Emotional Colours: Relationship Between Light Wavelengths and Emotional Activation for Enhancing Memory Processes

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Abstract
The research project seeks to reassess and redefine the educational tools and environment to establish optimal learning conditions by harnessing the potential of luminous stimuli inherent in didactics. Literature has underscored how the wavelength of various colours correlates with differing levels of engagement in children, as it is associated with varied emotions experienced upon encountering the coloured stimulus. Consequently, owing to the strong link between emotion and memory, research has revealed how colours can positively influence the memorisation of concepts. The objective is to delineate the impact of coloured stimuli on the memory processes of elementary school children, through deliberate employment of specific wavelengths, such as 255-0-0 (700.47nm), 0-255-0 (546.09nm), 0-0-255 (435.79nm), 121-0-255 (428 nm), 69-255-0 (534 nm) and 255-248-128 (572 nm), chosen based on the heightened sensitivity of human eye photoreceptors. The study entailed an initial phase of individual-level colour-emotion association utilising software capable of discerning the subject's emotion through facial muscle contractions. Subsequently, following the customisation of the educational tools and environment, a mnemonic test was conducted to ascertain the memorisation of academic content. This pilot study, conducted on a sample of 134 primary school children, has yielded highly intriguing results, revealing that a conscious utilisation of colour within the educational context can enhance mnemonic processes in 30% of cases. The project's potential lies in its considerable practicality and customisation, enabling the adaptation of the proposal to suit the specific needs and requirements of each student, thus respecting the diversities within the class group.

Keywords: Engagement, Primary School, Children, Learning, Color

Introduction

Learning environments play a crucial role in the complex task of knowledge acquisition. To create a space that facilitates memory processes, their structuring should consider the multitude of stimuli with which students interact daily. Achieving such an organisation can benefit from the conscious use of tools, materials, and educational aids, whose functional application can substantially contribute to sustaining a positive emotional experience in the learning process (Gaines et al., 2023).

The latter draws upon various activations that enable the analysis, understanding, and subsequent assimilation of available information. Among these, the visual acquisition of stimuli allows for the processing of a significant portion of their characteristics, and the physiology of vision, which studies its functioning, helps us understand how these stimuli play a fundamental role in the information-processing process (Sinha et al., 2024). Specifically, it emerges that the role played by colour, and its various wavelengths, enriches the visual experience, providing a higher level of engagement based on the response of biological, cultural, and experiential components (Farley et al., 2019; Dalke et al., 2018). In the literature, it is reported that high levels of emotions are associated with better memory retention (Kensinger et al., 2020); thus, the conscious choice of colour in the educational context and its materials can optimise the process, making the understanding and assimilation of information more efficient. Moreover, studies report that different wavelengths convey emotional content that activates emotional memory processes. This plays a fundamental role in the learning phases, as the qualitative aspect of such types of information carries significant weight in the stages of acquisition, maintenance, and retrieval.

Based on these findings, the research project "Emotional Colours" was developed, with the primary aim of investigating the impact of colours on the mnemonic processes of primary school children, to guide a more conscious use of coloured stimuli within educational tools. Following the pilot study (Cipollone, 2022) and an initial analysis regarding the coloured stimuli present in the learning environment (Cipollone et al., 2024; Cipollone et al., 2024), this new research specifically explored the extent to which wavelengths impact emotional levels in primary school students.

The "Emotional Colours" project adopts a multidisciplinary approach, integrating studies from Educational Neuroscience, the physiology of vision, and psychology. This educational methodology leverages natural learning processes to enhance the educational experience.

Educational Neuroscience provides a scientific foundation for understanding how cognitive and neural processes intertwine while acquiring new information, using neuroimaging techniques to observe brain responses to coloured visual stimuli and how such responses influence memory and attention (Bowers & House, 2019). The physiology of vision clarifies how the brain processes visual information through different wavelengths, enabling us to understand which wavelengths are most effective in promoting engagement and memory retention (Elliot & Maier, 2014). Psychology explores how emotions and perceptions influence the ability to memorise and recall information, studying emotional reactions to colours to develop strategies that evoke positive emotions and enhance learning (Pekrun, 2017).

