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Analysis of the Teacher Perspective About the Implementation of a Colour-Adaptive Lighting System in Smart Classrooms

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Abstract

This study explores primary school teachers' perspectives on the implementation of a colour-adaptive lighting system in smart classrooms. While previous research has primarily focused on the effects of correlated colour temperature (CCT) on learning and cognition, studies on coloured lighting remain limited. To address this gap, a focus group discussion was conducted with seven primary school teachers in Andalusia, Spain, each with varying levels of experience and exposure to colour lighting in classrooms. The discussion examined general environmental factors, emotional responses, the perceived benefits and challenges of colour lighting, and potential solutions for its integration into smart classrooms. A thematic analysis, supported by AI-assisted coding, identified key themes such as the role of environmental factors in learning, the influence of coloured lighting on student engagement, and the practical barriers to its implementation. Findings highlight teachers' recognition of environmental conditions as influential in the learning process, concerns regarding classroom adaptability, and the need for flexible, research-informed lighting solutions. The study contributes to the ongoing discourse on smart classroom design by integrating qualitative insights from educators, emphasizing the necessity of a user-centered approach to educational technology.

Keywords: *Colour Lighting, Smart Classroom, Environmental Factors, Qualitative Research, Learning Environment.*

Introduction

The nuanced influence of colour within educational settings has been the subject of rigorous scholarly inquiry for several decades. However, a thorough exploration of coloured lighting remains markedly underrepresented in academic discourse. Coloured lighting refers to the deliberate application of diverse hues of illumination within educational environments to modulate and enhance students' cognitive performance, academic engagement, emotional equilibrium, and, consequently, their holistic learning experience. In this regard, the study conducted by Quiles-Rodríguez & Palau (2023) serves as a systematic review of extant literature on the effects of traditionally perceived colour—that is, its physical presence in classroom spaces—while neglecting the potential implications of coloured lighting. By means of an exhaustive and systematic analysis of colour elements in educational contexts, both independently and in conjunction with other environmental variables, the authors synthesise their findings into two principal categories: one delineating colour's impact on cognitive functions and another addressing its influence on emotional and social dynamics. This classification, alongside the inclusion of fundamental instrumental learning (linguistic and mathematical proficiency), will constitute the cornerstone of this article, as will be expanded upon in subsequent sections.

Background

It is imperative to underscore that while the relationship between correlated colour temperature (CCT) and brightness in relation to academic performance has been extensively examined, particularly regarding its effects on attention, concentration, and students' emotional and motivational states, there exists a profound dearth of research dedicated exclusively to the pedagogical ramifications of coloured lighting (Arbona, 2021). A crucial distinction must be made between these two parameters—colour temperature (CCT) and light colour—as they possess fundamentally disparate characteristics and are quantified using different units: kelvin for the former and nanometres for the latter. Scholars such as Suh et al. (2020), Rajae-Joordens (2010), and Kombeiz & Steidle (2018) have pioneered this nascent yet rapidly expanding field of educational

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research on coloured lighting, which, despite its relative infancy, has been extensively explored in other disciplines, including interior design (Poldma, 2009), agricultural methodologies (Hogewoning et al., 2010; Johkan et al., 2012), medical science (Araujo et al., 2020), and aerospace studies (Jiang et al., 2022).

Research concerning the impact of environmental colour in educational contexts often suffers from an absence of rigorous, systematic methodologies (Manca et al., 2020). This deficiency extends to the limited body of literature on coloured lighting (Quiles-Rodríguez & Palau, 2024a). For instance, Von Castell et al. (2017) argue that the effects of ambient colour are so inherently variable and inconsistent that deriving practical applications presents a formidable challenge. In a similar vein, certain studies posit that visual disturbances and colour fluctuations may negatively influence academic performance (Godwin et al., 2022). Conversely, some scholars have sought to elevate the methodological rigour of environmental research, including studies on colour, through extensive longitudinal analyses (Barrett et al., 2015, 2017).

The urgency of this discussion is further heightened when we consider students' cognitive processes, a broad spectrum of neural activities that function independently of socio-affective mechanisms (Smith & Kosslyn, 2008). While a wealth of research on environmental colour, as traditionally conceptualised, has identified correlations between physical colour and cognitive performance (Quiles-Rodríguez & Palau, 2023), there remains a stark paucity of empirical studies dedicated to the specific cognitive effects of coloured lighting. Notable exceptions include Kombeiz & Steidle (2018), who investigated the influence of coloured lighting on creativity within a German university setting, and prior studies conducted in primary education (Manca et al., 2020). Of paramount importance is the foundational research of Quiles-Rodríguez & Palau (2024a), who conducted an exploratory intervention within a primary school context, unveiling substantial cognitive, academic, and emotional outcomes associated with the integration of coloured lighting in classrooms, thereby providing a compelling impetus for further inquiry.

