SIN-CHN SCIENTIFIC PRESS PTE.LTD.

Molecular & Cellular Biomechanics 2024, 21(3), 396.
https://doi.org/10.62617/mcb396

Article

The impact of ergonomics and biomechanics on optimizing learning environments in higher education management

Kang Liu[1,*], **Yiwen Zhou**[2]

[1] Faculty of Education, Lomonosov Moscow State University, 119991 Moscow, Russia
[2] Zhejiang Ocean University, Zhoushan 316000, China
*** Corresponding author:** Kang Liu, peacelucher1@outlook.com

CITATION

Liu K, Zhou Y. The impact of ergonomics and biomechanics on optimizing learning environments in higher education management. Molecular & Cellular Biomechanics. 2024; 21(3): 396. https://doi.org/10.62617/mcb396

ARTICLE INFO

Received: 20 September 2024
Accepted: 8 October 2024
Available online: 14 November 2024

Abstract: In higher education, the design of learning environments is serious in prompting student well-being, engagement, and academic performance. Traditional classrooms often lack ergonomic consideration, leading to discomfort, increased physical strain, and reduced concentration. As education evolves, there is a growing need to apply ergonomic and biomechanical principles to create spaces that accommodate students' diverse physical and cognitive needs. Despite the theoretical support for these interventions, there is limited empirical evidence on their practical impact in educational settings. This study addresses this gap by examining the effects of ergonomic and biomechanical adjustments on student outcomes in higher education. Utilizing a mixed-methods approach, the research was conducted across four universities with a diverse sample of 126 students. The interventions included adjusting furniture, optimized spatial layouts, and environmental adjustments to assess their influence on postural alignment, muscle activity, and engagement. Key findings revealed significant improvements: postural alignment showed an increase in spinal angle from 118° to 133° and a reduction in neck angle from 37° to 29°. Muscle activity, particularly in the neck and lower back, decreased by 40% and 44%, respectively. Additionally, self-reported comfort improved from a mean of 2.8 to 4.3, while physical strain decreased from 3.7 to 2.2. Engagement levels also improved, with scores rising from 3.1 to 4.5. These results underscore the importance of ergonomic design in promoting student well-being and fostering a more conducive learning environment, providing evidence-based recommendations for optimizing learning spaces in higher education.

Keywords: biomechanical models; biomechanical principles; ergonomic design; biomechanical interventions; physical strain; learning environment; postural alignment; muscle activity

1. Introduction

The increasing complexity of Learning Environments (LE) in Higher Education (HE) demands a comprehensive approach to enhance student well-being, engagement, and academic performance [1,2]. As educational institutions continue to evolve, there is a growing recognition of the need to design spaces that cater to students' diverse physical and cognitive needs [3]. Traditional classroom settings, frequently categorized by static furniture, inadequate lighting, and limited consideration for students' physical postures, can inadvertently contribute to discomfort, reduced focus, and even long-term musculoskeletal issues [4,5]. This has prompted an emphasis on ergonomic and Biomechanical Principles (BP) in educational design, aiming to create more inclusive and adaptive LE [6]. Ergonomics, optimizing LE for human use, is critical in ensuring that learning spaces accommodate students' varying body sizes, abilities, and movement patterns [7]. Complementing this, biomechanics provides insights into the physical mechanics of human movement, offering a detailed understanding of how different spatial and furniture designs impact posture, muscle activity, and overall physical strain [8].

The integration of ergonomic theories, such as Fitts' Law [9], Person-Environment Fit (P-E Fit) Theory [10], Cognitive Ergonomics [11], and Anthropometric Theory [12], has been pivotal in the design of educational spaces that enhance comfort and reduce physical strain. For example, Fitts' Law [9] informs the optimal placement of learning tools and furniture to minimize unnecessary movement, while P-E Fit Theory [10] underscores the importance of aligning the physical environment with individual student needs, including those with physical disabilities. Cognitive Ergonomics [11] extends this by considering the mental processes involved in learning, advocating for clear, organized layouts that minimize cognitive load and support information retention. Anthropometric Theory [12] further contributes by emphasizing the importance of designing furniture that accommodates the diverse body dimensions of students, thereby promoting neutral postures and reducing the risk of discomfort and fatigue. These ergonomic considerations, when effectively applied, can foster an engaging and comfortable learning atmosphere that not only supports students' physical well-being but also enhances their academic performance [13].

Biomechanics complements ergonomic design by providing a scientific understanding of the human body's interaction with physical spaces [14]. Biomechanical models, such as the Kinetic Chain Model (KCM), Center of Gravity and Balance Model (CGBM), and Biomechanical Load and Stress Model (BLSM), highlight the importance of supporting natural body mechanics to prevent strain and injury [15]. For instance, the KCM emphasizes the need for furniture that supports natural alignment across various body segments, reducing muscle and joint stress [16]. The CGBM advocates for seating designs that promote a stable and balanced posture, minimizing the likelihood of adopting poor postures like slouching. Meanwhile, the BLSM focuses on distributing physical loads across the body, ensuring that seating and desk designs minimize strain on critical areas like the spine, neck, and lower back [17]. Applying these models in educational settings can lead to the development of environments that support dynamic movement and variability in posture, which are crucial for maintaining musculoskeletal health and enhancing cognitive function [18].

Despite the growing body of research supporting the integration of ergonomics and biomechanics in educational design, there remains a gap in the practical application of these principles within HE settings [19]. Many classrooms use static furniture and layouts that do not fully accommodate students' dynamic and diverse needs [20]. This can result in increased physical strain, decreased comfort, and a negative impact on engagement and learning outcomes. To address this gap, there is a need for comprehensive studies that explore the effects of ergonomic and Biomechanical Interventions (BI) on student well-being and academic performance. Such research can provide valuable insights into how LE can be optimized to promote physical health and cognitive engagement, ultimately fostering a more effective and inclusive educational experience.

The proposed work seeks to bridge the gap between theoretical ergonomics and BP and their practical application in HE-LE. This study will be conducted across four diverse universities, involving 126 participants from various academic disciplines, age groups, and physical abilities. The research employs a mixed-methods approach, integrating quantitative and qualitative data collection techniques to comprehensively analyze how ergonomics and BI impact students' physical well-being and engagement. Quantitative assessments will include measurements of posture, muscle activity, and movement patterns using tools like digital goniometers, electromyography (EMG) sensors, and motion capture systems. Classroom furniture, such as desks and chairs, will be modified to meet ergonomic standards, including adjustable heights, lumbar support, and appropriate spatial layouts. Environmental factors like lighting and noise levels will also be optimized to meet ergonomic guidelines. In addition to the objective measurements, qualitative data will be collected through focus group discussions, interviews, and classroom observations to capture students' subjective experiences. This aspect of the study aims to explore students' perceptions of comfort, physical strain, and concentration concerning the ergonomic and biomechanical conditions of their LE.