The objective is to create learning environments that positively stimulate students, fostering memory retention and content comprehension through the strategic use of colours and emotions. The project aims to develop visually appealing educational tools that enhance learning effectiveness. The conscious use of colours can transform the educational environment, making it more engaging and motivating, thereby facilitating the acquisition of new knowledge in a more efficient and lasting manner (Barrett et al., 2015).

Scientific Literature

Colour vision is a complex phenomenon that begins when light enters the eye through the cornea, passes through the pupil, and then through the lens, allowing a clear image to form on the retina, located at the back of the eye. The retina is a complex, light-sensitive structure composed of millions of photoreceptors. These photoreceptors are divided into two main categories: rods and cones. Rods are responsible for vision in low-light conditions and do not detect colour. Cones, on the other hand, are crucial for colour vision and function best in bright light conditions. There are three types of cones, each sensitive to different wavelengths of light (Shapley, 2019; Torisawa et al., 2015).

When light strikes the cones, it triggers chemical reactions that convert light energy into electrical signals. These electrical signals are transmitted via the optic nerve to the brain, specifically to the visual cortex, where they are processed and interpreted. The different wavelengths of light correspond to different colours perceived by the human eye, each of which can influence mood and emotions in distinct ways. These effects are due to the interaction of light with the photoreceptors in the retina, which then send signals to the brain, influencing the production of neurotransmitters and hormones that regulate mood (Persson et al., 2024).

Wavelengths of colour represent a fundamental determinant in the educational landscape for the attentional, emotional, and mnemonic dimensions of students (Cipollone & Peluso, 2021). The various mechanisms of neurophysiological activation, related to changes and movements of the eyes (Van der Wel et al., 2018), allow for the perception of the broad range of characteristics that define the completeness of elements. Supporting this evidence, it has been demonstrated that chromatic stimuli, compared to achromatic ones, result in longer fixation durations and larger pupil diameters (Liu et al., 2021). The relevant literature strongly suggests that the perception of colour activates networks of brain connectivity during learning tasks, capturing visual attention and stimulating emotional activation (Chai et al., 2023). This reveals a significant overlap of brain areas involved in emotion and motivation processes, suggesting that these functions are closely interconnected (Cromwell et al., 2020).

Consequently, the chromatic component of stimuli can be identified as a variable influencing brain activation processes, supporting information processing in the surrounding environment. Colour enriches the characteristics of the stimulus, making it not only more visually appealing but also more distinctive and memorable. This visual quality facilitates cognitive processing and the creation of mnemonic associations, enhancing the emotional impact and the subsequent recall of information, laying the foundation for meaningful learning. As a result, stimuli with a chromatic variable are more likely to activate attentional and mnemonic processes than achromatic stimuli, facilitating their subsequent retrieval by the student.

Emotions associated with colours play a significant role in memory optimisation, as they influence the encoding, storage, and retrieval of information (Immordino-Yang & Damasio, 2018). When a colour evokes a specific emotion, it activates the amygdala, a key brain structure for emotion regulation, closely linked to the hippocampus, essential for memory formation. The amygdala activation during an emotional experience strengthens memory encoding, increasing the likelihood that the information will be stored in the long term. This process is known as "memory consolidation," and it is particularly effective when information is associated with a strong emotional response (Titz et al., 2021; Park et al., 2018). Moreover, emotions also influence memory retrieval. During information recall, emotions can act as a powerful retrieval cue, facilitating access to memories that have been previously stored (Linnenbrink-Garcia et al., 2019). Colourful experiences that evoke positive emotions not only enhance memory retention but also make memories more vivid and enduring (Schott & Dörfel, 2019). This is particularly relevant in an educational context, where the strategic use of colour can transform educational materials into powerful learning tools, capable of stimulating engagement and facilitating the assimilation of information.

Therefore, emotions associated with colours enhance memory by activating specific neural circuits that favour the encoding and retrieval of information, making learning not only more effective but also more enduring. Consequently, the conscious choice of colour in educational contexts and materials can optimise the memory experience, significantly improving understanding and assimilating information.

Research Project

Emotional Colours is a project that, for the past two years, has aimed to explore the relationship between colours and mnemonic processes in primary school children. The objective is to identify the impact of wavelengths on cognitive functioning to facilitate the creation of stimulating learning environments.

