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How does Coloured Lighting Influence the Affective Processes of Pupils?

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Abstract. Nowadays, the progressive incorporation of technological elements in classrooms adds new possibilities to be explored in the field of colour and environment. In this sense, LED lighting as a source of "coloured light" is a resource that has not yet been analysed. The present quasi-experimental design had a pre-test and was carried out for a single group in a primary school for two months, focusing on the dependent variables "energy level", "enjoyment level" and "feeling", whose values were collected by means of a self-perception survey. The results obtained are significant in the post hoc analysis of variance for some scenarios of the variable "feelings", but less so for the others. The disparity of results according to the colour analysed, with violet sometimes having a greater impact than orange at other times, also leads us to consider the need for dynamism positively.

Keywords: Educational environment, lighting, affective processes, Smart Classroom, Dynamic Colour, learning environment.

1 Introduction

As Quiles-Rodríguez & Palau [1] systematically state, since the mid-20th century there have been numerous studies on the effect of colour on learning processes in general and on the affective processes of students in particular. Despite the efforts of authors such as Barret et al. [2, 3] with longitudinal, extensive and systematic research, others such as Von Castell et al. [4] conclude that the studies on this subject are inconsistent, with no possibility of real educational application. More scholars are also in favour of the latter [5, 6]. The evolution of environmental colour towards current technological possibilities facilitated by the use of LED lighting, gives rise to an overcoming of obvious traditional limitations [7]. On this progression towards LED "coloured light" we do not yet have much data [7], although we do have data on its parallel on "correlated colour temperature-CCT" [8, 9, 10].

We find a similar situation when we focus the literature review on the influence of environmental colour on the affective processes of pupils in particular. We understand with Gross [11] that to speak of learning is to refer to skills, knowledge and abilities, but also to behaviours or values, and therefore to affective processes. In this regard, Mora [12] also clearly indicates that there is no learning without emotion. Knowing this, the inclusion of traditional environmental colour has been studied in relation to stress and anxiety [13, 14], to motivation [15], to calmness [16, 17, 18], to energy [19, 20, 21], and further affective parameters. As already mentioned above, in this respect too, the findings do not coincide in their homegeneity [1].

As far as "coloured light" is concerned, the few previous studies also tend to focus on affective processes, with the majority of the work being the dependent variable. Kombeiz & Steidle [22] study approach motivation associated with red or blue coloured light; Rajae-Joordens [23] analyses human arousal and satisfaction in relation to red, green or blue light; Suh et al. [24] provide data on students' mood (feelings), energy and satisfaction in relation to purple, green and orange light scenarios. The latter, together with Quiles-Rodríguez & Palau [7], are central to the present work as they have inspired the use of the same self-perception survey used by them.

From fields far removed from education, such as astronautics or medicine, interesting results have recently been obtained on coloured light and its influence on emotions. Specifically from medicine, it has been shown that blue light increases parasympathetic activity, thus causing calm, while red light decreases it [25]. From astronautics, it is revealing to know that multicolour lighting reduces negative emotions and anxiety of participants in a simulated habitat for seven days [26]. This is coupled with growing evidence that the impact on emotion of coloured light is different from that of a traditionally coloured object [27], which also affects educational differentiation in terms of the provenance of both colour sources.

Finally, we would like to add that, although there are many publications on correlated colour temperature (CCT), it is not the main subject of this article. It is only considerable insofar as the concept of "dynamic lighting" has been coined [8], establishing the potential of its changing technological possibilities, and which we will use again here in its analogy with "dynamic colour", a concept already used in Quiles-Rodríguez & Palau [1, 7, 28].

2 Statement of the Problem. Objectives, Questions and Hypotheses

The research problem we are trying to answer translates into the following four research questions:

RQ1. Which coloured light scenarios improve primary school pupils' self-perception of energy level?

RQ2. Which coloured light scenarios improve primary school pupils' self-perceived satisfaction level?

RQ3. Which coloured light scenarios produce more positive feelings in primary school pupils?

RQ4. Is "dynamic colour" useful for the improvement of affective processes in primary school pupils?

The exploratory study with small samples by Quiles-Rodríguez & Palau [7], already addressed a similar issue, while a different experimental design is now being carried out, in a different context and trying to obtain a larger sample. This will add value to the initial data and will allow us to continue the line of research already initiated. The general objectives are:

O1. To identify coloured light scenarios that favour some affective processes in primary school pupils.