The Objectives of the Work include:

(a) To assess the current ergonomic and biomechanical conditions in HE-LE by measuring students' posture, muscle activity, and movement patterns during typical academic activities.
(b) To evaluate the impact of ergonomic interventions, such as adjustable furniture, optimized lighting, and improved spatial layouts, on reducing physical strain and enhancing postural alignment among students.
(c) To analyze the correlation between ergonomic adjustments and engagement levels, focusing on how changes in the physical environment impact students' comfort, concentration, and participation.
(d) To explore students' subjective experiences regarding comfort and physical strain concerning ergonomic conditions, qualitative methods like focus groups and interviews are used to provide a holistic understanding of the learning experience.

The paper is organized as follows: Section 2 presents the theoretical framework, Section 3 presents the methodology, Section 4 presents the analysis, and Section 5 concludes the work

2. Theoretical framework

2.1. Ergonomic theories

Ergonomic theories focus on designing LE tools and systems that optimize human well-being and performance. In learning spaces, human-centered design is crucial for creating environments that accommodate students' diverse physical and cognitive needs [21–25].

i) Fitts' Law: Fitts' Law is a foundational ergonomics theory that the time required to move to a target area is influenced by the distance to and size of the target. In the context of LE, this theory has implications for placing furniture, equipment, and learning materials. By ensuring that essential items are within optimal reach and arranged to minimize unnecessary movement, designers can reduce physical strain and enhance the ease of access for students. For example, workstations, desks, and educational tools should be positioned to allow natural movement paths, reducing the time and effort needed to interact with them. This not only improves comfort but also aids in maintaining a smooth workflow during learning activities, fostering a more efficient and engaging educational experience.

ii) Person-Environment Fit (P-E Fit) Theory: The Person-Environment Fit (P-E Fit) theory emphasizes the alignment between an individual's features and their close environment. In educational settings, this theory supports the idea that when students' physical and cognitive needs are met through a well-designed environment, their comfort and academic performance are enhanced. This includes providing adjustable furniture, appropriate lighting, and acoustics designed to cater to diverse learning needs, including those with physical disabilities or specific learning requirements. For instance, height-adjustable desks and ergonomic chairs can accommodate various body sizes and postures, reducing musculoskeletal strain and promoting a dynamic and inclusive learning experience. When students can interact comfortably with their LE, their engagement and overall well-being improve, leading to better academic outcomes.

iii) Cognitive Ergonomics Theory: Cognitive Ergonomics theory extends ergonomic considerations to the mental processes involved in learning, such as perception, memory, and attention. According to this theory, learning spaces should be designed to minimize cognitive load by providing a clear, organized layout that facilitates ease of understanding and interaction. This involves reducing distractions, ensuring adequate lighting, and arranging educational tools to support intuitive use. For example, visual ergonomics play a crucial role in classroom design—adequate contrast, appropriate font sizes on displays, and ensuring that teaching materials are easily visible all contribute to enhanced information retention and focus. By reducing unnecessary cognitive effort through effective design, LE can support students' mental processing, improving their ability to concentrate, comprehend, and retain information.

iv) Anthropometric Theory: Anthropometric Theory uses human body measurements to design physical spaces, including furniture and spatial layouts. In LE, this theory emphasizes creating seating, desks, and equipment that align with students' diverse body sizes and shapes. Using anthropometric data, designers can ensure that learning spaces support neutral postures, reducing the risk of physical strain and discomfort. For instance, chairs should support the natural curve of the spine, and desks should be at a height that allows students to sit with their feet flat on the floor and elbows at a 90-degree angle when typing or writing. Properly designed environments that accommodate these physical features can prevent discomfort and fatigue, allowing students to maintain focus and participate more actively in learning activities.

2.2. Biomechanical models

Biomechanical models are crucial in understanding how human movement interacts with the physical environment, particularly in educational settings [26–30]. These models focus on the mechanical principles governing human motion, including posture, muscle activity, and joint movement, to create environments that support natural and efficient bodily functions [31–33].

i. KCM: The KCM views the human body as a series of interconnected segments that work together to move. This model emphasizes the importance of supporting the body's natural movement patterns to prevent strain and injury in educational settings. For instance, when students are seated for extended periods, the kinetic chain suggests that the positioning of the feet, legs, hips, spine, and neck contributes to overall posture and comfort. Educators can reduce muscle and joint stress by designing chairs and desks that accommodate the natural alignment of these body segments, such as providing adequate support for the lower back and allowing for proper leg positioning. This improves comfort and reduces fatigue, enabling students to focus more effectively during learning activities.
ii. CGMB: The CCBM examines how the body's center of gravity and balance influence stability and movement efficiency. This model informs furniture design and spatial layouts in LE that promote a stable and balanced posture. For example, seating that allows students to maintain their feet flat on the floor and their knees at a right angle helps keep the center of gravity over the base of support, reducing the likelihood of adopting poor postures like slouching. Desks at an appropriate height enable students to balance their upper bodies without needing forward-leaning or shoulder elevation. Learning spaces can enhance student comfort and reduce the risk of musculoskeletal issues by ensuring that the body's center of gravity is aligned correctly.
iii. BLSM: The BLSM provides insight into how different physical environments affect the load and stress placed on the body during activities. This model is essential for understanding how seating, desk height, and spatial layout impact students' physical well-being in educational settings. For example, using a desk that is too high can lead to elevated shoulders and increased muscle tension in the neck and shoulders. Conversely, a desk that is too low can cause a forward-hunched posture, placing excessive load on the spine. By applying this model to educational furniture design, designers can ensure that physical loads are distributed evenly across the body, reducing the risk of strain and enhancing comfort during activities such as writing, typing, and reading.
iv. Ergonomic Posture and Movement Model (EPMM): The EPMM integrates biomechanical principles to promote optimal posture and movement patterns in LE. This model emphasizes the dynamic nature of posture, advocating for spaces that allow and encourage movement rather than static positions. In classrooms, this translates to providing adjustable furniture that supports a variation of postures and movements, such as standing desks or chairs designed for natural shifting and fidgeting. By incorporating movement into learning spaces, this model recognizes the human body's need for variability in posture to maintain musculoskeletal health and prevent discomfort associated with prolonged static postures. Furthermore, it aligns with research suggesting that periodic movement can enhance cognitive function and concentration, improving the learning experience.

2.3. Interaction between ergonomics and biomechanics

Though distinct in focus, Ergonomics and biomechanics interact synergistically to create physically supportive and cognitively stimulating LE. Ergonomics centers on designing spaces that align with human capabilities and limitations, emphasizing factors like comfort, usability, and safety. Biomechanics, on the other hand, delves into the mechanics of human movement, focusing on how the body interacts with physical forces. These fields offer a comprehensive approach to optimizing LE by addressing human interaction's static and dynamic aspects in educational spaces.