When examining correlated colour temperature (CCT) and its respective impact on cognitive processes, the existing literature is demonstrably more expansive. For example, Mogas-Recalde & Palau (2021) provide a comprehensive synthesis of 18 studies that collectively scrutinise the intricate interplay between CCT and various cognitive faculties, while Llinares et al. (2021) examine CCT's influence on attention and memory retention. Furthermore, Hviid et al. (2020) assess how CCT, in conjunction with ventilation, affects crucial cognitive functions such as logical reasoning, concentration, and processing speed. While some overlap exists between these investigations and the present study, none directly address the variable of coloured illumination.

A parallel situation emerges when we consider the role of environmental colour in students' affective processes. We align with Gross (2015), who contends that discussions surrounding learning must extend beyond skills, knowledge, and abilities to encompass behaviours and values, thereby inherently integrating affective dimensions. Mora (2013) further clarifies that learning is inextricably linked to emotional engagement. Traditional conceptualisations of environmental colour have been examined in relation to affective parameters such as stress and anxiety (Lewinski, 2015; Pourbagher et al., 2020), motivation (Tuszyńska-Bogucka et al., 2018), calmness (Vidal-Rojas & Vera-Avendaño, 2020; Stone, 2001; Gilavand, 2016), and energy levels (Englebrecht, 2024; Kuller et al., 2009; Salleh et al., 2015). However, as previously noted, research findings in this domain are neither uniform nor consistent (Quiles-Rodríguez & Palau, 2024a).

Despite these limitations, a substantial number of studies on coloured lighting do consider affective responses as primary dependent variables. Kombeiz & Steidle (2018), for instance, investigate the complex interplay between approach motivation and red/blue light exposure, while Rajae-Joordens (2010) explores psychological arousal and satisfaction levels in response to red, green, and blue lighting. Moreover, Suh et al. (2020) contribute empirical data on students' mood, energy, and overall satisfaction in diverse illuminated scenarios, akin to Quiles-Rodríguez et al. (2024). Such findings have been instrumental in shaping the self-perception survey employed in the present study.

Beyond the domain of education, significant findings have emerged from medical and astronautical research on coloured light's impact on emotional states. Studies indicate that blue light exposure enhances

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parasympathetic activity, fostering relaxation, whereas red light is associated with reduced calmness (Araujo et al., 2020). Similarly, astronautical studies reveal that multicolour lighting can mitigate anxiety and negative emotions in confined environments (Jiang et al., 2022). This distinction underscores the divergent effects of coloured light relative to traditional colour applications (Lee et al., 2021), a consideration with profound educational implications.

In subsequent sections, we shall delineate the materials and methodologies employed in this experimental framework, encompassing three integrated experimental conditions. The findings will be presented via a triadic analytical approach (descriptive, variance, and comparative), culminating in definitive conclusions following a critical discourse.

Methodology

As many of the preceding articles on coloured lighting are quantitative, it was necessary to delve deeper into the how of the implementation processes and thus to deepen our aim, and thus establish a general objective, on the possible benefits and detriments of installing coloured lighting systems, and thus to seek a deeper understanding (Flick et al., 2004). To this end, it was decided to conduct a focus group discussion session with the participation of a purposive sample of primary school teachers with different backgrounds and experience in relation to coloured lighting in classrooms. This approach, widely supported in qualitative research (Mason, 2002; Creswell, 2009), is distinguished by its ability to generate knowledge from the interaction between participants. Unlike other methods of data collection, focus groups allow different dynamics to emerge that are valuable in studies such as this one, where previous qualitative research is scarce. In this study, we sought to obtain sufficient information to answer the following research questions derived from the general objective:

RQ 1: How could coloured lighting influence the teaching and learning experience in smart classrooms?

RQ2: What would be the main barriers in an implementation of coloured lighting systems in smart classrooms?

RQ3: What strategies and solutions would be effective in overcoming the challenges in implementing these systems?

