparisons with this variable, we have identified medical research that explores parasympathetic responses in human males (which are somewhat related to emotional states) and their relationship to various coloured light scenarios [9]. This research indicates

that the parasympathetic system shows an increased response to blue light, while showing a decreased reaction to red light. Unfortunately, these particular light scenarios are not included in our independent variable, which limits the discourse around this topic. However, using the coding methodology described in Table 1, which has been designed by Quiles-Rodríguez et al. [12,34,60], we have extended the analysis. Consequently, based on the data presented in Section 3, we can state that all coloured light conditions within the experimental group elicit more favourable emotional responses compared to those involving natural light. Notably, the orange and violet colours yield the highest scores, and the variance between the scenarios is statistically significant, indicated by a p -value of 0.009. Subsequent analyses highlight this significance, specifically in the contrasts between natural orange and natural violet, as both show considerable effect sizes. These findings are consistent with the earlier conclusions of Quiles-Rodríguez et al. [34,60], who subsequently revised their initial research, in which Quiles-Rodríguez et al. [12] identified green as the most influential hue.

From a global perspective, therefore, we find that the three coloured light scenarios alternate in their potentiality according to the dependent variable studied. While in the affective processes as a whole there is a predominance of a better response from students with the orange scenario, in the affective processes the violet condition appears as the dominant one in terms of effectiveness (closely followed by the green condition). The discussion of the conforming dimensions of instrumental learning established a dominance of any coloured versus natural lighting condition, with a slight predominance of the orange condition. From the above, and in the same overall perspective, the green condition is the least preferred after the natural condition. Although we cannot establish a causal why, as this was not the aim or design of this extensive study, this overview does allow us to see the overall impact of coloured lighting.

Table 19 presents a complete aggregation of the extreme values, both maximum and minimum, obtained for all variables (dimensions and/or indicators). The previously established trends in relation to the effectiveness of coloured light are again evident. It is noteworthy that only two of the nine analysed data categories show their maximum values in natural light conditions when considering mean values; on the contrary, three categories show this pattern when examining median values. It is imperative to note that all these natural conditions belong to a control group, which initially yields superior data, in stark contrast to those of the experimental group with regard to certain variables. Similarly, and unequivocally, all minimum values—both means and medians—of all variables, dimensions and indicators are associated with natural lighting scenarios, regardless of whether they belong to the experimental or control group.

The dynamism of coloured lighting, as explained above, can be exploited to optimise its variable conditions. Several scholars advocate the integration of dynamic lighting systems in intelligent educational environments [40], while others make a stronger case for it, albeit in relation to the field of interior design [6]. Suh et al. [3] claim that the advantages of coloured lighting allow for the creation of spaces with appropriate lighting adapted to specific activities. Mogas-Recalde and Palau [22] emphasise the need to adapt lighting to the various activities and requirements of classrooms, a view echoed by Quiles-Rodríguez et al. [12]. Consequently, the identified theoretical frameworks converge on the notion that the dynamism of light, whether coloured or characterised by its CCT, is advantageous. The results presented in this article further reinforce the importance of this dynamism, as they indicate that orange, green or violet lighting is variably optimal depending on different factors, suggesting that these lighting conditions should be used depending on the specific classroom activity. It should be noted that, in contrast to previous authors [12], none of the three types of lighting appears to be directly harmful, as they

do not reach equivalent minimum thresholds (with the exception of orange and green in relation to impulse control). In this regard, the studies by Nieto-Vallejo et al. [61] are very convincing, as they clearly conclude that dynamic lighting can have a great impact on education, specifically on selective and sustained attention, by controlling photometric variables such as colour temperature and illuminance.

