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ORIGINAL RESEARCH PAPER

Examining the Impact of Ceiling Slope on Student Stress and Cognitive Performance: A Neuro-Architectural Study Utilizing VR

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ABSTRACT

Background and Objectives: The learning environment refers to different settings in which students partake in their studies or learning. In recent years, there has been a focus on implementing diverse research to analyze physical settings to improve students' performance in educational settings. The emergence of Neuro-architecture, a growing field that integrates neuroscience principles into architectural design, has gained popularity in optimizing student engagement and learning outcomes. By understanding the neural mechanisms that influence interactions with the built environment, neuro-architecture provides novel avenues for developing learning spaces that support optimal students' performance. Previous Neuro-architecture research has explored various physical aspects within educational settings, including classroom size, color palettes, lighting, acoustics, and indoor air quality, revealing their impacts on memory, attention, emotional reactions, cognitive abilities, and learning advancement. However, limited attention has been given to stress-induced arousal, as well as the influence of classroom ceiling slope on students' stress levels and cognitive abilities. This study seeks to fill this gap by examining how the classroom ceiling slope relates to students' stress levels and cognitive function. Employing Virtual Reality (VR) simulations, cognitive assessments, and physiological measures, the study aims to answer the research question: How do varying ceiling slope orientations affect physiological responses linked to stress-induced arousal and cognitive function? The findings of this study will enhance the realm of research on learning environments by providing insight into the influence of physical features, such as the slope angle of classroom ceilings, on student wellness and academic performance.

Materials and Methods: The research employed a quasi-experimental design to explore the effects of various Ceiling Slope Variations (CSV) on stress-induced arousal and cognitive performance. A total of 18 participants, comprising nine males and nine females, participated in the experiment, selected based on five inclusion criteria established to maintain study consistency and reliability. In the first phase, participants' stress levels were evaluated through the utilization of an Emotibit bio-data logger and Visual Analogue Scales (VAS) test for measuring and mapping psychological responses. This involved monitoring heart rate variability (HRV) and electrodermal activity (EDA) in the surveyed individuals, with the objective of understanding how various ceiling slope orientations affected stress levels. The subsequent phase focused on assessing participants' cognitive abilities by utilizing the N-back test, a well-established task for gauging working memory and attention. The aim was to investigate how different CSV configurations influenced cognitive performance. In the final phase, the relationship between participants' psychological and physiological responses was analyzed using the Analysis of Variance (ANOVA) test. This examination aimed to uncover the connection between stress-induced arousal and cognitive performance in relation to the diverse ceiling slope orientations.

Findings: The findings highlight the important role of ceiling slope orientation in impacting stress levels and cognitive performance among students. Specifically, the research emphasizes that a backward-sloping ceiling design, particularly in relation to the class board, is associated with enhanced cognitive abilities, including higher accuracy rates and reduced instances of incorrect answers, compared to traditional classroom layouts. Conversely, the conventional classroom design results in the lowest cognitive performance levels. Furthermore, the study indicates that variations in ceiling slope can also trigger physiological responses in students, such as changes in heart rate and skin conductance, leading to diverse stress levels. The results suggest that integrating a backward sloping ceiling design can significantly alleviate stress levels in the surveyed participants, showcasing the potential benefits of such ceilings in educational environments.

Conclusions: This research highlights the critical importance of educational space design in alleviating stress and enhancing cognitive abilities among students. Through the utilization of VR simulations and the assessment of physiological and cognitive reactions, the study offers valuable insights into how variations in ceiling slope can impact stress levels and cognitive performance. The results indicate that integrating a backward sloping ceiling design can play a significant role in reducing stress and boosting cognitive functions in students. These findings underscore the importance of developing educational environments that prioritize neuro-architectural principles to promote optimal learning outcomes and student welfare. It is imperative for educational institutions to take into account these considerations when structuring classrooms, ensuring the creation of spaces that nurture students' cognitive processes and overall well-being.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
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مقاله پژوهشی

بررسی تاثیر شیب سقف بر استرس و عملکرد شناختی دانشجویان: با رویکرد معماری عصب محور در VR

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پیشینه و اهداف: محیط یادگیری به هر گونه محیطی اطلاق می شود که فرایند یادگیری در آن اتفاق می افتد. در سال‌های اخیر، پژوهش‌های متنوعی با رویکردهای متفاوت به تجزیه و تحلیل کیفیت‌های محیط فیزیکی یادگیری به منظور بهبود و ارتقا عملکرد یادگیرندگان در محیط های یادگیری پرداخته اند. در همین راستا پیشرفت‌های شکل گرفته در رویکرد معماری عصب محور، زمینه‌ای رو به رشد که اصول علوم اعصاب را در طراحی معماری ادغام می کند، منجر به کاربست این رویکرد جدید در بهینه سازی ویژگی‌های محیط‌های یادگیری و ارتقا عملکرد یادگیرندگان شده است. تحقیقات قبلی در زمینه معماری عصب محور، ویژگی‌های فیزیکی مختلفی را در محیط‌های آموزشی، از جمله اندازه کلاس، رنگ کلاس، نورو صدا،و آسایش حرارتی در محیط‌های یادگیری را بررسی کرده‌اند و تأثیرات آن‌ها را بر حافظه، توجه، واکنش‌های عاطفی، عملکرد شناختی و پیشرفت یادگیری آشکار کرده‌اند .با این وجود، بررسی ها نشان داد که در این پژوهش‌ها توجه محدودی به بررسی تاثیر شیب سقف کلاس بر سطح استرس و عملکردهای شناختی دانشجویان شده است. در همین راستا، هدف این پژوهش آنست که با ارزیابی‌های شناختی و عملکرد فیزیولوژیکی مخاطبان در مواجهه با کلاس درس به این سوال پاسخ دهد که چگونه جهت‌گیری‌های شیب سقف بر پاسخ‌های فیزیولوژیکی مرتبط با برانگیختگی استرس مخاطبان و همچنین عملکرد شناختی آنها تأثیر می‌گذارد؟ یافته‌های این پژوهش به حوزه معماری عصب محور کمک می‌کند و بینش جدیدی در مورد اینکه چگونه عوامل فیزیکی، به‌ویژه شیب سقف کلاس‌ها، بر سلامت روان و عملکرد شناختی یادگیرندگان تأثیر می‌گذارد، ارائه می‌کند.

