OmniaScience

Journal of Technology and Science Education

JOTSE, 2024 – 14(2): 484-506 – Online ISSN: 2013-6374 – Print ISSN: 2014-5349

https://doi.org/10.3926/jotse.2236

EFFECTS OF COLORED LIGHTING ON LEARNING PROCESSES: TOWARDS A SMART CLASSROOM

José Quiles-Rodríguez[1*], Ramon Palau[2]

[1]Consejería de Desarrollo Educativo y Formación Profesional, Junta de Andalucía (Spain)

[2]Department of Pedagogy, Universitat Rovira i Virgili (Spain)

[*]*Corresponding author: jquirod512@g.educaand.es*
ramon.palau@urv.cat

Received May 2023
Accepted September 2023

Abstract

Colour in the classroom, either in isolation or in conjunction with other environmental factors, is an element that has been widely discussed in the scientific literature, albeit not systematically. On the other hand, its evolution towards coloured light, made possible in recent years by light emitting diode (LED) technology, has hardly found a place among researchers. Despite the progressive rise of smart classrooms, intelligent learning environments or references by some authors to "dynamic lighting", its analogous concept, "dynamic colour", hardly appears in reviews of the scientific literature. This exploratory, quasi-experimental study shows how coloured light affects the learning process in primary school classroom environments, integrating cognitive processes, instrumental learning and affective processes, and helping to define the dynamic potential of its use. The experimental part has been carried out for four weeks, collecting data that are analysed descriptively, comparatively with the control group and in the internal variance of the experimental group. The results show positive influence tendencies in the cognitive and affective processes of the students, although not so much in instrumental learning.

***Keywords* –** Educational environment, Light colour, Cognition, Emotional development, Dynamic colour, Learning environment.

To cite this article:

Quiles-Rodríguez, J., & Palau, R. (2024). Effects of colored lighting on learning processes: Towards a smart classroom. *Journal of Technology and Science Education,* 14(2), 484-506. https://doi.org/10.3926/jotse.2236

----

1. Introduction

While classroom colour has been studied since the middle of the last century with multiple analyses, "coloured light" has not (Quiles-Rodríguez & Palau, 2023). In learning spaces where technology-enhanced enjoyment, efficiency and effectiveness are sought, as indicated by Goodyear and Retalis (2010), the improvement of academic performance is likely to be evident with the introduction of coloured lighting (Suh, Park & Iwamoto, 2020). Even more so considering the possibility of its dynamism, little studied educationally according to Poldma (2009), although it has been done with "dynamic lighting" (Mogas-Recalde & Palau, 2021).

Only three studies shed some light on the subject: Rajae-Joordens (2010), Kombeiz and Steidle (2018) and Suh et al. (2020). A fourth article, Mogas-Recalde and Palau (2021), while not focusing on coloured light directly, is interesting in terms of its contribution to classroom lighting in general and its consideration of dynamism.

The research by Rajae-Joordens (2010) is carried out exclusively in a laboratory environment linked to the company Philips Research, using 20 of its employees. Both human arousal and liking are measured subjectively and objectively in relation to the variable coloured light. The subjective measurements are based on self-perception questionnaires, which are common in this type of work, and the objective measurements are based on data collected by technical instruments for the analysis of psychophysiological manifestations. The results of the study show no overlap between the two measurements.

The study by Kombeiz and Steidle (2018), framed in the field of ergonomics and psychology within a German university, is a quantitative study which aims to test two hypotheses in relation to blue and red light (approach motivation and creativity). The article coins the concept of "context colour". A total of 146 individuals with an average age of 21 participated in the experiment, validating both hypotheses. It is considerable the appreciation that they consider themselves as "one of the few works that bridges the gap between colour and lighting research" (Kombeiz and Steidle, 2018: page 14), recognising interesting implications for the design of workplaces for creative activities.

The study by Suh et al. (2020) shows a connection between the emotional state of students and colour-filtered lighting. The experimentation, conducted in the USA in two different contexts, one with 25 students and four instructors in an interior design studio, and the other with 33 students and three instructors in an education classroom (ages 18-45), suggests that coloured lighting can have an effect on students' mood, energy and level of liking. Overall, students had higher levels of liking under purple filtered lighting (relaxing and calming effect), while they felt more energetic under green light. This leads to the suggestion that future studies can explore how different coloured lighting affects a student's psychological states. Continued research on the relationship between coloured lighting and emotional state can guide designers to create an environment with coloured lights appropriate for different activities, including integrating their dynamic nature.

The work of Mogas-Recalde and Palau (2021) consists of a systematic review of the literature on classroom lighting, focusing on the effect of lighting on learning processes. The combination of natural and artificial light is seen as the optimal classroom state for better student attention and academic performance, highlighting the dynamism of classroom lighting.

It is curious that three of the articles located do not occur until 2018, 2020 and 2021, and even more so that only the second of these, Suh et al. (2020), occurs in the classroom setting. And even more so that they barely focus on what will be dependent variable "cognitive processes" or "instrumental learning" being much more linked to affect, energy, liking, emotion, arousal. The article by Kombeiz and Steidle (2018) does focus on creativity, serving as a precedent for this study as will be seen in the discussion section.

It seems that education is missing out on the possibilities offered by technology, especially when educational research tends to be ahead of practice, which suggests that it will not be many years before coloured light reaches the classroom.

2. Questions, Hypothesis and Objetives

The above-mentioned scientific vacuum on the use of coloured light in the classroom poses a research problem that we now address through two general questions: How does coloured light influence learning processes in the classroom? What is the potential of "dynamic colour" in terms of its contribution to learning processes in the classroom? With the first question, we intend to explore whether and in what sense coloured light influences learning processes of different kinds in the classroom environment. Purely curricular instrumental learning, the work of different cognitive processes that are characteristically human and their affects are of interest. None of the previous studies have been carried out in primary sschool contexts, nor have they taken into account as many variables as those we will explore here. Our approach is exploratory, therefore broad and dispersed, as it seeks to obtain data on as many variables as possible (Ramírez, 2003).

The second of the questions seeks to delve into the dynamic specificity of coloured light, since it is not a question of exploring its influence on learning processes, but of knowing the specific associations of certain colours with certain learning processes, to their benefit or detriment, allowing the instantaneous selection of different types of colours thanks to LED lighting. Such a dynamic conception is impossible with the traditional conception of classroom colour. Now the educational impact of coloured light can be greater, becoming an important element in the design of future smart-classrooms.

On a more concrete level, our 4 research questions emerge. Knowing the FINER criteria -feasible, interesting, novel, ethical, relevant- on the assessment of research questions as collected by Eschenhagen, Vélez-Cuartas, Maldonado and Pino (2018), we pose them as follows:

RQ1. How does coloured light affect students' cognitive processes in primary school classroom settings?

RQ2. How does coloured light affect students' instrumental learning in primary classroom settings?

RQ3. How does coloured light affect students' affective processes in primary classroom settings?

RQ4. What are the benefits and drawbacks of using "dynamic colour" in primary school classroom settings?

Hence, our specific goals expressed in the form of specific objectives are:

SO1. To show the incidence of coloured light on the cognitive processes of pupils in primary school classroom environments.

SO2. To show the incidence of coloured light on the basic instrumental learning of pupils in primary education classroom environments.

SO3. To show the incidence of coloured light on the affective processes of pupils in primary classroom settings.

SO4.To analyse the benefits and drawbacks of using "dynamic colour" in primary school classroom environments.

In order to answer this question, we carried out a quasi-experimental exploratory approach that will try to "determine trends, identify potential relationships between variables and set the tone for further, more rigorous research" (Dankhe, 1986: page 412). It involved two research groups from a primary school, an experimental and a control group. A total of 75 individuals took five different tests during the month of March 2021.

Speculating on the possible response to the problem posed when formulating the hypotheses (Buendía et al, 2001, as cited in Román-García & Prendes 2018) and aware of the variables handled, the existing theoretical framework, the purpose of being empirically contrasted as well as their clarity of definition (López Fuentes & Salmerón Vilchez, 2011), the hypotheses proposed are:

H1. The use of coloured light in primary education classroom environments generates an improvement in the development of students' cognitive processes.

H2. The use of coloured light in primary education classroom environments generates an improvement in the acquisition of instrumental learning in students.

H3. The use of coloured light in primary school classroom environments leads to an improvement in the self-perception of the pupils' affective processes.

H4. The use of "dynamic colour" in primary school classroom environments has the benefit of the adaptability of coloured light to the needs of each activity.

From the above we draw our general objectives, being:

GO1. To study the influence of coloured light on learning processes in primary school classroom environments.

GO2. To explore the potential of "Dynamic Colour" in primary school classroom environments for its contribution to learning processes.