O2. To know the potential of "dynamic colour" in the classroom for its contribution to the affective processes of pupils.

From the above, our research has four hypotheses that seek to be empirically contrasted [29]. These hypotheses, speculations on the possible solution to the problem posed [30], are:

H1. Some coloured light scenarios in the primary classroom environment make it possible to improve the self-perceived energy level of students.

H2. Some coloured light scenarios in the primary classroom environment enable the improvement of the students' self-perceived satisfaction level.

H3. Some coloured light scenarios in the primary classroom environment make it possible to improve pupils' self-perceived feelings.

H4. The use of dynamic colour makes it possible to adapt the coloured light to the needs of the different affective processes of the pupils.

3 Methodology

This is a quasi-experimental study with a pre-test, but without a control group. In this study we made 16 measurements on 16 different days, four for each "coloured light" scenario, calculating the mean of each group of four measurements in the same scenario for statistical treatment. Each measurement, in turn, collects data on the three dependent variables that make up the affective processes. This type of experimentation has much in common with the "equivalent materials design" [31]. The so-called "coloured light" scenarios are the independent variable, consisting of "natural light" (a combination of natural outdoor light and ordinary indoor lighting), which serves as a pretest, and three coloured scenarios (orange, green and violet). The latter are combined with ordinary classroom lighting, to which coloured LED spotlights have been added, but isolated from the outside light. The choice of colours is inspired by Suh et al. [24], who state that they were chosen because they are very common colours in natural environments. In Quiles-Rodríguez & Palau [7], it were also used the same colours for an exploratory study with affective influence. In contrast to the independent variable, the dependent variables that make up the affective processes are:

DV1. Energy level

DV2. Satisfaction level

DV3. Feelings

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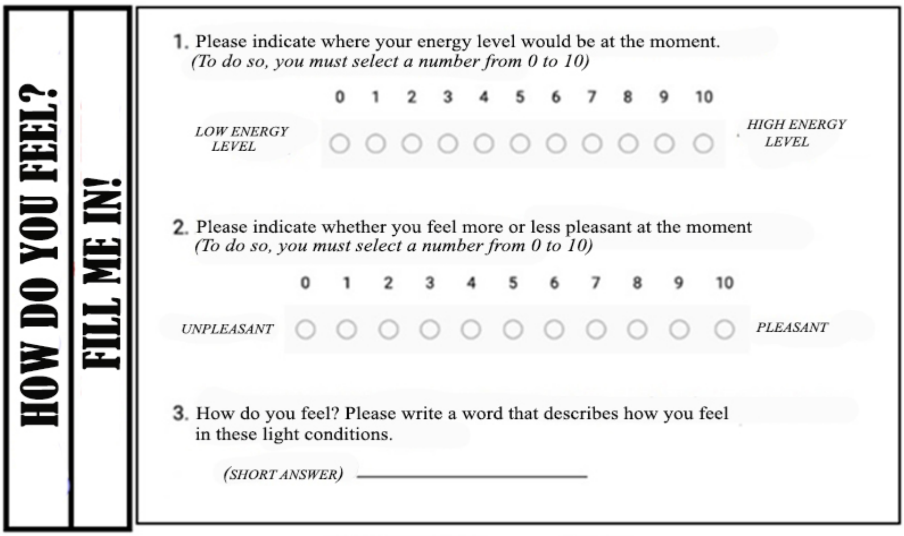
For data collection we used the self-perception survey defined by Suh et al. [24], translated into spanish and with very slight modifications, as shown in figure 1. The survey consists of three self-perception questions that the students answer in a normal classroom situation, prior to the completion of ordinary scheduled tasks according to the defined day. While the first two questions are answered on a Likert scale (quantitative), the third question is qualitative. We have developed a conversion table in order to be able to treat these qualitative results statistically (table 1). Similar instruments were also used in Quiles-Rodríguez & Palau [1].


HOW DO YOU FEEL?

FILL ME IN!

1. Please indicate where your energy level would be at the moment.
(To do so, you must select a number from 0 to 10)

LOW ENERGY LEVEL 0 1 2 3 4 5 6 7 8 9 10 HIGH ENERGY LEVEL

2. Please indicate whether you feel more or less pleasant at the moment
(To do so, you must select a number from 0 to 10)

UNPLEASANT 0 1 2 3 4 5 6 7 8 9 10 PLEASANT

3. How do you feel? Please write a word that describes how you feel in these light conditions.

(SHORT ANSWER) ____________

Fig. 1. Self-perception surveys with students.