The participants were purposively selected from the teaching staff of a primary school where three coloured lighting installations have been carried out in different classrooms. Seven teachers responded to the call, which is considered a sufficient sample according to Creswell (2009). The quality of the sample is also optimal given that it alternates between teachers with previous experience in quantitative research on coloured lighting, teachers with colour installations in their classrooms but without research experience, and teachers who are not familiar with the subject of coloured lighting, so the heterogeneity of the sample is evident. Systematised data can be seen in Table 1.

Table 1. Profile of Teachers Participating in the Focus Group.

	Gender	**Age**	**Educational stage**	**Years of teaching experience**	**Profile of teachers participating in the focus group**
Participant 1	Woman	40-49	Primary education	26	Previous participation in quantitative research
Participant 2	Woman	30-39	Primary education	10	Unrelated

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Participant 3	Man	40-49	Primary education	17	Tutor in a classroom with coloured light installation but without specific training
Participant 4	Hombre	30-39	Primary education	13	Tutor in a classroom with coloured light installation but without specific training
Participant 5	Mujer	30-39	Primary education	5	Unrelated
Participant 6	Hombre	40-49	Primary education	25	Unrelated
Participant 7	Mujer	50-59	Primary education	29	Unrelated

The focus group session took place in the primary school where all participants teach, in a rural area in the centre of Andalusia (southern Spain) during the month of February 2025. The session lasted an hour and a quarter, with the first 15 minutes being devoted to an informative introduction by the research team, while the rest of the session was devoted to the answers and debate arising from the questions posed. The five questions posed to the participants were:

How much importance do you attach to the influence of environmental factors on the teaching-learning process in your classes?

Do you place a high or low value on the general lighting in your teaching-learning environment and why do you do so?

From your perspective as a teacher, how would you rate the existence of a professionalised coloured lighting system outside the ordinary classroom luminaire?

How do you think the existence of a professional coloured lighting system in the classroom could affect your students in the complex learning process?

What are the main barriers or challenges for the real implementation of a coloured lighting system in future smart classrooms in Andalusian and Spanish schools? What solutions do you think are possible to overcome these barriers?

The moderator played a role far removed from his own intervention, devoting himself to raising questions, clarifying possible concepts not well assimilated by the teaching staff and redirecting the debate in the event of a departure from the main lines put forward. Participants were encouraged to respond on the basis of their professional experience and knowledge, encouraging critical reflection and the exchange of perspectives. The questions asked during the debate responded to different levels of analysis, starting from a more general approach to progressively reach the real objective of the analysis, being the barriers and solutions for an implementation of coloured lighting systems in smart classrooms. This methodology allowed not only to gather valuable information on teachers' perceptions of smart classrooms, but also to identify key points for the development of effective implementation strategies within the current educational context.

Análisis De Datos

The focus group was videotaped and subsequently transcribed in the original language (spanish) by one of the researchers. Subsequently, AI assistance was used using the Chat GPT-4o Mini software, applying a

