Advances in Social Science, Education and Humanities Research, volume 602
ARTEPOLIS 8 - The 8th Biannual International Conference (ARTEPOLIS 2020)

Visual Environment for Learning in the Digital Era: A Review

Rizky Amalia Achsani[1,*], Surjamanto Wonorahardjo[1], Sugeng Triyadi[1]

[1] *School of Architecture, Planning and Policy Development, Institut Teknologi Bandung, Indonesia)*
[*] *Corresponding author. Email: rizky.amalia7@gmail.com*

ABSTRACT
Technology is being widely applied in and is disrupting daily life, especially in the learning environment. Technological developments affect existing indoor visual environments and thereby influence the teaching and learning processes. This study examines the problems and opportunities from using technology in the visual environment for learning through a literature review method. The review results were divided into problems and opportunities. The results revealed various problems and opportunities related to glare, visual fatigue, visual engagement, visibility, and non-image-forming effects. Teachers and students must minimize problems and maximize opportunities to create a better visual environment for learning. The visual environment in the digital era will change the interactions between the physical settings and users' activities. Policies must be established to create a better visual environment for learning. Multidisciplinary research can help understand the visual environment holistically to support dynamic teaching and learning processes better.

Keywords: *Lighting Technology, Digital Technology, Visual Environment, Learning Environment.*

1. INTRODUCTION

Technology is being widely applied in and is disrupting daily life, especially in the learning environment. Two main types of technology are used in the learning environment: digital technology and lighting technology. Digital technology includes screen projectors, interactive whiteboards, and video display terminals (VDTs) such as television, computers, notebooks, and tablets. In contrast, lighting technology includes digital sensors and dynamic or smart building components. Implementing such technologies changes the interactions that occur in the learning environment and requires teachers and students to make adaptations in their teaching and learning processes, respectively [1,2]. Although there are several technical obstacles to using technology as a tool to structure lessons and support activities, overall, teachers and students have demonstrated a positive response to it [3,4].

The visual environment is an indoor environmental quality that influences the teaching and learning processes. Indoor environmental qualities such as thermal, air quality, acoustics, and lighting have positive and negative associations with student outcomes [5,6]. The visual environment is formed by a light source that illuminates the environment in which human activity occurs. There are two primary sources of lighting: natural lighting and artificial lighting. Natural lighting has uniformed, static, and light-reflective characteristics, while artificial lighting has non-uniform, non-static, and light-emitting characteristics [7,8]. The stimuli obtained from the light source activate the image-forming and non-image-forming pathways on the retina, which affects its psychological functioning. The effects of image-forming include: visual performance, visual comfort, and visual experience, and those of non-image-forming include: circadian effects and acute effects. Nonetheless, both image-forming and non-image-forming effects contribute to the same mental process [7].

Technological developments will affect the existing visual environment and, in turn, the teaching and learning processes. When humans interact with the environment, their sensory mechanisms (visual, auditory, and haptic) send signals to the central processor (energy generation and information processing regulator), which influences human behaviors and actions in the teaching and learning processes [2,9]. This interaction could explain why 42% of school students are annoyed by glare from sunlight in their classrooms [6]. However, teachers and

students are often exposed to artificial lighting with technological developments, which has light-emitting characteristics [8]. This causes the sensory mechanism to receive inputs from the results of human interactions with the environment (both general and immediate) and displays and controls before finally being forwarded to the central processor [9]. This interaction will undoubtedly affect the spatial and temporal learning environment [8]. This study aims to examine the problems and opportunities arising from the use of technology in the visual environment for learning. The study results should help decision-makers, such as teachers, schools, designers, and stakeholders, improve classroom visual environments.