روش‌ها: در این پژوهش از روش شبه آزمایشی برای بررسی تأثیر تغییرات مختلف شیب سقف بر برانگیختگی ناشی از استرس و عملکرد شناختی شرکت‌کنندگان استفاده شده است. در این راستا ۱۸ شرکت کننده، شامل ۹ دانشجوی مرد

و ۹ دانشجوی زن، در محیط واقعیت مجازی(VR) مورد آزمایش قرارگرفتند، که انتخاب آنها به صورت نمونه گیری دو مرحله ای از بین داوطلبین شرکت در آزمایش و بر اساس پنج معیار تعیین شده برای حفظ روایی و پایایی پژوهش شکل گرفت. فرایند آزمایش شامل سه گام جداگانه بود: ۱) سطح استرس شرکت‌کنندگان از طریق استفاده از حسگر فیزیولوژیکی Emotibit و آزمون مقیاس‌های آنالوگ دیداری (VAS) مورد ارزیابی قرار گرفت. این فرایند شامل ثبت تنوع ضربان قلب (HRV) و فعالیت الکترودرمال (EDA) آنها بود. ۲) با استفاده از آزمون استاندارد N-back حین تجربه مجازی فضای کلاس‌ها، به ارزیابی عملکرد شناختی شرکت‌کنندگان پرداخته شد. هدف این دو گام آن بود که بررسی شود چگونه جهت گیری های مختلف سقف بر عملکرد شناختی و سطح برانگیختگی استرس شرکت‌کنندگان تأثیر می‌گذارد.۳) رابطه بین جهت گیری های مختلف سقف و پاسخ‌های شناختی و فیزیولوژیکی شرکت‌کنندگان با استفاده از آزمون تحلیل واریانس (ANOVA) مورد تجزیه و تحلیل قرار گرفت. این بررسی با هدف تعیین ارتباط بین برانگیختگی ناشی از استرس و عملکرد شناختی در رابطه با جهت‌گیری‌های متنوع شیب سقف انجام شد.

یافته‌ها: یافته ها نشان می دهد که جهت شیب سقف، به سمت جلو و عقب کلاس درس، به طور معناداری بر سطح استرس و عملکرد شناختی شرکت کنندگان تأثیر می گذارد. طراحی سقف با شیب به سمت عقب کلاس درس، عملکرد شناختی بهتر و تعداد پاسخ های نادرست پایین تر در آزمون شناختی N-back را در مقایسه با کلاس‌های درس با سقف بدون شیب و یا با شیب سقف به سمت جلو نشان می دهد. این مطالعه همچنین نشان می‌دهد که تغییرات شیب سقف باعث ایجاد تغییراتی در پاسخ‌های فیزیولوژیکی شرکت کنندگان می‌شود.از نتایج دیتالاگر Emotibit و آزمون VAS شرکت‌کنندگان مشخص می‌گردد، کلاس با سقف شیبدار به سمت عقب کلاس می‌تواند به طور قابل‌توجهی سطح استرس را در شرکت‌کنندگان مورد بررسی کاهش دهد.

نتیجه‌گیری: این پژوهش بر نقش کلیدی کیفیت طراحی محیط‌های فیزیکی یادگیری در کاهش استرس و ارتقای عملکرد شناختی در بین یادگیرندگان تأکید می‌کند. نتایج نشان می‌دهند استفاده از طراحی سقف کلاس‌های درس با شیب به سمت عقب کلاس می‌تواند منجر به کاهش سطح استرس و ارتقا عملکرد شناختی دانشجویان شود. این پژوهش هم راستا با مطالعات معماری عصب محور پیشین در زمینه محیط‌های یادگیری، تاکید می کند که در طراحی کلاس‌های درس، طراحان آموزشی باید به کیفیت‌های فیزیکی محیط‌های یادگیری از جمله جهت شیب سقف کلاس‌ها توجه مضاعف داشته باشند تا محیط‌هایی را ایجاد کنند که فرآیندهای شناختی-احساسی-ادراکی یادگیرندگان را پشتیبانی کرده و به یادگیری، رشد، و در نهایت بهزیستی کلی دانشجویان و یادگیرندگان کمک کنند.

Introduction

The term 'learning environment' encompasses various settings and factors in which students engage in studying or learning, ultimately impacting their educational experience and outcomes. These factors include the quality of teachers, availability of classroom resources, peer relationships, and the overall school culture. Additionally, family support, socioeconomic status, and individual learning preferences play crucial roles in creating an environment conducive to learning and growth. Educators play a significant role in shaping the learning environment by considering and addressing these factors to provide optimal support for all students. The physical environment of the classroom, including elements such as lighting, temperature, and seating arrangements, also plays a key role in influencing learning outcomes. Recent research highlights the importance of various physical attributes, such as color schemes, ventilation, acoustics, thermal comfort, scenic views, class size, and layout, in enhancing student performance and engagement in educational settings.

Moreover, factors like natural and artificial lighting, as well as ergonomic furniture, have been identified as key contributors to improving student well-being and performance in school environments. By recognizing the impact of these elements on student learning, educators can create an environment that promotes successful academic achievement and overall well-being.

In recent years, various design approaches and strategies have been implemented to enhance students' performance in learning environments [1]. Neuro-architecture, as a novel approach, has shown significant progress and has expanded its influence into different architectural domains, particularly within educational settings. This innovative method has been successfully integrated into educational environments to optimize learning outcomes and promote increased student engagement. Incorporating neuroscience principles into the design of educational settings has immense potential for enhancing focus, learning, innovation, and overall academic success. Nevertheless, investigating this correlation is intricate due to the diverse array of variables involved and the interconnected cognitive-emotional and neurophysiological effects they generate. Consequently, numerous variables in this field have yet to be fully explored.

Accordingly, this research aims to investigate a relatively unexplored physical factor, specifically, the impact of the slope of a classroom ceiling on stress-induced arousal and cognitive performance among university students. To overcome existing limitations, the researchers utilized VR simulations to recreate classroom settings, measuring stress levels and cognitive performance through the N-back test and physiological responses. The research aimed to answer two central questions:

(1) Does the orientation of the ceiling slope, particularly in relation to visibility of the class board, have a significant impact on students' stress levels and cognitive performance?

(2) How do different orientations of the ceiling slope influence physiological processes related to stress-induced arousal and cognitive performance?

Review of the Related Literature

In its emerging phase, neuro-architecture primarily concentrated on comprehending and improving the design and functionality of spaces related to healthcare [2]. These settings were considered as essential due to their impact on human health and well-being. Early studies in neuro-architecture often examined hospitals [3], clinics [4], and healthcare facilities [5] to explore how the physical environment could influence factors like stress levels, attention span, and overall emotional and cognitive performance. By incorporating insights from neuroscience, architecture aimed to develop spaces that promote healing, comfort, and enhanced performance [6].