3. Methodology

This is a quantitative exploratory quasi-experimental study with a control group as we can see in the research overview in Figure 1. According to Castañeda (2018) in Social Sciences, the control of all variables is almost impossible, with extraneous variables frequently appearing, making it difficult to establish cause-effect and, therefore, necessarily being quasi-experimental. It is appropriate to point out that no pre-test or post-test is carried out in this study, but there is a control group with which to carry out a comparative analysis, in addition to the analysis of variance in the four scenarios of the experimental group itself, thus achieving greater consistency. With this analysis, which we present in the results section, we will try to confirm or refute the hypotheses set out above, for which we make use of the variables described below.

The independent variable is coloured light in class. Based on the aforementioned study by Suh et al. (2020), the coloured light will establish four experimental scenarios: natural light (exclusively natural light, without interference from other light), orange light, green light and violet light (these three mixed with natural light). Suh et al. (2020) justify the use of the three artificial orange-green-violet components as they are very frequent colours in nature. Unlike them, we decided not to completely eliminate the influence of natural light, as research such as Barrett et al. (2015, 2017) supports the combination of natural and artificial light as the optimal classroom situation.

The dependent variables whose influence is measured are: cognitive processes, instrumental learning and affective processes. The approach to these variables is not intended to cover them in their entirety, which is impossible for this work, but is consistent with our exploratory, broad and dispersed nature (Ramírez, 2003). Thus:

V1. Cognitive processes: We will measure three of its dimensions (figurative creativity, net attention and impulsivity control). Kombeiz and Steidle (2018) have conducted a similar study regarding creativity, although with a different approach and way of measurement (see discussion). We obtain figurative creativity through four indicators: originality, elaboration, fluency and flexibility.

V2. Instrumental learning: We will measure in two of its dimensions (written linguistic competence and mathematical competence). The written linguistic competence score is obtained through two indicators: written expression and written comprehension.

V3. Affective processes: We will measure in three of its dimensions (level of liking, level of energy and feelings). The third dimension is nominal but coded to number for statistical analytical treatment.

Aware of the particularity of the social sciences, we do not rule out the presence of extraneous variables. According to Bisquerra-Alzina (2009) we understand that these can influence the results, although they are not a controlled part of the experiment. Isolating such influence is important, but not always possible. In our approach, we have detected some of them, such as the fact that each class has different students, with different teachers. In addition, although we have not carried out a pre-test or post-test due to time constraints, we do have data on the different average academic levels of each group in relation to the instrumental areas and prior to the experimentation. Another possible extraneous variable is the design of the experimental group as incompletely counterbalanced, dividing it into subgroups that perform different tests each day. In this way, not all subjects perform the same tests with the same scenarios, which could affect the final result. The last two extraneous variables foreseen are the incidence of natural light, which by its very nature is changeable, and absenteeism due to Covid. The study was carried out with sixth grade students. The overview of all variables can be seen in Table 1.

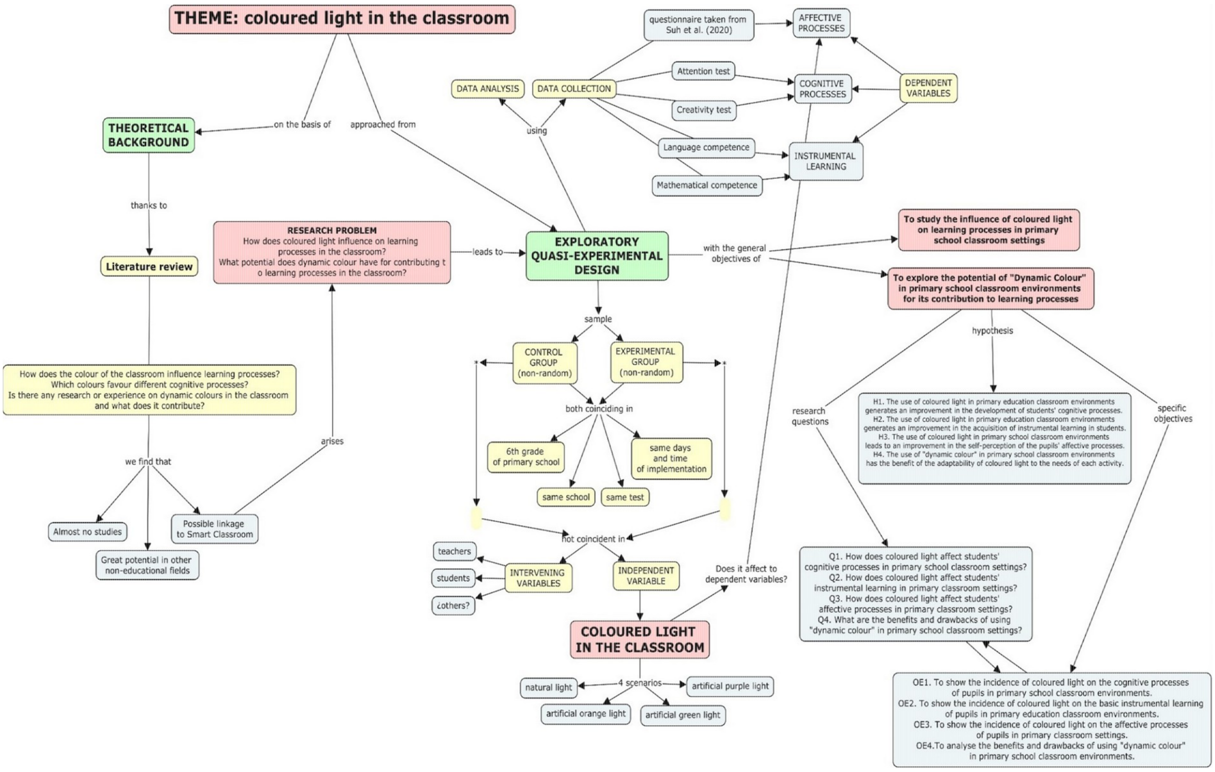

Figure 1. Overall view of the research

Variable type	Variables in this experimental situation	Independent variable scenarios	Dimensions and indicators of some dependent variables
Independent variable	Colour light	Natural light Orange light Green light Purple light	
Dependent variables	Cognitive processes		Figurative creativity (indicators: originality, elaboration, fluency, flexibility) Attention Impulsivity control
	Affective processes		Level of satisfaction Energy level Feeling
	Instrumental learning		Written linguistic competence (indicators: written expression, reading comprehension) Mathematical competence
Odd variables	Different teachers in different classes Different students in different classes Different previous levels Changing natural light Absenteeism aggravated by COVID situation Different pupil in incomplete counterbalanced design		

Table 1. Complete view of variables, dimensions and indicators

Regarding the incomplete counterbalanced design subdividing the experimental group into four internal subgroups, with each subgroup performing one of the test-tests on each test day (light scenario), it was necessary to avoid:

- Incidence of the memory or learning effect (Chacón-Moscoso & Sanduvete-Chávez, 2018): If the same subjects performed the same tests on nearby days, this effect would make the results of the latter scenarios better than those of the first days.
- Excessive duration: The tests are designed to take an actual average of 45 minutes. If all students in the experimental group (25 students) were to take all the tests in all the scenarios, we would have to spend 16 evaluation moments. Since each data collection is done on a weekly basis (to avoid motivation effect) this would mean 16 weeks, which is too long for the school and the students.

Thus, at the end of four weeks all subgroups have taken all the tests, but not all have taken them in the same lighting conditions (Figure 2). This causes the value of "n" in each scenario to drop. Therefore, according to Cuestas (2010) we cannot speak of a cross-case design (the comparisons are not exactly intrasubject) but of an incomplete counterbalanced design (Barroso, 2015).

Our design includes a control group, although this is neither necessary nor usual in a counterbalanced design. Given the exploratory character, the control group allows for comparative analyses that not have been possible otherwise, adding relevant improvements to the study. In order not to increase the expected extraneous variables, the control group performs the same incomplete counterbalanced design described above, on the same days and at the same time as the experimental group, the teachers having received the same exhaustive oral and written instructions. The test-tests are carried out every Friday in March 2021 at 10:00h. The aim is also to avoid the Hawthorne motivation effect in the experimental group by exposing them to coloured light for one hour on each of the four days prior to the test-test each week, inspired by Suh et al. (2020).