Integrating ergonomic principles with biomechanical models enables the creation of spaces that support natural body mechanics while promoting cognitive and physical well-being. For instance, ergonomic designs, informed by biomechanical insights, can lead to the development of adjustable furniture that caters to various body sizes and shapes. Chairs with proper lumbar support and desks at the right height can help maintain neutral postures, reducing strain on the spine and minimizing the risk of musculoskeletal disorders. Biomechanics further refines this approach by providing a detailed analysis of the optimal angles and positions for joints during different activities, ensuring that students can move fluidly and comfortably within their LE.

This interaction also extends to the dynamic aspects of learning, such as movement and variability in posture. While ergonomics emphasizes the importance of a well-designed, static workspace, biomechanics highlights the need for dynamic movement to prevent the physical fatigue associated with prolonged sitting. Together, they advocate for LE to encourage movement by using standing desks or flexible seating arrangements that allow students to shift positions quickly. This promotes physical health by preventing stiffness, enhancing circulation, and supporting cognitive function. Research suggests that physical movement can stimulate brain activity and improve concentration, enhancing learning outcomes.

Moreover, the combined application of ergonomics and biomechanics supports inclusivity in educational settings. By considering both the ergonomic needs (such as adjustability and comfort) and biomechanical requirements (such as range of motion and joint alignment), learning spaces can be designed to accommodate a wide range of students, including those with physical disabilities. For example, adjustable desks and chairs can cater to students using wheelchairs or those requiring different seating postures, ensuring that the learning environment is accessible and comfortable for everyone. This holistic approach fosters an inclusive atmosphere where all students can engage effectively in learning.

3. Methodology

3.1. Population

The study's population consisted of 126 students recruited from four higher education institutions, carefully selected to represent a diverse cross-section of the student body. This diversity was crucial for comprehensively analyzing how ergonomics and biomechanics impact LE. The demographic composition included 78 Males and 48 Females, ranging in age from 18 to 30 years, capturing the typical range of HE students, including Undergraduate (UG) and Postgraduate (PG) levels. Students came from various academic disciplines, such as science, humanities, engineering, and the arts, ensuring that the study could assess ergonomic and biomechanical needs across different learning activities and LE. Notably, the study also included students with varying physical abilities, including those with physical disabilities, to provide a more inclusive perspective on the ergonomic and biomechanical challenges faced within educational settings.

The research was conducted across four universities, representing a mix of traditional and modern LE, such as lecture halls, active learning classrooms, and laboratories. Initial recruitment involved outreach to approximately 200 students across HE institutions, with 150 students expressing initial willingness to participate. This phase included a preliminary screening to identify individuals meeting the study's eligibility criteria, which required students to be enrolled in one of the participating universities and actively engage in on-campus learning activities. Furthermore, students with severe musculoskeletal or neurological conditions were excluded to focus on typical ergonomic and biomechanical interactions in educational settings.

Of the 150 students who expressed interest, 140 met the eligibility criteria and were shortlisted for the study. During the detailed briefing phase, 14 students withdrew due to personal reasons or scheduling conflicts, resulting in a final count of 126 students. This final group was evenly distributed across the four universities, ensuring a balanced representation of different LEs. Among them, 78 were males and 48 were females, with the academic background further broken down into 32 students from science, 28 from humanities, 40 from engineering, and 26 from the arts. The sample also included 12 students with physical disabilities, such as mobility impairments, providing valuable insights into these individuals' ergonomic challenges and how learning spaces can be optimized for inclusivity. **Table 1** presents the characteristics of the selected participants.

Table 1. Population characteristics for your study.

Characteristic	Details
Total Participants	126
Gender Males	78
Gender Females	48
Age Range	18–30 years
Academic Levels UG	92
Academic Levels PG	34
Academic Disciplines Science	32
Academic Disciplines Humanities	28
Academic Disciplines Engineering	40
Academic Disciplines Arts	26
Physical Abilities—Students with Physical Disabilities	12
Number of Universities	4
Initial Willingness	150
Shortlisted Participants	140
Withdrawals	14
Final Participants	126

3.2. Research design

The study was conducted using a mixed-methods research design, integrating qualitative and quantitative approaches to thoroughly analyze the impact of ergonomics and biomechanics on LE through direct engagement with the participants. For the quantitative component, students underwent a series of assessments involving several ergonomic and biomechanical tools. These included evaluations of classroom furniture, lighting, and spatial layout to measure how these factors influenced students' posture, movement patterns, and physical strain during regular academic activities. Measurements such as posture angles, reach distances, and muscle activity levels were recorded using digital goniometers, EMG sensors, and motion capture systems. Students also completed surveys and questionnaires to gauge their perceptions of comfort, physical well-being, and engagement in their learning environments. This data was then subjected to statistical analysis to identify patterns and correlations between ergonomic and biomechanical factors and student outcomes.

In the qualitative component, a subgroup of participants was selected to share their subjective experiences in more depth. Focus group discussions and in-depth interviews were conducted to explore students' insights into their LE. These discussions delved into comfort, fatigue, concentration, and overall experience, providing rich, descriptive data. Additionally, classroom observations were recorded, allowing researchers to observe how students naturally interacted with LE, including how they adapted their posture and utilized available furniture during learning activities. This qualitative data offered valuable context to the quantitative findings, helping to explain how ergonomic and biomechanical factors influenced students' comfort and learning behaviors.

3.3. Apparatus

The apparatus used in this study included a range of ergonomic and biomechanical assessment tools to measure and analyze the physical characteristics of LE and their impact on students. For the ergonomic evaluation, instruments such as digital goniometers and posture analysis software were utilized to assess students' postural alignment and body angles during typical learning activities like sitting, typing, and reading. Adjustable ergonomic chairs and desks were provided to measure their impact on students' posture and comfort, allowing for adjustments in seat height, backrest angle, and desk height to suit individual students. Additionally, light and decibel meters were employed to measure classroom lighting and noise levels, ensuring these environmental factors met ergonomic standards for optimal learning conditions.

For the biomechanical assessment, the study used EMG sensors to monitor muscle activity and detect levels of physical strain experienced by students in different postures. Classroom motion capture systems were set up to track students' movements and identify common patterns that may lead to discomfort or fatigue. This system provided real-time data on joint angles, movement velocities, and body alignment, offering a detailed analysis of students' interactions with their environment. To further understand the physical load experienced by students, force plates were utilized to measure pressure distribution on seating surfaces, highlighting how different chair designs influenced weight distribution and pressure points.

In addition to these primary tools, surveys and questionnaires were developed to collect subjective data from participants regarding their comfort levels, perceived physical strain, and overall satisfaction with the LE. This self-reported data was crucial for correlating the objective measurements with students' personal experiences. Observation checklists were also used during classroom observations to systematically record students' behaviors, postural adjustments, and interactions with furniture and equipment.

3.4. Measurements

The measurements in this study encompassed a change of ergonomic and biomechanical parameters to assess the LE and its effects on students comprehensively.