Neuro-architecture, initially introduced in healthcare design, has witnessed significant advancements that have extended its application to various architectural domains, including learning environments [7]. Recently, this approach has been employed in educational settings to enhance learning outcomes [1, 8, 9] and promote student engagement [10]. The incorporation of neuroscience principles into the design of learning environments holds immense potential in fostering concentration, learning, creativity, and overall academic performance. By understanding the neural mechanisms that govern our interactions with the built environment and recognizing the profound influence of architectural design on human cognitive processes, the field of neuro-architecture paves the way for innovative and insightful approaches to constructing spaces that facilitate optimal learning experiences. Neuro-architecture provides a diverse range of methodologies, experimental settings, and assessment tools to explore the impact of environmental and architectural stimuli as independent variables on students' unique conditions and characteristics as dependent variables.

Research in neuro-architecture for learning environments has been conducted in two distinct settings: physical and virtual. The first group involved participants interacting with real built environments [11-13], while the second group explored immersive virtual environments [14-16]. Although studies have traditionally focused on real settings, recent developments have shifted towards using virtual reality (VR) environments. Review papers note a growing interest in merging neuroscience with learning by leveraging VR technology to create realistic simulations [17]. VR enables researchers to create interactive computer simulations that provide users with a realistic sense of 'being there' in a space that does not feel synthetic [18]. Additionally, VR allows for efficient and cost-effective manipulation and isolation of variables in controlled laboratory conditions, which would be impractical in real-world settings. However, limitations exist in these studies related to the methods used to create virtual environments and the monitoring of environmental factors [19]. These constraints could impact our comprehension of the specific characteristics and manipulations in virtual environments and their potential implications. Moreover, it is important to validate the results of VR applications, which is why many studies have utilized the System Usability Scale (SUS) questionnaire to validate VR environments [20]. SUS is the most widely used standardized questionnaire for the VR assessment of perceived usability [21].

A review of relevant literature reveals that previous research has explored various independent variables in neuroarchitecture studies of learning spaces. These variables focus on environmental aspects such as classroom physical features (e.g., size and ceiling height), temperature, thermal comfort, acoustics, lighting, and wall colors. Findings indicate that classroom size, particularly width, impacts memory and attention, with narrower widths correlating to enhanced performance in memory tasks [15]. Brühwiler and Blatchford's study examining the impact of classroom size on learning progress concluded that smaller class sizes positively influence students' learning advancements. Additionally, ceiling height has been found to affect attention, with lower ceilings linked to quicker reaction times and improved performance [10, 22].

Color also plays a pivotal role in shaping the classroom atmosphere [23]. Color influences the classroom ambiance, with cooler hues boosting focus and memory retention [24]. Conversely, bright and vibrant colors can enhance learning outcomes [11, 25]. A study conducted in actual classrooms examined three color categories: neutral, warm, and cool. Cream represented the neutral tone, pink the warm tone, and blue the cool tone. The findings unequivocally demonstrate that the utilization of diverse colors in a classroom setting significantly impacts the perceptual abilities of male students [26].

Regarding lighting, research suggests that classrooms with ample natural light from spacious windows enhance learning outcomes, especially for reading and science activities [12]. Inadequate or unsuitable lighting may impede visual learning tasks like reading, impacting students' performance and attitudes [7, 27]. Furthermore, notable increments in ambient light can impact memory and learning [24]. The color temperature of lighting is also noted to impact cognitive processing, with higher temperatures linked to increased cognitive processing [28].

Furthermore, acoustics can play an important role in the learning process, with factors like noise, reverberation, and distance between the speaker and listener impacting students' perception of spoken information in the classroom [29, 30]. Studies have indicated that sound can impact the way speech is perceived. For example, one study replicated a scenario where a teacher spoke one meter away in a noisy environment to explore its impact on student learning [31]. Other studies highlight the significance of indoor environmental quality (IEQ) elements like thermal comfort, temperature, view, and ventilation in educational spaces [8, 32]. Research has demonstrated that indoor air quality has a significant impact on students' academic performance in educational settings. A conducive indoor air quality enhances college students' performance and contributes to attaining high levels of academic achievement within educational institutions [33].

The impact of the mentioned independent variables on various dependent variables has been investigated in neuro-architectural studies in learning environments. These include memory [34], attention [35], emotional response [36], cognitive function [27], educational engagement [11], learning advancement [10, 37, 38], mood [39], sensation [27], perception [26], perceptual ability [8], and alertness [40]. Memory and attention are the most studied neurological variables, followed by perception, learning, and cognitive performance. However, neurological variables such as stress, alertness, interaction, focus, visual perception, and emotional reaction have also received attention. Memory, vital for knowledge retention and application, is of significant importance as a dependent variable in educational settings [16]. Attention has also been extensively studied in relation to these dependent variables, with research measuring attention through reaction time and performance [41]. Cognitive performance has been another focal point examined in the reviewed literature [28]. Neuro-architectural studies often prioritize memory, attention and cognitive performance within learning environments due to their extensive research in the field of neuroscience, where its mechanisms and neural correlates have been extensively explored and understood. The emphasis on these factors in neuro-architectural studies could be attributed to their compatibility with commonly used analysis techniques such as Electroencephalography (EEG). EEG allows researchers to directly measure brain activity associated with memory and cognitive processes, facilitating a deeper understanding of how the built environment impacts memory formation and cognitive performance.

It is worth noting that despite various tools available for measuring stress-induced arousal in neuro-architectural research, such as neurophysiological data like EEG and physiological data including heart rate and skin conductance, quantitative studies exploring stress as a neural factor in classroom settings are scarce. Stress has been linked to decreased performance in children and adolescents [42]. Multiple studies have consistently found that students reporting lower stress levels related to personal and school matters tend to achieve higher GPAs [43], demonstrate increased academic success [42], and are less inclined to engage in behaviors that may harm performance, such as skipping school or quitting altogether [44].

After the investigations, it is clear that stress has not been given enough focus as a key factor in enhancing students' learning. Additionally, it is notable that there is a lack of studies examining how the shape, form, or slope of classrooms' ceilings affect students' stress levels and cognitive abilities. Therefore, this is an area that will be explored in the current study. This research aims to investigate the influence of changing the slope of classroom ceilings on students' stress levels and cognitive performance.