Finally, and directly derived from the necessary dynamism of coloured light, authors such as Muñoz et al. [62] highlight that the use of artificial intelligence (AI) could play a key role in managing this dynamism-derived personalisation, as AI possesses the ability to collect, classify and make decisions about the configuration of light at a speed and with an accuracy that surpasses human educators. This is an advance over other authors such as Llurba et al. [63] in advocating the benefits on how Learning Analytics (LA) can be used as a tool provided to aid teacher and student practice and how it can help teachers think and make decisions related to the teaching and learning process, which is considerably more powerful with the use of AI. Moreover, this decision-making can be well managed through digital tools such as the one prototyped by Unciti et al. [64], again more advanced with the assumed integration of AI. So much so that quite recent studies, such as the one by Colomer et al. [65] already use AI to improve student performance through classroom design, which includes, among other factors, lighting where both attention and memory are improved with 6500 K CCT. On a similar note, research by Sajja et al. [66] presents a novel framework for an AI-enabled intelligent assistant that provides personalised and adaptive learning support in higher education using advanced AI and natural language processing techniques to create an interactive and engaging learning platform, which, if adaptive, could be applied to dynamic lighting decision-making. As well as the systematic review by Shi et al. [67] discusses how AI has supported and transformed teaching practices around three prominent pedagogical roles of AI: as an instructional partner, an evaluative partner and a pedagogical decision partner. These roles show how AI can support decision-making in teaching, including areas such as dynamic lighting. Or, as a further demonstration of the assisting power of algorithm-based intelligence on lighting, Fang et al. [68] succeed in building a prototype for real-time, relatively low-error lighting decision-making. Therefore, and although more theoretical than empirical, our discussion has enough documentary sources to believe in the support of teacher decision-making through AI in relation to the empirically shown dynamic lighting.

From the above, and again taking into account the writing of Muñoz et al. [62], it seems quite clear that it remains crucial to recognise that, despite advanced AI capabilities, the final decision-making must still rest with humans, who must take into account social and emotional factors that go beyond the mere data provided by AI systems, ensuring that the application of coloured light is effective and sensitive to the needs of all people involved.

For all these reasons, the impact of coloured lighting in educational environments should not be underestimated. Its effectiveness has been validated by a wide range of experiments related to learning processes. While the benefits may not be evenly distributed across all dimensions tested, the effects appear to be significant. This underlines the importance of its dynamic nature in smart learning environments, as it could involve automation that could be managed by artificial intelligence, which in turn collects data from learners through sensors and physiological metrics. The design of the chromatic lighting framework in classrooms could be differentiated from conventional lighting, which would improve its flexibility and focus on periods considered educationally advantageous. Current LED technology facilitates economical and functional installations, simplifying the integration of improvements in learning outcomes.

On a pedagogical level, educators can choose lighting conditions adapted to the specific activities being carried out and can also combine several lighting conditions in

a single session to suit different tasks. From an administrative point of view, upgrading educational institutions with additional LED lighting represents a rational investment, not only because of its reduced energy consumption, but also because of its negligible heat production. The establishment of a standardised framework by an industry in this field could speed up its adoption, which would represent an interesting niche market.

5. Conclusions

After an exhaustive analysis, it can be concluded that the initial research question that was answered with the articulated hypothesis ‘the use of chromatic lighting in primary school environments favours the development of pupils’ cognitive processes’ is confirmed, which is supported by the results and discussion section of this article, mainly in the Section 3.1.4 created expressly for this purpose.

As for the second hypothesis, aligned with the second research question and referring to the improvement in the acquisition of instrumental learning and expressly stated as ‘the implementation of coloured lighting in primary education classrooms facilitates an improvement in pupils’ achievement of basic instrumental learning’, it has been corroborated once again, supported in the results and discussion section of this article, mainly in Section 3.2.4 which was created expressly for this purpose.

The third hypothesis on pupils’ affective processes is also corroborated, articulated as ‘the implementation of coloured lighting in primary schools facilitates an improvement in pupils’ self-evaluation of affective processes’, again supported in the results and discussion section of this article, mainly in Section 3.3.4 which was created expressly for this purpose.

