Enhancing Student's Learning Experience in the Classroom Using Lighting Stimulation

Henry Candra[a*,] Endah Setyaningsih[b], Jeanny Pragantha[c], Rifai Chai[d],
[a]Electrical Engineering Department, Universitas Trisakti, Jakarta, Indonesia
[b,c]Electrical Engineering Study Program, Universitas Tarumanagara, Jakarta, Indonesia, [d]Department of Telecommunications, Electrical, Robotics and Biomedical Engineering, Swinburne, University of Technology, Melbourne, Australia, Email: [a*]henrycandra@trisakti.ac.id

Education is a lifelong learning process that includes formal study in a classroom. However, some students struggle to concentrate in the classroom. This study shows that the classroom focus of students can be improved using lighting stimulation. The effects of lighting stimulation were studied. An experimental classroom was prepared with a standard illumination, and equipped with three differently coloured lighting temperatures. Students were then asked to relate, on a questionnaire, their level of comfort and focus to the lighting stimulation. An electroencephalogram of some students' brainwaves was also recorded. The analysis of the questionnaire results and the brainwave pattern confirmed that the lighting stimulation enhanced the learning experience in the classroom, by altering the brainwave pattern to a more focused state.

Key words: *Focus, concentration, lighting stimulation, colour temperature, Electroencephalography.*

Introduction

Different colours of light play an important aspect in numerous factors of physiology and behaviour in animals and humans, including daily activity and sleep regulation. This fact suggests that artificial lighting may alter behaviour in both domestic and working areas (Pilorz et al., 2016).

Electroencephalography (EEG) has been used to monitor and improve the brainwave pattern of people with severely high stress levels, children who have a difficulty concentrating, and

people with sleep disorder (insomnia) (Moghimi et al., 2013). This can be carried out by measuring the emotional state of the person using Russel's Circumplex model, by mapping it into two-dimensional quadrants consisting of arousal (enthusiasm) and valence (pleasant) (Candra et al., 2015).

Using a specific method and algorithm, the EEG signals can be divided into five frequency bands: delta (δ) (3-4Hz); theta (θ) (5-8Hz); alpha (α) (9-16Hz); beta (β) (17-32Hz); and gamma (γ) (33-64Hz) (Candra et al., 2017). The EEG was also used to observe learning activities, by investigating the brainwave pattern that related to the attentiveness and inattentiveness of students to the instructor. The degree of focus and concentration are related to the increase of alpha and beta band in the brainwave pattern (Liu et al., 2013).

The illuminance in the classroom impacts the concentration of students (Singh & Arora, 2014). According to the Illuminating Engineering Society (IES) (2011), the illuminance standard of lighting used in a workspace for study is 300 Lux.

Further investigation showed that different colour lighting temperature altered human physiological signals such as heart rate, galvanic skin response, and the brain frequency pattern (Metz et al., 2017). More specifically, the colour temperature and intensity of the light may alter the alpha band to give a pleasant or relaxed feeling (Park et al., 2013). Daylight also increased the beta band of people while doing activity in a building (Mangkuto et al., 2009).

This paper investigates the effect of lighting adjustment and selection of three different colours' lighting temperature, to improve the focus and concentration of classroom students. Questionnaires measure their comfort, arousal, valence, and focus. The EEG also recorded the brainwave pattern of some students, to identify the frequencies associated with focus levels. The results showed significant effects from the arrangement and selection.

Method and Data Collection
Method

The research was conducted by first preparing a small classroom with the capacity for six students. The classroom met the standard illuminance according to the IES which is 300 Lux. It was also equipped with various colours' lighting temperatures. Pre-measurement was performed using a Lux meter. The measurement was conducted in the room with 3×3 matrices of 9 points. The illuminance of the room was obtained from the average of the measurement results.

Based on the measurement, a simulation using a Dialux application was carried out. It redesigned the room to meet the illumination standard, and prepared the colour lighting temperature selection system. The classroom was then rearranged in accordance with the simulation result. The room was also supplied with audio-visual presentation equipment.

Data Collection

In total 36 students were involved in the data collection. They were divided into six groups with six students in each group. Each group was asked to watch a video of a mathematical subject; 30 minutes in duration. During the presentation the lighting was changed with three different types of colour temperature, with each colour enduring for 10 minutes. This research applied three types of colour temperature for the lighting, based on the specification of the lights represented in Table 1.

Table 1: Types of lighting and colour temperature according to the specification of the lights used

	Types of Lighting		
	Cool Daylight	Cool White	Warm White
Colour Temperature	6500 K	4000 K	3000 K

After the presentation, the students filled out the questionnaire. First, they were asked to rank the three types of colour temperature from the most desired (ranked 1) to the most undesired (ranked 3). They also assessed their comfort, arousal, valence, and focus, with the score of 5 for the highest and 1 for the lowest.