Our analysis uncovers intriguing patterns in utilizing experimental methods to explore the effects of design characteristics on educational environments through theories and practices of neuro-architecture. Previous research predominantly depended on qualitative surveys and observations, with minimal implementation of physiological or neurological instruments [8, 10, 31, 35, 36, 45]. However, as the discipline has advanced, there has been a shifting inclination towards utilizing physiological devices like heart rate monitors and skin conductance sensors, as well as neurological instruments such as electroencephalography (EEG). Consequently, in our present investigation examining the influence of classroom ceilings on students' stress levels and cognitive abilities, we have incorporated physiological sensors and cognitive performance tests.

Method

Participants

A total of 18 participants took part in the experiment, consisting of 9 males and 9 females. The participants had an average age of 23.36 years, with a standard deviation (σ) of 4.64. To maintain the study's consistency and reliability, five inclusion criteria were established for selecting participants, drawing from findings in systematic review papers related to previous similar research [46]. Firstly, participants needed to be university students to ensure they were familiar with the classroom environment and could provide relevant insights[11, 20, 33]. Secondly, they were required to have normal or corrected-to-normal vision using contact lenses, as the use of spectacles with the HMD could potentially introduce complications or discomfort [14, 15]. Thirdly, the age range for participants was set between 20 and 28 years to ensure a relatively homogeneous sample within a specific age bracket [13, 32]. This helped minimize potential confounding factors associated with age-related differences in cognitive processing. Fourthly, participants needed to be born and currently reside in Iran. This criterion aimed to avoid potential cultural effects and variations that may arise from participants with different cultural backgrounds [46]. Lastly, participants were required to have abstained from consuming performance-altering substances, such as caffeine, within the 24 hours preceding the experiment. This criterion was put in place to minimize the potential influence of substances on participants' physiological and cognitive responses during the study [16, 32]. By implementing these inclusion criteria, the study aimed to ensure a consistent and homogeneous participant group, enabling more valid and reliable results.

Instruments

The participants in the study utilized a virtual head-mounted display (VR HMD) to visualize the different CSVs (as shown in Figure 1). All research activities were conducted within the same laboratory setting. The HMD device utilized in the research was the HTC Vive. This device offers a total resolution of 2160 × 1200 pixels, with each eye having a resolution of 1080 × 1200 pixels. The refresh rate of the device was set at 90Hz, and it provided a field of view of 110 degrees. These specifications ensured a high-quality visual experience for the participants during the simulations. The simulations of the different classrooms were created through a process of modeling and rendering. SketchUp Pro (v23.1.340) was used for the 3D modeling phase, allowing for the creation of a virtual representation of the classroom spaces. Twinmotion (v.2021.1×64) was then utilized for the rendering process, enhancing the visual quality of the virtual environments. Additionally, Twinmotion was used for the virtual implementation of the simulations. Throughout the experiments, the perspective of a student sitting in the middle of the fourth row of tables was maintained. This viewpoint was chosen to provide a comprehensive understanding of the entire classroom space during the duration of the experiment. By adopting this perspective, participants were able to observe and interact with the virtual environment from a position that closely resembled their typical seating arrangement in a physical classroom.

To gather physiological data from participants, the research utilized the Open BCI Emotibit bio-datalogger. The EmotiBit is a wearable device specifically crafted for capturing and monitoring emotional, physiological, and kinetic information in real-time. This compact and lightweight gadget comes equipped with sensors capable of overseeing a broad spectrum of biometric parameters, enabling researchers to stream over 16 data channels from the individual's body. These include PPG for heart rate, heart rate variability, respiration, oxygen saturation, and hydration; EDA/GSR for electrodermal activity and galvanic skin response, demonstrating sympathetic nervous system reactions triggered by cognitive and emotional stimulation; a 9-axis IMU for deriving movements, activity, gestures, rotation, and cardinal direction; and body temperature assessment for health and emotional response evaluations. EmotiBit offers scientifically validated sensing technology that is open-source and Arduino-compatible, allowing wireless data streaming to any platform for real-time insight into the participant's dynamic physiological and cognitive processes. This enables researchers to log participants' physical and psycho-emotional alterations throughout any specific timeframe and monitor real-time biometric data changes to establish a comprehensive long-term physiological profile.

Procedure

The research study employed a quasi-experimental design to investigate the research objective. The main focus was to examine the impact of different variations of ceiling slopes, known as CSV (Ceiling Slope Variations), on participants' stress-induced arousal and cognitive performance. The study utilized a VR setting to present participants with various CSV configurations. Data was collected through cognitive performance tests and psychological responses. The analysis of the study was divided into three phases, each addressing specific research questions.

In the first phase, the participants' stress levels were assessed based on the different ceiling slope variations. This was measured using psychological responses, including heart rate variability (HRV) and electrodermal activity (EDA). The aim was to determine if different ceiling slope orientations had a significant impact on participants' stress levels.

The second phase focused on evaluating participants' cognitive performance based on the ceiling slope variations. This was done using the N-back test, a cognitive task that measures working memory and attention. The objective was to determine if different CSV configurations influenced participants' cognitive performance.

The third phase of the analysis involved examining the correlation between participants' psychological and physiological responses. This step aimed to explore the relationship between stress-induced arousal and cognitive performance based on the different ceiling slope orientations. Prior to conducting the analyses, the validity of VR environment used in the study was assessed. This was done by evaluating the participants' sense of presence, ensuring that the VR simulation effectively created an immersive classroom environment. The provided figures (1 and 2) illustrate the general outline of the methodology employed in the study, showcasing the three phases of analysis and the overall research design.

In this study, a virtual representation of a classroom at the Faculty of Art and Architecture in Shiraz University was created. The selection of this particular classroom was based on its representativeness of typical physical teaching spaces found in universities. The simulated classroom had dimensions of 8.20×5.50×3.80 meters and was designed to reflect the neutral characteristics of an actual classroom.

To explore the impact of different ceiling slopes on student arousal and cognitive performance, two additional classrooms were simulated. These classrooms featured a 10% sloping ceiling with a height of 90 centimeters. The simulations were conducted under three scenarios: 1) the ceiling sloping towards the classroom board, 2) the ceiling sloping towards the end of the classroom, and 3) a neutral classroom without any slope (as depicted in Fig. 1).

The aim of these simulations was to examine how the viewing angle of students, determined by the orientation of the ceiling slope, influenced their levels of stress-induced arousal and cognitive performance. By comparing the responses of participants in the different simulated classrooms, the study sought to understand the relationship between ceiling slope variations and student well-being and academic performance.