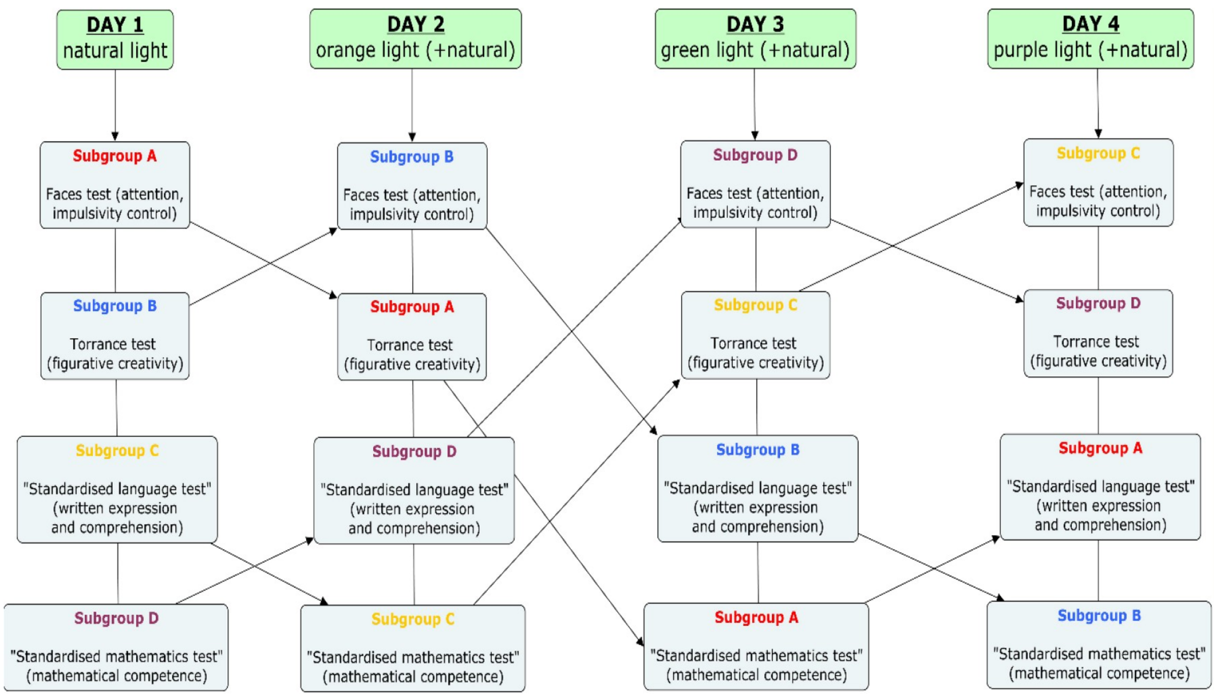

Figure 2. Incomplete counterbalanced design of the subgroups of the experimental group

3.1. Sample

The participants in this study were 75 pupils, n = 25 were the experimental group and n = 50 the control group. It is a non-probabilistic sample made up of the sixth grade class-groups of CEIP EL TEJAR, an infant and primary school, respecting the previous configuration of the centre. The experimental group is the group-class in whose classroom the technological interventions necessary to have coloured light have been carried out, while the control group is made up of the other two groups-classes that complete the level. Although it would have been sufficient to use only one of the class-groups, for various ethical considerations we have used both class-groups. The ages of the pupils range between 11 and 12 years. The special conditions of the pandemic situation have increased absenteeism and have had an intermittent effect on school attendance.

3.2. Ethical Considerations

The code of ethics established for educational research by the American Educational Research Association (2011) is governed by the principles of professional competence, integrity, professional-scientific-academic responsibility, respect for the rights, dignity and diversity of individuals, and social responsibility. In this context, under standard 5, "avoidance of harm", and standard 2, "non-discrimination", we understood that the entire sixth-grade student body had to participate in the designed tests. Standard 13 on "informed consent" was respected from the beginning of the contacts with the school. Standard 12 on "confidentiality" is taken into account at all times, being aware of the legal provisions on data protection, both at European and national level (DOUE, 2016; BOE, 2018). Other ethical standards are always present in educational research, such as absence of conflict of interest, public communications or authorship credit.

3.3. Context of the Study. Experimental Situation

The study was carried out in the sixth year of primary school named "EL TEJAR" (Figure 3), an infant and primary school located in Fuengirola (Malaga). With an expected participation of 75 pupils, although affected by absenteeism due to the special pandemic situation, the number was finally lower and unstable. There were three class groups, one group formed the experimental group while the other two formed the control group. There have been different coordination meetings with the teacher-tutor in charge of passing the test-tests, combining criteria that were recorded in documents. At no time was prior information given to pupils about the purpose of the test-tests, the teachers presenting it as a standard class test. The school environment belongs to a coastal town, with a predominance of tourist activity and the service sector as the main sources of employment, the socio-economic index being situated on a medium-high threshold.

For the technological preparation of the experimental classroom, several coloured LED spotlights have been placed, ensuring a homogeneous distribution of light (Figure 4). The presence of natural light entering from one of the sides of the classroom has also been measured. For this purpose, a smartphone with the "evo lightspectrum pro" application was used. Several considerations are necessary with regard to the measurements:

All measurements were taken a posteriori, on days with cloudiness levels comparable to those on which the tests were carried out, which was necessary so as not to interfere with the normal development of classes, and due to the limitations of presence outside the school due to the pandemic situation.

- Thirteen measurements were made in each classroom group, one per student table. The physical location of the daylight entrance of the experimental group is south-east (morning sun). The physical location of the daylight inlet in the two classrooms of the control group is north-west (afternoon sun).
- The measurements have taken into account three values: brightness (expressed in lux -lx-), the correlated colour temperature CCT (expressed in kelvin -K-) and the colour of the light (expressed in nanometres -nm-).

- The results of the measurements are shown in Tables 2 (overall mean of all values in the classroom of the experimental group) and 3 (overall mean of all values in the two classrooms of the control group).

Figure 3. Orientation of control and experimental classrooms

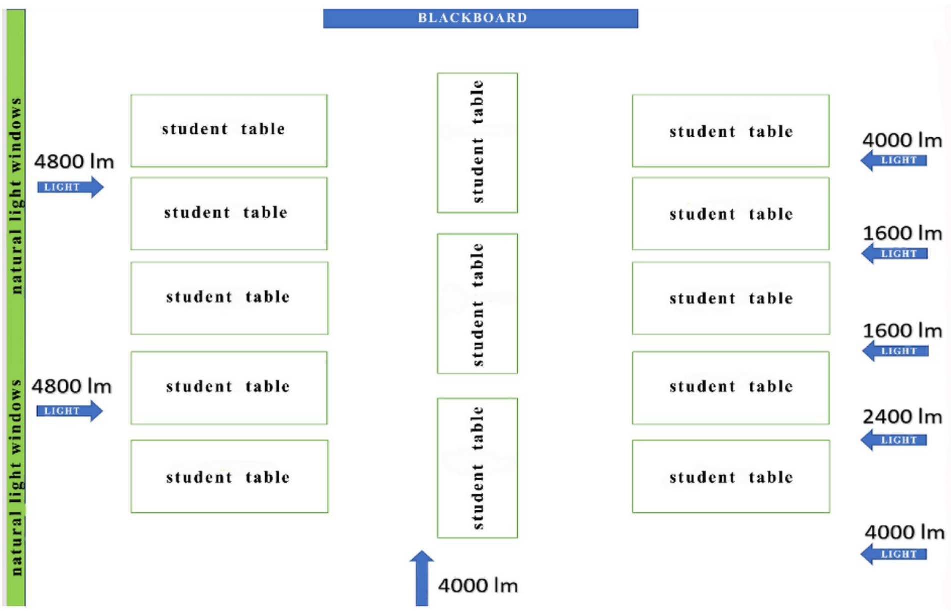

Figure 4. Placement of the LED spotlights in the experimental classroom

	Natural light
Cloudy day	821 lx 5005 K Wavelength: peak values at 460nm and 700nm
Clear day	1842 lx 3208 K Wavelength: peak values at 460nm and 700nm

Table 2. Light measurements of the control group, total class average for each value

	Natural light	Orange light	Green light	Purple light
Cloudy day	1009 lx 5100 K Wavelength: peak values at 460nm and 700nm	1375 lx 4658 K Wavelength: peak values at 720nm	1691 lx 5037 K Wavelength: medium and equal density between 460nm and 650nm	1437 lx 5150 K Wavelength: peak values at 360nm and 800nm
Clear day	1692 lx 3453 K Wavelength: peak values at 460nm and 700nm	1851 lx 3171 K Wavelength: peak values at 680nm	2083 lx 4047 K Wavelength: medium and equal density between 460nm and 650nm	1893 lx 4133 K Wavelength: peak values at 360nm and 800nm

Table 3. Light measurements of the experimental group (total class average for each scenario and value, according to the atmospheric states)

3.4. Data Collection Tools. Experimental Procedure

In the selection of the data collection tools, consideration was given to scientific rigour, age-appropriateness, availability, suitability for the objectives and appropriate timing. Fulfilling these five requirements, the instruments were as follows:

- For the variable "cognitive processes": the Torrance creativity test as collected by Artiles-Hernández, Jiménez-González, Rodríguez-Rodríguez & García-Miranda (2007), with four indicators (originality, elaboration, fluency and flexibility), and the Faces attention test, according to Thurstone and Yela (2019) with attention-net and impulsivity control.
- For the variable "instrumental learning": regional standardised tests of language (only dimensions of written expression and comprehension) and mathematics, although adapted to the expected test duration (Agencia Andaluza de Evaluación Educativa, 2018a,b).
- For the variable "affective processes": questionnaire including the benchmark study by Suh et al. (2020), consisting of three self-perception questions (two answered by Likert scale and one nominal). For the coding of the last question, which can be treated statistically, we used the conversion criteria shown in Table 4.