The fourth hypothesis, articulated as ‘the implementation of “dynamic colour” lighting in primary educational environments offers the advantage of the flexibility of coloured lighting to adapt to the requirements of various activities’, has been effectively corroborated when examined through a thorough analysis of the data collected, revealing no detrimental effects on the process. It is becoming increasingly clear how the inherent dynamic characteristics of different colours can be exploited to the maximum advantage to facilitate different learning experiences and cognitive/instrumental/affective processes, so that one or the other should be selected depending on the educational activity to be carried out.

The last hypothesis that ‘artificial intelligence can be a good assistant for making didactic decisions about dynamic lighting’ is also confirmed by the data obtained in the experimental sample and mainly by providing the confirmed dynamism of light with a broad theoretical basis that gives us a basis for the confirmation of the hypothesis. This has already been discussed in the previous section and, as we said, although we do not have empirical evidence for the same, as it was not the purpose of the study, its theoretical confirmation has been shown.

From the above, practical recommendations are made that allow for a real implementation of the conclusions drawn. In order to improve the cognitive development of students, it is recommended that priority be given to the use of green and violet lighting in classrooms. These lighting conditions have proven to be effective in promoting cognitive processes, while the exclusive use of natural light has shown inferior performance in all dimensions evaluated. In addition, it is essential to use intelligent lighting systems that allow for dynamic adaptation of colours according to the activity and the individual needs of the pupils.

The application of coloured lighting in activities that require sustained attention and figurative creativity is essential. This practice has been shown to improve these skills, provided that lighting levels are monitored to maintain an appropriate balance between visual stimulation and eye comfort. Impulse control in students can benefit from the use of violet lighting.

Coloured lighting can also improve instrumental learning in writing and mathematical competence activities. In this context, orange lighting could be a viable option to support reading comprehension, although no significant improvement in this area has been observed. Students' emotional well-being and energy can be enhanced through the use of lighting in the orange spectrum. Tailoring lighting conditions to the specific needs of each group of students is essential to ensure a comfortable and stimulating learning environment.

The implementation of dynamic lighting systems in classrooms allows for adjustments in colour temperature and intensity according to the type of educational activity. Establishing specific lighting protocols for each subject or activity, such as blue light for concentration, orange for expression and socialisation activities and green for mathematical learning, is beneficial.

6. Limitations and Future Lines of Research

Our coloured light installation, while innovative and creative in its approach, unfortunately does not meet the high standards of a fully professional installation, and there are several areas where it could be significantly improved to achieve a more optimal performance: specifically, we could achieve higher brightness levels, improve the distribution of light throughout the installation and implement a centralised control system that would allow for more precise adjustments. If we were to move to a professional-level installation, we could certainly maximise the aesthetic and functional effects of coloured light, creating a more immersive experience for all participants. In addition, another limitation we face, which at the same time represents a unique opportunity for further exploration and development, is the incorporation of natural light alongside artificial light sources; we have previously recognised that this combination represents an ideal scenario for lighting enhancement, although it is still susceptible to fluctuations caused by atmospheric changes and variable weather conditions. Furthermore, the non-probabilistic sample selection method we have employed limits our ability to make statistically accurate generalisations about the effectiveness of our installation, which restricts the reliability of our results.

Going forward, it is imperative that we contact specialised companies with the expertise and resources to collaborate with us in creating a professional, coloured light installation, thereby improving the overall quality and impact of our project. Furthermore, it should be noted that future research should be extended to cover a variety of educational contexts, not only targeting different levels within primary education, but also extending to other educational stages, as well as considering various geographical and socio-cultural environments that may influence the effectiveness of the coloured light installation. In this sense, we could either continue to use the same colours, which would allow for a more in-depth examination of their effects, or explore the possible advantages of using alternative characteristic colours that may yield different results. Also along these lines, it would be interesting for future research to discern whether there is a contextual effect, so that we have objective data on whether the rural or urban origin of the students, or their socio-economic differences, affect the results of the application of coloured lighting, or whether it helps to reduce academic variability among students and therefore to improve their results more homogeneously.