During the presentation sessions, the EEG for one out of six students in each group was recorded with 16 channels EEG in 256 samples/sec, which gives a total of six recorded EEGs. The EEEG was configured with a 10/20 international system. The channel selection is as follows: FP1, FP2, F3, F4, F7, F8, C3, C4, T3, T4, T5, T6, P3, P4, O1, O2 and was referenced to Cz.

The recorded EEG must be pre-processed to remove artifacts by using a 50 Hz notch filter and five to 45 Hz band pass filter, and then averaged to a common reference. Discrete Wavelet Transform (DWT) processing was then applied to the pre-processed EEG data, to acquire the frequency distribution. The DWT can be calculated with the following steps (Candra et al., 2015). First, by calculating the DWT coefficients based on the dyadic scales and positions with the following equation:

$$DWT(j,k) = \int_{-\infty}^{\infty} x(t) \frac{1}{\sqrt{2^j}} \psi\left(\frac{t - 2^j k}{2^j}\right) dt \qquad (1)$$

where $\psi\,(t)$ denotes the mother wavelet function and 2^j and $2^j\,k$ are the scale and time localization, respectively. Next, calculating the coefficient of wavelet decomposition for a given EEG signal in a channel y(t) with the following equation:

$$y(t) = \sum_{k=-\infty}^{\infty} A(k)\psi_k(t) + \sum_{j=0}^{\infty} \sum_{k=-\infty}^{\infty} D(j,k)\psi_{j,k}(t) \qquad (2)$$

In this experiment, Daubechies (db5) wavelet is used as the wavelet function to divide the decomposition EEG signal with sampling rate 256 sample/second and give the results into five bands: delta (δ); Theta (θ); Alpha (α); Beta (β); and Gamma (γ). The energy of related frequency bands is then obtained. Only two out of five bands are used: α and β.

The energy of wavelet coefficients for both detail and approximation is then represented as:

$$E_k = \sum_{k=1}^{N} |C_{j,k}|^2, j = 1,\dots,l \qquad (3)$$

where N is the number of wavelet coefficients at each decomposition level and $C_{j,k}$ is the approximation or detail.

The energy of the wavelet packet is then normalized by comparing the energy of detail or approximation to the total energy of the signal with the following equation:

$$|E_k| = \frac{E_k}{E_t} \qquad (4)$$

where E_t is total energy of the signal as in:

$$E_t = \sum_k E_k \qquad (5)$$

The relative energy of the α and β band for each channel is then mapped to the top view of the scalp, to illustrate the distribution of each frequency band on the scalp, for different types of colour lighting temperature selection.

Results and Discussion

The Illuminance Measurement of the Classroom Before and after Rearrangement

The measurement of the illuminance in the classroom before the restoration is displayed in Table 2.

Table 2: The illuminance of the classroom before the restoration

Illuminance (Lux)		
203.7	221.3	240.1
178.4	195.6	211.8
225.1	232.2	238.5
Average = 216.3		

Table 2 shows that the minimum illuminance of the classroom is 178.4 Lux, the maximum illuminance is 240.1 Lux, and the average is 216.3 Lux. This means that the classroom had less illuminance than the standard recommended by the IES. Therefore, adjustment is necessary to improve the illuminance.

The simulation result using Dialux to redesign the illuminance of the classroom suggests that the room needs three parallel tube lights to obtain standard illuminance. By following the recommendation of the simulation, an average of illuminance above 300 Lux will be achieved.

Based on the simulation, the classroom is renovated and equipped with three different types of colour lighting temperature, which are: cool daylight, cool white, and warm white. The new system was then measured with the Lux meter for each colour temperature, to verify that the new installation has met the recommended standard illuminance. The illuminance measurement results for each colour temperature of the lighting system, using nine points in 3 × 3 matrices are presented in Table 3, 4, and 5 consecutively.

Table 3: The illuminance measurement of the classroom using cool daylight colour temperature

Illuminance (Lux)		
267.7	398.2	350.2
344.2	421.1	358.1
252.4	310.6	271.7
Average = 330.5		

Table 4: The illuminance measurement of the classroom using cool white colour temperature

Illuminance (Lux)		
247.1	372.1	339.7
344.6	437.7	372.8
263.2	357.3	300.2
Average = 337.2		

Table 5: The illuminance measurement of the classroom using warm white colour temperature

Illuminance (Lux)		
257.6	362.2	320.7
359.1	446.6	384.7
277.6	392.6	333.7
Average = 348.3		

Table 3, 4, and 5 inform that the new installation for each colour temperature has met the average illuminance standard, with the average results of 330.5 Lux for cool daylight, 337.2 Lux for cool white, and 348.3 Lux for warm white.