Assigned score	Sentiment expressed by students
1	empty, pressured, anxious, disappointed
2	uncomfortable, bored, bored, scared, a little bit bad, overwhelmed, tired, weird, can't see, strange, blind, confused
3	equal, normal, nothing, regular, calm, hard-working, quiet, relaxed, gentle, prepared, prepared
4	kind, easy-going, agreeable, comfortable, motivated, excited/sentimental, contented, joyous, proud, inspired, nervous/hyperactive, ambient, cheerful, confident
5	very good, happy, great, excellent, very excited, thrilled, very happy, energetic, excited

Table 4. Coding to number of feelings collected

4. Results

The data collected and analysed are presented in three sub-sections (one for each dependent variable), each subdivided into another three, corresponding to the type of analysis (descriptive, variance, comparative) as we can see in the Figure 5. The statistical package used to carry out the analyses was Jasp, version 0.14.1.0. Finally, a fourth sub-section is added where the maximum and minimum values of all the variables and their dimensions are included, considering their means and medians.

For the descriptive analysis, we will use the "mean", but also "median" more typical of non-parametric values. For the analysis of variance of the experimental group in their light scenarios, we used the

Kruskal-Wallis test (non-parametric quantitative data); we also performed a comparative analysis between Dunn's post hoc scenarios to try to find more data. For the comparative analysis we applied the Mann-Whitney test (n-small samples, non-parametric), to which we added an effect size column. Exceptionally, we applied Friedman's test in our analysis of variance (with Conover's post hoc) for the affective processes variable, since it was designed as repeated measures, with the same group of students providing data in each and every one of the defined scenarios.

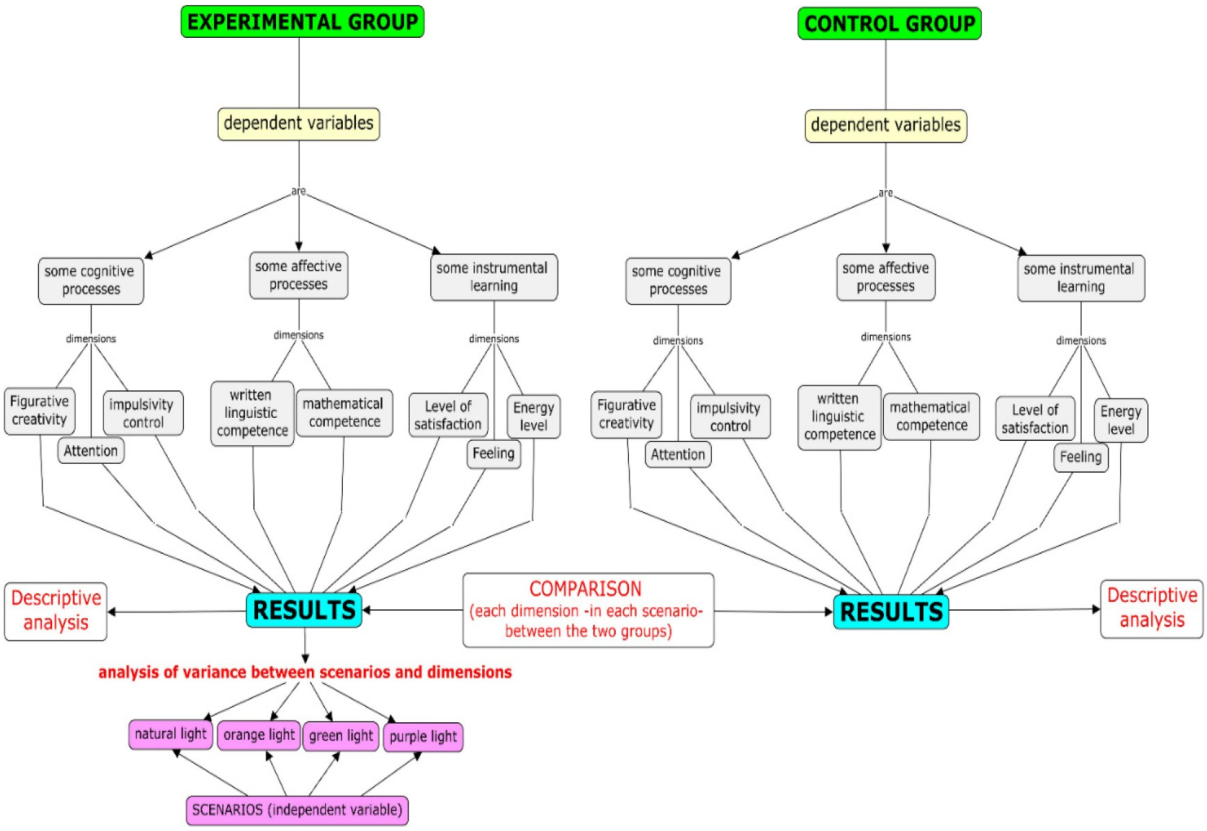

Figure 5. Overview of the different data analyses performed

4.1. Cognitive Processes

4.1.1. Descriptive Analysis

The dimensions analysed were net attention (A-E), impulsivity control index (ICI) and figurative creativity (assessed through the indicators originality, elaboration, fluency and flexibility). The descriptive results can be seen in Table 5 for the experimental group, and in Table 6 for the control group. All tables include the "n" for each dimension analysed in the different lighting scenarios. Each lighting scenario corresponds to a different day (explained above in the methodological design).

The experimental group shows higher A-E and ICI values in all coloured light scenarios compared to the natural light scenario. When compared with the results of the control group on a day-to-day basis, the net attention of the experimental group is much lower in the natural light environment, while it is higher in all coloured light scenarios than in the natural light scenario of the control group. This is not exactly the case for the ICI.

In relation to figurative creativity (and most of its dimensions), the experimental group already shows quite high values on the first day of natural light, being improved only with green light and considerably worse with violet light. Compared to the values of the control group, all the values of the experimental group except for the violet light scenario are higher than the values of the control group.

	Experimental group							
	1.Natural light		2.Orange light		3.Green light		4.Purple light	
Net attention (A-E) (level over 60)	33,8 33	n = 5	47,2 44	n = 5	42,2 31	n = 5	50,2 51	n = 5
Impulsivity control (ICI) (level over 100)	90,24 96.6	n = 5	91,3 94.7	n = 5	91,56 79.4	n = 5	96,24 96.6	n = 5
Originality	95,6 94	n = 5	79,5 87	n = 4	116,8 110	n = 5	61,5 63.5	n = 4
Elaboration	30,8 29		42,5 35		29,8 33		35 43.5	
Fluency	21,2 21		20,75 21		28,2 26		14 14.5	
Flexibility	18,4 20		18 19		21,6 22		12 12.5	
Figurative creativity	166 164		160,8 162		196,4 166		122,5 134	

Table 5. Descriptive means and medians of the cognitive processes in the experimental group

	Control group							
	1.Natural light		2.Natural light		3.Natural light		4.Natural light	
Net attention (A-E) (level over 60)	44,63 40	n = 11	44,45 47	n = 11	39.18 38	n = 11	46.22 50	n = 9
Impulsivity control (ICI) (level over 100)	86,24 95.7	n = 11	91,8 92.4	n = 11	92.08 94.5	n = 11	87.06 89.2	n = 9
Originality	49,2 49	n = 10	61.66 55.5	n = 12	80.9 85	n = 11	68.09 68	n = 11
Elaboration	24,4 23.5		27 19.5		25.9 24		24.36 28	
Fluency	11,6 10		15.66 14.5		20.09 21		16.63 15	
Flexibility	10,1 10		13.25 12		16.18 17		13.81 13	
Figurative creativity	95,3 96		117.58 99.5		143.09 159		123.81 127	

Table 6. Descriptive means and medians of the cognitive processes in the control group

4.1.2. Variance Analysis

The analysis of variance in the experimental group, the Kruskal-Wallis test, shows that none of the dimensions/indicators analysed has a $p < 0.05$ (Tables 7 and 8). Differences in p-values are observed, although they do not reach the significance. However, in Dunn's Post Hoc comparisons (Tables 9 and 10), we do observe values of $p < 0.05$. These significant p-values mark interesting trends although they are not totally definitive. Figures 6 and 7 show graphs on the analysis of variance of the dimensions/indicators comprising the variable "cognitive processes", in order to provide an illustrative visual approach.