Table 1. Coding to number of collected sentiments.

Score assigned	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, can't 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, hard-working, impacted, very comfortable, imaginative

As defined by Campbell & Stanley [31], this study is rigorous in its internal validation, although it presents some room for improvement in its external validity. Aware of the difficulties of isolation in a standardised classroom environment, we did try to:

a) Avoid influences of weather on lighting conditions (except in the so-called "daylight" scenario).

b) Increase the sample by testing for four consecutive days for each scenario. Although this does not really affect "n", since we have taken the average of the four measurements of each student in each light scenario, it does minimise the possible influences of uncontrolled variables on the affective levels collected, knowing that especially in Social Sciences the control of all variables is almost impossible, with extraneous variables appearing frequently [32]

c) Turning on the coloured lights for four months prior to data collection, on a weekly basis and associated with regular scheduled classroom activities (theatre, exhibitions), trying to avoid the hawthorne/motivation effect.

d) Eliminate the memory/learning effect [33]. For this purpose, the pretest data collection was spaced one month apart with respect to the first light scenario. Subsequently, each light scenario was spaced two weeks apart. With the same objective in mind, no explanation was given to the students about what happened, avoiding any comments that might arouse any kind of alert, everything being seen as part of everyday normality.

3.1 Sample

We used a non-probabilistic sample as it was a previously constituted class from a rural public school in Andalusia (southern Spain). Twenty boys and girls between 10 and 12 years of age (fifth year of primary school) participated. The experimental physical space (classroom) has been added with the necessary LED technology to obtain the coloured light scenarios of the independent variable.

3.2 Ethical considerations

Children's parents under 14 years of age (the entire sample) have signed the express prior informed consent, as provided for by the legal provisions [34, 35]. At no time will personal data of the minors be disseminated, only the analysis of the survey carried out. We informed the Ethics Committee for Research on People, Society and the Environment (CEIPSA) of the Rovira i Virgili University of both the action report and the information and informed consent form, which gave its approval.

Interaction Design and Architecture(s) Journal - IxD&A, N.60, 2024, pp. 103 - 121
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3.3 Context of the study. Experimental situation

The experimental situation takes place in a rural locality with a medium socio-economic index, highly dependent on agricultural activity, in the centre of Andalusia (southern Spain). The students, according to official evaluation reports, have an average academic level. At no time have they received information about the research carried out, being faced as a natural element of the class given the intermittent exposure to the independent variable during the previous four months. The technological preparation with coloured LED spotlights is as shown in figure 2. We have collected the light values of the light with the application "evo ligthspectrum pro", using a smart mobile device. These values, presented in table 2, are the average of the four measurements made for each light scenario (four days for each scenario), and of the 20 measurements of each day (one for each student table). The colour temperature (CCT) is expressed in kelvin (k), the luminance in lux (lx) and the light colour in nanometres (nm). All measurements were made without the presence of students.

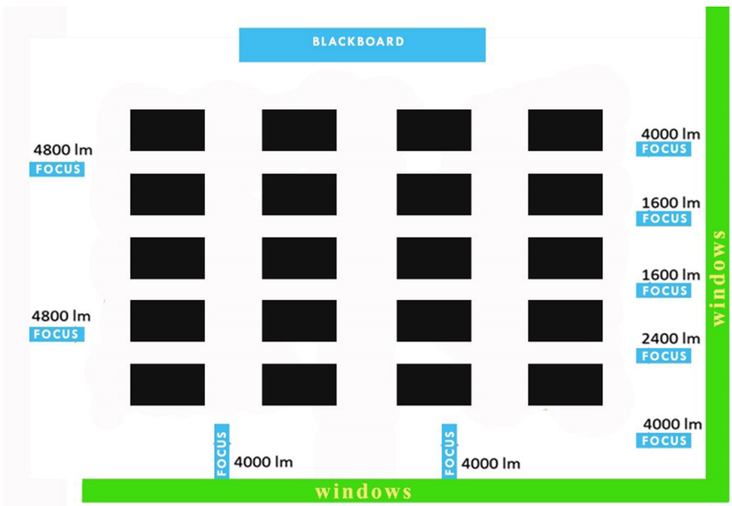

Fig. 2. Placement of the coloured LED spotlights in the experimental classroom.