The pilot study (Cipollone, 2022) conducted on 72 subjects highlighted how the memorisation of words could depend on the type of colour and the emotional valence associated with it, revealing that coloured words enhanced memorisation by 20%. Given the positive results of the pilot study, Emotional Colours continued its investigation by evaluating the variables involved. An initial analysis focused on the impact of colour on the student's attention level (Cipollone, Lembo, et al., 2024). This study revealed that the high level of engagement provided by colour was associated with a high level of attention, regardless of the type of wavelength.

Following this study, the relationship between the level of engagement provided by colour and the mnemonic process was analysed (Cipollone, Chierichetti, et al., 2024). This third analysis revealed that a high level of engagement provided by colour does not always guarantee a high level of memorisation, indicating that other variables come into play in this process.

The research project is therefore continuing this analysis, and the current focus is on evaluating the impact of emotion associated with colour on mnemonic processes. In this phase, the research hypothesis establishes that wavelength influences memorisation through emotional activation.

The sample was composed of 134 students, aged between 6 and 11 years, with an average age of 9.35. The sample (m=70; f=64) was drawn from 2 public and 2 private schools in Rome and was randomly divided into an experimental group (N=75) and a control group (N=59). A consent form and information sheet were provided to all the parents of the children. Informed consent was negotiated with them and pseudonyms have replaced the names of participants. Participants (including child participants) were given the opportunity to withdraw from the study at any time.

The selection of the wavelengths on which to focus the study was based on a thorough analysis of the literature and human physiology. This analysis revealed that the three cones, the photoreceptors present in the retina responsible for photopic vision, are specialised in the perception of three colours: 0-0-255, 0-255-0, and 255-0-0, with peaks of sensitivity at 121-0-255, 69-255-0, and 255-248-128, respectively. The nomenclature used for the naming of colours follows the RGB format.

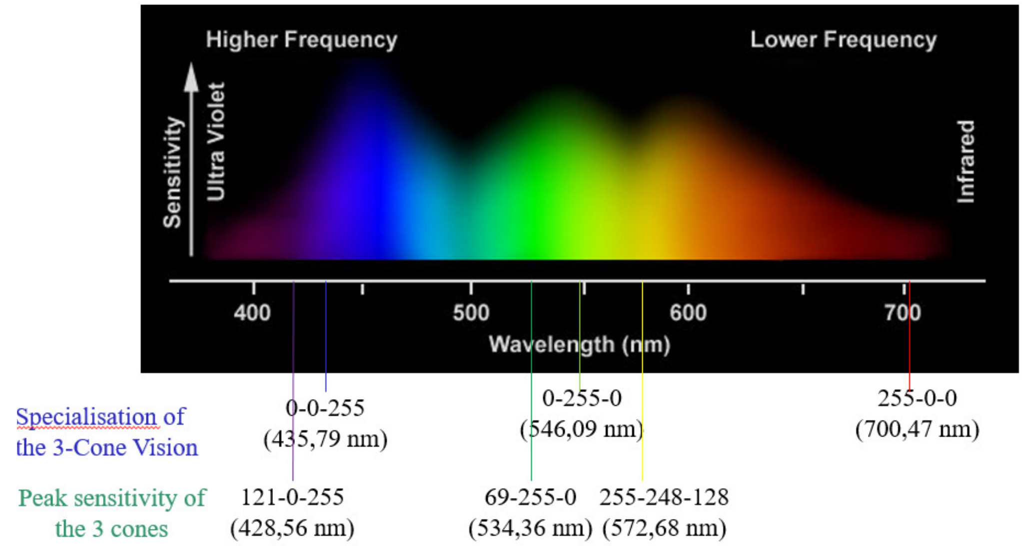

Figure 1: wavelength selection

In light of this evidence, it was decided to focus on the wavelengths associated with these colours, specifically: 700.47 nm, 546.09 nm, 435.79 nm, 428.56 nm, 534.36 nm, and 572.68 nm.

