Optimization of the cognitive processes involved in the learning of university students in a virtual classroom

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1 Introduction

The importance of the environment in different aspects of the human being is evident. In this sense, the influence that the contextual keys of the spaces have on the mental states and internal psychological processes of the subject has been studied a lot. Specifically, in educational and academic contexts, most studies have focused on promoting the development of cognitive processes involved in learning. For instance, it has been proved that outer physical space influences human perception and behavior, including cognitive performance. The most studied factors are the color and lighting of the classroom [1,2], but it has also been shown, although to a lesser extent, the influence of the classroom dimension.

Recently, the use of virtual reality is gaining more and more relevance, both in the gaming field and in the academic field, but there are few studies that address the characteristics of the virtual environment [2,3] supporting the results found in real environments. The use of validated virtual classrooms is beneficial to design online learning spaces, being able to extrapolate the data to physical classrooms, without assuming the cost of a real construction. These types of studies have focused on specific cognitive processes such as memory or attention. However, few efforts have been found to address the improvement of psychological well-being even though it can be closely related to learning.

There is a growing trend of interest in how to improve the teaching processes of education at different levels through the configurations of the learning space. In this sense, the objective of this study is to know what configurations of a virtual classroom can affect human behavior to enhance memory and attention, while allowing the space to be perceived as pleasant. For this, the facts of the internal lighting of the classroom, the color of its walls and its spatial dimensions were studied.

To address this objective, a data collection (memory, attention and perception of likes of the environment) was carried out in an experimental context using virtual reality. Different modified classroom scenarios were presented in terms of geometry, lighting and color, the means of the

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psychological data in each parameter were obtained and an optimization problem was solved with the aid of Multiobjective Integer Linear Programming (MOILP) and the use of *Wolfram Mathematica* v12.1.

2 Methodology

A total of 112 students participated in the study (50.9% men and 49.1% women, the mean age was 23.24 years, with a standard deviation of 3.79).

A virtual reality replica of a representative classroom of the Polytechnic University of Valencia was represented. The original characteristics of the classroom were maintained, modifying the different parameters studied independently. From among all the possible values for the different parameters, a set of specific values were selected for this study. The criteria for choosing these values were subject to the standard measurements in the construction of removable ceilings, to the normal values in the commercialization of light bulbs and to the equitable distribution of colors in the Itten chromatic circle [4].

As a result, a total of 29 values of the parameters of a classroom were obtained: 4 for height, 6 for width, 10 for color tone, 2 for color saturation, 3 for lighting and 4 for temperature of color, to study which combination optimizes the levels of memory, attention and ”likes”. The study of the 5760 possible combinations ($4 \times 6 \times 10 \times 2 \times 3 \times 4$) separately is not feasible for the experimental procedure. Note that each visualization, with the corresponding data collection, has a minimum duration of 25 minutes and must be visualized by at least 6 subjects, this would be, approximately, 14,400 hours.

Therefore, an attempt was made to reduce the number of combinations, to a total of 56 variables. These variables studied are those resulting from the combinations of the 2 parameters that make up each factor (Tables 1-3). Each variable corresponds to a modification of the base classroom. In this way, each modification consisted of changing the values of the two parameters that made up each factor studied: lighting, dimension and color. The different changes were applied separately to the two parameters of each factor, keeping the rest of the parameters with their original values.

In each visualization presented, data on memory, attention and “I like” were collected. All of them were statistically normalized.

Psychological semantic memory was measured with the number of words remembered from the total of a list presented in an auditory way after a task similar to the tests of the DRM paradigm [5]. There were a total of 16 different lists, each one contained a total of 15 words related to each other because they belonged to the same semantic field. In each visualization a set of 3 randomized lists was presented and with a delay interval between them of approximately 30 seconds. The total number of correct words remembered among the 45 presented were counted. A greater number of words remembered implies a better memory.