Kruskal-Wallis Test	Net Attention (level over 60)			Impulsivity Control (level over 100)			Figurative Creativity		
Factor	Statistic	df	P	Statistic	df	p	Statistic	df	p
Scenarios	5.481	3	0.140	1920	3	0.589	2.053	3	0.562

Table 7. Analysis of variance in the experimental group, 3 cognitive dimensions, 4 scenarios

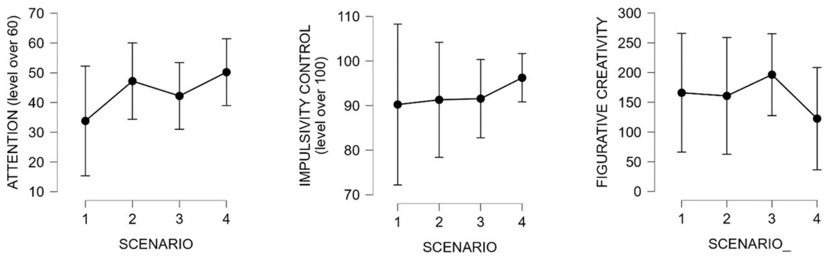

Figure 6. Graphs on the variance in the experimental group (3 cognitive dimensions, 4 scenarios)

Kruskal-Wallis Test	Originality			Elaboration			Fluency			Flexibility		
Factor	Statistic	df	P	Statistic	df	p	Statistic	df	p	Statistic	df	p
Scenarios	4.126	3	0.248	1013	3	0.798	4.589	3	0.205	4.931	3	0.177

Table 8. Analysis of variance in the experimental group (4 creativity dimension indicators, 4 scenarios)

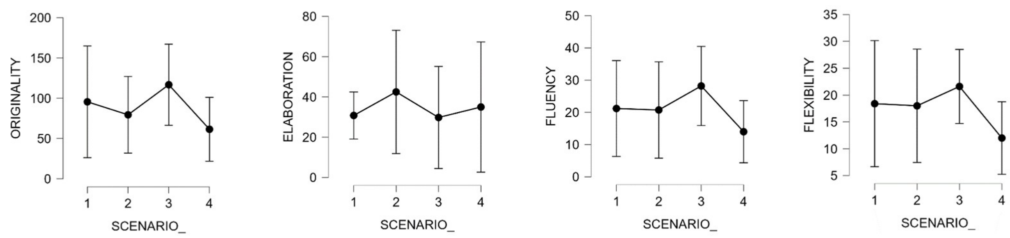

Figure 7. Plots on variance in the experimental group (4 creativity dimension indicators, 4 scenarios)

Dunn's Post Hoc Comparisons		A-E (level over 60)	ICI (level over 100)	Figurative creativity
		p	p	p
1	2	0.039	0.295	0.467
	3	0.161	0.250	0.297
	4	0.015	0.286	0.178
2	3	0.219	0.446	0.279
	4	0.344	0.135	0.213
3	4	0.119	0.108	0.077

Table 9. Post Hoc after variance in the experimental group (3 cognitive dimensions, 4 scenarios)

Dunn's Post Hoc Comparisons		Originality	Elaboration	Fluency	Flexibility
		p	p	p	p
1	2	0.455	0.211	0.455	0.472
	3	0.187	0.406	0.187	0.220
	4	0.099	0.211	0.099	0.071
2	3	0.233	0.281	0.233	0.212
	4	0.092	0.500	0.092	0.092
3	4	0.017	0.281	0.017	0.014

Table 10. Post Hoc after variance in the experimental group (4 creativity dimension indicators, 4 scenarios)

4.1.3. Comparative Analysis

The Mann-Whitney test for non-parametric comparisons has been performed on a day-by-day basis between experimental and control groups (Table 11). This adds more accuracy to the observations derived from the descriptive analysis. Again, although we do not see any p-values that would make it significant, we do see trends. Thus, A-E changes from a negative effect size in all daylight scenarios to a positive effect size in all coloured light scenarios. ICI reaches its maximum value in violet light. Figurative creativity, decreasing its effect size progressively until it reaches its minimum difference with the violet scenario.

Experimental and control group (Independent Samples T-Test)								
	Day 1 Natural Light		Day 2 Orange Light		Day 3 Green Light		Day 4 Purple Light	
Comparison	P	Effect Size	P	Effect Size	P	Effect Size	P	Effect Size
Net attention (over 60)	0.140	0.491	0.909	0.055	0.692	0.145	0.546	0.222
Impulsivity control (over 100)	0.954	0.036	1.000	0.000	0.819	0.091	0.200 [a]	0.444
Originality	0.075[a]	0.600	0.379	0.333	0.145	0.491	0.851	-0.091
Elaboration	0.327	0.340	0.163	0.500	0.821	0.091	0.177	0.500
Fluency	0.083	0.580	0.362	0.333	0.139	0.491	0.512	-0.250
Flexibility	0.085[a]	0.580	0.247	0.417	0.111	0.527	0.510	-0.250
Figurative creativity	0.055	0.640	0.262	0.417	0.308	0.345	0.896	0.068

Note. For the Mann-Whitney test, effect size is given by the rank biserial correlation.
[a]Levene's test is significant ($p < .05$), suggesting a violation of the equal variance assumption

Table 11. Comparison of cognitive processes between experimental and control groups on the four experimental days

4.2. Instrumental Learning

4.2.1. Descriptive Analysis

The dimensions analysed are written linguistic competence (indicators for written expression and written comprehension) and mathematical competence (assessed as a whole). We include the descriptive results in Table 12 for the experimental group and in Table 13 for the control group. All tables include the "n" for each dimension analysed in the different lighting scenarios. Each lighting scenario corresponds to a different day (explained above in the methodological design).

The experimental group's values for reading comprehension are higher in all coloured light scenarios than in natural light, with only a score of 14.8. On the other hand, written expression remained fairly stable in natural and coloured light scenarios, with the exception of the colour green, which had the lowest value of 6.8 points. In the daily comparison of the experimental group with the control group, written comprehension is already much higher in the control group from day one with natural light parity in both groups.

In relation to mathematical competence, the experimental group shows a score that improves with the change from daylight to orange, and even more so to green. At the end there is a very sharp drop in violet light with only 4.66 points, compared to the 9.4 points obtained in the preceding green light. The day-to-day comparison with the control group is always beneficial for the latter.

	Experimental group							
	1.Natural light		2.Orange light		3.Green light		4.Purple light	
Reading comprehension (level over 22)	14,8 18	n = 5	17,75 20	n = 4	18,8 19	n = 5	20,17 20.5	n = 6
Written expression (level over 12)	8,2 9	n = 5	8,5 8	n = 4	6,8 9	n = 5	8,4 9	n = 6
Mathematical competence (level over 15)	7,83 7	n = 6	9 8.5	n = 4	9,4 9	n = 5	4,66 5	n = 3

Table 12. Descriptive of the instrumental learning in the experimental group (reading, written, mathematical)

	Control group							
	1.Natural light		2.Natural light		3.Natural light		4.Natural light	
Reading comprehension (level over 22)	20.5 20	n = 10	21.167 21	n = 12	20.917 21	n = 12	19.667 20.5	n = 12
Written expression (level over 12)	7.9 8.5	n = 10	8.5 9.5	n = 12	9 9	n = 12	7.364 8	n = 11
Mathematical competence (level over 15)	8.83 9	n = 12	9.167 8	n = 12	10.455 11	n = 11	9.833 10	n = 12

Table 13. Descriptive of the instrumental learning in the control group (reading, written, mathematical)

4.2.2. Variance analysis

The variance of the experimental group, again using the Kruskal-Wallis test for non-parametric data, again indicates that none of the analysed dimensions of instrumental learning, or indicators of them, is significant (Table 14 AND 15). The lowest "p" value is found for mathematical competence ($p = 0.187$), due to the sharp drop in the violet light scenario already mentioned in the descriptive data. This is precisely why the Post Hoc (Dunn) comparisons present values of $p < 0.05$ in mathematical competence when contrasting scenarios 2 and 4 ($p = 0.043$) and scenarios 3 and 4 ($p = 0.019$).

Figure 8 shows graphs on the analysis of variance of the dimensions and indicators that make up the "instrumental learning" variable, in order to provide a more illustrative visual approach.