The Design of Study

The experiment process can be summarized as follows (see Fig. 2):

- **Participants' System Usability Scale (SUS) Questionnaire Evaluation**: The participants were asked to complete the SUS questionnaire, which includes ten items that are rated on a Likert scale ranging from 0 to 4. The aim of this questionnaire was to evaluate the level of satisfaction among participants and determine whether the virtual reality simulations were deemed satisfactory.
- **VR Immersion and Physiological Recordings**: After completing the SUS questionnaire, participants were immersed in a simulated environment using VR technology for 6 minutes and 30 seconds. During this time, their heart rate variability (HRV) and electrodermal activity (EDA) data were recorded using the Emotibit device (Fig.1). These data were recorded to evaluate the arousal induced by stress in each environment.

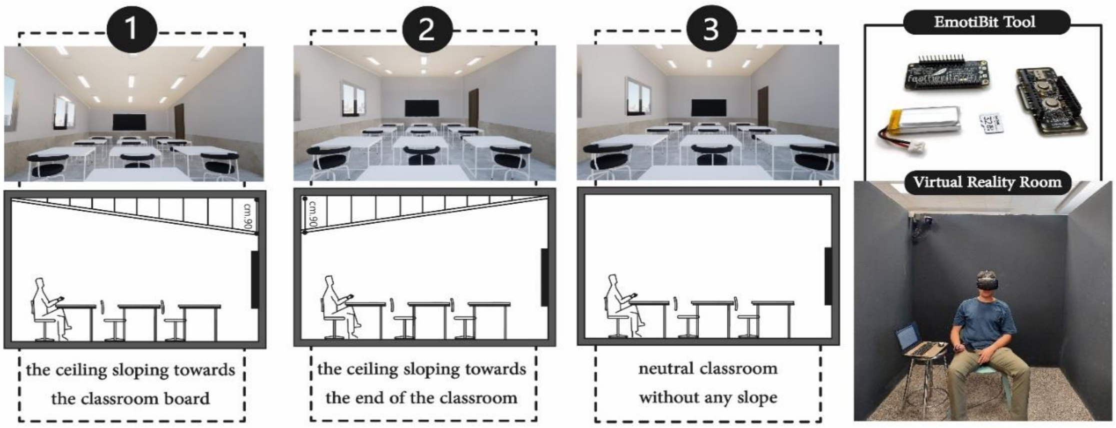


Fig. 1: The simulated environment, experimental setting, and utilized tools for the experiment.

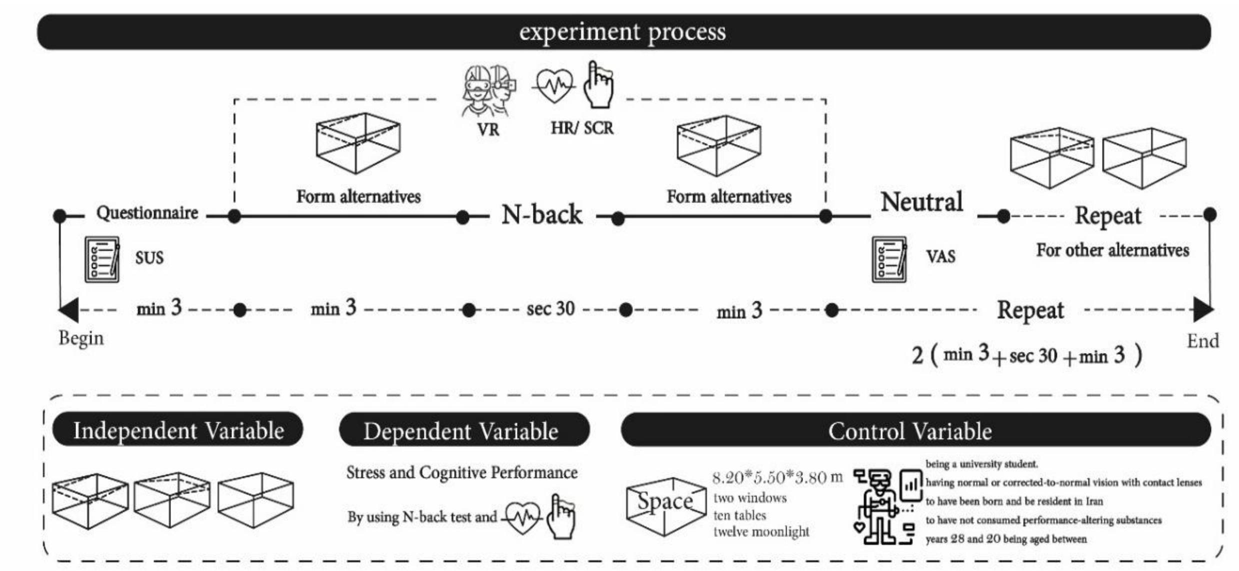


Fig. 2: Experiment process and variables

- **Cognitive Performance Testing (N-back test)**: After spending three minutes in each simulated space, participants were presented with the N-back test displayed on a simulated classroom board. They were asked to respond to the test while their physiological data was simultaneously recorded. The N-back test served two purposes in the experiment: first, to induce stress in participants and assess the impact of the environment on their stress levels before and after the test, and second, to measure participants' cognitive performance in the environment.
- **Visual Analogue Scales (VAS) Questionnaire Evaluation**: The objective of this questionnaire was twofold, to determine the level of stress induced by each environment on the participants and to assess the stress-inducing nature of the N-back test in each environment. This evaluation aimed to ensure that the N-back test elicited a similar level of stress across all environments and to control for stress factors in the experiment.
- **Statistical Analysis**: The data collected, both through the N-back test and psychological responses, were subsequently utilized to conduct the necessary statistical analyses to investigate the study questions. physiological data was extracted using the Emotibit device software. Furthermore, GraphPad Prism software (v.9.1.0) was employed for this purpose.

Results and Findings

Validation of the VR CSV

In the study, a cohort of 27 university students took part in the SUS questionnaire administration. Out of the participants present in the experiment, only 18 achieved a score exceeding 50%, which was set as the threshold for measuring satisfaction with the VR HMD simulation. Fig. 3 illustrates the average sense of presence levels per participant as assessed through the SUS questionnaire.