Table 2. Light measurements of the experimental group (total class average in each scenario and value).

	Natural light	Orange light	Green light	Purple light
Classroom scenarios	1292 lx 5189 K Wavelength: peak values at 450nm and 700nm	1126 lx 3989 K Wavelength: peak values at 720nm	1675 lx 5685 K Wavelength: medium and equal density between 460nm and 620nm	1479 lx 5545 K Wavelength: peak values at 350nm and 790nm

4 Results

Although we have collected four values for each light scenario and student (trying to minimise the influence of external factors, as explained above), for analytical treatment we have calculated the mean of these values in each light scenario (each group of four values corresponds to the same subject without the independent variable having been altered). The application of the Shapiro test yields p-values that suggest non-normality, so we prefer to analyse the data as non-parametric, thus securing the results. We structure the presentation of results in four sub-sections, one corresponding to each dependent variable, plus a final one where a global view of all maximum and minimum values is given. At the same time, we present each variable with broad descriptive values, including mean, but also median, mode, variance and quartiles (among others). This, being non-parametric, allows a better view of the results, having both central and position and dispersion data. Everything is completed with box and whisker plots. Each variable is also presented with its variance through Friedman's test (anova for repeated measures). With this we see how the different light scenarios affect the independent variables comparatively. To this we add the Conover post-hoc (with Bonferroni and Holm corrections), allowing for greater precision. As with the descriptive values, variance plots are now also included. We adopted, as usual, 0.05 as the α value to establish significance.

The use of the statistical package Jasp, in its version 0.14.1.0, has allowed us to carry out all the calculations expressed.

4.1 Energy

Descriptive analysis. The descriptive values are shown in table 3 and are plotted in figure 3. We found higher values in coloured light scenarios, which will be analysed later in the discussion.

Table 3. Descriptive values of the self-perceived energy level in the different coloured light scenarios.

	Natural light	Orange light	Green light	Purple light
Valid	20	20	20	20
Mode	7.500	10.000	10.000	10.000
Median	8.500	9.500	8.500	9.125
Mean	8.088	8.912	8.254	8.400
Std. Deviation	1.740	1.533	1.772	1.927
Shapiro-Wilk	0.902	0.727	0.868	0.793
P-value of Shapiro-Wilk	0.046	< .001	0.011	< .001
Range	6.000	5.750	5.250	5.500
Minimum	4.000	4.250	4.750	4.500
Maximum	10.000	10.000	10.000	10.000
25th percentile	7.375	8.813	7.313	6.438
50th percentile	8.500	9.500	8.500	9.125
75th percentile	9.500	10.000	9.813	10.000

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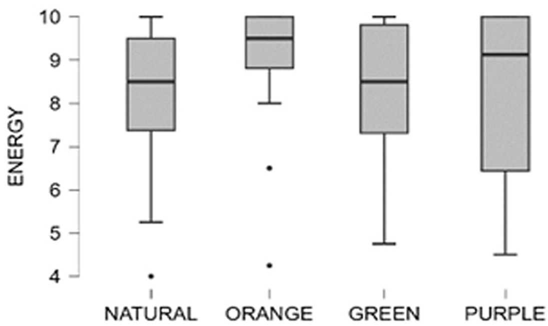

Fig. 3. Box and whisker plot of the self-perceived energy level in the different coloured light scenarios.

Variance analysis. The differences in the above descriptive values do not translate into significant p-values of variance according to Friedman's test (table 4). In contrast, the Conover post hoc does yield some more precise data, especially with respect to the orange scenario (table 5), shown graphically in figure 4.

Table 4. Repeated measures analysis of variance (Friedman Test) on the self-perceived energy level in the different coloured light scenarios.

Factor	Chi-Squared	df	p	Kendall's W
Scenarios (energy)	7.676	3	0.053	0.128

Table 5. Conover post hoc on the variance of self-perceived energy level in different coloured light scenarios.