As the relevant literature has highlighted a lack of studies on these topics in children and significant interindividual variability in colour perception, this project was structured into two fundamental phases:

- Assessment of the individual association between wavelength and emotion in children: in this phase, participants viewed coloured stimuli while being exposed to the AI software "EMOJI," which is capable of detecting their level of engagement and the emotions experienced, through the detection of facial muscles, in line with Paul Ekman's neuromuscular theory of emotions (Ekman, 1992).
- Verification of the link between wavelength and mnemonic processes: in this phase, a memory test based on the structure of the NEPSY-II M6 subtest was administered. The children read a text and were subsequently evaluated on three memory tasks: free recall, cued recall, and recognition. The control group viewed the text in black and white, while the experimental group received a text with 18 coloured words (3 for each wavelength), randomly selected through software. This phase allowed for the verification of the level of memorisation of the coloured stimuli.

In both phases, the selected colours were viewed according to the RGB classification.

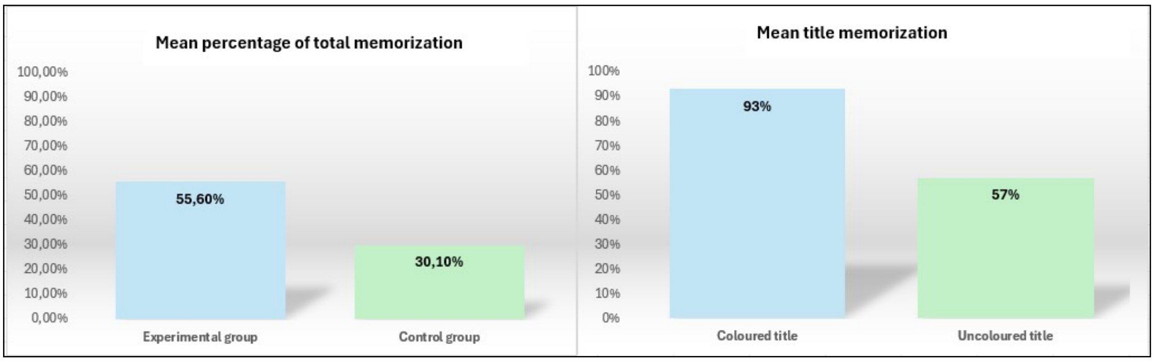

Figure 2: mean percentage of memorization

Figure 2 shows the scores obtained in the memory test. In the graph on the right, the total scores of the test are displayed, while the graph on the left shows the scores related to the memorisation of the title. As seen in both graphs, the experimental group achieved significantly higher scores than the control group, with a mean difference in memorisation level of 30%.

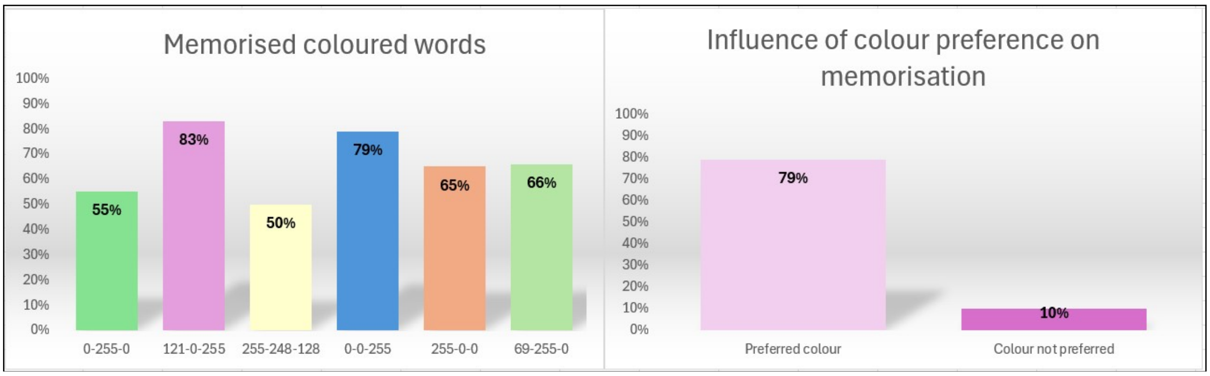

Figure 3: colour – emotion relationship

Figure 2 reveals the results divided by colour. In the right graph, it is shown how the colour that most favoured memorisation was 121-0-255, followed by 0-0-255 and 69-255-0. The data reveals that these three colours were perceived as associated with positive emotions, such as happiness and relaxation.