Kruskal-Wallis Test	Mathematical competence (level over 15)			Reading comprehension (level over 22)			Written expression (level over 12)		
Factor	Statistic	df	P	Statistic	df	p	Statistic	df	p
Scenarios	4.807	3	0.187	1.027	3	0.795	0.289	3	0.962

Table 14. Analysis of variance in the experimental group (dimensions and indicators of the "instrumental learning" variable, 4 scenarios)

Dunn's Post Hoc Comparisons				
		Mathematical competence (level over 15)	Reading comprehension (level over 22)	Written expression (level over 12)
		p	p	p
1	2	0.251	0.337	0.489
	3	0.147	0.294	0.314
	4	0.107	0.157	0.443
2	3	0.381	0.464	0.334
	4	0.043	0.306	0.457
3	4	0.019	0.329	0.366

Table 15. Post Hoc analysis of variance in the experimental group (dimensions and indicators of the variable "instrumental learning", 4 scenarios)

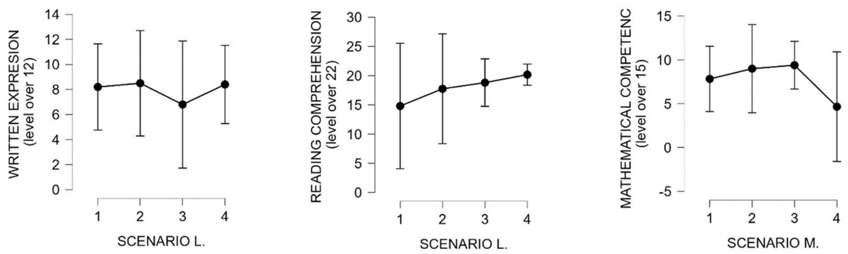

Figure 8. Plots of variance in the experimental group (dimensions and indicators of variable "instrumental learning", 4 scenarios)

4.2.3. Comparative Analysis

Reflected in Table 16 are the results of the Mann-Whitney test (including effect size), using the daily parallelism between experimental and control groups. Only the value of p = 0.020 (mathematical competence), with an effect size of -0.917, is significant, which is not surprising given the results already explained in previous analyses. Of the remaining values, only reading comprehension on the second day (orange light), with p = 0.161, comes close to significant values (this time again with a negative effect size).

Experimental and control group (Independent Samples T-Test)								
	Day 1 Natural Light		Day 2 Orange Light		Day 3 Green Light		Day 4 Purple Light	
Comparison	P	Effect Size	P	Effect Size	P	Effect Size	P	Effect Size
Mathematical competence (level over 15)	0.509	0.208	0.902	-0.063	0.356	-0.309	0.020	-0.917
Reading comprehension (level over 22)	0.235[a]	0.400	0.161[a]	-0.479	0.406[a]	-0.267	0.774	0.097
Written expression (level over 12)	0.710	0.140	1.000	-0.021	0.311	-0.333	0.568	0.200

Note. For the Mann-Whitney test, effect size is given by the rank biserial correlation.
[a]Levene's test is significant ($p < .05$), suggesting a violation of the equal variance assumption

Table 16. Comparison of instrumental learning between experimental and control groups on the four experimental days

4.3. Affective Processes

4.3.1. Descriptive Analysis

Our research design has included the dimensions energy level, liking and feeling as components of the affective processes variable. Looking at Table 17 for the experimental group and Table 18 for the control group, the experimental group shows higher values for all affective dimensions in the colour versus natural light scenarios. The highest value of energy appears with a value of 8 points in violet light (compared to the natural minimum of 6.9), the highest value of liking occurs with 7.75 in green light (compared to the natural minimum of 6.95), and the best exponent of feelings (being more positive) is manifested in green light (3.75, while the natural minimum is 3.19).

The daily contrast with the control group gives minimal but stable differences. While on day 1 all the values of the control group are higher than those of the experimental group (both groups being in natural light), in the rest of the colour scenarios (except for the energy measurement on day 3) the perceptions of the experimental group are always higher.

	Experimental group							
	1.Natural light		2.Orange light		3.Green light		4.Purple light	
Energy	6.9 8	n = 21	7.58 8	n = 17	7.3 7	n = 20	8 8.5	n = 18
Satisfaction	6.95 7	n = 21	7.41 8	n = 17	7.75 8	n = 20	7.55 8	n = 18
Feeling	3.19 3	n = 21	3.7 4	n = 17	3.75 4	n = 20	3.66 4	n = 18

Table 17. Descriptive of the affective processes in the experimental group (energy, satisfaction, feeling)

	Control group							
	1.Natural light		2.Natural light		3.Natural light		4.Natural light	
Energy	7.538	n = 43	7.127	n = 47	7.958	n = 45	7.818	n = 44
Satisfaction	7.308	n = 43	6.857	n = 47	7.548	n = 45	7.458	n = 44
Feeling	3.383	n = 43	3.313	n = 47	3.724	n = 45	3.614	n = 44

Table 18. Descriptive of the affective processes in the control group (energy, satisfaction, feeling)

4.3.2. Variance Analysis

The Friedman test for repeated measures shows once again that the analysed dimensions of affective processes are not significant (Tables 19 and 20). We do see that the lowest "p" value appears with the measurements of feelings ($p = 0.294$). Perhaps this is why the Post Hoc comparisons (Conover) present the lowest values too, although never below $p < 0.05$. Figure 9 shows graphs on the analysis of variance of the dimensions/indicators of the variable "cognitive processes".

Friedman Test				
Factor	Chi-Squared	df	p	Kendall's W
Scenarios (energy)	2.739	3	0.434	0.091
Scenarios (satisfaction)	0.593	3	0.898	0.020
Scenarios (feeling)	3.712	3	0.294	0.124

Table 19. Analysis of variance in the experimental group (3 affective dimensions, 4 scenarios)

Conover's Post Hoc Comparisons				
		Energy	Satisfaction	Feeling
		p	p	p
1	2	0.259	0.647	0.097
	3	0.535	0.783	0.121
	4	0.128	0.854	0.430
2	3	0.605	0.465	0.910
	4	0.678	0.783	0.368
3	4	0.354	0.647	0.430

Table 20. Post Hoc after variance in the experimental group (3 affective dimensions, 4 scenarios)

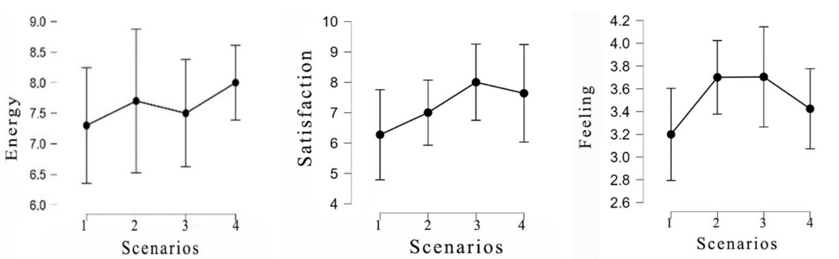

Figure 9. Plots of variance in the experimental group (3 affective dimensions, 4 scenarios)

4.3.3. Comparative Analysis

In the usual Mann-Whitney test we again note the absence of a significant p-value (Table 21). In this occasion the lowest ($p = 0.103$) was found in the comparison of day 2 (experimental orange light versus control natural light).

Experimental and control group (Independent Samples T-Test)								
	Day 1 Natural Light		Day 2 Orange Light		Day 3 Green Light		Day 4 Purple Light	
Comparison	**P**	**Effect Size**	**P**	**Effect Size**	**P**	**Effect Size**	**P**	**Effect Size**
Energy	0.471[a]	-0.111	0.538	0.101	0.207	-0.196	0.653	0.073
Satisfaction	0.497	-0.105	0.548	0.099	0.666	0.068	0.919	0.018
Feeling	0.543	-0.000	0.103	0.258	0.668	0.063	0.760	0.048

Note. For the Mann-Whitney test, effect size is given by the rank biserial correlation.
[a]Levene's test is significant (p < .05), suggesting a violation of the equal variance assumption

Table 21. Comparison of affective dimensions between experimental and control groups on the four experimental days

4.4. Extreme Values of the Dependent Variables

Table 22 allows a quick look at the main descriptive values for each variable and dimension. These maxima and minima give a picture where it is absolutely always light-coloured scenarios that are the most favoured, often violet, and occasionally green or orange. On the other hand, with two exceptions in orange, the minimum indicators are always in the natural scenario.