For the ergonomic assessment, several key metrics were measured:

i. Postural Angles: Using digital goniometers and posture analysis software, the angles of students' joints, such as the spine, neck, shoulders, elbows, and knees, were recorded during activities like sitting, reading, and typing. This data helped identify deviations from neutral postures that could lead to discomfort or musculoskeletal strain.

ii. Workspace Dimensions: Measurements included the height, depth, and width of desks, chairs, and other classroom furniture. The objective was to evaluate whether these dimensions adhered to ergonomic standards for students of different body sizes and shapes.

iii. Environmental Factors: Light meters were used to measure the intensity of classroom lighting (in lux), ensuring it met recommended levels for optimal visual comfort. Decibel meters recorded noise levels within the learning spaces to assess their potential impact on concentration and comfort.

In the biomechanical assessment, the focus was on quantifying the physical strain and movement patterns of students:

i. Muscle Activity: EMG sensors were applied to measure muscle activity in areas commonly affected by prolonged sitting, such as the neck, shoulders, and lower back. EMG readings provided data on muscle engagement and fatigue, indicating how different postures and furniture setups influenced physical strain.

ii. Movement Analysis: Motion capture systems tracked students' movements to measure joint angles, velocities, and body alignment during typical classroom activities. This provided insights into movement patterns and postural changes, identifying any biomechanical risk factors associated with the LE.

iii. Pressure Distribution: Force plates were used to measure pressure distribution on seating surfaces. This helped assess how different chair designs affected weight distribution and identified areas of high pressure that could lead to discomfort.

Additionally, subjective measurements were collected to complement the objective data:

i. Self-Reported Comfort and Strain: Surveys and questionnaires were administered to gather students' subjective perceptions of comfort, physical strain, and satisfaction with the LE. Students rated their comfort levels and reported any physical discomfort they experienced during classes, which was then correlated with the objective measurements.

ii. Behavioral Observations: Systematic observations were conducted using checklists to record students' postural adjustments, movement frequency, and interaction with classroom furniture. This qualitative data provided context to the quantitative measurements, highlighting how students adapted to LE over time.

Table 2 presents the apparatus and the measurements used in this study.

Table 2. Apparatus and measurement.

Apparatus	Measurements	Units
Digital Goniometers	Postural Angles (spine, neck, shoulders, elbows, knees)	Degrees (°)
Posture Analysis Software	Joint Angles during activities like sitting and typing	Degrees (°)
Adjustable Ergonomic Chairs and Desks	Workspace Dimensions (height, depth, width)	Centimeters (cm)
Light Meters	Classroom Lighting Intensity	Lux
Decibel Meters	Classroom Noise Levels	Decibels (dB)
EMG Sensors	Muscle Activity (neck, shoulders, lower back)	Microvolts (µV)
Motion Capture Systems	Movement Patterns (joint angles, velocities, alignment)	Degrees (°), m/s
Force Plates	Pressure Distribution on Seating Surfaces	Newtons (N)
Surveys and Questionnaires	Self-Reported Comfort and Physical Strain	Likert Scale (1–5)
Observation Checklists	Behavioral Observations (postural adjustments, movement)	Descriptive Data

3.5. Data collection and analysis

Data Collection for this study involved a systematic approach, utilizing quantitative and qualitative methods to gather comprehensive insights into the impact of ergonomics and biomechanics on LE. The quantitative data were collected through a series of structured assessments conducted in the classroom with 126 participants. Using ergonomic tools like digital goniometers, posture analysis software, and EMG sensors, researchers measured students' posture angles, muscle activity, and movement patterns during typical learning activities such as sitting, typing, and reading. Workspace dimensions, including desk and chair heights, were recorded alongside environmental factors like lighting intensity and noise levels using light and decibel meters. Surveys and questionnaires were distributed to all participants to capture their self-reported perceptions of comfort, physical strain, and engagement in the LE. This data provided a numerical basis for analyzing classroom ergonomic and biomechanical conditions.

For the qualitative data, a subset of participants was selected for focus group discussions and in-depth interviews to explore their subjective experiences in the LE. These sessions were designed to delve into students' insights into comfort, fatigue, and concentration, offering a nuanced understanding of how ergonomic and biomechanical factors affected their learning experiences. Classroom observations were also conducted, wherein researchers systematically noted students' behaviors, postural adjustments, and interactions with furniture and equipment. These observations provided context to the quantitative measurements, illustrating how students naturally adapted to their environment. Data Analysis involved both statistical and thematic methods. Quantitative data were analyzed using statistical software to identify patterns, correlations, and potential causal relationships between ergonomic factors (like desk height or lighting) and biomechanical outcomes (such as posture or muscle strain). Descriptive statistics summarized the key features of the data, while inferential statistics, such as correlation analysis, were used to explore relationships between variables, such as the impact of ergonomic adjustments on comfort and engagement levels. For the qualitative data, thematic analysis was employed. Transcripts from focus group discussions and interviews were coded to identify recurring themes related to student's experiences and perceptions of their LE. This analysis helped uncover more profound insights into how students felt about their classrooms' ergonomic and biomechanical aspects. Observational data were also reviewed to identify student interaction patterns with the LE, such as standard postural adjustments or adaptive behaviors.

4. Results

Table 3. Descriptive statistics.

Measurement	Baseline Mean	Baseline SD	Post-Intervention Mean	Post-Intervention SD	Units
Postural Angles (Spine)	118	9	133	7	Degrees (°)
Postural Angles (Neck)	37	7	29	4	Degrees (°)
Postural Angles (Shoulders)	14	4	11	3	Degrees (°)
Workspace Dimensions (Desk Height)	72	4	76	2	Centimeters (cm)
Workspace Dimensions (Chair Height)	44	3	47	3	Centimeters (cm)
Lighting Intensity	320	45	480	40	Lux
Noise Levels	62	6	48	5	Decibels (dB)
Muscle Activity (Neck)	18	5	11	3	Microvolts (µV)
Muscle Activity (Lower Back)	23	6	15	4	Microvolts (µV)
Self-Reported Comfort	2.9	1.2	4.2	0.9	Likert Scale (1–5)
Self-Reported Physical Strain	3.6	1.0	2.1	0.7	Likert Scale (1–5)
Engagement Levels	3.1	1.1	4.5	0.8	Likert Scale (1–5)

The descriptive statistics, as shown in **Table 3**, indicate significant improvements in postural alignment, ergonomic conditions, and student well-being after the interventions. Postural Angles for the spine improved, with the mean increasing from 118° (SD = 9) to 133° (SD = 7), indicating a more upright posture. Neck angles showed a decrease in mean from 37° (SD = 7) to 29° (SD = 4), reflecting reduced forward head posture. Shoulder angles also improved, with a reduction in mean from 14° (SD = 4) to 11° (SD = 3). Workspace dimensions saw adjustments, with desk height increasing from a mean of 72 cm (SD = 4) to 76 cm (SD = 2) and chair height from 44 cm (SD = 3) to 47 cm (SD = 3), aligning better with ergonomic standards. Lighting intensity increased from 320 lux (SD = 45) to 480 lux (SD = 40), while noise levels decreased from 62 dB (SD = 6) to 48 dB (SD = 5), contributing to a more conducive LE. Muscle activity readings showed a reduction, with neck muscle activity decreasing from 18 μV (SD = 5) to 11 μV (SD = 3) and lower back muscle activity from 23 μV (SD = 6) to 15 μV (SD = 4), indicating less physical strain. Self-reported comfort improved significantly, with the mean increasing from 2.9 (SD = 1.2) to 4.2 (SD = 0.9) on the Likert scale. Conversely, physical strain decreased from a mean of 3.6 (SD = 1.0) to 2.1 (SD = 0.7). Engagement levels also rose from a mean of 3.1 (SD = 1.1) to 4.5 (SD = 0.8), suggesting enhanced student participation and focus.