Attention task was measured by response time to target auditory stimuli while avoiding other distractors, with a task similar to continuous auditory performance tests [6]. Four different sounds were presented and only one was the target. These were randomized in a succession of 39 sounds repeated 3 times. The reaction time with a mouse click to the target stimulus out of a total of 117 sounds was counted. Therefore, a shorter reaction time means better care results.

On the other hand, the perception of "likes" was evaluated with a Likert scale from -4 to 4 answered by the subjects at the end of each visualization. The exact question was "in general, I like this classroom." It was specified before the question that there were no correct or incorrect answers to avoid a biased answer by the subject. This implies that better "like" results correspond to higher results close to $+4$.

Each participant visualized a total of 3 classrooms, each with different random modifications of the base classroom. Each visualization was modified in the parameters of only 1 of the studied factors: a) interior lighting (illuminance and color temperature), b) wall color (hue and saturation) or c) dimension (width and height of the walls). Each visualization was viewed by 6 participants from whom 3 different psychological metrics were collected. These data were normalized obtaining, in a first phase, the mean values of each psychological variable for each VR scenario (Table 1-3).

For a better understanding of the data collection obtained and the formulation presented in this paper, the next notation is given:

- Let a_{ij}^x, a_{ij}^y and a_{ij}^z be the mean of the level of attention obtained in the lighting conditions, in the dimension conditions and in the color conditions of the base classroom respectively, for each given combination. These values correspond to column 5 in Tables 1 to 3, from where the sets where i and j vary in each case can be obtained.
- Let m_{ij}^x, m_{ij}^y and m_{ij}^z be the mean of the level of memory obtained in the lighting conditions, in the dimension conditions and in the color conditions of the base classroom respectively, for each given combination. These values correspond to column 4 in Tables 1 to 3, with the same sets for i and j cited above.
- Let l_{ij}^x, l_{ij}^y and l_{ij}^z be the mean of the level of "I like it" obtained in the lighting conditions, in the dimension conditions and in the color conditions of the base classroom respectively, for each given combination. These values correspond to column 6 in Tables 1 to 3, with the same sets for i and j cited above.
- Let $\bar{a}^x$, $\bar{a}^y$, $\bar{a}^z$, $\overline{m}^x$, $\overline{m}^y$, $\overline{m}^z$, $\bar{l}^x$, $\bar{l}^y$ and $\bar{l}^z$ be the mean values of a_{ij}^x, a_{ij}^y, a_{ij}^z, m_{ij}^x, m_{ij}^y, m_{ij}^z, l_{ij}^x, l_{ij}^y and l_{ij}^z respectively, with their respective variations of i and j. Those values are shown at the end of the respective columns in Tables 1 to 3.
- Let x_{ij}, y_{ij} and z_{ij} be 0-1 variables whose values 1 indicate that the classroom is composed of a lighting with illuminance of type i and color temperature of type j, a dimension with height type i and width type j, and a color of the walls with hue type i and saturation type j respectively, with 0 otherwise. These variables are shown in column 3 of Tables 1 to 3 respectively.

3 Problem formulation and solutions

This work addresses the problem of finding the combinations of the six parameters studied in the classroom (illuminance, temperature, width, height, hue and saturation) that provide the best levels of memory, attention and perception of "I like it" of the students. To solve this problem, it will be modelized in this section as a MOILP problem with three functions to optimize. Note that to find the best solutions, values obtained for memory and "I like it" must be maximized,