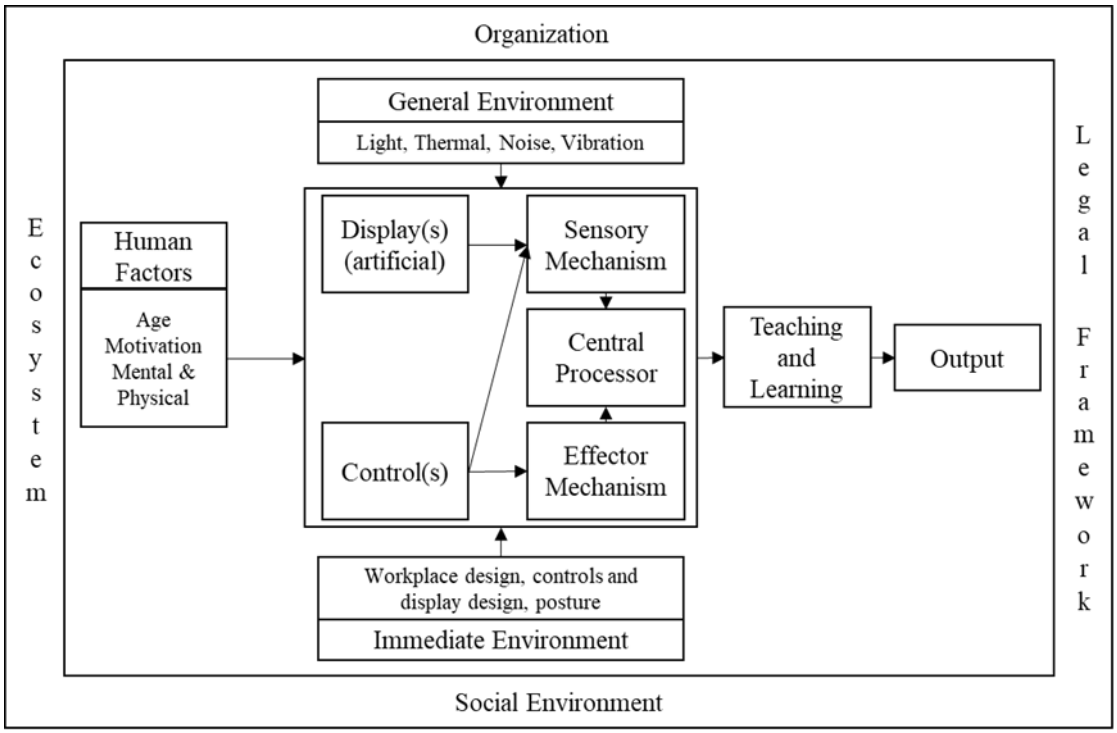

Figure 1. Human-machine model in a technology-enabled classroom. Source: Adapted from [2,9]

2. METHOD

This study uses a literature review method. The review was conducted from March to June 2020 by searching for articles and reviews and then encoding the topics found as a result. An article search was performed using Scopus and Google with keywords such as *illumination*, *daylight*, *LED*, *dynamic lighting*, *student*, *teacher*, *classroom*, *visual task*, *visual comfort*, *glare*, *alertness*, *technology*, and *digital*. The search focused on articles in English without any limitations on the year of publication. The review results were divided into problems and opportunities in the classroom visual environment. These topics were further explained using the codes obtained from the review results.

3. FINDINGS

The literature review results revealed several problems and opportunities arising from the use of technology in the visual environment for learning. Light-emitting technology in the learning environment causes the image-forming and non-image-forming processes to affect human behaviors and actions, especially in terms of visual performance, visual comfort, circadian rhythm, and acute effects.