Conover's Post Hoc Comparisons - Scenarios (ENERGY)								
		T-Stat	df	W_i	W_j	p	p_{bonf}	p_{holm}
Natural	Orange	2.251	57	42.000	59.000	0.028	0.169	0.169
	Green	0.199	57	42.000	43.500	0.843	1.000	1.000
	Purple	1.788	57	42.000	55.500	0.079	0.475	0.316
Orange	Green	2.053	57	59.000	43.500	0.045	0.268	0.224
	Purple	0.464	57	59.000	55.500	0.645	1.000	1.000
Green	Purple	1.589	57	43.500	55.500	0.118	0.705	0.353

Note. Grouped by subject.

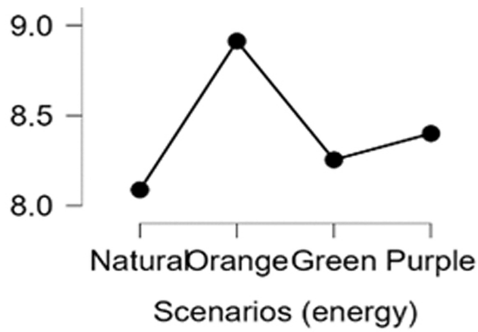

Fig. 4. Variance plot of the self-perceived energy level in the different coloured light scenarios.

4.2 Satisfaction

Descriptive analysis. As with the energy level, table 6 now shows full descriptive results on self-perceived level of enjoyment. Figure 5 is the graphical translation. Although we will be discuss the results in the appropriate section, it is again striking that all coloured light scenarios have higher means than natural light (although with a lot of similarity). When considering the median, the ratings vary slightly. Figure 5 is the graphical translation of the non-parametric results.

Table 6. Descriptive values of the self-perceived satisfaction level in the different coloured light scenarios.

	Natural light	Orange light	Green light	Purple light
Valid	20	20	20	20
Mode	10.000	10.000	10.000	10.000
Median	8.750	9.500	9.250	9.125
Mean	8.438	8.662	8.646	8.675
Std. Deviation	1.500	1.809	1.679	1.414
Shapiro-Wilk	0.897	0.764	0.811	0.855
P-value of Shapiro-Wilk	0.036	< .001	0.001	0.007
Range	5.250	6.000	5.750	4.500
Minimum	4.750	4.000	4.250	5.500
Maximum	10.000	10.000	10.000	10.000
25th percentile	7.688	8.125	7.688	7.875
50th percentile	8.750	9.500	9.250	9.125
75th percentile	10.000	10.000	10.000	9.813

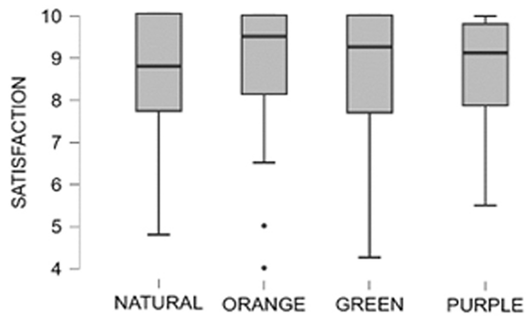

Fig. 5. Box and whisker plot of the self-perceived satisfaction level in the different coloured light scenarios.

Variance analysis. The already announced superiority of means in all coloured light scenarios, as shown in figure 6, does not translate into significant variance values (table 7). Neither are they observed in the Conover post hoc according to table 8, given the high uniformity of results.

Table 7. Repeated measures analysis of variance (Friedman Test) on the self-perceived satisfaction level in the different coloured light scenarios.

Factor	Chi-Squared	df	p	Kendall's W
Scenarios (satisfaction)	3.247	3	0.355	0.054

Table 8. Conover post hoc on the variance of self-perceived satisfaction level in different coloured light scenarios.

Conover's Post Hoc Comparisons - Scenarios (SATISFACTION)								
		T-Stat	df	W_i	W_j	p	p_{bonf}	p_{holm}
Natural	Orange	1.032	57	42.500	50.000	0.306	1.000	1.000
	Green	1.651	57	42.500	54.500	0.104	0.625	0.625
	Purple	1.445	57	42.500	53.000	0.154	0.924	0.770
Orange	Green	0.619	57	50.000	54.500	0.538	1.000	1.000
	Purple	0.413	57	50.000	53.000	0.681	1.000	1.000
Green	Purple	0.206	57	54.500	53.000	0.837	1.000	1.000

Note. Grouped by subject.