In the left graph, the influence of the favourite colour on the memorisation process is shown. It emerges that the child's favourite colour influences memorisation in 79% of cases, as it is associated with positive emotions.

For the statistical analysis, the JAMOVI software (version 2.3.28) was used.

At first, it was necessary to verify whether the differences in the memorization of the two groups were statistically significant. For this reason, an independent sample t-test was used.

Displayed below are the verification results for the assumptions: as can be seen from Table 1 and Table 2, both assumptions are satisfied.

Homogeneity of Variance Test (Leven's)		
	F	p - value
Memorisation	0.110	0.742

Table 1: Homogeneity of Variance Test

Normality Test (Shapiro-Wilk)		
	W	p - value
Memorisation	0.955	0.163

Table 2: Normality Test

A student t-test was performed (Table 3), revealing a p-value lower than 0.001. This data suggests that the differences in memorisation scores between the two groups are statistically significant.

Independent Sample t-test			
		Statistic	p - value
Memorisation	t student	5.500	< .001
Note: H_a μ Control $\neq$ μ Experimental			

Table 3: student t-test

Subsequently there was a need to examine the effect of two independent variables: colour and colour preference, on our dependent variable, namely the memorisation scores. For this type of analysis, a two-way ANOVA was selected.

Homogeneity of Variance Test (Leven's)		
	F	p - value
Memorisation	0.110	< .001
Note: a low p-value suggests a violation of the assumption of homogeneity		

Table 4: Homogeneity of Variance Test

Normality Test (Shapiro-Wilk)		
	F	p - value
Memorisation	0.995	< .001
Note: a low p-value suggests a violation of the assumption of homogeneity		

Table 5: Normality Test

ANOVA	Sum of squares	F	p-value
Colour	2.408e-30	0.213	0.927
Preferences	3.939	1.736e+30	< .001
Colour * Preferences	4.924e-31	0.043	0.999
Residual	3.621e-29	NaN	NaN

Table 6: two-way ANOVA

After an assumption analysis (Table 4 and Table 5), we performed the ANOVA (Table 6). The relevant data that emerges is that the effect of colour preference is highly significant.

Conclusion

The Emotional Colours project seeks to deepen the understanding of the relationship between wavelengths, emotions, and colours to optimise memory processes. The findings of this study suggest that the use of specific colours can significantly enhance the recall of stimuli. However, it is essential to delve into the mechanisms behind this enhancement to comprehend its implications fully.

The data revealed that the colours most effective in enhancing memorisation correspond to the peaks of cone sensitivity in the human eye, particularly when these colours were associated with positive emotions, such as happiness. This finding aligns with existing research, which suggests that emotional arousal plays a crucial role in the encoding and retrieval of memories. According to Kensinger and Schacter (2018), emotionally charged stimuli are more likely to be encoded deeply and retrieved more easily than neutral stimuli. Thus, the combination of chromatic characteristics and the emotional response they elicit appears to be a potent factor in memory enhancement.

Specifically, the colours of peak sensitivity - such as 121-0-255 and 69-255-0 - were found to interact positively with emotional memory. This interaction highlights the significant role of the biological component in memory processes, as these colours correspond to the wavelengths that the human visual system is most attuned to (Elliot & Maier, 2014). This suggests that our physiological predisposition to certain colours can be leveraged to enhance cognitive functions like memory, particularly when these colours are linked to positive emotional experiences.

Another key finding of the study is the enhanced memorisation associated with the presence of the participant's favourite colour. This observation underscores the importance of personal experiences and individual preferences in cognitive processes. The role of personal relevance in memory has been well documented in the literature. For example, research by Conway and Pleydell-Pearce (2020) suggests that autobiographical memories, which are often tied to personal preferences, are particularly resilient and vivid. This indicates that when educational materials incorporate colours that are personally meaningful to the learner, the likelihood of memory retention increases.

Therefore, the study concludes that colour positively influences memorisation, and the strength of this influence is significantly determined by the emotional response the colour elicits. This is consistent with the broader literature on the intersection of emotion, cognition, and visual perception (Kuhbandner & Pekrun, 2019). By integrating these findings into educational practices, educators can create learning environments that not only enhance memory retention but also engage students on a deeper, more personal level.