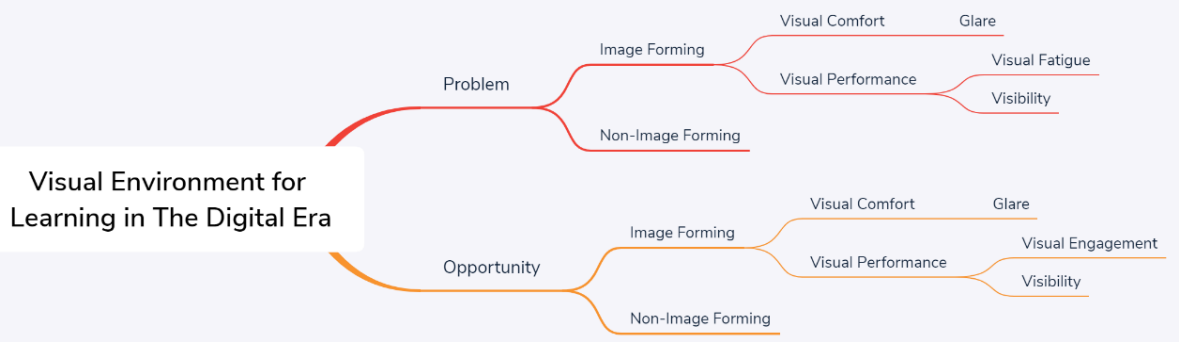

Figure 2. Problems and opportunities arising from the use of technology in the visual environment for learning

3.1 Problem

The visual environment problems arising from the use of technology in learning are related to visual fatigue and visibility, glare, and non-image-forming effects. Visual fatigue can be explained as "*a decrease in performance of the human vision system*" (p.3) [10]. It can be caused by constant exposure to a screen projector or VDT and can, in turn, lead to various disturbances such as eye strain, visual impairment, surface impairment of the eye, and the out-of-eye problem [1,11]. Technological developments such as curved displays that enable more efficient movement and utilize more display area simultaneously still cause visual fatigue after 15 min of use [12,13].

Visibility is an essential factor for the well-being of teachers and students [4]. In classrooms, visibility problems are caused by the interaction between ambient light and digital technology. Four problems cause a decrease in the visibility of the reflected image on a VDT: decreased contrast of the display image, reflection level of the display screen material, disruption of the user's attention, and different focal distances between the display and the reflected images [14,15]. Further, the need for ambient light that meets standards on student desks can reduce the image contrast on interactive whiteboards [16].

Glare is the main problem in visual comfort. It occurs when a bright contrast exists between one part of the visual scene and the rest of the field of view [16]. Glare caused by non-uniform and non-static light sources has become increasingly important because of the number of light-emitting technologies used by humans increases [7]. The presence of glare spots on interactive whiteboards owing to a screen projector or ambient light can cause discomfort and even disability glare in students [3,16].

The use of artificial light in either lighting or digital technology causes the problem of non-image-forming effects. Although digital technology emits less blue light than lighting technology, policies must regulate these adverse effects, especially in learning environments [17].

Figure 3. (a) Visual fatigue from VDT, (b) visibility and glare in the screen projector, and (c) the non-image-forming effect from artificial light. Source: [33,34,35]

3.2 Opportunity

The opportunities arising from using technology in learning environments are related to visual engagement, visibility, glare, and non-image-forming effects. Visual engagement is closely related to visual attention and has four levels: presentation, partially engaging, partial eye contact, and engaging. Further, visual attention has four levels: away, sleepy, satisfactory, and attentive [18]. Most students stated that digital technology is an audio-visual tool that leads to better learning and that teachers can promote more physical activities indoors [3,19]. Digital technology design needs to adhere to nine principles: multimedia, spatial, temporal contiguity, coherence, modality, redundancy, pre-training, signaling, and personalization [20].

The use of technology can ensure the fulfillment of teachers' and students' needs regarding visibility and glare. Further, teachers can use dynamic light in the learning environment to adjust the atmosphere in response to activities, sunlight movement, seasonal changes, and glare [4].