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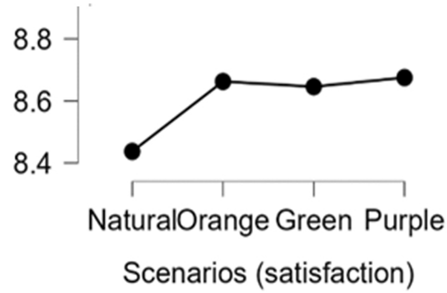

Fig. 6. Variance plot of the self-perceived satisfaction level in the different coloured light scenarios.

4.3 Feelings

Descriptive analysis. Table 9 shows the descriptive results of the pupils' qualitative self-perception in relation to feelings. As already mentioned, a statistical treatment has been carried out thanks to the application of equivalences expressed in table 1. Figure 7 gives a graphical view of the same.

Table 9. Descriptive values of the self-perceived feelings in the different coloured light scenarios.

	Natural light	Orange light	Green light	Purple light
Valid	20	20	20	20
Mode	4.000	4.000	4.000	5.000
Median	3.875	4.000	4.000	4.000
Mean	3.700	3.925	3.600	4.063
Std. Deviation	0.652	0.867	0.958	0.794
Shapiro-Wilk	0.899	0.908	0.926	0.910
P-value of Shapiro-Wilk	0.040	0.059	0.132	0.064
Range	2.750	3.500	3.250	3.000
Minimum	2.000	1.500	1.750	2.000
Maximum	4.750	5.000	5.000	5.000
25th percentile	3.500	3.458	3.000	3.750
50th percentile	3.875	4.000	4.000	4.000
75th percentile	4.000	4.542	4.125	4.625

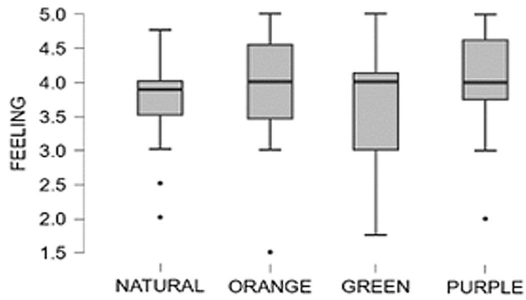

Fig. 7. Box and whisker plot of the self-perceived feelings in the different coloured light scenarios.

Variance analysis. Analyses of variance with Friedman's test show no significant p-values (table 10) although they are close to the alpha value 0.5. Something similar occurs in the post hoc specified in table 11, which also fails to show any significant variance although it is quite close. Figure 8 shows this variance graphically.

Table 10. Repeated measures analysis of variance (Friedman Test) on the self-perceived feeling in the different coloured light scenarios.

Factor	**Chi-Squared**	**df**	**p**	**Kendall's W**
Scenarios (feeling)	6.844	3	0.077	0.114

Table 11. Conover post hoc on the variance of self-perceived feeling in different coloured light scenarios.

Conover's Post Hoc Comparisons - Scenarios (SATISFACTION)								
		T-Stat	**df**	W_i	W_j	**p**	p_{bonf}	p_{holm}
Natural	Orange	1.846	57	43.500	57.000	0.070	0.421	0.364
	Green	0.068	57	43.500	43.000	0.946	1.000	1.000
	Purple	1.777	57	43.500	56.500	0.081	0.485	0.364
Orange	Green	1.914	57	57.000	43.000	0.061	0.364	0.364
	Purple	0.068	57	57.000	56.500	0.946	1.000	1.000
Green	Purple	1.846	57	43.000	56.500	0.070	0.421	0.364

Note. Grouped by subject.

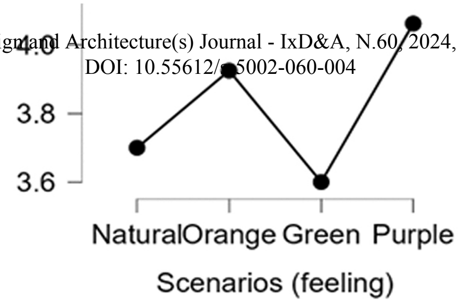

Fig. 8. Variance plot of the self-perceived feeling in the different coloured light scenarios.

4.4 Extreme values of the dependent variables

This last subsection includes the maximum and minimum values of all dependent variables, both in terms of mean and median. The predominance of means with maximum values in coloured scenarios is observed, as opposed to low values in natural light.

Table 12. Main maximum and minimum descriptive values of the dependent variables and their dimensions.