Iluminance	**Temperature of color**	**Variable**	$\boldsymbol{m^x_{ij}}$	$\boldsymbol{a^x_{ij}}$	$\boldsymbol{l^x_{ij}}$
500 lx	10500 K	x_{11}	-0.3573	0.4647	0.7778
	6500 K	x_{12}	0.1104	-0.2373	0.6154
	4000 K	x_{13}	-0.0857	0.208	0.6429
	3000 K	x_{14}	-0.1174	0.0887	-0.3571
300 lx	10500 K	x_{21}	-0.5019	-0.1531	0.3333
	6500 K	x_{22}	0.4349	-0.7734	0.0714
	4000 K	x_{23}	-0.0525	0.0225	0.011
	3000 K	x_{24}	0.2053	-0.2405	0.4615
100 lx	10500 K	x_{31}	-0.1168	0.0298	0.5714
	6500 K	x_{32}	0.5459	-0.2542	1.3846
	4000 K	x_{33}	0.4598	0.1283	1
	3000 K	x_{34}	-0.1188	0.2714	0.7059
			$\boldsymbol{\overline{m}^x}$	$\boldsymbol{\bar{a}^x}$	$\boldsymbol{\bar{l}^x}$
			0.0338	-0.0371	0.5182

Table 1: Grouping of variables for each parameter of the illumination factor

while values obtained for attention must be minimized.

Considering all the notations given in Section 2, the problem of providing the best levels of memory, attention and perception of "I like it" of the students is formulated here as the following MOILP problem:

$$Maximize \begin{pmatrix} \sum_{i=1}^{3}\sum_{j=1}^{4} m^x_{ij}\cdot x_{ij} + \sum_{i=1}^{4}\sum_{j=1}^{6} m^y_{ij}\cdot y_{ij} + \sum_{i=1}^{10}\sum_{j=1}^{2} m^z_{ij}\cdot z_{ij}, \\ -\sum_{i=1}^{3}\sum_{j=1}^{4} a^x_{ij}\cdot x_{ij} - \sum_{i=1}^{4}\sum_{j=1}^{6} a^y_{ij}\cdot y_{ij} - \sum_{i=1}^{10}\sum_{j=1}^{2} a^z_{ij}\cdot z_{ij}, \\ \sum_{i=1}^{3}\sum_{j=1}^{4} l^x_{ij}\cdot x_{ij} + \sum_{i=1}^{4}\sum_{j=1}^{6} l^y_{ij}\cdot y_{ij} + \sum_{i=1}^{10}\sum_{j=1}^{2} l^z_{ij}\cdot z_{ij} \end{pmatrix} \tag{1}$$

s.t:

$$\sum_{i=1}^{3}\sum_{j=1}^{4} x_{ij} = 1, \qquad \sum_{i=1}^{4}\sum_{j=1}^{6} y_{ij} = 1, \qquad \sum_{i=1}^{10}\sum_{j=1}^{2} z_{ij} = 1 \tag{2}$$

$$\sum_{i=1}^{3}\sum_{j=1}^{4} m^x_{ij}\cdot x_{ij} + \sum_{i=1}^{4}\sum_{j=1}^{6} m^y_{ij}\cdot y_{ij} + \sum_{i=1}^{10}\sum_{j=1}^{2} m^z_{ij}\cdot z_{ij} \geq \overline{m}^x + \overline{m}^y + \overline{m}^z \tag{3}$$

$$-\sum_{i=1}^{3}\sum_{j=1}^{4} a^x_{ij}\cdot x_{ij} - \sum_{i=1}^{4}\sum_{j=1}^{6} a^y_{ij}\cdot y_{ij} - \sum_{i=1}^{10}\sum_{j=1}^{2} a^z_{ij}\cdot z_{ij} \geq -\bar{a}^x - \bar{a}^y - \bar{a}^z \tag{4}$$

$$\sum_{i=1}^{3}\sum_{j=1}^{4} l^x_{ij}\cdot x_{ij} + \sum_{i=1}^{4}\sum_{j=1}^{6} l^y_{ij}\cdot y_{ij} + \sum_{i=1}^{10}\sum_{j=1}^{2} l^z_{ij}\cdot z_{ij} \geq \bar{l}^x + \bar{l}^y + \bar{l}^z \tag{5}$$