Figure 4. Opportunities arising from the use of technology are related to visual engagement, visibility, and non-image-forming effects. Source: [36]

Technological advancements have made it easier for researchers to develop lighting that mimics natural light conditions by changing the spectrum and color temperature. Calculation results revealed that the use of "daylight-LED" could positively affect visual comfort, alertness, mood, and sleep intensity [21]. The use of blue luminaire in dynamic lighting provides a resemblance to outside skylights indoors and creates a more relaxing and pleasing environment [22]. Further, a broad spectrum makes color perception more natural and enhances visual and non-visual performance (circadian rhythms) [23]. A high correlated color temperature range makes students more alert and enables them to perform better on cognitive tasks [24]. Further, using an RGBW LED solution affects both the circadian effect and daylight's visual brightness appearance [25].

4. DISCUSSION

The findings indicate that technological developments can change the visual environment for learning. The problems and opportunities arising from using technology in such environments are related to glare, visual fatigue, visual engagement, visibility, and non-image-forming effects. Teachers and students must be able to adapt to maximize the opportunities and minimize the problems. Interaction with technology can encourage activity and communication in the teaching and learning processes, influence student activity and behavior, create an atmosphere, and support visual tasks and comfort [4].

Changes in the visual environment will also change the interactions between the physical settings and users' activities. Four physical factors affect the visual environment: classroom functionality and layout, natural environment, light technology, and digital technology. A classroom layout should be considering the seating position to the projector; whiteboards tilt angle that reduces glare and color of walls and windows frame [6,16,26]. The presence of a natural environment and the adjustment of the visual environment in response to daily and seasonal changes are essential in the classroom because it can influence students' activity and behavior [4]. A technology-enabled classroom should be designed considering the interaction between user responses and physical settings such as digital technology parameters and lighting technology parameters [27]. The light technology used in classrooms must consider the interaction between

ambient light and the need for task lighting [16,26]. Meanwhile, the digital technology used in classrooms must consider the size and luminance from the projector and display screen, specular reflectance, and the effect of haze reflection [26,28]. All these physical settings must also be adjusted to the activities and conditions in the classroom, such as following existing standards, using a smartboard, engaging the students, and establishing a relaxing and informal atmosphere and cozy and pleasant sensation [4,29].

School policies must cover the changing interaction between physical settings and user activity in the visual environment. Poor policies can lead to an inadequate visual environment and, in turn, poor student achievement [30]. Policymakers can use technological developments such as high-frequency control circuity and automatic luminaire dimming or doing simple actions such as change the whiteboard's tilt angle and maintain the technology to create a suitable environment [16]. Further, teachers need training on visual environment assessment levels and the need for frequent short breaks to reduce visual fatigue and other non-image-forming effects in students [13,16,17]. Ultimately, school policymakers influence these decisions [31].

Table 1. Physical setting, activity, and policy in the visual environment for learning in the digital era

Physical Setting	Activity	Policy
1. Classroom functionality layout - Seating position - Board position and tilt angle - Colour of walls and window frame **2.** Natural environment - Daily and seasonal change **3.** Light technology - Ambient lighting - Task lighting **4.** Digital technology - Size and luminance from projector and display screen - Specular reflectance - Effect of haze reflection	**1.** Follow existing standards **2.** Use the smartboard **3.** Engage students **4.** Establish a relaxing and informal atmosphere **5.** Establish a cozy and pleasant sensation	**1.** Control and automatic system **2.** Maintain technology and classroom **3.** Teacher training related to the visual environment level **4.** Frequent short breaks

The reviewed literature presents many different scientific viewpoints that support each other. Technological developments for visual environments span multiple disciplines, including energy, human health, photobiology, telecommunications, and human physiology [32]. Multidisciplinary research can help understand the visual environment holistically to support dynamic teaching and learning processes better.

5. CONCLUSION

The study result indicates that the use of technology for learning results in various problems and opportunities in the visual environment related to glare, visual fatigue, visual engagement, visibility, and non-image-forming effects. Problems must be minimized, and opportunities must be maximized to create an excellent visual environment in a classroom. Changes in the visual environment due to technology use create different interactions with physical settings and user activities. Policies must be established to create a better visual environment for learning. Multidisciplinary research can help understand the visual environment holistically to support dynamic teaching and learning processes better.