	Maximun value		**Minimun value**	
	Mean	Median	Mean	Median
Energy	8.912	9.500	8.088	8.500
	Orange light	Orange light	Natural light	Natural and Green light
Satisfaction	8.675	9.500	8.438	8.750
	Purple light	Orange light	Natural light	Natural light
Feeling	4.063 Purple light	4.000 Orange, green and purple light	3.600 Green light	3.875 Natural light

5 Discussion

The present study follows the same line of research as the one already published by Quiles-Rodríguez & Palau [7]. Currently the context, sample and experimental approach is different from that of the previous authors (already explained in previous sections), but together with them it does aim to create a growing corpus of data, which will be discussed below. As will also be seen in this section, there are other authors with whom the results can be discussed, but their studies are never carried out directly with primary school students in a school context (which it doing Quiles-Rodríguez & Palau [7]).

In a logical order of progression through each variable, with respect to energy level, the work of Suh et al. [24] shows how green light is more energetic for the adult participants in their study. Quiles-Rodríguez & Palau [7], now directly with children, obtain better results with a violet light scenario, while at present it is orange light that obtains better ratings, significant when compared with the natural and green light scenario (post Hoc de Conover). In any case, all three studies agree that all coloured light scenarios score better than the daylight scenario alone. We have not found such a variable thus defined as "energy" in more studies related to coloured light, although we have found it with colour traditionally conceived as paint [19, 20, 21]. However, as stated by Lee et al. [27], the two differentiated colour source impacts are not comparable. Perhaps similar to energy might be considered "motivation", where Kombeiz & Steidle [22] indicate that blue light elicits approach while red light does not, but neither of these lights are part of our experimental scenarios.

Regarding the variable satisfaction level, previous studies reverse their best results in relation to energy. Thus Suh et al. [24] show better numbers in the violet scenario (with adults), while Quiles-Rodríguez & Palau [7] find the green scenario to be more pleasant for children. Currently we see that violet again gives us the highest values, although without significance either globally or in post hoc. As in the case of energy, there is agreement in the three studies on the superiority of the pleasantness of all the coloured light scenarios over the strictly natural one. In this respect, only two more studies analysed could be compared with the previous ones. Thus, Rajae-Joordens [23] states that there is a greater perception of enjoyment with green or blue light compared to red, and Mogas-Recalde & Palau [8] state more generally that good classroom lighting leads to greater visual enjoyment.

The last of the variables, the self-perception of the feeling evoked by the coloured light scenario, is again directly inspired by Suh et al. [24], although they do not carry out a statistical treatment of it and therefore there is no possibility of comparison. However, Quiles-Rodríguez & Palau [7] do treat the information statistically by means of numerical equivalences, which we do again here as expressed in table 1. Again the "p" value is still not significant although it is close enough. When refining with Conover's post hoc, the highest variance values (lowest p-values, never reaching 0.5) appear in the natural-orange, orange-green and green-violet comparisons, always in favour of violet and orange (violet is the highest descriptive value). The low value of the green scenario is surprising, which is not only slightly lower than the natural one, but was also the best considered in the work of Quiles-Rodríguez & Palau [7], precisely with a statistical equivalence table practically the same as ours (table 1). There are no other educational studies with which to establish parallels in this variable; however, we have found a medical study that studies human parasympathetic activity (to some extent related to emotions) and its link with coloured light scenarios [25]. The study concludes that the parasympathetic system increases with blue light and decreases with red light. These light scenarios are not included in our independent variable, which precludes further discussion.

Based on what has been described above, together with the values shown in table 12, we see a necessary dynamism of coloured light. Perhaps less than expected, as the violet light scenario tends to obtain better values in two of the variables, but it does not monopolise total hegemony, so dynamism is necessary. Mogas-Recalde & Palau [8] have already spoken of the need for lighting to be adapted to the school task. Also Poldma [36], from interior design, insists a lot on the need for the dynamism of coloured light, easy in today's world with LED technology. Suh et al. [24], now from the educational field, are very resolute in indicating that coloured lights are necessary for every classroom need. Quiles-Rodríguez & Palau [7] go a step further, as they not only see the benefits of the dynamism of coloured light scenarios, but also advance the possible damage that some scenarios could cause in certain types of cognitive, affective or instrumental learning processes. In the same vein, we are now also expressing ourselves, because by analysing a situation, a green light scenario could have a good impact on the satisfaction level, and yet be even detrimental with respect to self-perceived feelings (according to the results shown above).