While this study offers valuable insights into the relationship between colour, emotion, and memory, it is important to acknowledge several limitations. Firstly, the sample size, although indicative, may not be large or diverse enough to generalise the findings across different populations. The study's participants were limited to a specific age range and geographic location, which may not fully represent the variability in colour-emotion responses seen in broader, more heterogeneous groups. Additionally, the experimental conditions may not perfectly replicate real-world educational environments, potentially limiting the ecological validity of the findings. Another limitation is the focus on a specific set of colours and wavelengths; a broader exploration of a wider range of colours and their interactions with different emotions might yield more comprehensive insights. Finally, the study does not account for the potential long-term effects of colour-based interventions on memory and learning outcomes, as the impact was measured in a relatively short timeframe. Future research should address these limitations by expanding the sample, incorporating more objective measures of emotional engagement, and exploring the long-term implications of personalised colour use in education.

At this point, it becomes crucial to understand how to utilise this relationship effectively within the educational context. To achieve this, the project must undergo further essential developments, each aimed at enhancing the applicability of the findings in real-world settings.

Firstly, expanding the sample size is a vital step in establishing a more robust and generalisable relationship between the variables examined. A larger, more diverse sample would allow for a better understanding of how colour-emotion preferences and their impact on memory processes vary across different age groups, cultural backgrounds, and cognitive profiles. This will help identify whether the observed effects are consistent across various populations or if they require adaptation to suit specific groups. Such data could provide a stronger foundation for developing universally effective educational strategies that leverage the power of colour in learning.

Secondly, there is significant potential in developing a software tool that can assess individual colour-emotion preferences. This tool, designed for easy use by teachers, could be implemented in schools to gather personalised information on each student. By integrating such a tool into the educational system, teachers could gain insights into the specific colours that resonate emotionally with each student, thereby tailoring their teaching materials to optimise engagement and memory retention. The availability of such software would not only streamline the personalisation process but also empower educators to make data-driven decisions in their teaching practices. This approach aligns with the growing emphasis on personalised learning, which has been shown to improve educational outcomes by catering to the unique needs and preferences of each student (Pane et al., 2018).

Finally, the insights gained from this research could pave the way for a more personalised approach to the educational environment. This could involve incorporating calibrated coloured elements into various aspects of the classroom, from designing learning materials such as rulers and pencils to the tools teachers use for marking and correction. By customising these elements based on the colour preferences and emotional responses of students, the educational space could become a more engaging and supportive environment for learning.

The potential of colour as a tool for influencing cognitive processes is particularly promising not only for typically developing students but also for those with atypical developmental trajectories. Research has shown that sensory experiences, including colour, play a critical role in cognitive development and learning in children with special educational needs (Baranek et al., 2019). Therefore, it would be particularly intriguing to explore how a personalised, colour-based approach could enhance learning outcomes for these students. By structuring a student's daily educational experience around their unique emotional and cognitive responses to colour, educators could create a learning environment that is not only more effective but also more inclusive and supportive of individual differences.

In summary, the next steps of this project should focus on expanding the sample size, developing user-friendly tools for assessing colour-emotion preferences and exploring the potential for personalised educational spaces. Such efforts could significantly enhance the impact of colour on learning and contribute to the development of more tailored, effective educational practices.

References

Baranek, G. T., Little, L. M., Parham, L. D., Bodfish, J. W., & Sensory Experiences Project. (2019). Sensory features and repetitive behaviours in autism: Connecting the dots. *Journal of Autism and Developmental Disorders, 49*(11), 4231-4250. DOI:10.1007/s10803-019-04182-3

Barrett, L. F., Lewis, M., & Haviland-Jones, J. M. (2015). *Handbook of emotions*. Guilford publications.