The integration of physiological sensors, as proposed by Rajae-Joordens [4], has the potential to open up new avenues of research that could greatly improve our understanding of the interaction between coloured light and human cognitive processes. In the near future, this innovative approach could facilitate the automation of coloured light applications by exploiting its dynamic properties, allowing us to delimit spaces in specific sectors that can be personalised to cater to the different cognitive processes of individuals.

Author Contributions: Conceptualization, J.Q.-R. and R.P.; methodology, J.Q.-R. and R.P.; software, J.Q.-R.; formal analysis, J.Q.-R., J.M.M.-S. and R.P.; investigation, J.Q.-R. and R.P.; writing—original draft preparation, J.Q.-R.; writing—review and editing, J.Q.-R. and R.P.; resources, J.Q.-R.; supervision, R.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of Universitat Rovira i Virgili -CEIPSA- (23 November 2023) with the serial number CEIPSA-2023-TD-0009.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Readers can obtain the dataset from the author through <https://drive.google.com/drive/folders/1zt2s7K8V19KGBrxyFFQm8vChn-Tq5Igs?usp=sharing> (accessed on 24 March 2025).

Acknowledgments: To all the students, families, teachers and educational centres that have made this experiment possible.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

AI	Artificial intelligence
CCT	Correlated colour temperature
GO	General objective
SO	Specific objective
RQ	Research question
H	Hypotheses
V	Variable
LED	Light-emitting diode

References

- Quiles-Rodríguez, J.; Palau, R. Effects of Classroom Colour on Learning Processes for a Future Smart Classroom: A Systematic Review. In *Challenges of the Educational System in Contemporary Society*; Antolí, J., Ed.; IGI Global: Hershey, PA, USA, 2023; pp. 222–241. [\[CrossRef\]](#)
- Arbona Hidalgo, L. Estudio de la Influencia de la Iluminación en la Percepción de los Estudiantes Universitarios. Ph.D. Dissertation, Universitat Politècnica de València, Valencia, Spain, 2021.
- Suh, J.K.; Park, E.K.; Iwamoto, D. Color-filtered lighting: Visual and emotional impact in learning environments. *Intern. J. Arch. Spat. Environ. Des.* **2020**, *14*, 41–55. [\[CrossRef\]](#)
- Rajae-Joordens, R.J.E. The Effects of Colored Light on Valence and Arousal. In *Philips Research Book Series*; Westerink, J., Krans, M., Ouwkerk, M., Eds.; Springer: Berlin/Heidelberg, Germany, 2010; Volume 12, pp. 65–84. [\[CrossRef\]](#)
- Kombeiz, O.; Steidle, A. Facilitation of creative performance by using blue and red accent lighting in work and learning areas. *Ergonomics* **2018**, *61*, 456–463. [\[CrossRef\]](#) [\[PubMed\]](#)
- Poldma, T. Learning the dynamic processes of color and light in interior design. *J. Inter. Des.* **2009**, *34*, 19–33. [\[CrossRef\]](#)
- Hogewoning, S.W.; Trouwborst, G.; Maljaars, H.; Poort, H.; Van Leperen, W.; Harbinson, J. Blue light dose-responses of leaf photosynthesis, morphology, and chemical composition of *Cucumis sativus* grown under different combinations of red and blue light. *J. Exp. Bot.* **2010**, *61*, 3107–3117. [\[CrossRef\]](#)
- Johkan, M.; Shoji, F.; Goto, F.; Hahida, S.; Yoshihara, T. Effect of green light wavelength and intensity on photomorphogenesis and photosynthesis in *Lactuca sativa*. *Environ. Exp. Bot.* **2010**, *75*, 128–133. [\[CrossRef\]](#)
- Araujo, J.; Rodriguez, M.J.; Postolache, O.; Cercas, F.; Martín, F.F.; Martínez, A.L. Heart Rate Variability Analysis in Healthy Subjects Under Different Colored Lighting Conditions. In Proceedings of the IEEE International Instrumentation and Measurement Technology Conference (I2MTC), Dubrovnik, Croatia, 25–28 May 2020; IEEE: Piscataway, NJ, USA, 2020. [\[CrossRef\]](#)
- Jiang, A.; Schlacht, I.L.; Yao, X.; Foing, B.; Fang, Z.; Westland, S.; Hemingray, C.; Yao, W. Space Habitat Astronautics: Multicolour Lighting Psychology in a 7-Day Simulated Habitat. *Space Sci. Technol.* **2022**, *2022*, 9782706. [\[CrossRef\]](#)