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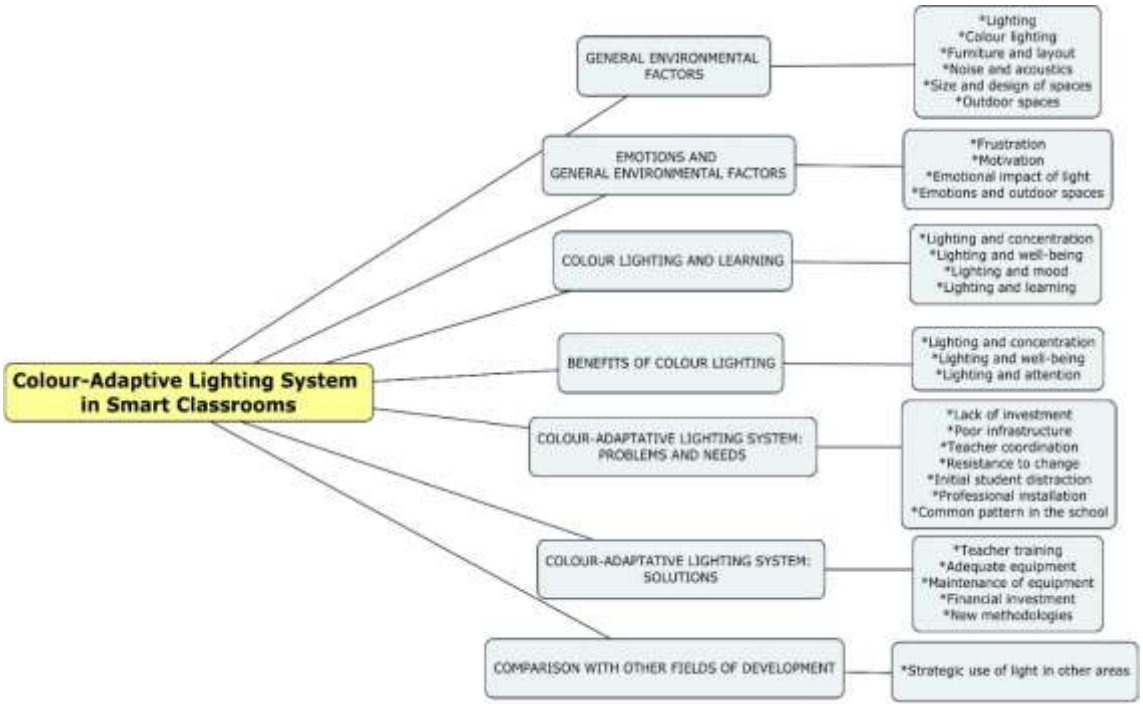
thematic analysis approach on the input of the written transcript of the focus group (Braun and Clarke, 2006), agglutinating this analysis into codes that constitute themes. For this purpose, two possible perspectives were indicated: a general perspective from the consideration of environmental factors understood as a whole, and, on the other hand, a more specific perspective from the perspective of classroom lighting. After each AI-assisted process, the research team reviewed and adapted, if necessary, the results provided in consideration of the human interpretation of the transcribed focus group text. In most cases the primary codes generated were agreed upon, although the agglutination into a higher thematic stratum by affinity was modified, eliminating those themes that were not the direct object of the study. The research team also enriched the AI input with some verbatim transcripts of the teacher discussion, allowing for exemplifications which can be read in the following sections.

Consideraciones Éticas

Before starting the focus group session, participants received an informed consent document issued by the Universitat Rovira i Virgili. This document specified in detail their rights as participants, as well as the obligations and commitments of the research team. It was ensured that each participant fully understood the aims and scope of the study, as well as the format of the discussion, before giving their voluntary and explicit consent. As part of the ethical protocol, participants were informed about the video recording of the session, noting that this material would be used exclusively for analytical purposes within the framework of the research. It was emphasised that their participation was completely voluntary and that they could withdraw at any time without consequence. In addition, the research team underlined its commitment to protecting the identity of participants, to strict compliance with data protection regulations and to respecting the ethical principles of research. It was assured that the information collected would be used confidentially and for the sole purpose of contributing to the study, minimising any possible risk or impact to participants.

Results

The results of this focus group study are presented grouped into seven themes that emerged from the analysis of all available textual data. Given the structure of the questions posed, and which can be read above, the first two groupings by theme are less specific, serving as contextualisation for the following ones, which do delve deeper into our proposed objective. Thus, the themes generated are: general environmental



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factors, emotions and general environmental factors, colour lighting and learning, benefits of colour lighting, colour-adaptive lighting system: problems and needs, colour-adaptive lighting system: solutions, comparison with other fields of development. Figure 1 shows these themes, but in addition, each theme is composed of several codes associated with them, which can be seen schematically in the visual representation shown.

Figure 1. Codes and Themes That Emerged in the Focus Group

General Environmental Factors

In general, teachers attach considerable importance to the environmental factors of the classroom environment, even if it is only by intuition and without having read specific literature on the subject. The analysis shows that the most important elements taken into account are lighting, furniture and its arrangement, noise and acoustics, class size and design, the possibility of using outdoor spaces and even coloured lighting. Not all the participants' interventions have the same impact on the different codes, nor do they do so with the same number of occurrences, but in a qualitative analysis we have decided to include all those that provide variability so as not to lose the nuances of the discourse generated among the participants. Thus, interventions such as the following, reproduced verbatim, exemplify this coding:

I attach a lot of importance to it. I think that environmental factors, both the light and the colours, as well as everything else, have a huge influence on both the pupils and the teachers. (Participant 1)

Natural lighting is also important. In the other school we had blinds that you move with your finger and the light doesn't come in properly and we had the lights always on. (Participant 3)

That this doesn't work. That it's not a warm environment, it's not an environment where they feel good. That the children don't want to come to school. If this was so nice, if it was something, a welcoming environment, they would come to school. (Participant 1)

When I walked in the door of the school, well, of my class, and I saw this table, I said no way. It was horrible because the other ones, even if they were individual, you could put them together in different spaces. But they have to be joined together by force (Participant 2).