The Analysis of Questionnaire Results

The selection of preferred and undesired colour temperatures conducted by the participants in the experiment were recorded. The questionnaires also recorded their score for the level of comfort, arousal, valence, and focus while listening to the video presentation in the renovated classroom. They are collectively summarized in Table 6.

Table 6: Summary of the students' selection of the colour temperature, and their related score level for comfort, arousal, valence, and focus

Questionnaire component	Selected Colour Temperature		
	Cool Daylight	*Cool White*	*Warm White*
Number of students who selected the colour temperature	15	13	8
% of students who selected the colour temperature	41.7%	36.1%	22.2%
Total score of comfort given to the selected colour temperature	62	51	29
Average score of comfort given to the selected colour temperature	4.1	3.9	3.6
Total score of arousal given to the selected colour temperature	61	48	29

Questionnaire component	Selected Colour Temperature		
	Cool Daylight	*Cool White*	*Warm White*
Average score of arousal given to the selected colour temperature	4.1	3.7	3.6
Total score of valence given to the selected colour temperature	59	48	27
Average score of valence given to the selected colour temperature	3.9	3.7	3.4
Total score of focus given to the selected colour temperature	62	47	31
Average score of focus given to the selected colour temperature	4.1	3.6	3.9

Table 6 shows that the most selected colour temperature is cool daylight with 41.7% of respondents, followed by cool white with 36.1% of respondents, and warm white with only 22.2% of respondents. Furthermore, Table 6 also records that the score level of the comfort, arousal, valence, and focus level given by the students for their selected colour temperature is also consistent for each colour temperature. To give a better understanding of the results, a graphic of the score level for those four components is presented in Figure 1. Figure 1 shows that the average score level of the four components for each of the colour temperature has a similar trend. The highest level for each component of comfort, arousal, valence, and focus is dominated by cool daylight colour temperature, followed by cool white in second place, and warm white at the lowest. It means that the questionnaire results possess a very high confidence level. These results also inform that cool daylight colour temperature gives significant impact to most participants. This result is supported by the analysis of the brainwave pattern for each colour temperature, discussed in the following subsection.

Figure 1. Graphical representation of the score level for comfort, arousal, valence, and focus for each colour temperature.
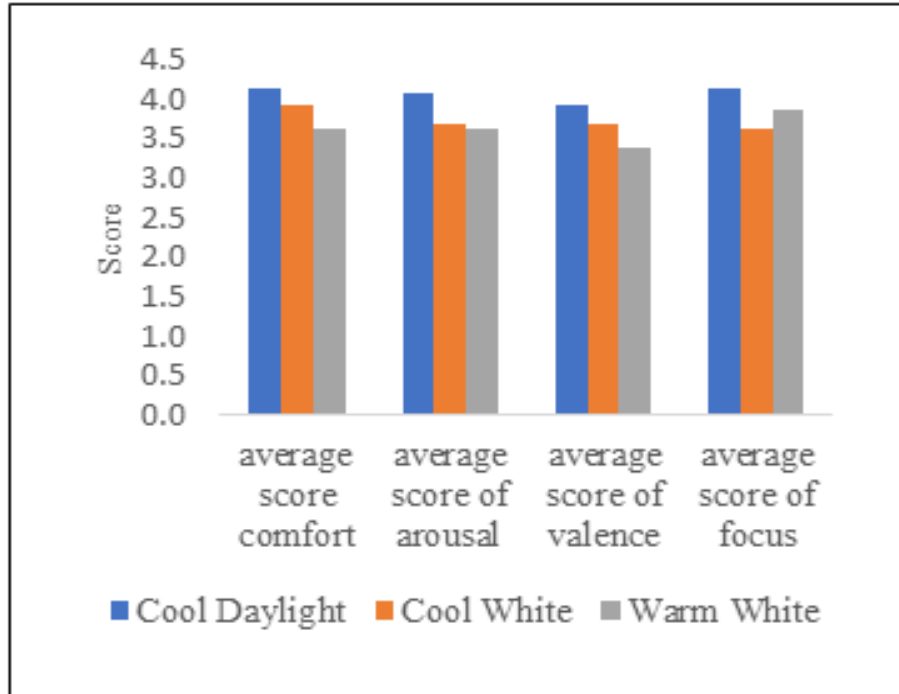
***Analysis of Brainwave Pattern Related to the Selection of Colour Temperature***

The brainwave recordings were pre-processed. The DWT was then applied to extract the relative wavelet energy of α and β bands. The distribution of the relative wavelet energy for each EEG channel was mapped onto the top view of the scalp in accordance with the position of each EEG channel on the scalp. The results were then compared to the brainwave pattern of a desired colour temperature, and an undesired colour temperature. The brainwave patterns of three students were chosen with each representing three different desired colour temperatures, which were: Cool daylight, cool white, and warm white. The comparison of the brainwave pattern for each student is presented in Figure 2, Figure 3, and Figure 4, respectively.