11. Manca, S.; Cerina, V.; Tobia, V.; Sacchi, S.; Fornara, F. The effect of school design on users' responses: A systematic review (2008–2017). *Sustainability* **2020**, *12*, 3453. [CrossRef]
12. Quiles-Rodríguez, J.; Palau, R. Effects of colored lighting on learning processes: Towards a smart classroom. *J. Technol. Sci. Educ.* **2024**, *14*, 484–506. [CrossRef]
13. Von Castell, C.; Stelzmann, D.; Oberfeld, D.; Welsch, R.; Hecht, H. Cognitive performance and emotion are indifferent to ambient color. *Color Res. Appl.* **2017**, *43*, 65–74. [CrossRef]
14. Godwin, K.; Leroux, A.; Scupelli, P.; Fisher, A. Classroom Design and Children's Attention Allocation: Beyond the Laboratory and into the Classroom. *Mind Brain Educ.* **2022**, *16*, 239–251. [CrossRef]
15. Barrett, P.; Davies, F.; Zhang, Y.; Barrett, L. The impact of classroom design on pupils' learning: Final results of a holistic, multi-level analysis. *Build. Environ.* **2015**, *89*, 118–133. [CrossRef]
16. Barrett, P.; Davies, F.; Zhang, Y.; Barrett, L. The Holistic Impact of Classroom Spaces on Learning in Specific Subjects. *Environ. Behav.* **2017**, *49*, 425–451. [CrossRef] [PubMed]
17. Smith, E.E.; Kosslyn, S.M. *Cognitive Psychology. Mind and Brain*; Pearson Education Limited: Harlow, UK, 2014.
18. Mehta, R.; Zhu, R.J. Blue or red? Exploring the effect of color on cognitive task performances. *Science* **2009**, *5918*, 1226–1229. [CrossRef]
19. Duyan, F.; Ünver, R. A research on the effect of classroom wall colours on student's attention. *A/Z ITU J. Fac. Architec.* **2016**, *13*, 73–78. [CrossRef]
20. Tuszyńska-Bogucka, W.; Borys, M.; Dzieńkowski, M.; Kwiatkowski, B.; Kocki, W.; Pełka, J.; Bogucki, J. Use of Eye Tracking for Designing of Learning Spaces. In Proceedings of the ICERI2018 Proceedings 11th Annual International Conference of Education, Research and Innovation Seville, Spain, 12–14 November 2018; IATED: Seville, Spain, 2018; pp. 5360–5368. [CrossRef]
21. Pourbagher, S.; Azemati, H.R.; Saleh Sedgh Pour, B. Classroom wall color: A multiple variance analysis on social stress and concentration in learning environments. *Int. J. Educ. Manag.* **2020**, *35*, 189–200. [CrossRef]
22. Mogas-Recalde, J.; Palau, R. Classroom lighting and its effect on student learning and performance: Towards smarter conditions. *Smart Innovat. Syst. Tech.* **2021**, *197*, 3–12. [CrossRef]
23. Llinares, C.; Castilla, N.; Higuera-Trujillo, J.L. Do attention and memory tasks require the same lighting? A study in university classrooms. *Sustainability* **2021**, *13*, 8374. [CrossRef]
24. Hviid, C.; Pedersen, C.; Dabelsteen, K. A field study of the individual and combined effect of ventilation rate and lighting conditions on pupils' performance. *Build. Environ.* **2020**, *171*, 106608. [CrossRef]
25. Gross, R. *Psychology: The Science of Mind and Behaviour*, 7th ed.; Hodder Education: London, UK, 2015.
26. Mora, F. *Neuroeducación, Solo Se Puede Aprender Aquello Que Se Ama*; Alianza Ensayo: Madrid, Spain, 2013.
27. Lewinski, P. Effects of classrooms' architecture on academic performance in view of telic versus paratelic motivation: A review. *Front. Psych.* **2015**, *6*, 746. [CrossRef]
28. Vidal Rojas, R.A.; Vera Avendaño, C. Influencia del color del aula en los resultados de aprendizaje en 3 año básico: Estudio comparativo en un colegio particular subvencionado en Santiago de Chile. *Rev. Educ.* **2020**, *44*, 91–113. [CrossRef]
29. Stone, N. Designing effective study environments. *J. Environ. Psychol.* **2001**, *21*, 179–190. [CrossRef]
30. Gilavand, A. Investigating the Impact of Environmental Factors on Learning and Academic Achievement of Elementary Students: Review. *Inter. Jour. Med. Res. H. Sci.* **2016**, *5*, 360–369.
31. Englebrecht, K. The Impact of Color on Learning. Available online: <http://sdpl.coe.uga.edu/HTML/W305.pdf> (accessed on 1 November 2024).
32. Küller, R.; Mikellides, B.; Janssens, J. Color, arousal, and performance—A comparison of three experiments. *Color Res. Appl.* **2009**, *34*, 141–152. [CrossRef]
33. Salleh, N.M.; Kamaruzzaman, S.N.; Riley, M.; Ahmad Zawawi, E.M.; Sulaiman, R. A quantitative evaluation of indoor environmental quality in refurbished kindergarten buildings: A Malaysian case study. *Build. Environ.* **2015**, *94*, 723–733. [CrossRef]
34. Quiles-Rodríguez, J.; Mateo-Sanz, J.M.; Palau, R. How does Coloured Lighting Influence the Affective Processes of Pupils? *Interact. Des. Arch. J.* **2024**, *60*, 103–121. [CrossRef]
35. Lee, H.; Park, J.; Lee, J. Comparison between psychological responses to 'object colour produced by paint colour' and 'object colour produced by light source. *Indoor Built Environ.* **2021**, *30*, 502–519. [CrossRef]
36. Ley Orgánica 3/2020, de 29 de Diciembre, por la que se Modifica la Ley Orgánica 2/2006, de 3 de Mayo, de Educación. BOE núm. 340. Available online: <https://www.boe.es/eli/es/lo/2020/12/29/3> (accessed on 22 March 2025).
37. Quiles-Rodríguez, J.; Palau, R. Efectos de la luz de color sobre la competencia lingüística escrita del alumnado de Primaria. *Prof. Rev. Curric. Form. Profr.* **2024**, *28*, 179–200. [CrossRef]
38. Quiles-Rodríguez, J.; Palau, R. ¿Puede la luz de color ayudar a mejorar la adquisición de la competencia matemática? In *Innovación e Investigación con Tecnología Educativa: Explorando las Posibilidades de la Educación del Futuro*; Tejada Garitano, E., Garay Ruiz, U., López de la Serna, A., Eds.; Dykinson: Madrid, Spain, 2024.