Height	Width	Variable	m^y_{ij}	a^y_{ij}	l^y_{ij}
3.2 m	8.4 m	y_{11}	0.2123	-0.4279	1
	6.2 m	y_{12}	0.0964	0.0556	0.1333
	6 m	y_{13}	0.3807	-0.1804	1.1429
	4.8 m	y_{14}	-0.3999	0.2504	-0.625
	3.6 m	y_{15}	-0.1748	0.4341	-2
	2.4 m	y_{16}	-0.6995	0.6277	0
3.8 m	8.4 m	y_{21}	-0.0828	0.1032	-0.0814
	6.2 m	y_{22}	0.1614	-0.0116	0.1333
	6 m	y_{23}	-0.3945	0.5679	0.3333
	4.8 m	y_{24}	0.0007	0.5091	-0.375
	3.6 m	y_{25}	-0.4977	-0.5824	0
	2.4 m	y_{26}	-0.0565	-0.1736	-2.1667
4.4 m	8.4 m	y_{31}	0.1639	-0.6203	1.1429
	6.2 m	y_{32}	0.0575	-0.27	-0.1
	6 m	y_{33}	-0.5299	0.0587	-1
	4.8 m	y_{34}	0.0537	0.1453	-0.1429
	3.6 m	y_{35}	-0.1942	-0.2556	-1.3333
	2.4 m	y_{36}	-0.5925	0.916	-0.8333
2.6 m	8.4 m	y_{41}	-0.2256	-0.432	0.5455
	6.2 m	y_{42}	-0.1003	-0.2714	0.3077
	6 m	y_{43}	-0.1668	2.2663	-1.2857
	4.8 m	y_{44}	-0.2615	0.117	1
	3.6 m	y_{45}	0.1623	-0.0309	-2.625
	2.4 m	y_{46}	0.0421	0.7354	-1.7143
			$\overline{m}^y$	$\bar{a}^y$	$\bar{l}^y$
			-0.1269	0.1471	-0.3417

Table 2: Grouping of variables for each parameter of the dimension factor

$$x_{ij},\, y_{ij},\, z_{ij} \in \{0,1\} \quad \forall i,j \tag{6}$$

Where Eq. (1) represents the multiobjective function, that is, the vector with components level of memory, attention and perception of “like it” of the students. Eq. (2) guarantees that each classroom is composed of a single parameter of illuminance and temperature of the lighting aspect, a single parameter of height and width of the aspect size and a single parameter of hue and saturation of the color aspect of the walls respectively. Eq. (3), (4) and (5) ensures that the total memory value is higher than the sum of memory means, the total attention value is higher than the sum of attention means, and the total “I like it” value is higher than the sum of “I like it” means respectively. Note that these three inequations represent logical lower bounds for the functions and they could be changed for other inequations more (or less) demanding. These restrictions will be discussed again later, especially the reason for their inclusion in the formulation. Finally, Eq. (6) defines the problem variables as binaries.

Hue	Saturation	Variable	m^y_{ij}	a^y_{ij}	l^y_{ij}
5B	High	z_{11}	0.9211	0.0702	-0.3333
	Low	z_{12}	-0.0039	0.2269	-0.1667
5G	High	z_{21}	-0.4155	0.2138	-0.2
	Low	z_{22}	-0.2939	0.4916	-2.1429
5GY	High	z_{31}	-0.0421	-0.0328	-0.8333
	Low	z_{32}	-0.0758	0.3397	1.4286
5Y	High	z_{41}	-0.6764	-0.3718	1.1429
	Low	z_{42}	-0.1845	-0.6578	1.8571
5YR	High	z_{51}	0.0605	-0.1496	0.5
	Low	z_{52}	0.0816	-0.3638	-0.3333
5R	High	z_{61}	-0.1929	0.3043	-2.125
	Low	z_{62}	-0.309	0.2662	1.5
5RP	High	z_{71}	-0.2257	0.6897	-0.625
	Low	z_{72}	-0.544	-0.3037	-2.1429
5P	High	z_{81}	0.3314	0.0233	-1.1667
	Low	z_{82}	0.9799	-0.127	-0.8333
5PB	High	z_{91}	-0.1766	-0.3066	0.2222
	Low	z_{92}	0.249	-0.073	1.5714
5GB	High	$z_{10\,1}$	-0.1321	-0.0261	0.6667
	Low	$z_{10\,2}$	0.0734	0.0751	-0.1429
			$\overline{m}^z$	$\bar{a}^z$	$\bar{l}^z$
			-0.0288	0.0144	-0.1078