During Covid we worked terribly with the noise (Participant 1).

Noise is a very important environmental factor (Participant 2).

The classes are very small. You go to other countries and it's not like that. And the size of the class gives us what it gives us (Participant 4).

The important thing would be for the playground to be ready to be able to teach. (Participant 4)

On Thursday we went to the playground, looking at the beautiful part, and we read better. (Participant 5)

Emotions and General Environmental Factors

Although it is not the main objective of this article, it is true that teachers are comfortable, and therefore fluent in their discourse, talking about general factors. Within these, we have noticed, and therefore codified and grouped into specific themes, a natural relationship between them and emotions. Sometimes these statements overlap with the previous thematic categorisation, as teachers tend to justify their contributions (in the absence of more objective data) with emotional states perceived in pupils. Even so, this emotional impact, far from being repetitive, once again allows us to see the qualitative richness of the discourse. Again using literal fragments, we include:

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That it doesn't work. That this is not a warm environment, it's not an environment where they feel good. That the children don't want to come to school. If it were that nice, if it were something, a welcoming environment, they would come to school. (Participant 1)

And then, for example, the issue of the light inside the classroom, I have to raise the blinds every day, I can't teach with me, for example, as we are now, it's overwhelming. (Participant 2)

When it's like this, I'm looking at the light and as my body is asking me, to raise the window, to raise the blinds. (Participant 4)

It's true that when I have worked maybe in the playground, some activities in the playground, I have always noticed that apart from the fact that the children are much more motivated and they relate to each other, they are outside the classroom environment, so they are happier. (Participant 2)

Colour Lighting and Learning

Focusing now on the subject of lighting, the answers given by the teachers moved vaguely from general lighting to coloured lighting. Although the moderator's interventions focused the responses, the natural tendency was once again to mix the two concepts, probably due to the partial lack of knowledge of a coloured lighting system in the classroom, since, as we have said, some of the teachers have experience in this area and others do not. Despite this natural mixture, we have been able to clearly extract the theme 'Colour lighting and learning', given that in one way or another (coloured lighting or generically understood) the teachers are aware of its effect on learning, and sometimes they even talk about colour dissected from the concept of 'coloured lighting'. We reproduce the discourse as follows:

There was a method of teaching and learning that already had an impact on the furniture, on the light and all that (Participant 5).

What is also clear is that in order for this to have an influence on learning, on lighting, we also need training. (Participant 3)

I think that if we turn the classrooms into a space for curiosity, for learning, with light (Participant 1).

Because as each colour is associated with creativity, it is supposed to be associated with one colour, concentration is associated with another, reading is associated with another colour, so come on. (Participant 1)

Of course, serenity, I don't know, and of course, that is going to condition the curricular aspect, if the child is more serene, more concentrated, then that is going to have a direct influence on his curricular development. (Participant 6)

The absence of light is also part of the classroom climate, the fact that there is no light for certain activities or that a dimmer light can be used, a more relaxing light. (Participant 1)

Benefits of Colour Lighting

Closely linked to the previous theme, but on this occasion teachers make it clear that they see a benefit to coloured lighting in its impact on pupils. Again, as in previous themes, some of the coding can be assigned to different but related themes. We still choose not to lose the nuances of it. Similarly, teachers speak indistinctly of attention or concentration. We do not perceive any differences in their accounts, but we are aware that concentration implies a greater effort to sustain the activity over time, while attention is usually mentioned as an initial effort to capture it. We therefore maintain both as distinct benefits. Turning again to the primary source:

What specifically? Concentration. Concentration. That they don't get scattered in the change from one activity to another, because if they have associated that such and such a colour is because there is a concentration activity, that such and such a colour is... these changes from one thing to another, maybe they don't lose so much attention. Attention, motivation and non-dispersion. (Participant 5)

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For example, last year, clearly, when there were some children who, for example, with the green light they felt very stressed, they had a headache, teacher, I can't work with this light. (Participant 1)