Bowers, J. S., & House, A. (2019). The role of visual experience in the perception of color. *Psychological Science, 30(9),* 1311-1319. DOI:10.1177/0956797619863400

Chai, M., & Tang, T. (2023). Microstates of Dynamic Directed Connectivity Networks Revealing Visual Color Influences on the Brain Information Processing During Learning. *IEEE Access, 11*, 14256-14273. https://doi.org/10.1109/ACCESS.2023.3244066

Cipollone, E., (2022). The influence of colors on emotional memory: how colors can improve learning in primary school children*, Italian Journal of Health Education, Sports and Inclusive Didactics, anno 6*, n.1 https://doi.org/10.32043/gsd.v6i1.601

Cipollone, E., Lembo L. & Peluso FC. (2024). Emotional Colors: relationship between light wavelengths and educational settings for enhancing learning processes, Conference on Embodied Education Proceedings (printing).

Cipollone, E., Chierichetti, C., Morsanuto, S., Peluso, FC. (2024). Emotional Colours: which wavelength promotes memorization through colour engagement in primary school children, *Studi e ricerche sui processi di apprendimento-insegnamento e valutazione* (printing).

Cipollone E., Peluso FC. (2021). *Apprendere con il cuore: come le emozioni influenzano l'apprendimento.* Edizioni Romane Universitarie: Roma.

Conway, M. A., & Pleydell-Pearce, C. W. (2020). The Construction of Autobiographical Memories in the Self-Memory System. *Psychological Review, 107*(2), 261-288. 10.1037/0033-295X.107.2.261.

Cromwell, H., Abe, N., Barrett, K., Caldwell-Harris, C., Gendolla, G., Koncz, R., & Sachdev, P. (2020). Mapping the interconnected neural systems underlying motivation and emotion: A key step toward understanding the human affectome. *Neuroscience & Biobehavioral Reviews, 113*, 204-226. https://doi.org/10.1016/j.neubiorev.2020.02.032

Dalke, H., Little, J., Niemann, E., Camgoz, N., Steadman, G., Hill, S., & Stott, L. (2018). Simultaneous evaluation of the role of color preferences and the effect of color memory with the approach of improving students' quality of learning: A case study—Learning environments for 6-to-7-year-old children. *Learning Environments Research, 21*(2), 123-145. https://doi.org/10.1007/s10984-018-9262-5

Ekman, P. (1992). Facial expressions of emotion: An old controversy and new findings. Philosophical Transactions of the Royal Society of London. *Series B: Biological Sciences*, 335(1273), 63-69. https://doi.org/10.1098/rstb.1992.0008

Elliot, A. J., & Maier, M. A. (2014). Color psychology: Effects of perceiving color on psychological functioning in humans. *Annual Review of Psychology, 65*, 95-120. 10.1146/annurev-psych-010213-115035.

Farley, F., & Grant, A. (2019). The impact of colors on human memory in learning English collocations: Evidence from South Asian tertiary ESL students. *Asian-Pacific Journal of Second and Foreign Language Education, 4(1),* 1-17. https://doi.org/10.1186/s40862-019-0079-9

Gaines, K. S., & Curry, Z. D. (2023). The inclusive classroom: The effects of color on learning and behavior. *Journal of Family and Consumer Sciences Education, 29(1).*

Güneş E., Olguntürk N. (2020). Color□emotion associations in interiors. *Color Research & Application*, *45*, 129-141. DOI: 10.1002/col.22443.

Guthrie, J. T., Wigfield, A., & You, W. (2014). Instructional Contexts for Engagement and *Achievement in Reading. Educational Psychologist*, *49*(2), 99-107. DOI:10.1080/00461520.2014.887721

Ikeda, S. (2020). Influence of color on emotion recognition is not bedirectional: an investigation of the associations between color and emotion using a Stroop-Light task, *Psychological reports, 123*(4), 1226-39. DOI:10.1177/0033294119853280

Immordino-Yang, M. H., & Damasio, A. (2007). We feel, therefore we learn: The relevance of affective and social neuroscience to education. *Mind, Brain, and Education, 1*(1), 3-10. DOI:10.1111/j.1751-228X.2007.00004.x.