Table 3: Grouping of variables for each parameter of the dimension factor

On the other hand, it is highly unlikely that a MOILP had a single optimal solution and, therefore, solving a MOILP consists of finding its set of efficient solutions. Remember that given the MOILP $Maximize\{Cx : Ax \geq b, x \geq 0 \text{ and integer}\}$, a feasible solution x' is efficient if there is no other feasible solution x such that $Cx' \leq Cx$ with at least one strict inequality [7]. In this case, the objective vector Cx' is called non-dominated.

Given the complexity of solving a MOILP, following some ideas from Alves and Clímaco [8], a heuristic interactive procedure (based on solving many ILP problems with a single objective function) has been used to obtain a set of efficient solutions. Due to the limitations in number of pages to this article, it is impossible to show the details of this heuristic procedure, and therefore, only the results are given. From 3531 solved ILP problems, only 13 different efficient solutions have been obtained (see Table 4). According to these solutions, classrooms with large dimensions (height 3.2 - 4.4 m and width 8.4 - 6 m) are preferable to promote memory, attention and "like". Also, the optimal color temperature is 6500K with an illuminance of 100 lx - 300 lx. On the other hand, preferred set of wall colors for the classroom include both cool and warm tones.

To solve the 3531 ILP problems, *Mathematica* was run on a PC Intel®CoreTM I5-7500 with 3.40

Solution	Memory	Attention	I like
1: $x_{22} = 1, y_{13} = 1, z_{82} = 1$	1.7955	1.0808	0.381
2: $x_{22} = 1, y_{31} = 1, z_{42} = 1$	0.4143	2.0515	3.0714
3: $x_{22} = 1, y_{31} = 1, z_{82} = 1$	1.5787	1.5207	0.381
4: $x_{32} = 1, y_{13} = 1, z_{11} = 1$	1.8477	0.3644	2.1924
5: $x_{32} = 1, y_{13} = 1, z_{42} = 1$	0.7421	1.0924	4.3846
6: $x_{32} = 1, y_{13} = 1, z_{82} = 1$	1.9065	0.5616	1.6942
7: $x_{32} = 1, y_{13} = 1, z_{92} = 1$	1.1756	0.5076	4.0989
8: $x_{32} = 1, y_{31} = 1, z_{42} = 1$	0.5253	1.5323	4.3846
9: $x_{32} = 1, y_{31} = 1, z_{82} = 1$	1.6897	1.0015	1.6942
10: $x_{32} = 1, y_{31} = 1, z_{92} = 1$	0.9588	0.9475	4.0989
11: $x_{22} = 1, y_{31} = 1, z_{51} = 1$	0.6593	1.5433	1.7143
12: $x_{22} = 1, y_{31} = 1, z_{92} = 1$	0.8478	1.4667	2.7857
13: $x_{32} = 1, y_{11} = 1, z_{92} = 1$	1.0072	0.7551	3.956

Table 4: Set of efficient solutions obtained.

GHz and 16GB RAM. All 3531 ILP problems were found feasible. The average CPU time to obtain the optimal solution was 0.0035 s.

4 Conclusions

The proposal of this work shows that the different parameters of a spatial configuration can affect memory, attention and "I like" differently. In any case, the experimenter's decision will allow the best choice from among all the efficient possible solutions obtained. Neither of these solutions is dominated, so the choice of one over the other will be made according to different criteria depending on the needs of the classroom. Knowing the perception of what is pleasant and the levels of attention and memory in students can be of great help for the most optimal design of different types of classrooms: for exams or for teaching. This should serve as the beginning of the development of effective classroom design keys to improve the academic performance of all students.

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