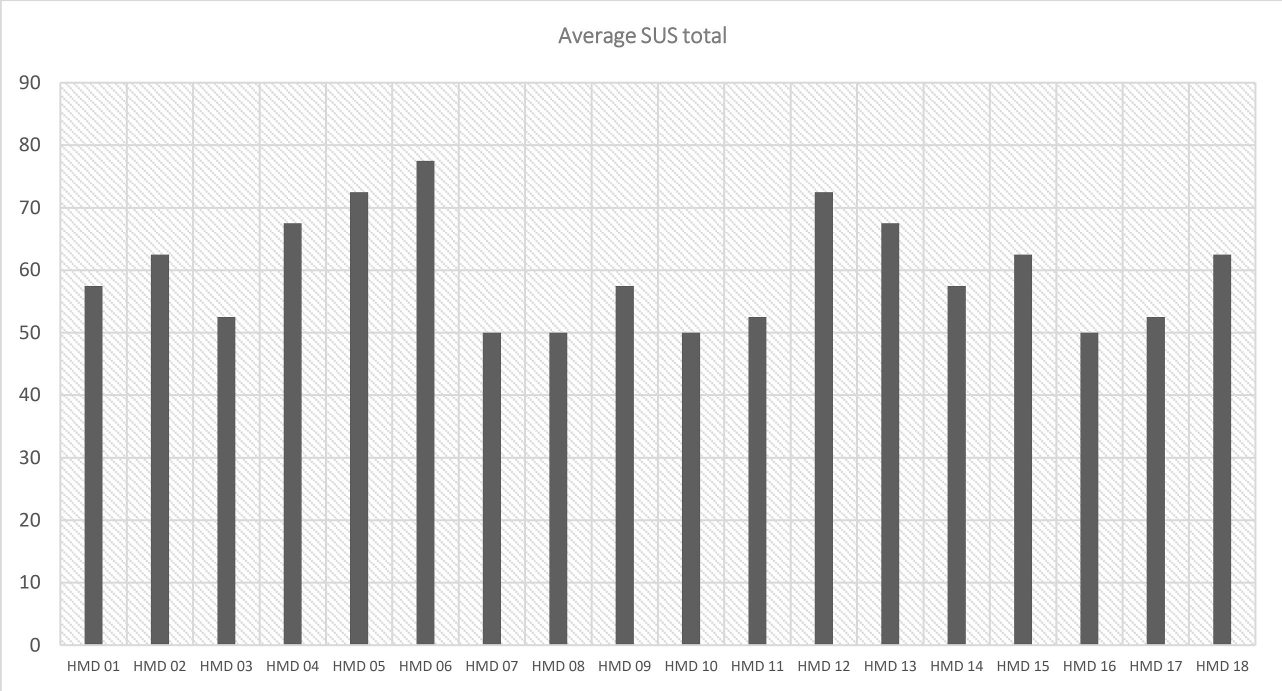


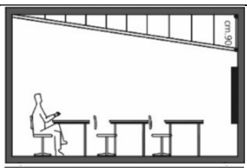
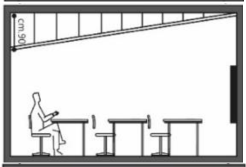
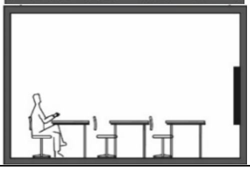
Fig. 3. The average level of sense of presence per participant

Analysis of the N-back cognition performance test

The N-back test is a common task used in cognitive psychology and neuroscience research to assess working memory. In this test, individuals are required to continuously monitor a series of stimuli and remember if the current stimulus matches the one that occurred "n" steps back in the sequence. The "n" can vary, with higher values typically indicating greater cognitive demand. By performing the N-back test, researchers can gain valuable information about an individual's working memory capacity and cognitive control abilities. In the current study, the N-back test is a versatile tool used for cognitive assessment with various purposes. In addition to inducing stress during the experiment and measuring stress-related arousal levels, it is also utilized to evaluate cognitive functions such as attention, working memory, and decision-making [32]. This evaluation is important for gaining insights into an individual's cognitive abilities and performance levels. The results of the N-back test are analyzed and documented in Table 1 to provide a comprehensive assessment of cognitive function.

According to the analysis, it was found that individuals performed exceptionally well in Form (2) of the cognitive assessment, with an impressive 22.26% accuracy rate in providing correct answers. Moreover, they exhibited the lowest rate of incorrect answers, standing at just 11.34%. These results signify a high level of cognitive proficiency and a strong ability to respond accurately to the tasks presented in scenario (2). Conversely, scenario (3) displayed the poorest cognitive performance, with only 18.06% of answers being correct. Additionally, it had the lowest rate of higher answers, which amounted to 14.74%. These findings suggest a relatively lower level of cognitive functioning and a higher likelihood of errors in responding to the stimuli or tasks presented in the scenario (3). Also, scenario 1 has a slight difference in the rate of incorrect responses compared to scenario (2).

Table 1: Results of the N-back cognitive performance test

Nu. scenario		N-back result					HRV (mean)	EDA (mean)
		T	T(%)	F	F(%)	all		
scenario 1		51	21.42%	29	12.18%	80	76.62	3.6
scenario 2		53	22.26%	27	11.34%	80	80.8	3.78
scenario 3		43	18.06%	35	14.74%	78	78.9	2.68

To calculate the percentage, the total sum of responses is 238.

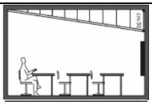
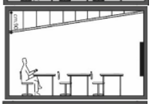
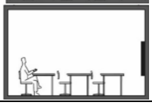
Analysis of the physiological responses

The EmotiBit device is a physiological sensor system that can measure various physiological signals, such as heart rate variability (HRV) and electrodermal activity (EDA), to provide insights into individuals' emotional and stress responses. By monitoring these physiological indicators, researchers can gain a better understanding of the impact of stress on individuals. Heart rate variability (HRV) is a commonly used physiological measure that reflects the number of times the heart beats per minute. During periods of stress, the body's sympathetic nervous system is activated, leading to an increase in heart rate. Monitoring changes in heart rate can provide valuable information about an individual's physiological response to stress [12, 47]. Electrodermal activity (EDA), also known as *galvanic skin response* or *skin conductance*, is another measure that can indicate emotional arousal and stress levels. It measures the electrical conductance of the skin, which is influenced by sweat gland activity. When a person experiences emotional arousal or stress, there is an increase in sweat gland activity, leading to changes in skin conductance [11, 48-50].

In this study, the EmotiBit device was utilized to measure Heart Rate Variability (HRV) and Electrodermal Activity (EDA) in individuals both before and after engaging in a stress-inducing task known as the N-back test in different virtually simulated scenarios. The N-back test is not only used to assess cognitive performance but also to induce stress in the participants. By analyzing the differences in HRV and EDA levels before and after the test in each scenario, we can evaluate how the classroom environment responds to stress. The findings of this comparison are presented in Table 2.