ACKNOWLEDGMENTS

This publication and research were supported by PTNBH Research Program 2020 contract: 002/SP2H/AMD/LT/DRPM/2020 and Indonesia Endowment Fund for Education (Beasiswa LPDP).

REFERENCES

[1] A. Leme, I. Maia. Evaluation of Fatigue at Work in Teachers Using Modern Resources in the Classroom Procedia Manuf, 2015, 3 4852.

[2] R. Rajesh, M. Reena. A Review on Work System Interactions in a Technology-Enabled Classroom. Int. J. Technol. Enhance Learn., 2015, Volume 7(2), 99.

[3] B. Akkoyunlu., S. A. Erkan Study on Student and Teacher Views on Technology Use. Procedia Soc.

Behav. Sci. (Turkey), 2013, Vol 103 (Elsevier), pp. 68.

[4] K. Schledermann, H. Pihlajaniemi, S. Sen, E. K. Hansen. Dynamic Lighting in Classrooms: A New Interactive Tool for Teaching. Handb. Exp. Pharmacol., 2019, pp. 374-384.

[5] S. Choi, D. A. Guerin, H.Y. Kim, J. K. Brigham, T. Bauer. Indoor Environmental Quality of Classrooms and Student Outcomes: A Path Analysis Approach. J. Learn. Spaces 2(2) 2013.

[6] P. M. Bluyssen, D. Zhang, S. Kurvers, M. Overtoom, M. Ortiz-Sanchez. Self-Reported Health and Comfort of School Children in 54 Classrooms of 21 Dutch School Buildings. Build. Environ., 2018, 138 106.

[7] Y A de Kort. Tutorial: Theoretical Considerations When Planning Research on Human Factors in Lighting. Leukos, 2019, Volume 15(2-3), 85.

[8] J. Sproul, J. MacCallum, S. Ledger. Screens and Teens with Migraines: Visually Sensitive Learners in Contemporary Digital Classrooms. Disabil. Soc., 2017, 32(8), 1275.

[9] R. Bridger. Introduction to Human Factors and Ergonomics 4th Edition. CRC Press, Florida, 2018.

[10] M. Lambooij, M. Fortuin, I. Heynderickx, W. IJsselsteijn. Visual Discomfort and Visual Fatigue of Stereoscopic Displays: A Review. J. Imaging Sci. Technol., 2009, Volume 53(3), 030201-030203.

[11] H. Rajabi-Vardanjani, E. Habibi, S. Pourabdian, H. Dehghan, M. R. Maracy. Designing and Validation a Visual Fatigue Questionnaire for Video Display Terminals Operators. Int. J. Prev. Med., 2014, Volume 5(7), 841.

[12] L Shupp, C Andrews, M Dickey-Kurdziolek, B Yost, C North. Shaping the Display of the Future: the Effects of Display Size and Curvature on User Performance And Insights. Hum. Comput. Interact., 2009, Volume 24(1-2)v 230.

[13] D. Choi, G. Kyung, K. Nam, S. Park. Effects of Display Curvature, Presbyopia, and Task Duration on Visual Fatigue, Task Performance, and User Satisfaction. Hum. Factors, 2019, Volume 61(2), 273.

[14] C. J. Lloyd, M. Mizukami, P. R. Boyce. A Preliminary Model of Lighting-Display Interaction. J. of the Illuminating Eng. Society, 1996, Volume 25(2), 59.

[15] S. Fotios, T. Ramasoot. New Lighting Recommendations for the Classroom of the Future Based on Luminous Parameters of Display Screen Equipment. J. Light Vis. Environ. 2010, Volume 34(3), 165.

[16] M. Winterbottom, A. Wilkins. Lighting and Discomfort in the Classroom J. Environ. Psychol., 2009, Volume 29(1), 63.

[17] D. B. Moyano, M. S. J. Fernández, R. A. G. Lezcano Towards a Sustainable Indoor Lighting, 2020.