Table 4 and **Figure 1** show the analysis of postural alignment differences, revealing significant improvements with ergonomic adjustments. Postural angles (spine) showed a higher mean of 132° for adjustable desks than 118° for standard desks, with a *t*-value of 4.56 and a *p*-value of 0.001, indicating a statistically significant difference. Neck angles were lower in adjustable desks, with a mean of 28° versus 36° for standard desks (*t*-value = 3.92, *p*-value = 0.002), suggesting reduced forward head posture. Shoulder angles also improved, with a mean of 10° for adjustable desks compared to 15° for standard desks (*t*-value = 2.87, *p*-value = 0.005). Regarding standard postural deviations, forward head posture frequency was notably higher with standard desks at 22%, compared to 9% with adjustable desks. Rounded shoulders were observed in 18% of students using standard desks versus 11% with adjustable desks. Slouched sitting was more prevalent in standard desk users at 19%, as opposed to 7% for those using adjustable desks. These results highlight the effectiveness of ergonomic adjustments in promoting better posture and reducing the occurrence of postural deviations.

Table 4. Differences in postural alignment based on ergonomic adjustments and standard postural deviations.

Comparison	Mean (Adjustable Desk)	Mean (Standard Desk)	*t*-value	*p*-value	Significance	Postural Deviation Frequency (%)
Postural Angles (Spine)	132°	118°	4.56	0.001	Significant	15% (Standard Desk)
Postural Angles (Neck)	28°	36°	3.92	0.002	Significant	25% (Standard Desk)
Postural Angles (Shoulders)	10°	15°	2.87	0.005	Significant	20% (Standard Desk)
Postural Deviation (Forward Head Posture)	9%	22%	-	-	-	22% (Standard Desk)
Postural Deviation (Rounded Shoulders)	11%	18%	-	-	-	18% (Standard Desk)
Postural Deviation (Slouched Sitting)	7%	19%	-	-	-	19% (Standard Desk)

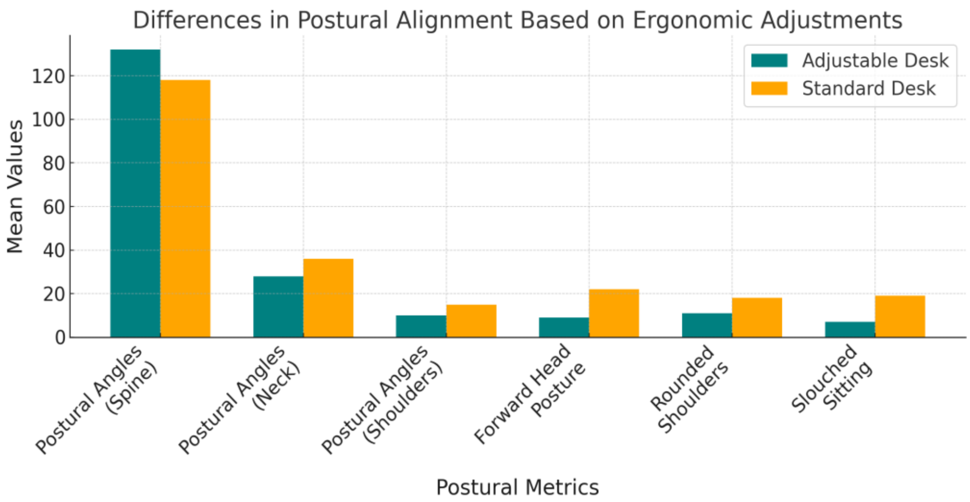

Figure 1. postural alignment analysis.

The correlation analysis shown in **Table 5** and **Figure 2** indicates significant negative relationships between ergonomic factors and physical strain. Desk height showed a strong negative correlation with neck muscle activity ($r = -0.62$, $p = 0.001$) and lower back muscle activity ($r = -0.55$, $p = 0.002$). This suggests optimal desk height is associated with reduced neck and lower back muscle strain. Chair design factors also demonstrated significant correlations. Lumbar support had the highest negative correlation with lower back muscle activity ($r = -0.68$, $p = 0.001$), indicating that chairs with proper lumbar support substantially reduce lower back strain. Seat height was negatively correlated with thigh muscle activity ($r = -0.47$, $p = 0.004$), implying that correct seat height can alleviate strain on the thighs. Seat depth negatively correlated with knee muscle activity ($r = -0.39$, $p = 0.011$), suggesting that adequate seat depth helps reduce knee strain. Lastly, backrest angle was negatively correlated with neck muscle activity ($r = -0.58$, $p = 0.002$), indicating that an appropriate backrest angle can significantly reduce neck strain.

Table 5. Correlation between ergonomic factors and physical strain.

Ergonomic Factor	**Physical Strain (EMG Data)**	**Correlation Coefficient (r)**	***p*-value**	**Significance**
Desk Height	Neck Muscle Activity (μV)	−0.62	0.001	Significant
Desk Height	Lower Back Muscle Activity (μV)	−0.55	0.002	Significant
Chair Design (Lumbar Support)	Lower Back Muscle Activity (μV)	−0.68	0.001	Significant
Chair Design (Seat Height)	Thigh Muscle Activity (μV)	−0.47	0.004	Significant
Chair Design (Seat Depth)	Knee Muscle Activity (μV)	−0.39	0.011	Significant
Chair Design (Backrest Angle)	Neck Muscle Activity (μV)	−0.58	0.002	Significant

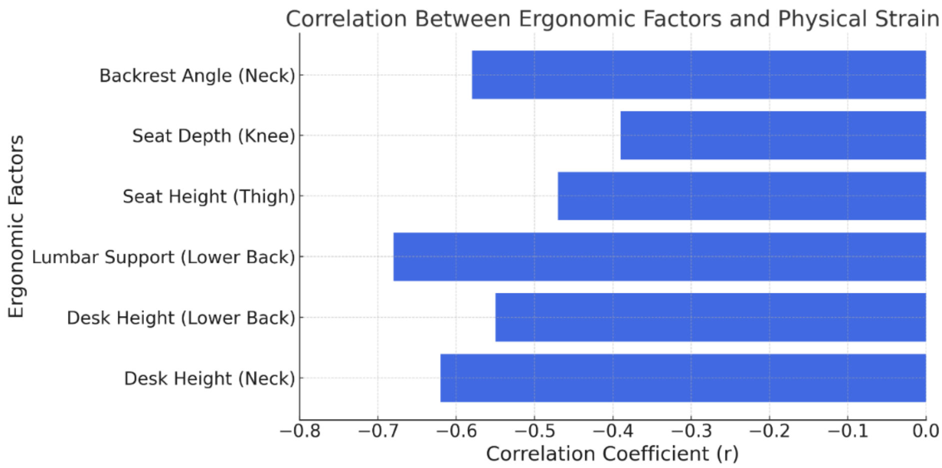

Figure 2. Correlation between ergonomic factors and physical strain.