The Analysis of Variance (ANOVA) test is a robust statistical method used to compare means among three or more groups. In this study, we employed ANOVA to explore the impact of varying simulated ceilings' slope orientations on individual stress levels. Specifically, we conducted an ANOVA analysis to determine whether there were significant differences in stress levels before and after administering the N-back test in each scenario.

Table 2: Results of the physiological responses (HRV & EDA)

Scenario Number		HRV			EDA				Significancy
		P value HRV	Before test (mean)	After test (mean)	P value EDA	Before test (mean)	After test (mean)	Difference	
scenario1		0.41	76.85	78.84	0.13	3.17	3.67	-0.5	ns
scenario 2		0.58	79.32	77.63	0.35	3.55	2.67	0.88	ns
scenario 3		0.34	77.53	78.56	0.82	3.20	3.11	0.09	ns

ns=Not Significant (P < 0.05 is considered as Significant)

Accordingly, we conducted an ANOVA analysis on the Heart Rate Variability (HRV) and Electrodermal Activity (EDA) data of 18 participants to assess changes in stress levels across different scenarios. Specifically, we examined whether there was a significant difference in stress levels before and after each scenario, with a focus on the mean HRV and EDA values as indicators of stress.

Our analysis sought to identify scenarios where stress levels remained consistent before and after the experiment, as evidenced by non-significant changes in HRV and EDA readings. Desirability in this context was defined by results with higher p-values, signifying a lack of significance. Essentially, it was aimed to determine if the mean stress levels of each scenario accurately reflected the overall stress experienced by participants.

In essence, the findings revealed that stress levels did not significantly vary before and after the N-back test, with a p-value greater than 0.05 indicating no discernible difference in HRV and EDA responses pre and post-test. This suggests that the scenarios examined did not have a substantial impact on participants' stress levels, irrespective of individual differences in EDA and HRV measurements.

Based on the analysis of physiological data utilizing ANOVA, it was determined that there were no significant differences observed across all three scenarios. Notably, scenario 2 (refer to Fig. 1) exhibited the highest P-value for HRV at 0.58, with an EDA difference of 0.88. Conversely, scenario 3 displayed the lowest outcomes, indicating a P-value for HRV of 0.34 and an EDA difference of 0.09.

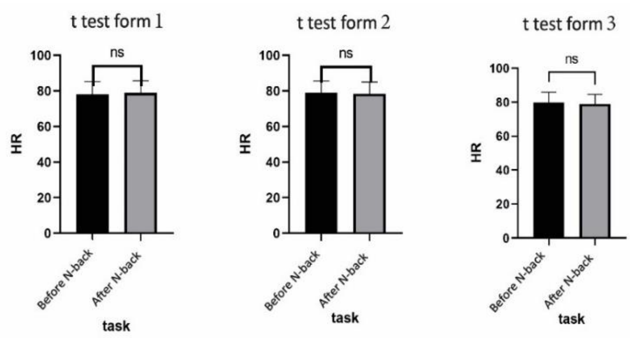


Fig. 4: Results of the physiological responses (HRV & EDA) according to the ANOVA test.

Visual Analogue Scales (VAS) Questionnaire

Visual analogue scales (VAS) are psychometric measuring instruments designed to capture and quantify stress levels in surveyed individuals, enabling a swift and reliable classification of perceived stress. Operating on a scale of 1 to 10, VAS offers a straightforward and user-friendly method for participants to articulate their stress levels, streamlining data collection processes. By using the VAS Questionnaire, researchers can obtain precise and quantitative measurements of participants' stress levels, facilitating an accurate analysis of stress factors and trends.

The findings from the VAS questionnaire revealed that the inclusion of the N-back test as a controlled variable induced similar levels of stress across all scenarios. Specifically, stress levels varied marginally, with a stress-inducing effect of 33.59% in scenarios 2 and 3, and 32.82% in scenario 1. Additionally, an analysis of individual stress susceptibility highlighted that scenario 3 elicited the highest stress levels, followed by scenarios 1 and 2, which exhibited comparatively lower levels of stress.

Correlation between the cognition performance and the physiological and VAS responses

The results of the analysis provide further insights into the relationship between different classroom forms (scenario 1, scenario 2, and scenario 3) and cognitive performance as well as stress levels. Scenario 3, being the common and prevalent form in classroom settings, was found to have the lowest cognitive performance among the individuals. This suggests that the layout or design of scenario 3 may not be optimized for cognitive performance. Additionally, it exhibited the highest level of stress among the participants, indicating that the environment created by scenario 3 may be more stressful or less conducive to a relaxed and focused state of mind. In contrast, scenario 2, characterized by a backward sloping ceiling towards the back of the classroom, demonstrated the most desirable state in terms of cognitive performance and stress levels. The layout of scenario 2 seems to support better cognitive functioning, potentially allowing for improved attention and concentration. Moreover, individuals in scenario 2 experienced lower levels of stress, indicating a more conducive and comfortable learning environment. Interestingly, although participants rated scenario 1 with the lowest score in terms of perceived environmental stress based on the VAS questionnaire, the results from both the physiological data and the N-back test analysis consistently favored scenario 2, albeit with a slight difference compared to scenario 1. This suggests that the objective measurements of cognitive performance and stress levels align more closely with the superiority of scenario 2, despite the participants' subjective perception of stress in scenario 1.

Discussion

In the current study, multiple experimental phases were conducted to investigate the relationship between different classroom ceiling orientations (scenarios 1, 2, and 3) and their impact on cognitive performance and stress levels. Initially, participants completed a System Usability Scale (SUS) questionnaire to assess their compatibility with VR simulations. Those who scored below the standard were removed from subsequent study phases. In the next phase, physiological data, including heart rate variability (HRV) and electrodermal activity (EDA), were collected using an Emotibit device while participants experienced virtual classrooms with varying ceiling slopes in different scenarios. Cognitive performance was measured using the N-back test, which also served as a stress-inducing task. Moreover, participants' stress levels were evaluated through a Visual Analog Scale (VAS) questionnaire. The analysis of the results provides valuable insights into the relationship between different classroom ceiling orientations and their impact on cognitive performance and stress levels.