39. Jee, S.D.; Kim, C.B. Subjective evaluation on the color temperatures of LED illumination in the classroom. *J. Korean Inst. Illum. Electr. Install. Eng.* **2011**, *25*, 30–41. [[CrossRef](#)]
40. Choi, K.; Suk, H. Dynamic lighting system for the learning environment: Performance of elementary students. *Opt. Express* **2016**, *24*, A907–A916. [[CrossRef](#)]
41. Lekan-Kehinde, M.; Asojo, A. Impact of lighting on children’s learning environment: A literature review. *WIT Trans. Ecol. Environ.* **2021**, *253*, 371–380. [[CrossRef](#)]
42. Plympton, P.; Conway, S.; Epstein, K. Daylighting in Schools: Improving Student Performance and Health at a Price Schools Can Afford. In Proceedings of the American Solar Energy Society Conference, Madison, WI, USA, 16 June 2000.
43. López-Villanueva, D.; Palau, R.; Santiago, R. ¿Cómo puede la IA ayudar a la personalización del aprendizaje? In *Inteligencia Artificial en la Microeducación: Transformando el Aula del Futuro*; Muñoz, J.M., Lorenzo, N., Suñé, X., Eds.; Observatorio de Innovación Educativa y Cultura Digital (ODITE): Barcelona, Spain, 2024.
44. Román-García, M.; Prendes-Espinosa, M.P. El informe del TFM. In *Trabajo Fin de Máster en Tecnología Educativa. Orientaciones para la Elaboración y Criterios de Calidad*; Prendes Espinosa, M.P., González Calatayud, V., Eds.; Universidad de Murcia: Murcia, Spain, 2018; pp. 59–67.
45. López Fuentes, R.; Salmerón Vilchez, P. Proceso de Investigación Educativa I: Investigación Experimental. In *Innovación Docente e Investigación Educativa. Máster Universitario de Educación Secundaria Obligatoria y Bachillerato, Formación Profesional y Enseñanza de Idiomas*; López Fuentes, R., Ed.; Universidad de Granada: Granada, Spain, 2011; pp. 24–40. Available online: <https://dialnet.unirioja.es/servlet/articulo?codigo=3855936> (accessed on 15 March 2025).
46. Campbell, D.T.; Stanley, J.C. *Experimental and Quasi-Experimental Designs for Research*; Rand McNally & Company: Chicago, IL, USA, 1966.
47. Luri, G. *La Escuela No Es un Parque de Atracciones. Una Defensa del Conocimiento Poderoso*; Ariel: Barcelona, Spain, 2020; p. 410.
48. Toala Ponce, S.R.; Gómez Pinillo, L.Y.; Guevara Heredia, R.N.; Quiñonez Ortiz, E.C. Application of Bloom’s taxonomy to improve teaching-learning. *Sapientia Int. J. Interdis. Stud.* **2022**, *3*, 176–189. [[CrossRef](#)]
49. Artiles Hernández, C.; Jiménez González, J.E.; Rodríguez Rodríguez, C.; García Miranda, E. *Adaptación y Baremación del Test de Pensamiento Creativo de Torrance: Expresión Figurada. Educación Primaria y Secundaria*; Consejería de Educación, Cultura y Deportes del Gobierno de Canarias, Dirección General de Ordenación e Innovación Educativa: Santa Cruz de Tenerife, Spain, 2007.