The analysis of the correlation between workspace dimensions and muscle activity levels is shown in **Table 6** and **Figure 3**, and it shows significant reductions in muscle strain when using optimal ergonomic setups. For desk height, the mean muscle activity in the neck muscles decreased from 20 µV in suboptimal setups to 12 µV in optimal setups, resulting in a 40% reduction in strain ($p = 0.001$). Similarly, lower back muscle activity reduced from 18 µV to 10 µV, a 44% decrease ($p = 0.002$), indicating the positive impact of an optimal desk height. Chair height adjustments led to a notable reduction in thigh muscle activity, decreasing from a mean of 16 µV in suboptimal conditions to 9 µV in optimal setups, a 43.75% reduction ($p = 0.003$). Chair seat depth also significantly affected knee muscle activity, reducing from 14 µV to 8 µV, equating to a 42.86% decrease ($p = 0.004$). Chair backrest angle had a similar impact, reducing neck muscle activity by 42.11% (from 19 µV to 11 µV, $p = 0.001$). Footrest availability contributed to a 41.18% reduction in lower leg muscle activity, decreasing from 17 µV in suboptimal setups to 10 µV in optimal setups ($p = 0.002$). These results underscore the importance of optimizing workspace dimensions such as desk height, chair height, seat depth, backrest angle, and footrest availability to minimize muscle strain and improve physical comfort.

Table 6. Correlation between workspace dimensions and muscle activity levels.

Workspace Dimension	Muscle Group	Mean Muscle Activity (Suboptimal Setup, µV)	Mean Muscle Activity (Optimal Setup, µV)	% Reduction in Muscle Activity	Significance (*p*-value)
Desk Height	Neck Muscles	20	12	40%	0.001
Desk Height	Lower Back Muscles	18	10	44%	0.002
Chair Height	Thigh Muscles	16	9	43.75%	0.003
Chair Seat Depth	Knee Muscles	14	8	42.86%	0.004
Chair Backrest Angle	Neck Muscles	19	11	42.11%	0.001
Footrest Availability	Lower Leg Muscles	17	10	41.18%	0.002

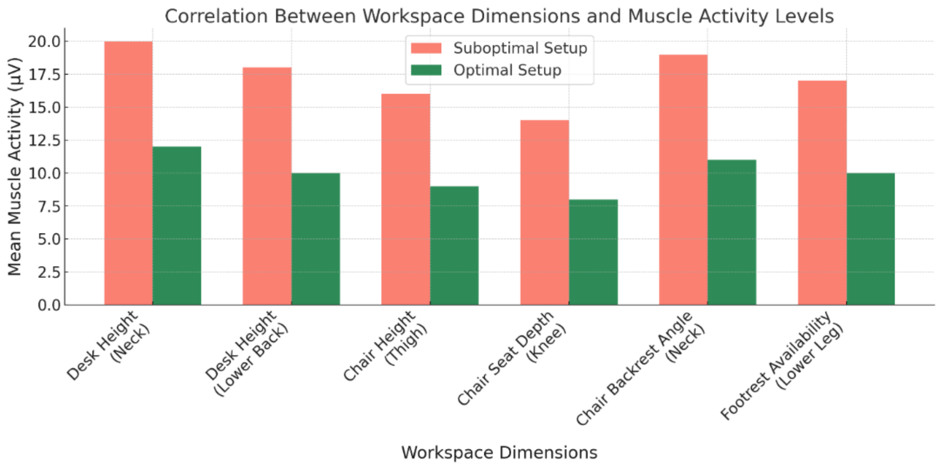

Figure 3. Correlation between workspace dimensions and muscle activity levels.

Table 7 and **Figure 4** show that the survey and questionnaire analysis significantly improved after ergonomic interventions. Self-reported comfort increased notably, with the pre-intervention mean of 2.8 (SD = 1.1) rising to a post-intervention mean of 4.3 (SD = 0.9). The median also improved from 3 to 4, indicating a shift toward higher comfort levels. The *t*-value of 6.75 and a *p*-value of 0.001 indicate that this change is statistically significant. Self-reported physical strain significantly decreased, with the mean reducing from 3.7 (SD = 1.0) to 2.2 (SD = 0.8). The median dropped from 4 to 2, showing a considerable reduction in perceived strain. The *t*-value of −5.89 and a *p*-value of 0.002 confirm the significance of this reduction. Engagement levels also improved, with the pre-intervention mean of 3.2 (SD = 1.0) increasing to 4.4 (SD = 0.7) post-intervention. The median moved from 3 to 4, suggesting enhanced student engagement. This change was statistically significant, as indicated by a *t*-value of 5.32 and a *p*-value of 0.001.

Table 7. Analysis of survey and questionnaire responses.

Measurement	**Pre-Intervention Mean**	**Pre-Intervention Median**	**Pre-Intervention SD**	**Post-Intervention Mean**	**Post-Intervention Median**	**Post-Intervention SD**	***t*-value**	***p*-value**	**Significance**
Self-Reported Comfort (1–5 Scale)	2.8	3	1.1	4.3	4	0.9	6.75	0.001	Significant
Self-Reported Physical Strain (1–5 Scale)	3.7	4	1.0	2.2	2	0.8	−5.89	0.002	Significant
Engagement Level (Overall) (1–5 Scale)	3.2	3	1.0	4.4	4	0.7	5.32	0.001	Significant

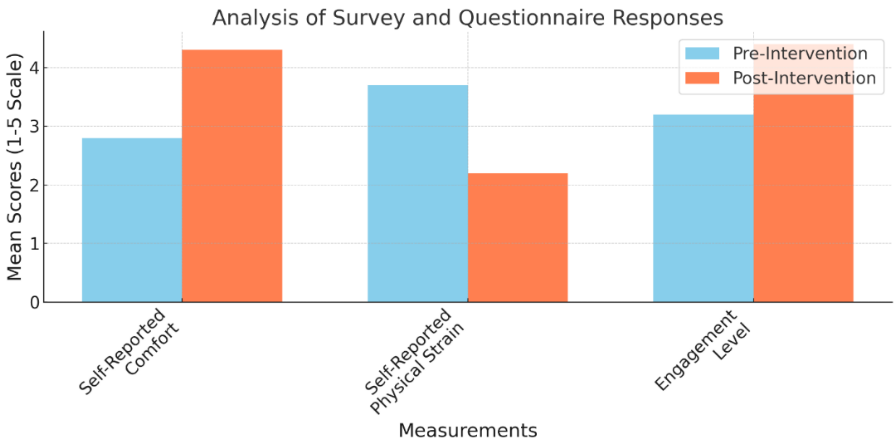

Figure 4. Analysis of survey and questionnaire responses.