Jan L. Plass, Steffi Heidig, Elizabeth O. Hayward, Bruce D. Homer, Enjoon Um, (2014). Emotional design in multimedia learning: *Effects of shape and color on affect and learning, Learning and Instruction, 29*, pp. 128-140, https://doi.org/10.1016/j.learninstruc.2013.02.006

Kensinger, E. A., & Schacter, D. L. (2018). Cognitive and Neural Effects of Emotion on Memory in Healthy Aging and Early Alzheimer's Disease. *Current Opinion in Behavioral Sciences, 19*, 61-66. DOI:10.1016/j.cobeha.2017.09.006

Kensinger, E. A., & Ford, J. H. (2020). Retrieval of emotional events from memory. *Annual review of psychology*, *71*(1), 251-272.

Kramer R., Prior J. (2019). Colour association in children and adults. *The Quarterly Journal of Experimental Psychology, 72*, 1977-83. https://doi.org/10.1177/1747021818822948

Linnenbrink-Garcia, L., Patall, E. A., & Pekrun, R. (2016). Adaptive Motivation and Emotion in Education: Research and Principles for Instructional Design. *Policy Insights from the Behavioral and Brain Sciences, 3*(2), 228-236. DOI:10.1177/2372732216644450

Liu, J., & Van Iersel, M. W. (2021). Photosynthetic physiology of blue, green, and red light: Light intensity effects and underlying mechanisms. *Frontiers in plant science, 12*, 328. DOI:10.3389/fpls.2021.619987

Liu, Y., Ma, W., Guo, X., Lin, X., Wu, C., & Zhu, T. (2021). Impacts of Color Coding on Programming Learning in Multimedia Learning: Moving Toward a Multimodal Methodology. *Frontiers in Psychology, 12*. https://doi.org/10.3389/fpsyg.2021.773328.

Pane, J. F., Steiner, E. D., Baird, M. D., & Hamilton, L. S. (2018). Informing Progress: Insights on Personalized Learning Implementation and Effects. *RAND Corporation*

Park, B., Holloway, S. D., Arendtsz, A., Bempechat, J., & Li, J. (2015). What makes students engaged in learning? A time-use study of within- and between-individual predictors of emotional engagement in low-performing high schools. *Journal of Youth and Adolescence, 44(2)*, 247-265. DOI:10.1007/s10964-014-0080-1

Pekrun, R. (2017). Emotion and achievement during adolescence. *Child Development Perspectives, 11(*3), 215-221. DOI:10.1111/cdep.12237

Persson, P. B., & Bondke Persson, A. (2024). Color in physiology. *Acta Physiologica, e14182.*

Ram M., Shamanna B., Bhardwaj R., Bhagvati C., Theagarayan B. (2021). Color and emotion associations in Dravidian Culture. *Journal of Vision, 21(9),* 2406. DOI:10.1167/jov.21.9.2406

Schott, B. H., & Dörfel, D. (2019). Dopamine-dependent memory consolidation: The role of affective engagement. *Nature Reviews Neuroscience, 20*(6), 347-360. DOI:10.1038/s41583-019-0165-4

Schunk, D. H., & DiBenedetto, M. K. (2020). Motivation and Social Cognitive Theory. *Contemporary Educational Psychology, 60,* 101832. DOI:10.1016/j.cedpsych.2019.101832

Shapley, R. (2019). *Physiology of color vision in primates*. In Oxford Research Encyclopedia of Neuroscience. DOI:10.1093/acrefore/9780190264086.013.59

Sinha, P., Diamond, S., Vogelsang, M., Vogelsang, L., Gupta, P., Gandhi, T. K., Shah, P., Swami, P., Gilad-Gutnick, S., Ben-Ami, S., & Ganesh, S. (2024). Impact of early visual experience on later usage of color cues. *Science, 384(6698),* 907-912. DOI:10.1126/science.adk9587

Titz, C., & Karbach, J. (2021). Cognitive and Non-cognitive Factors in the Development of Kindergarten Children's School Readiness. *Frontiers in Psychology, 12*, 617640. DOI:10.3389/fpsyg.2021.617640

Torisawa, S., Fukuda, H., & Takagi, T. (2015). Visual physiology. In Biology and ecology of bluefin tuna (pp. 309-324). CRC Press, Boca Raton.

Van der Wel, P., & van Steenbergen, H. (2018). Pupil dilation as an index of effort in cognitive control tasks: A review. *Psychon Bull Rev, 25,* 2005–2015. DOI:10.3758/s13423-018-1432-y

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