Colour-Adaptative Lighting System: Problems and Needs

The most precise thematic concretisation comes with this typification around the adaptive coloured lighting system. This is the thematic line that most coincides with the objective of this research, but which we have arrived at through a progressive and correct process of concretisation of the discourse and introduction of questions in the focus group. At this level, the first reflection that arises among the teaching staff is the natural fear of change that leads them to see the possible problems prior to the implementation of an adaptive coloured lighting system, despite being aware (as was made clear in previous topics) of its benefits. So much so that, as can be seen in the diagram in figure 1, this subject is the one that contains the greatest amount and most exact coding. It is true that sometimes the teachers in the sample again digress between the problems or need for a possible adaptive colour lighting system or the endemic problems of environmental factors that the education system suffers from. Although we have tried to separate and eliminate the latter, the line between the two is not always clear-cut in the discourse analysed. Returning to the literality of the oral verbal message:

But I'm going to dare, I'm going to go to the money barrier (Participant 6).

I don't know if the fear of the unknown has been mentioned, always breaking with routine always gives us an important psychological fear. And human beings move out of fear. Also the laziness of not doing something simply because it doesn't seem to be going well. (Participant 6)

And that is true, it has always been said that it looks like a prison. Not that it has good lighting (Participant 6).

But the other class has to do the same because otherwise, in the end, in terms of lighting, maybe if I use yellow light for reading, the other teacher also has to use yellow light. In the end it has to be a pattern and a centre code, I think, of course. (Participant 2)

Teacher coordination is also a barrier (Participant 4).

In the first moments, whatever colour you use, they are going to be fascinated and distracted. As soon as the lights are changed, they will be fascinated. Then they acclimatise to that and I imagine that they will have the effects that you want them to have. (Participant 6)

Professionalised. Professionalised, of course. And that's the problem we always encounter in classrooms, that they give us something. If we digitise schools, this is digitising a school or sending a few trolleys with 20 computers. No, that's not it. So that's the problem. As there are no means to do it well and do it professionally, the results are not going to change because in reality it is not going to be done well enough for that to happen. (Participant 1)

Colour-Adaptative Lighting System: Solutions

Closely related to the needs and problems indicated above are the solutions to them. Although the correspondences are not exact, there is a fairly direct relationship, especially in terms of the need for investment, quality of infrastructure and teacher training. Indirectly, it seems to be taken for granted that resistance to change, which is natural to human beings, does not have a direct solution (although it could also be understood that training does attenuate this resistance), nor does the initial over-motivation, distraction and distraction of pupils. The five codes used for this thematic categorisation are illustrated, among others, by these literal fragments:

Possible solutions for the money, well, let's look for it.... Or do activities in which you don't donate so much and keep it for the school, invest in what we are seeing that can improve the children's learning. (Participant 3)

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And then I think that the centres also include, that there are now good guidelines, a good skeleton, and that there are centres and many differences. I have been in a few centres that work really well and they have the same career. What is happening? They are giving more solutions. (Participant 3)

To ensure good maintenance in the centres (Participant 3).

It's training because it takes time. It is true that it is always difficult to change, it is always easier to do what you have always done with what has always been done. Because it works, but it doesn't work. I don't know why it is repeated over and over again, but it doesn't work, it has never worked (Participant 1).

Sometimes here we are like the idiots, come on, we are going to do this, we are going to do that. Come on, but it's not well founded. Why do you have to do it? It is true that I am the first one to live in an innovative environment, but it is true that we need training in new methodologies. (Participant 2)

Comparison With Other Fields of Development

Although this topic is only given by a code (strategic use of light in other areas), it is true that it is a relevant topic in the scientific literature, as we have already seen in the background section. Despite the lack of specific training of the participating teachers, as mentioned above, the emergence of this topic is interesting, a very likely sign of the eternal delay in development that is self-perceived by the educational community in general and specifically by one of its basic pillars, the teaching staff. The terms of its appearance were as follows:

I understand that if in restaurants, for example, clothing shops, museums, etc., they play with all these environmental conditioning factors, colour, temperature, smells, flexibility, they play with us so that we consume more, so that we buy more, so that we spend less time here. Therefore, we do have to put more effort from the administrations to really create a suitable environment in education so that children can perform, perform better and better. (Participant 6)

You go into a shop where there is that white light and you do that with just the light. And the way you put things on (Participant 2).