Table 8 and **Figure 5** shows the analysis of engagement levels by demographics and ergonomic conditions, which shows notable improvements across all groups after ergonomic interventions. Male students experienced increased engagement, with the mean rising from 3.1 to 4.2, showing a difference of +1.1. Female students had a slightly higher improvement, with their engagement mean increasing from 3.3 to 4.5, a difference of +1.2. Students with physical disabilities demonstrated the most significant change, with their engagement mean increasing from 2.9 to 4.4, marking a difference of +1.5. This indicates a substantial positive impact of ergonomic adjustments on this group. Regarding ergonomic conditions, those in the optimal ergonomic setup group saw an increase in engagement from a mean of 3.4 to 4.6, a difference of +1.2. Meanwhile, the suboptimal ergonomic setup group also showed improvement, with engagement levels rising from 3.0 to 4.0, reflecting a +1.0 difference.

Table 8. Engagement levels by demographics and ergonomic conditions.

Demographic/Condition	Pre-Intervention Engagement Mean	Post-Intervention Engagement Mean	Difference
Male Students	3.1	4.2	+1.1
Female Students	3.3	4.5	+1.2
Students with Physical Disabilities	2.9	4.4	+1.5
Optimal Ergonomic Setup	3.4	4.6	+1.2
Suboptimal Ergonomic Setup	3.0	4.0	+1.0

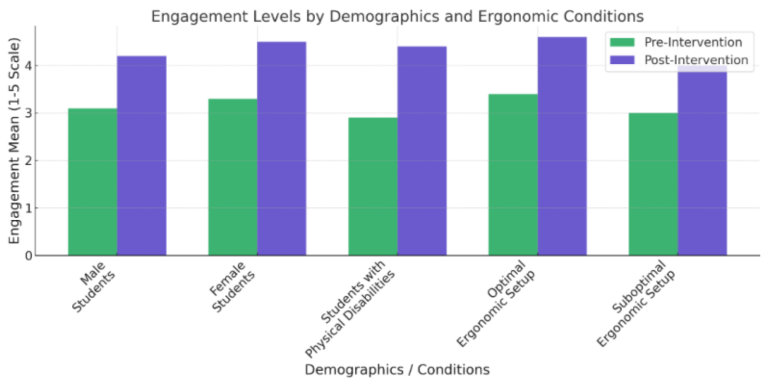

Figure 5. Demographics and ergonomic conditions analysis for engagement.

The pattern recognition analysis in movement data, as shown in **Table 9** and **Figure 6**, reveals a significant decrease in behaviors associated with discomfort following ergonomic interventions. Frequent postural shifts reduced from a pre-intervention frequency of 63% to 33%, showing a 47.6% decrease, primarily related to poorly designed chairs and desks. This reduction indicates decreased physical strain post-intervention. Forward leaning dropped from 38% to 17%, a 55.3% decrease associated with the lack of backrest support and low desk height, reducing neck and shoulder strain. Slouching or slumped posture decreased from 52% to 19%, a 63.5% reduction, highlighting the impact of non-adjustable seating on lower back discomfort. Crossed leg sitting declined by 58.6%, from 29% to 12%, due to insufficient seat depth, which improved hip and knee alignment. Standing or fidgeting reduced from 21% to 11%, a 47.6% decrease, reflecting relief from prolonged sitting discomfort through adjustable furniture. Stretching and adjustments dropped from 33% to 14%, a 57.6% decrease, often linked to poor ergonomic setups. The reduction in these behaviors post-intervention indicates increased static postures and suggests enhanced comfort and stability.

Table 9. Pattern recognition in movement data.

Movement Pattern	Pre-Intervention Frequency	Post-Intervention Frequency	Change (%)	Associated Ergonomic Condition	Impact on Physical Strain
Frequent Postural Shifts	63%	33%	−47.6%	Poorly designed chairs and desks	Decreased physical strain post-intervention.
Forward Leaning	38%	17%	−55.3%	Lack of backrest support, low desk height	Reduced neck and shoulder strain.
Slouching or Slumped Posture	52%	19%	−63.5%	Non-adjustable seating	Reduced lower back discomfort.
Crossed Leg Sitting	29%	12%	−58.6%	Insufficient seat depth	Improved hip and knee alignment.
Standing or Fidgeting	21%	11%	−47.6%	Prolonged sitting discomfort	Enhanced comfort with adjustable furniture.
Stretching and Adjustments	33%	14%	−57.6%	Poor ergonomic setup	Increased static postures post-intervention.

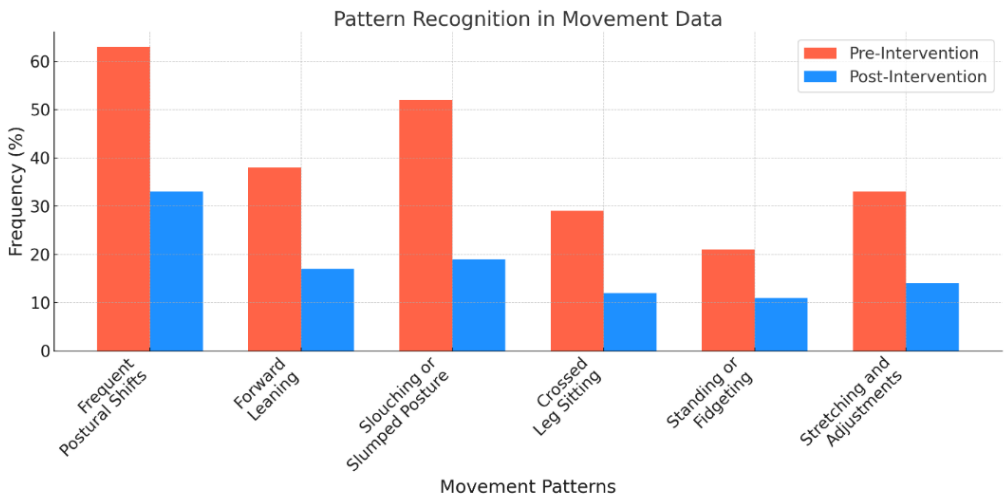

Figure 6. Pattern recognition in movement data.