Analysis of the brainwave pattern according to Figures 2 to 4 shows that the Cool daylight temperature triggered the increase of α and β bands throughout the area of the scalp. This event can be observed from Figure 2a. It shows the mapping of the brainwave pattern for desired cool daylight colour temperature. Moreover, the same result also takes place at Figure 4b, which represents the brainwave pattern of other students who rejected cool daylight colour temperature. Although he or she rejected the cool daylight colour temperature, the increase of α and β bands is still taking place in the brainwave pattern of this student. In contrast, the warm white colour temperature developed the reduction of α and β bands of the

brainwave pattern as shown in Figures 2b, 3b, and 4a. In addition, the cool white colour temperature provided similar effects as the cool daylight colour temperature, only in a moderate increase of α and β bands. Therefore, it can be deduced that the effect of a higher colour temperature is the increase of α and β bands in the brainwave pattern, while the lower colour temperature gave an opposite effect.

Figure 2. Comparison of brainwave pattern of a student with a desired colour temperature (Cool Daylight), undesired colour temperature (Warm white)
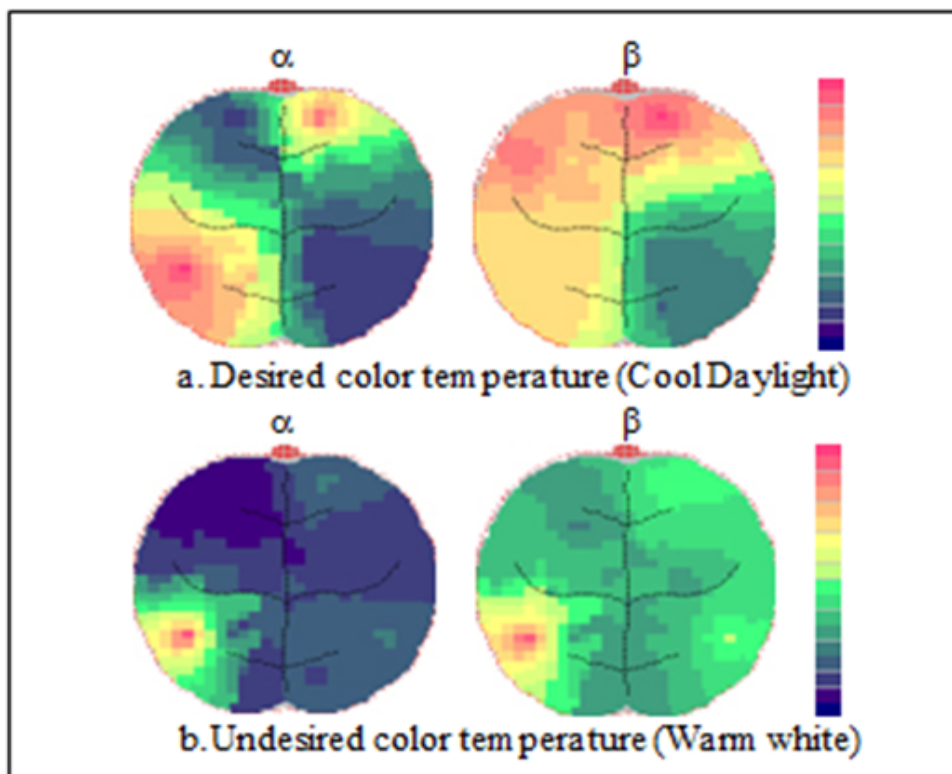
Figure 3. Comparison of brainwave of pattern of a student with a desired colour temperature (Cool White, undesired colour temperature (Warm white).