50. Thurstone, L.L.; Yela, M. *Caras-R. Test de Percepción de Diferencias-Revisado. Manual*, 13th ed; TEA Ediciones: Barcelona, Spain, 2019.
51. Agencia Andaluza de Evaluación Educativa (AGAEVE). *Evaluación Final de Educación Primaria. Competencia Lingüística*; Junta de Andalucía: Seville, Spain, 2017.
52. Agencia Andaluza de Evaluación Educativa (AGAEVE). *Evaluación Final de Educación Primaria. Competencia Matemática*; Junta de Andalucía: Seville, Spain, 2017.
53. Agencia Andaluza de Evaluación Educativa (AGAEVE). *Evaluación Final de Educación Primaria. Competencia Lingüística*; Junta de Andalucía: Seville, Spain, 2018.
54. Agencia Andaluza de Evaluación Educativa (AGAEVE). *Evaluación Final de Educación Primaria. Competencia Matemática*; Junta de Andalucía: Seville, Spain, 2018.
55. Agencia Andaluza de Evaluación Educativa (AGAEVE). *Evaluación Final de Educación Primaria. Competencia Lingüística*; Junta de Andalucía: Seville, Spain, 2019.
56. Agencia Andaluza de Evaluación Educativa (AGAEVE). *Evaluación Final de Educación Primaria. Competencia Matemática*; Junta de Andalucía: Seville, Spain, 2019.
57. European Parliament. Reglamento (UE) 2016/679 del Parlamento Europeo y del Consejo, de 27 de Abril de 2016, Relativo a la Protección de las Personas Físicas en lo Que Respecta al Tratamiento de Datos Personales y a la Libre Circulación de Estos Datos y por el Que se Deroga la Directiva 95/46/CE (Reglamento General de Protección de Datos). DOUE núm. 119. Available online: <https://www.boe.es/doue/2016/119/L00001-00088.pdf> (accessed on 22 March 2025).
58. Ley Orgánica 3/2018, de 5 de Diciembre, de Protección de Datos Personales y Garantía de los Derechos Digitales. BOE núm. 294. Available online: <https://www.boe.es/eli/es/lo/2018/12/05/3> (accessed on 22 March 2025).
59. Quiles-Rodríguez, J.; Palau, R. New evidence on the influence of coloured lighting on pupil’ cognitive processes. *Electronics* **2024**, *13*, 3005. [[CrossRef](#)]
60. Quiles-Rodríguez, J.; Palau, R. New evidence on the influence of coloured lighting on pupils’ affective processes. In *Educación 360: Emociones, Tecnología, Evaluación e Inclusión en la Era Digital*; Romero García, C., Buzón García, O., Eds.; Dykinson: Madrid, Spain, 2024.
61. Nieto-Vallejo, A.E.; Camacho, J.E.; Cuervo-Pulido, R.; Hernandez-Mihajlovic, E. Dynamic Lighting System to Increase the Attention of Design Students in the Classroom. *Revist. Facult. Ingen.* **2021**, *30*, e12233. [[CrossRef](#)]
62. Muñoz, J.M.; Lorenzo, N.; Suñé, X. Inteligencia artificial en la Microeducación: Transformando el Aula del Futuro. In *Inteligencia Artificial en la Microeducación: Transformando el Aula del Futuro*; Muñoz, J.M., Lorenzo, N., Suñé, X., Eds.; Observatorio de Innovación Educativa y Cultura Digital (ODITE): Barcelona, Spain, 2024.