6 Conclusions and implications

Following a systematic order in the confrontation with each of the hypotheses of this study, we start with the first hypothesis. This speculated on the improvement in the energy level caused by some coloured light scenarios, obviously compared to the natural light scenario. With the data from the study we can say that this is indeed the case, as all coloured light scenarios obtain better energy values. Even so, it is only the orange light scenario that shows "p" values lower than 0.5 with respect to natural light (not in the Bonferroni and Holm adjustments), being the only generalisable value.

Regarding the second hypothesis, expressed in similar terms to the first but in relation to the "satisfaction level" as an independent variable, the results are very lukewarm. There is indeed some improvement as all coloured light scenarios show better results in their means, but very slightly, and not noticeable if we consider the median of each scenario. Of course, no significance appears in the analysis of variance, neither at the general level nor in its post hoc particularities.

The third hypothesis, analogous to the previous ones but referring to "self-perceived feelings", is confirmed, albeit relatively, as we did not find any significant p-values. In addition, although the orange and especially the violet light scenario yield much higher values than natural light, the green scenario yields lower values than natural light. In Conover's post hoc after Friedman's test, p-values of less than 0.5 do not appear either, with the variance between green and orange being the closest value.

Analysing the last of the hypotheses, expressed as "the use of dynamic colour makes it possible to adapt the coloured light to the needs of the different affective processes of the pupils", we can confirm it, although with nuances. Thus, although the highest level of energy is found with orange light, the satisfaction level and the most positive feelings both appear in the purple scenario. Given the experimental situation explained above, and given the type of survey used, it is practically impossible to speak of a learning effect, taking the repetition in the violet light scenario as a reliable result. The low value of green light in the energy level and in the consideration of the self-expressed feelings of the pupils support the necessary dynamism of the coloured light, avoiding possible adverse effects as well as positive ones.

In view of the above, it follows that coloured light is related to the development of certain affective processes in students. The above-mentioned impact, even with a certain tendency towards violet light, could be more interesting if it were accompanied by dynamism. Future smart classrooms should take this into account, including the installation of a coloured light system in all primary school classrooms. This system could even create differentiated spaces, allowing for adaptability according to the activity programmed by the teacher in different work corners. The lighting system, differentiated from the general lighting system, could be used only when necessary, without the need for intensive use if it is not necessary, which would also save costs given the very low consumption of LED technology. A standardisation of the system would make it much easier to extend it geographically, allowing any industry seeking it to make a quick return on investment.

7 Limitations and future lines of research

Although we have multiplied the values of each scenario by four using the same individuals, minimising the influences of possible external variables not controlled before the students' arrival in the classroom, it would be desirable to achieve an increase in the "n" values by applying the test to a larger number of individuals. Similarly, the collection of information through self-perceived data does not achieve the same objectivity as a physiological measure of self-perception, especially in children, where self-perception may be fluctuating and dependent on uncontrolled variables. Future improvements could introduce such sensors, as has already been done in some studies [23].

On the other hand, there is little preceding literature as mentioned above, which is not homogeneous in terms of whether or not there is an influence of external natural light, although it tends to be considered that an adequate combination of both is the most useful. In this sense, our study has avoided external influence (except in the natural scenario) to avoid light variations with climatic change. Future mechanisms should be found to incorporate the influence of natural light by minimising its changing effect.

A further limitation is the use of a non-randomly selected group. In standardised classroom contexts this is very complex and practically impossible as the groups are officially pre-established. Achieving such randomisation would increase experimental rigour. The presence of a control group would also contribute to this, which has not been possible at present, although we did have a pretest with which to establish variance.

The last limitation we express is related to the professional installation of coloured light. We have not been able to obtain it due to the refusal of the companies contacted, so the installation has been carried out with our own resources. For this, and as already expressed in figure 2, we have tried to achieve a homogeneous distribution of light, but the management of this is complex and aesthetically produces an undesirable impact. Professionalising the installation will bring improvements in light quality, aesthetic concealment, ease and adaptability of handling, and standardisation of its integrated use in the classroom. This professionalisation will also allow the dynamism of the light, and even the differentiation of use by work zones, to be optimised to the maximum of its capacity.

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