Table 3. Results of VAS questionnaire evaluation

VAS Result	Scenario			N-back		
	Scenario 1	Scenario 2	Scenario 3	N-back scenario 1	N-back scenario 2	N-back scenario 3
Sum	32	34	43	42	43	43
Percentage	29.35%	31.19%	39.46%	32.82%	33.59%	33.59%

The experiment's findings are presented in two key categories. The first category focuses on how various ceiling slope scenarios impact cognitive performance. By evaluating performance on the N-back test across different scenarios, we measured participants' accuracy in responding to the test stimuli. The level of correct responsiveness in this test is directly linked to cognitive performance desirability. Interestingly, the results highlighted that Scenario 2, featuring a backward-sloping classroom ceiling, showed heightened correct responsiveness and significantly higher cognitive performance desirability compared to other scenarios. Conversely, Scenario 3, with a flat ceiling in the classroom, exhibited lower cognitive performance desirability.

The second category delves into the findings concerning how different forms impact surveyed participants' stress levels. Physiological data, such as Electrodermal Activity (EDA) and Heart Rate Variability (HRV), were examined to gauge these effects. Through statistical analysis using ANOVA, changes in individuals' physiological responses before and after exposure to stress-inducing scenarios were determined.

The findings revealed that Scenario 2 had a more pronounced effect on stress level reduction compared to other scenarios. To corroborate these results, a VAS questionnaire was concurrently administered to participants. By capturing self-reported stress levels in each scenario, the questionnaire enabled a cross-reference with the physiological data for a comprehensive analysis. The outcomes further illustrated that Scenarios 1 and 2 elicited lower stress levels in comparison to Scenario 3. Furthermore, the validation through the VAS questionnaire highlighted that the N-back test, functioning as a control, elicited a consistent level of stress across all scenarios, with minimal deviations detected.

Notably, the study found that scenario 3, the most commonly observed configuration in classroom settings, was associated with the lowest cognitive performance among participants. This implies that the design of flat ceilings may not be ideal for optimizing cognitive abilities. Furthermore, individuals in scenario 3 reported the highest stress levels, suggesting that this particular layout may create a more stressful environment that is less conducive to relaxation and concentration.

In contrast, scenario 2, distinguished by its sloping ceiling that angles towards the back of the classroom exhibited the most optimal conditions for cognitive performance and stress reduction. The design of scenario 2 appears to promote enhanced cognitive abilities, fostering improved attention and concentration among individuals. Additionally, participants in scenario 2 reported decreased stress levels, suggesting a more relaxing and conducive atmosphere for learning.

Surprisingly, while participants rated scenario 1 as having the least perceived environmental stress according to the VAS questionnaire, both the physiological data and N-back test results consistently favored scenario 2. Though the difference from scenario 1 was slight, this indicates that objective measures of cognitive performance and stress levels more strongly support the superiority of scenario 2, contrasting with participants' subjective stress perception in scenario 1.

The neuro-architectural study discussed here highlights the significant impact of ceiling slope variations, particularly backward sloping ceilings, on reducing stress levels and enhancing cognitive performance in students. This underscores the importance of incorporating neuro-architectural considerations in classroom design to cultivate environments that foster optimal learning and well-being. It is noteworthy that current university classrooms predominantly feature flat ceilings, which have been linked to lower cognitive performance and heightened stress levels among participants. This underscores the need for further exploration into the transformation of classroom environments to facilitate an ideal learning space. Moreover, the limited research on stress and cognitive performance as pivotal elements in improving students' learning experiences in educational settings accentuates the urgency for more in-depth investigations in this area.

Neuro-architecture, a cutting-edge field merging neuroscience and architecture, has made significant progress in deciphering how design influences individuals. This interdisciplinary approach has gained momentum, particularly in the realm of educational settings, with the primary objective of elevating learning results and fostering student engagement. Through the integration of neuroscience principles into the design process, educators and architects aspire to provide environments that foster heightened concentration, learning retention, creativity, and overall academic performance. Nevertheless, unraveling the intricate dynamics between neuroscience and learning environment design proves to be a challenging task, given the vast array of variables at play and the interrelated effects on cognition, emotion, and neurophysiology. Consequently, numerous unexplored facets remain in this burgeoning field.

To forge ahead, future studies should delve deeper into the correlation between learning environments' physical characteristics and learning outcomes, considering a wider spectrum of variables for a comprehensive analysis. Furthermore, investigations on the impact of form, scale, and proportion in classroom design warrant attention. Stress and cognitive performance, acknowledged as pivotal elements in enhancing students' learning journeys, deserve further scrutiny. By delving into these realms, researchers can advance the establishment of evidence-based design principles that optimize learning environments for students.

Conclusions

In conclusion, this research underscores the crucial importance of educational space design in mitigating stress and enhancing cognitive abilities in students, in line with the principles of neuro-architecture. The study delves into the specific impact of varying classroom ceiling slopes on stress-induced arousal and cognitive functionality in university students. Through the innovative use of VR simulations and the measurement of both physiological and cognitive responses, this research provides significant insights into how different ceiling slope orientations can affect stress levels and cognitive performance. These findings demonstrate that the orientation of the ceiling slope, particularly its visibility in relation to the class board, plays a key role in influencing stress levels and cognitive functioning among students.

The study reveals that different ceiling slope orientations not only impact cognitive processes but also influence physiological responses linked to stress arousal. Notably, a backward sloping ceiling design demonstrates the highest accuracy rate and lowest rate of incorrect answers, indicating superior cognitive abilities compared to the standard classroom layout. Conversely, the traditional classroom design displays the poorest cognitive performance.

Furthermore, the study identifies that ceiling slope variations trigger changes in students' physiological reactions, reflected in alterations in heart rate and skin conductance, ultimately leading to varying levels of stress among students. These findings underscore the essentiality of incorporating neuro-architectural considerations, such as ceiling slope orientation, in educational space planning. The research suggests that incorporating a backward sloping ceiling can notably decrease stress levels and enhance cognitive performance in students. Thus, emphasizing neuro-architectural factors in classroom design is vital to establishing conducive learning environments that promote optimal academic performance and student well-being.

Authors' Contribution

Reyhaneh Raisi was responsible for software simulations; conceptualization; resources; results and analysis; writing the original draft; and visualization.

Kaveh Fattahi was responsible for conceptualization; methodology; results and analysis; writing, reviewing and editing the manuscript; and supervision.

Seyed Mohammad Hossein Zakeri was responsible for conceptualization; methodology; results and analysis; writing, reviewing, and editing the manuscript; and supervision.

Sara Daneshmand was responsible for conceptualization; methodology; results and analysis; and writing, reviewing and editing the manuscript; and supervision.

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Conflicts of Interest

The authors would like to declare that there is no conflict of interest regarding the publication of this paper. We confirm that our research has been conducted objectively and without any influence from any financial or personal relationships that could be perceived as a conflict of interest .

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