Extreme values of the dependent variables (dimensions and indicators included)				
	Maximum value		Minimum value	
	Mean	**Median**	**Mean**	**Median**
Net attention (level over 60)	50,2 Experimental group Purple light	51 Experimental group Purple light	33,8 Experimental group Natural light	31 Experimental group Green light
Impulsivity control (level over 100)	96,24 Experimental group Purple light	96,6 Experimental group Purple and Natural light	86,24 Control group Natural light, day 1	79,4 Experimental group Green light
Originality	116,8 Experimental group Green light	110 Experimental group Green light	49,2 Control group Natural light, day 1	49 Control group Natural light, day 1
Elaboration	42,5 Experimental group Orange light	43,5 Experimental group Purple light	24,36 Control group Natural light, day 4	19.500 Control group Natural light, day 2
Fluency	28,2 Experimental group Green light	26 Experimental group Green light	11,6 Control group Natural light, day 1	10 Control group Natural light, day 1
Flexibility	21,6 Experimental group Green light	22 Experimental group Green light	10,1 Control group Natural light, day 1	10 Control group Natural light, day 1
Figurative creativity	196,4 Experimental group Green light	166 Experimental group Green light	95.300 Control group Natural light, day 1	96 Control group Natural light, day 1
Reading comprehension (level over 22)	21,16 Control group Natural light, day 2	22 Control group Natural light, day 2	14,8 Experimental group natural light	18 Experimental group natural light
Writing expression (level over 12)	9 Control group Natural light, day 3	9.5 Control group Natural light, day 2	6,8 Experimental group green light	8 Experimental group orange light , and control group, day 4
Mathematics competence (level over 15)	10,45 Control group Natural light, day 3	11 Control group Natural light, day 3	4,667 Experimental group purple light	5 Experimental group purple light

Extreme values of the dependent variables (dimensions and indicators included)				
	Maximum value		Minimum value	
	Mean	Median	Mean	Median
Energy	8 Experimental group purple light	8.5 Experimental group purple light	6,905 Experimental group natural light	7 Experimental group green light y control group, day 2
Satisfaction	7,75 Experimental group green light	8 Experimental group Green-orange-purple light Control group, day 1,3,4	6,85 Control group Natural light, day 2	7 Experimental group Natural light, Control group, day 2
Feeling	3,75 Experimental group green light	4 Experimental group Orange, green, purple light Control group Day 3,4	3,19 Experimental group natural light	3 Experimental group natural light Control group Day 1,2

Table 22. Maximum and minimum descriptive values of all measured dimensions and indicators

5. Discussion

Despite the exploratory nature of this quasi-experimental study with a control group, and the small “n”, the results shown allow us to observe certain trends. Without the possibility of generalisation, we have managed to obtain data on as many variables as possible (Ramírez, 2003). If we systematically review the data referenced for each variable, starting with net attention, there is no exact point of discussion in relation to other authors among those included in our theoretical framework. Only Mogas-Recalde and Palau (2021) make mention of it, where it is briefly indicated that the impact of lighting on attention is recognised as a factor. These authors do not address the colour of light as much as the correlated colour temperature. We agree with this statement. Something similar happens with the impulsivity control index, now more accentuated as we do not have a single preceding article. The experimental group performs better in all coloured light scenarios, although in contrast to the control group only green and violet shades are superior.

Figurative creativity does show precedents in papers of Kombeiz and Steidle (2018). They conclude that creativity tasks are best performed with red and blue lights. Again, our study is quite consistent, although neither the colours analysed, nor the environment (in our case school), nor the data collection instruments are similar. The nuances are many: our experimental group already presents very high values in the performance with natural light, only surpassed with the green light scenario, being similar with orange light and much lower with violet light (only scenario in which even the control group shows better values).

With respect to instrumental learning, the few assimilable references in the scientific literature refer to it as “academic performance”. Such is the case of Mogas-Recalde and Palau (2021) where it is established that the effect of lighting on academic performance, in relation to CCT, has been demonstrated. Suh et al. (2020) express that academic performance could improve with coloured lighting in the classroom. In this, our empirical data are not very enlightening as the only significant “p” shown affects the mathematical competence outcome in the violet lighting scenario, but to its detriment.

We add that we have found that the previous academic results of each of the groups studied are quite different. The average academic grades in the areas of language and mathematics, respectively, in the first trimester are 6.73 (linguistics experimental group) compared to 7.25 (control group), and 5.86 (mathematics experimental group) compared to 6.83 (control group). This makes us understand that all the mathematical comparisons with the control group are resolved in favour of the control group. But also precisely this makes us appreciate more the fact that with the violet light the linguistic evaluations collected in the experimental group are higher, reversing the previous results.

The internal variance of the experimental group shows a trend of slight progressive improvement with the different coloured lights with respect to written comprehension, rising gradually from the lowest natural light to the highest result with violet light. Written expression remains fairly stable, except for a decline in green light, and mathematical competence is better assessed in the coloured light scenarios, except for the sharp decline in violet light.

The last of the variables analysed, affective processes, is directly inspired by the study by Suh et al. (2020). It is interesting to note that while in the inspiration study the highest levels of liking are obtained with violet lighting, our study does so with green light, with the opposite being true for energy. We do agree on the rest of the values, especially on the low evaluation of light without colour in both studies. The liking also appears in Rajae-Joordens (2010), being higher with green and blue light and lower with red light.

Although Suh et al. (2020) include a section on feelings in their self-perception survey, the results obtained are not analysed at any point in their article. This may be due to the difficulty of coding it in the form of numbers to help establish relationships. Thanks to the coding explained in Table 4, we have been able to go a little further. Thus, all coloured light scenarios in the experimental group translate into more positive feelings than in natural light, with the highest value in green light.

A compilation of the maximum and minimum values collected for all variables (dimensions and/or indicators) can be seen in Table 22. The trends already shown with respect to the potential of coloured light are now once again evident. Thus, it is observed that only three of the 13 types of data handled have their maximum value in natural light scenarios, if we take into account the mean values, while there are also three in solitary taking into account the median, rising three more if we consider medians that are also shared by coloured light values. Similarly, only two of the 13 data types have a minimum value in coloured light scenarios if we take into account the median values, while it rises to three if we consider the medians alone, and to five if we also add the medians that are shared by daylight values. According to the medians, six maximum values occur in green light (one minimum), three occur in violet light (one minimum) and one only responds to orange light (no minimum). Meanwhile, when considering the medians, six maximum values occur in green light (three minimum), six occur in violet light (one minimum) and two only respond to orange light (one minimum).

From the above arises the already mentioned dynamism of coloured light, so that its changing conditions can be exploited. Some authors advocate dynamic lighting systems that would have a place in intelligent learning environments (Choi and Suk, 2016, as cited in Mogas-Recalde & Palau, 2021). Poldma (2009) a bases part of his research on this dynamism, associated with the world of interior design. Suh et al. (2020) conclude that the potential of coloured lighting can lead to environments with appropriate lighting for each activity. Mogas-Recalde and Palau (2021) write that lighting should be adapted to the activities and needs of the classroom. Therefore, the theoretical references found are unanimous in understanding that the dynamism of light (coloured, or in its CCT) is a benefit. The empirical work that has now been presented makes it clear that the same shade of light, such as green or violet, it may be very positive in terms of certain indicators but could be detrimental in others. This supports the need to change colour depending on the learning task being addressed.

Finally, although the work of Rajae-Joordens, 2010; Kombeiz & Steidle, 2018; Suh et al., 2020, isolate their studies to natural light, the most intensive work found (by number of years employed, number of samples, longitudinal nature), the research of Barrett et al. (2015, 2017) points out that optimal lighting conditions in classrooms require combining artificial and natural light (avoiding glare). Our experimental situation has combined the two types of light, being affected by the changes that natural light may experience, but also benefiting from its presence and defining a less artificial experimental environment.

6. Conclusions and Implications

Following an exhaustive order, we can say that the hypothesis that gave an answer to the first research question is confirmed, although with several nuances. Considering the averages, all the dimensions and indicators measured have yielded their maximum results in coloured light scenarios (green, violet or orange) and their minimum results in natural light (control group or the experimental group itself), with some changes in the consideration of medians. However, it is also true that no p-values are significant in the analyses performed, except in some post hoc analyses. This, together with the low "n" values, indicates that there is a tendency for cognitive processes to be improved by coloured light in the classroom, but we need more conclusive studies.

As for the second hypothesis, concerning the improvement in the acquisition of instrumental learning, it could not be confirmed, contrasting with the scarce previous literature. We did not find "p" values that allow us to be categorical, but precisely the most relevant value is the opposite of the one defended in the hypothesis. However, we cannot ignore the fact that in reading comprehension the experimental group shows its best results (internal variance) in all coloured light scenarios despite the different starting academic level explained above. The values of "n" are low.

The third hypothesis, in relation to the affective processes of the students, is confirmed with similar nuances to those put forward in the first hypothesis. The most notable difference lies in the much higher "n" value in the sample collected on this occasion, as well as in the self-perceptive nature of the collection instrument, introducing a subjective element absent in the previous data.

The last of the hypotheses, the use of "dynamic colour" for the benefit of the adaptability of coloured light to the needs of each activity, can be considered to have been demonstrated in the light of the data handled, and no harm has been found. With the nuances inherent to an exploratory study, but it has become clear how the dynamic quality of light would enable its true potential: different colours are optimal for different types of learning processes. While the same colours can be detrimental in other processes, dynamism is not only a benefit but also a necessity.

For all these reasons, the influence of coloured light in learning environments is not innocuous. Its potential has been shown by exploring a wide and different variety of processes linked to learning, although the benefit is not always homogeneous in all the variables analysed. This highlights the need for its dynamism in smart classrooms, even with possible automation. The design of the classroom coloured lighting system could well be a system differentiated from the general lighting, enhancing its adaptability and focus at times when it would be educationally productive. Current LED technology allows for a functional installation at low cost, which means that improvements in learning are easy to introduce.