In that sense, it's like we are a long way behind. Yes, yes, it has been shown that all of this, the smells, the temperature, the colours, play in favour of what they want to achieve with us. That they are, let's say, like leading us back. Well, here, in education, we should invest in this type of thing. (Participant 6)

Discussion

Having presented the qualitative results, as a starting point for this discussion we need to contextualise the contributions made by the teachers in our focus group and, from the outset, we can indicate that the general factors discussed by the teachers tend to be the usual ones that appear in the scientific literature (Barret et al., 2015, 2017). Being more precise about the constituent codes of the general environmental factors, and in a content quite coinciding with our qualitative study, we say that similar contributions on the importance of lighting are found in many specialised journals, with articles such as the one by Mogas & Palau (2021), where in addition to showing how lighting directly affects student cognition, a review of 130 articles that specify this influence on elements such as attention, work speed, productivity and accuracy is made. Regarding the environmental noise factor and its negative effect on learning, there are several sources in the literature, including Estrada-Rodríguez & Méndez-Ramírez (2015), who show how constant exposure to noisy environments causes concentration problems, fatigue and stress, affecting academic performance. Furniture is another of the elements considered in this focus group, and although it is not usually considered a main category in smart classrooms (Mogas et al., 2020), some studies do recognise the need for a comfortable and efficient physical space that meets the necessary flexibility of the classroom (MacLeod et al., 2018), and this despite the fact that some studies such as those by Murillo & Martínez-Garrido (2012) see no significant impact of classroom size on academic performance, which is also supported by López-Agudo & Marcenaro-Gutierrez (2021) for the region of Andalusia (Spain). For the last of the codes used in this theme, outdoor spaces, the discussion point leads us to consider the publication by Campillo (2024)

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who states that schools with green spaces can improve student performance, as nature acts as a promoter of emotional and cognitive well-being. However, more empirical studies are needed to establish a direct causal relationship with respect to this element.

In precise consideration of coloured lighting, the most developed coinciding studies in primary education are those carried out by Quiles-Rodríguez and Palau (2023, 2024, 2024a, 2024b, 2024c, 2024d), who not only talk about the influence of coloured light in the generation of warm environments (in the terminology of the teachers in this study), but much more than that, they provide substantial data on cognition, emotion and basic learning. In this sense, the relevance they give to coloured light illumination is highly significant, coinciding with the consideration of the teachers in our qualitative study. Moreover, sometimes very accurate contributions verbalised during the course of our focus group, collected in the previous section, also appear in the previous studies by Quiles-Rodríguez & Palau (2023, 2024, 2024a, 2024b, 2024c, 2024d). This is the case with the references to the incidence of coloured lighting on curricular performance (learning), with the initial motivational factor that the simple presence of a coloured lighting system in the classroom implies, with the necessary professionalisation of a correct installation, with the incidence on attention, and with the comparison with other fields, with the comparison with other fields of knowledge development, with the emotional/motivational impact on students, or with the necessary adaptability (and therefore dynamism) of coloured lighting, maximising its benefits and avoiding the possible harm of scenarios that are poorly adapted to the selected educational task.

From all of the above, we have sufficient information to answer the research questions. Thus:

RQ1: How could coloured lighting influence the teaching and learning experience in smart classrooms?

Coloured lighting in smart classrooms can significantly influence the teaching and learning experience. The findings highlight several key aspects around cognition and learning, with teachers recognising that lighting would affect concentration, attention and transition between activities, believing that associating certain colours with specific tasks could optimise the learning process. The influence on motivation and emotional state would also be considerable as teachers recognise that coloured lighting can contribute to a more welcoming environment, which would influence students' willingness to attend and participate in class, but also the use of specific colours could promote relaxation, focus or cognitive stimulation depending on the educational activity.

RQ2: What would be the main barriers in an implementation of coloured lighting systems in smart classrooms?

Teachers identify lack of financial resources as a key barrier. The implementation of a coloured lighting system requires an investment in infrastructure, materials and maintenance, which may be difficult for many educational institutions to afford, coupled with the fact that lack of maintenance could affect its operation and reduce its effectiveness over time. In addition, there would be a 'fear of the unknown' and a natural resistance to change established practices, which together with a lack of training on the benefits and proper use of coloured lighting would hinder its acceptance and effective application in the classroom. In addition, for the system to be effective, its use must be aligned throughout the school, as the absence of a common protocol on which colours to use in each activity could lead to inconsistencies in its application. A final barrier identified is that in the early stages, the change of lights may attract too much of the students' attention, distracting them from learning. However, it is suggested that this distraction is temporary and that students adapt over time.

RQ3: What strategies and solutions would be effective in overcoming the challenges in implementing these systems?