[18] M. Farhan, M. Aslam, S. Jabbar, S. Khalid. Multimedia based qualitative assessment methodology in eLearning: Student-teacher engagement analysis. Multimed. Tools Appl., 2018, 77(4), 4909.

[19] L. Ngo, July Wu FG. The effects of projector arrangement on children physical activity. In International Conference on Universal Access in Human-Computer Interaction 223. Springer, Berlin Heidelberg, 2013.

[20] RE Mayer. Multimedia learning In Psychology of Learning and Motivation 41 85. Academic Press, 2002.

[21] C. Cajochen, M .Freyburger, T. Basishvili, C. Garbazza, F. Rudzik, C. Renz, et all. Effect Of Daylight LED on Visual Comfort, Melatonin, Mood, Waking Performance and Sleep. Light. Res. Technol., 2019, 51(7), 1044.

[22] Z. Gou. Colourizing Daylight in Buildings: Visual Responses in a Daylit Room Supplemented with Colour-Changing Light-Emitting Diode Luminaires. Indoor Built Environ., 2018, 27(1), 34.

[23] J. Nie, Z. Chen, F. Jiao, C. Li, J. Zhan, Y. Chen, et all. Tunable LED Lighting with Five Channels Of RGCWW for High Circadian and Visual Performances. IEEE Photonics J., 2019, 11(6), 1.

[24] M. Ye, S.Q. Zheng, M.L. Wang, M.R. Luo. The Effect of Dynamic Correlated Colour Temperature Changes on Alertness and Performance. Light. Res. Technol. 2018, 50(7), 1070.

[25] Q. Dai, W. Cai, W. Shi, L. Hao, M. Wei. A Proposed Lighting-Design Space: Circadian Effect Versus Visual Illuminance. Build. Environ. 2017, 122, 287.

[26] S. Peng, Y. Chen, X. Tang, I. Heynderickx. November Lighting for Projector Use in School Classrooms to Improve Visibility. In 2014 11th China International Forum on Solid State Lighting (SSLCHINA) 9 IEEE, 2014.

[27] T Ramasoot, S Fotios. Lighting For the Classrooms of The Future. Electronic Classrooms: Aa New Challenge for School Lighting Guidance. Light Eng, 2009, 17(2), 62.

[28] T. Ramasoot, S.A. Fotios. Lighting And Display Screens: Models for Predicting Luminance Limits and Disturbance Light. Res. Technol., 2012, 44(2), 197.

[29] N. Castilla, C. Llinares, J.M. Bravo, V. Blanca. Subjective Assessment of University Classroom Environment. Build. Environ., 2017, 122, 72.

[30] S. Cheryan, S.A. Ziegler, V.C. Plaut, A.N. Meltzoff. Designing Classrooms to Maximize Student Achievement. Policy Insights Behav. Brain Sci., 2014, 1(1), 4.

[31] .SD. Kelting, M. Montoya. Green Building Policy, School Performance, And Educational Leaders' Perspectives In USA. Retrieved August 28th 2020. 2011. from: https://digitalcommons.calpoly.edu/cgi/viewcontent.cgi?article=1002&context=cmgt_fac

[32] I. Chew, D. Karunatilaka, C.P. Tan, V. Kalavally. Smart Lighting: The Way Forward? Reviewing The Past to Shape the Future. Energy Build., 2017, pp. 149-180.

[33] O. Akdoğan. Man Using Computer Inside Room. Unsplash. 2019 https://unsplash.com/photos/qYMkkREOHa4

[34] Neonbrand. Person Standing in Front Of Brown lectern. Unsplash, 2018. https://unsplash.com/photos/gYf49RB7bvE

[35] X. Wang. Grayscale Photo of Students in Room. Unsplash, 2019. https://unsplash.com/photos/NHGkfa-rDPw

[36] Neonbrand. Untitled Image of School. Unsplash, 2018. https://unsplash.com/photos/1-aA2Fadydc