63. Llurba, C.; Palau, R.; Mogas, J. Learning Analytics for Smart Classrooms. In *Encyclopedia of Data Science and Machine Learning*; Wang, J., Ed.; IGI Global Scientific Publishing: Hershey, PA, USA, 2023; pp. 1717–1731. [[CrossRef](#)]
64. Unciti, O.; Palau, R. Teacher decision making tool: Development of a prototype to facilitate teacher decision making in the classroom. *J. Technol. Sci. Educ.* **2023**, *13*, 740–760.
65. Colomer Granero, A.; Higuera Trujillo, J.L.; Naranjo Ornedo, V.; Llinares Millán, M.D.C. La Inteligencia Artificial y su contribución a la optimización de la atención y memoria de los estudiantes a través del diseño del aula. In Proceedings of the EDIFICATE. I Congreso de Escuelas de Edificación y Arquitectura Técnica de España, Valencia, Spain, 4–5 November 2021; Universitat Politècnica de València: Valencia, Spain, 2021; pp. 473–482. [[CrossRef](#)]
66. Sajja, R.; Sermet, Y.; Cikmaz, M.; Cwiertny, D.; Demir, I. Artificial Intelligence-Enabled Intelligent Assistant for Personalized and Adaptive Learning in Higher Education. *Information* **2024**, *15*, 596. [[CrossRef](#)]
67. Shi, L.; Choi, I. A Systematic Review on Artificial Intelligence in Supporting Teaching Practice: Application Types, Pedagogical Roles, and Technological Characteristics. In *Uses of Artificial Intelligence in STEM Education*; Zhai, X., Krajcik, J., Eds.; Oxford University Press: Oxford, UK, 2024. [[CrossRef](#)]
68. Fang, P.; Wang, M.; Li, J.; Zhao, Q.; Zheng, X.; Gao, H. A Distributed Intelligent Lighting Control System Based on Deep Reinforcement Learning. *Appl. Sci.* **2023**, *13*, 9057. [[CrossRef](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.