On the one hand, it would be necessary to seek funding through educational grants, government programmes or partnerships with technology companies, to which I would add the possibility of allocating part of the school budget to technological improvements that include coloured lighting, and even implement pilot projects in some classrooms before making a massive investment. Similarly, the

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development of training programmes that explain the benefits and proper use of coloured lighting in the classroom to teachers, the establishment of common protocols and codes of use within each educational institution to ensure consistency between classrooms or the promotion of collaborative work between teachers to define joint implementation strategies, would be good solutions.

Additional solutions discussed were the adjustment of the type of lighting according to the specific needs of each classroom and group of students, the evaluation of its impact or regular maintenance by technical staff.

Conclusions

In conclusion, this qualitative study has allowed us to explore the main barriers and solutions for the implementation of coloured lighting systems in smart classrooms from the teachers' perspective, thus fulfilling the main objective of the study. Through the focus group analysis, several factors have been identified that influence the viability of this technology in educational environments, thus answering the three research questions in the previous section.

Without wishing to be repetitive, but more as a brief summary, we can say that among the main barriers, teachers highlighted the lack of investment and economic resources, which would hinder the acquisition and installation of advanced lighting systems, the resistance to change and lack of specific training that would limit the appropriation of this tool by teachers, the absence of standardised protocols on the use of coloured lighting that would generate uncertainty about its effective implementation, the possible initial distractions for pupils and the need for continuous technical maintenance of any technical element installed.

Several strategies and solutions have been identified to overcome these obstacles. Firstly, it is recommended that both external and internal funding sources be sought to facilitate investment in infrastructure. In addition, teacher training would be key to ensure the proper use of coloured lighting and maximise its impact on learning, as well as coordination and standardisation within the schools.

Finally, there is no doubt that coloured lighting in smart classrooms has great potential to improve teaching and learning, although its implementation would require overcoming economic, organisational and pedagogical challenges, which are perfectly solvable through the adoption of well-structured strategies and adequate planning.

Implications, Limitations and Future Lines of Research

The findings of this study could have important implications in the educational, technological and organisational domains, providing a basis for future decisions on the implementation of coloured lighting systems in smart classrooms. From an educational perspective, the results highlight the need for specific teacher training on the pedagogical use of coloured lighting as well as the establishment of standardised usage protocols within educational institutions; from a technological perspective, this study reinforces the importance of developing adaptive lighting systems that are easy to manage and respond to the dynamic needs of the classroom, while from an organisational and educational policy point of view, the implementation of these systems would require sustained investment and funding strategies that enable their integration into educational institutions.

Despite the valuable contributions of this study on barriers and solutions for the implementation of coloured lighting systems in smart classrooms, it is important to recognise certain limitations that may influence the generalisability of the results. Firstly, the sample used in the study consisted of a small group of teachers from a single school in Andalusia, Spain. Although the purposive selection allowed for the inclusion of participants with different levels of experience in lighting of colour, the findings reflect particular perceptions of this context and may not be fully representative of other educational realities, especially in different regions or at different educational levels. Secondly, the qualitative nature of the study, based on a focus group, limits the possibility of establishing direct causal relationships between coloured lighting and its effects on teaching and learning. The data obtained are based on teachers' perception and

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experience, which implies a possible subjectivity in the responses. It would be advisable to complement these findings with quantitative studies that objectively measure the impact of coloured lighting on variables such as student attention, motivation and academic performance. Another limitation is the possible influence of unfamiliarity or uneven familiarity with coloured lighting among the participants. Some teachers had already worked in classrooms with coloured lighting, while others had no previous experience, which may have affected the depth and focus of their responses. A greater homogeneity in prior experience could provide more balanced data.

In conclusion, the findings of this study have identified several areas that require further exploration to optimise the implementation of coloured lighting systems in smart classrooms. In this sense, future research could focus on the longitudinal perspective by analysing prolonged exposure to coloured lighting, as well as exploring the adaptation of coloured lighting in consideration of factors such as age, learning style and even special educational needs. Other possible future lines would be the creation of standardised regulations and protocols in educational centres influencing the effectiveness and coherence of the use of coloured lighting in the classroom, the comparative study in different educational contexts or even the incidence of coloured lighting in interaction with other factors in the school environment (acoustics, furniture, ventilation, ...). In short, although this study provides a qualitative approach to the subject, future research should delve deeper into these aspects to generate a more solid frame of reference to guide the effective implementation of coloured lighting in the educational environment.

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