a. Desired color temperature (Cool White)

b. Undesired color temperature (Warm white)
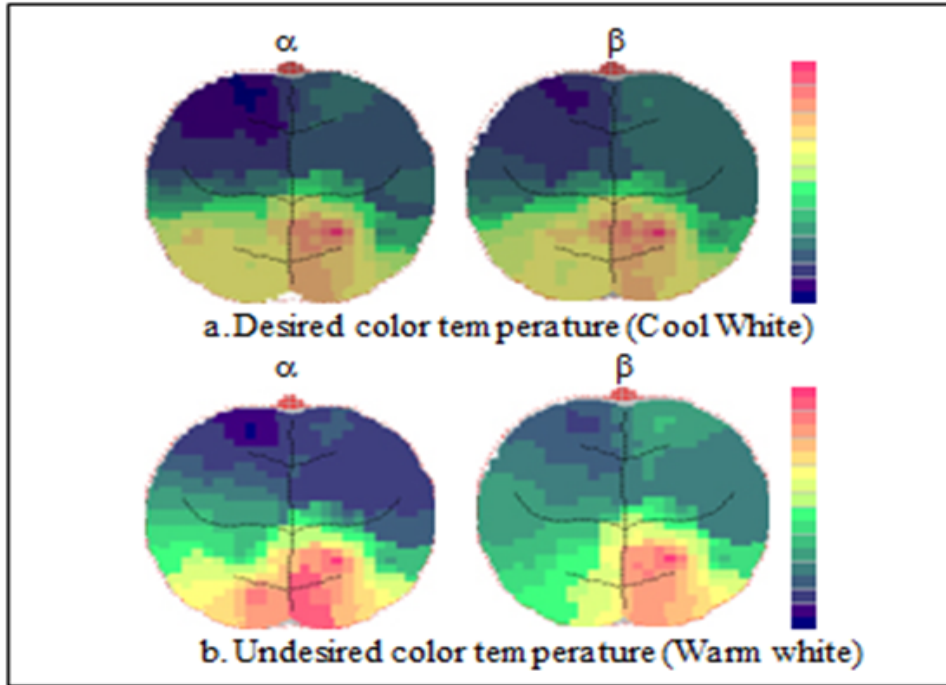
Figure 4. Comparison of brainwave of pattern of student with a desired colour temperature (Warm white), undesired colour temperature (Cool daylight).

a. Desired color temperature (Warm White)

b. Undesired color temperature (Cool Daylight)
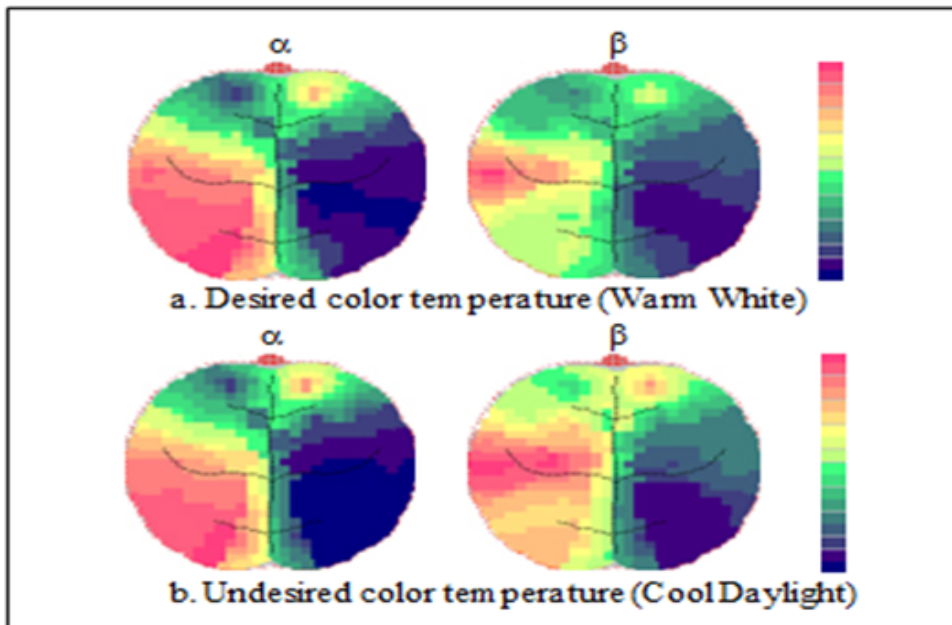
Conclusions and Further Work

The investigation of the effect of lighting adjustment and selection of colour temperature, to the brainwave pattern of students, while studying in a classroom, has been conducted and gave positive results. The results from both the questionnaire and the analysis of the brainwave pattern show that the higher colour temperature affects the brainwave pattern by increasing the α and β bands, which improve students' focus and attention. The lower colour temperature gives an opposite effect by reducing the α and β bands.

Further work includes the combination of the lighting rearrangement and selection with the audio brainwave stimulation, to further improve the focus and concentration of the students while studying in a classroom.

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