At the teaching level, teachers could select lighting environments adapted to the type of activities addressed, but they could also combine different environments in the same class, for differentiated work tasks. At the administrative level, upgrading schools with additional LED lighting is an assumable investment, but it is also necessary due to the lower energy consumption and almost zero heat dissipation. The development of a standardised system by an industry in the sector could facilitate its implementation, making it an interesting niche market.

Finally, our study contributes to filling the almost total scientific void surrounding the use of coloured light in the classroom. This was the origin of our research problem. Now that this data is the first to focus exclusively on primary education, they help to give consistency to this research topic, allowing other researchers to approach it with more background information. Much research is still needed on the topic.

7. Limitations and Future Lines of Research

Our coloured light installation is not strictly professional and can be improved in the following areas: higher brightness, better distribution and centralised control. A professional installation would maximise the effects of coloured light.

Data collection in a pandemic situation has also been a limitation because the high and intermittent absenteeism of the participating students (lowering the "n" values) and because the non-presence of the researcher within the school (facilitating coordination, measurement and implementation).

Another limitation, but also an opportunity, is the inclusion of natural light combined with artificial light. We already talked about this being an ideal situation but subject to atmospheric changes. A further limitation derives from the nature as an exploratory study, thus subject to broader but less in-depth measurements, marking potential trends or relationships as Dankhe (1986) admits. Similarly, the non-probabilistic sample selection limits generalisations with statistical precision. Although this was not the aim of the study, it must be taken into account.

Two other limitations are the different academic starting levels of the experimental and control groups (the application of controlled pretests would help to apply mechanisms to correct the mismatch); and the subjective nature of the self-perception questionnaire used in the measurement of affective processes.

Future work should build on the trends shown in this exploratory study and isolate its variables in independent work to achieve higher n-values, taking into account the other limitations mentioned and overcoming them. It would also be advisable to contact specialised companies that could collaborate with a professional coloured light installation.

It is also interesting that future work will take place in different educational contexts: other primary school levels (not only sixth grade), but also other educational stages and other geographical and socio-cultural backgrounds. With the same colours (deepening their study) or with other characteristic colours.

Taking a broader view of the future, there is nothing to prevent the influence of coloured light on learning processes from being studied by collecting data based on objective physiological indicators collected by the necessary technical equipment. Rajae-Joordens (2010) already pointed a little in this direction. This would pave the way for a possible automation of coloured light in the classroom based on immediate data collection.

And finally, we believe it is possible to consider the use of coloured light in the classroom differentiated by sectors. Often in classrooms, differentiated activities are carried out in corners that coloured light could support.

Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and publication of this article.

Funding

The authors received no financial support for the research, authorship, and publication of this article.

References

Agencia Andaluza de Evaluación Educativa (2018a). *Evaluación final de educación primaria. Competencia matemática.* Junta de Andalucía.

Agencia Andaluza de Evaluación Educativa (2018b). *Evaluación final de educación primaria. Competencia lingüística.* Junta de Andalucía.

American Educational Research Association (2011). AERA Code of Ethics. *Educational Researcher,* 40(3), 145-156. https://doi.org/10.3102/0013189X11410403

Artiles-Hernández, C., Jiménez-González, J.E., Rodríguez-Rodríguez, C., & García-Miranda, E. (2007). *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

Barrett, P., Davies, F., Zhang, Y., & Barrett, L. (2015). The impact of classroom design on pupils' learning: Final results ofaholistic, multi-level analysis. *Building and Environment,* 89, 118-133. https://doi.org/10.1016/j.buildenv.2015.02.013

Barrett, P., Davies, F., Zhang, Y., & Barrett, L. (2017). The Holistic Impact of Classroom Spaces on Learning in Specific Subjects. *Environment and Behavior,* 49(4), 425-451. https://doi.org/10.1177/0013916516648735

Barroso, J. (2015). *Equipo 4.Diseños experimentales conductuales y tradicionales.* Slideshare. Available at: https://es.slideshare.net/RosarioFL/equipo-4-diseos-experimentales-conductuales-y-tradicionales

Bisquerra-Alzina, R. (2009). *Metodología de la Investigación Educativa* (2ªed.). Editorial la Muralla.

BOE (2018). Ley Orgánica 3/2018, de 5 de diciembre, de Protección de Datos Personales y garantía de los derechos digitales. *BOE,* 294. Available at: https://www.boe.es/eli/es/lo/2018/12/05/3

Castañeda, L. (2018). Método y diseño de investigación. In Prendes, M.P., & González-Calatayud, V. (Coords.), *Trabajo Fin de Máster en Tecnología Educativa. Orientaciones para la elaboración y criterios de calidad* (71-91). Universidad de Murcia.

Chacón-Moscoso, S., & Sanduvete-Chavez, S. (2018). *Métodos, diseños y técnicas de investigación psicológica.* Universidad de Sevilla.

Cuestas (2010). *Diseño de casos cruzados.* Imbiomed. Available at: https://www.imbiomed.com.mx/articulo.php?id=67270

Dankhe, G. (1986). Investigación y comunicación. In Fernández-Collado, C., & Dankhe, G. (Eds), *La comunicación humana: ciencia social* (385-454). McGrawHill.

DOUE (2016). 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,* 119. Available at: https://www.boe.es/doue/2016/119/L00001-00088.pdf

Eschenhagen, M., Vélez-Cuartas, G., Maldonado, C., & Pino, G. (2018). *Construcción de problemas de investigación: Diálogos entre el interior y el exterior.* Universidad de Antioquia. https://doi.org/10.2307/j.ctvfc5506

Goodyear, P., & Retalis, S. (2010). Technology-enhanced learning: Design patterns and pattern languages. Sense Publishers. https://doi.org/10.1163/9789460910623

Kombeiz, O., & Steidle, A. (2018). Facilitation of creative performance by using blue and red accent lighting in work and learning areas. *Ergonomics,* 61(3), 456-463. https://doi.org/10.1080/00140139.2017.1349940

López-Fuentes, R., & Salmerón-Vilchez, P. (2011). Proceso De Investigación Educativa I : Investigación Experimental. In López-Fuentes, R. (Coord), *Innovación Docente e Investigación Educativa. Máster Universitario de Educación Secundaria Obligatoria y Bachillerato, Formación Profesional y Enseñanza de Idiomas* (24-40). Universidad de Granada. Available at: https://www.ugr.es/~emiliobl/Emilio_Berrocal_de_Luna/Master_files/UNIDAD%201%20El%20Proceso%20de%20Investigacio%CC%81n%20Empi%CC%81rico%20Experimental.pdf

Mogas-Recalde, J., & Palau, R. (2021). Classroom lighting and its effect on student learning and performance: Towards smarter conditions. *Smart Innovation, Systems and Technologies,* 197. Springer. https://doi.org/10.1007/978-981-15-7383-5_1

Poldma, T. (2009). Learning the dynamic processes of color and light in interior design. *Journal of Interior Design,* 34(2), 19-33. https://doi.org/10.1111/j.1939-1668.2008.01017.x

Quiles-Rodríguez, J., & Palau, R. (2023). Effects of Classroom Colour on Learning Processes for a Future Smart Classroom: A Systematic Review. In Antolí, J. (Ed.), *Challenges of the Educational System in Contemporary Society* (222-241). IGI Global. https://doi.org/10.4018/978-1-6684-8156-1.ch016

Rajae-Joordens, R.J.E. (2010). The Effects of Colored Light on Valence and Arousal. In Westerink, J., Krans M., & Ouwerkerk M. (Eds), *Sensing Emotions. Philips Research Book Series* (12, 65-84). Springer. https://doi.org/10.1007/978-90-481-3258-4_5

Ramírez, H. (2003). Metodología de la investigación para ejecutivos. Doctor electronic learning. Available at: http://www.dre-learning.com/download/cursos/mdli/

Román-García, M., & Prendes, M.P. (2018). El informe del TFM. In Prendes, M.P., & González-Calatayud, V. (Coords.), *Trabajo Fin de Máster en Tecnología Educativa. Orientaciones para la elaboración y criterios de calidad* (59-67). Universidad de Murcia.

Suh, J.K., Park, E.K., & Iwamoto, D. (2020). Color-filtered lighting: Visual and emotional impact in learning environments. *International Journal of Architectonic, Spatial, and Environmental Design,* 14(1), 41-55. https://doi.org/10.18848/2325-1662/CGP/v14i01/41-55

Thurstone, L.L., & Yela, M. (2019). *Caras-R. Test de percepción de diferencias-Revisado. Manual* (13ª ed.). TEA ediciones.

Published by OmniaScience (www.omniascience.com)

Journal of Technology and Science Education, 2024 (www.jotse.org)