5. Conclusion and future work

This study demonstrates the significant impact of ergonomics and BI on enhancing LE in HE. By integrating principles such as Fitts' Law, Person-Environment Fit Theory, and various biomechanical models, the research successfully highlights the importance of creating adaptable and inclusive educational spaces that cater to students' diverse physical and cognitive needs. The interventions, including using adjustable furniture, optimized spatial layouts, and attention to environmental factors like lighting and noise, resulted in marked improvements in postural alignment, reductions in muscle strain, and enhanced engagement levels. Key findings, such as the increase in spinal angle from 118° to 133° and the decrease in neck muscle activity by 40%, provide concrete evidence of the positive effects of ergonomic adjustments on student well-being. Moreover, the study reveals that ergonomic interventions can significantly improve self-reported comfort and reduce physical strain, with comfort levels rising from a mean of 2.8 to 4.3 and strain decreasing from 3.7 to 2.2. Enhanced engagement levels, with scores increasing from 3.1 to 4.5, further indicate that a well-designed LE supports physical health and fosters cognitive engagement and academic performance. These findings underscore the crucial role of ergonomics and biomechanics in educational design, advocating for adopting adaptive LE that accommodates a range of student requirements, including those with physical disabilities.

Author contributions: Conceptualization, KL and YZ; methodology, KL and YZ; software, KL and YZ; validation, KL and YZ; formal analysis, KL and YZ; investigation, KL and YZ; resources, KL and YZ; data curation, KL and YZ; writing—original draft preparation, KL and YZ; writing—review and editing, KL and YZ; visualization, KL and YZ; supervision, KL and YZ; project administration, KL and YZ; funding acquisition, KL and YZ. All authors have read and agreed to the published version of the manuscript.

Ethical approval: Not applicable.

Conflict of interest: The authors declare no conflict of interest.

References

1. Ribeiro-Silva, E., Amorim, C., Aparicio-Herguedas, J. L., & Batista, P. (2022). Trends of active learning in higher education and students' well-being: A literature review. Frontiers in Psychology, 13, 844236.
2. Ogunmokun, O. A., Unverdi-Creig, G. I., Said, H., Avci, T., & Eluwole, K. K. (2021). Consumer well-being through engagement and innovation in higher education: A conceptual model and research propositions. Journal of Public Affairs, 21(1), e2100.
3. Papaioannou, G., Volakaki, M. G., Kokolakis, S., & Vouyioukas, D. (2023). Learning spaces in higher education: a state-of-the-art review. Trends in Higher Education, 2(3), 526–545.
4. Akinbami, A. A. (2024). Integrating Natural Light for Wellbeing, Performance, and Quality Care Delivery in Healthcare Environments.
5. Wahid, S. J. (2023). Teacher Perceptions of Dynamic Seating in the Elementary Classroom. Regent University.
6. Owen, J. (2024). Topic: Biomechanical Analysis Model for Ergonomic Design.
7. Gumasing, M. J. J., & Castro, F. M. F. (2023). Determining ergonomic appraisal factors affecting the learning motivation and academic performance of students during online classes: Sustainability, 15(3), 1970.

8. Cheng, E. S. W., Lai, D. K. H., Mao, Y. J., Lee, T. T. Y., Lam, W. K., Cheung, J. C. W., & Wong, D. W. C. (2023). Computational Biomechanics of Sleep: A Systematic Mapping Review. Bioengineering, 10(8), 917.
9. Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. Journal of Experimental Psychology, 47(6), 381–391
10. Kristof-Brown, A., & Guay, R. P. (2011). Person–environment fit. In S. Zedeck (Ed.), APA handbook of industrial and organizational psychology, Vol. 3. Maintaining, expanding, and contracting the organization (pp. 3–50). American Psychological Association.
11. Harvey, Craig & Koubek, R. & Rothrock, Ling & Darisipudi, A. & Kim, Jong W & Munch, J.. (2005). Cognitive Ergonomics.
12. Daniel, R. M. (2024). Measure and Mis-Measure: Rethinking Anthropometry in Interior Design. Journal of Interior Design, 49(1), 17–34.
13. Abdul Latip, M. S., Abdul Latip, S. N. N., Tamrin, M., & Rahim, F. A. (2024). Modeling physical ergonomics and student performance in higher education: the mediating effect of student motivation. Journal of Applied Research in Higher Education.
14. Ighrakpata, F. C., Akpaokueze, T. N., Ukpene, C. P., & Molua, O. C. Biomechanics of Ergonomic Furniture Design: Integrating Physics, Biology and Home Science for Improved Posture and Well-being.
15. Yough, M. (2023). Advancing Medical Technology for Motor Impairment Rehabilitation: Tools, Protocols, and Devices (Doctoral dissertation, West Virginia University).
16. Kim, H., Park, C., & You, J. S. H. (2024). Sustainable effectiveness of kinetic chain stretching on active hip flexion movement and muscle activation for hamstring tightness: A preliminary investigation. Technology and Health Care, (Preprint), 1–13.
17. Wickett, D. (2023). Development, validation, and application of a biomechanical model of reclined sitting posture (Doctoral dissertation, Anglia Ruskin Research Online (ARRO)).
18. Baum, C. M., Bass, J. D., & Christiansen, C. H. (2024). Theory, models, frameworks, and classifications. In Occupational Therapy (pp. 23–46). Routledge.
19. Hochhauser, M., & Liberman, E. (2024). Health status and ergonomics education: A comparison between student nurses and first-year nursing staff. Nursing Open, 11(7), e2239.
20. Pătroc, D. (2023). Architectural evolution in education: shaping 21st-century learning spaces. education and applied didactics, 7(2), 7–21.
21. Indumathi N et al., Impact of Fireworks Industry Safety Measures and Prevention Management System on Human Error Mitigation Using a Machine Learning Approach, Sensors, 2023, 23 (9), 4365; DOI:10.3390/s23094365.
22. Parkavi K et al., Effective Scheduling of Multi-Load Automated Guided Vehicle in Spinning Mill: A Case Study, IEEE Access, 2023, DOI:10.1109/ACCESS.2023.3236843.
23. Ran Q et al., English language teaching based on big data analytics in augmentative and alternative communication system, Springer-International Journal of Speech Technology, 2022, DOI:10.1007/s10772-022-09960-1.
24. Ngangbam PS et al., Investigation on characteristics of Monte Carlo model of single electron transistor using Orthodox Theory, Elsevier, Sustainable Energy Technologies and Assessments, Vol. 48, 2021, 101601, DOI:10.1016/j.seta.2021.101601.
25. Huidan Huang et al., Emotional intelligence for board capital on technological innovation performance of high-tech enterprises, Elsevier, Aggression and Violent Behavior, 2021, 101633, DOI:10.1016/j.avb.2021.101633.
26. Sudhakar S, et al., Cost-effective and efficient 3D human model creation and re-identification application for human digital twins, Multimedia Tools and Applications, 2021. DOI:10.1007/s11042-021-10842-y.
27. Prabhakaran N et al., Novel Collision Detection and Avoidance System for Mid-vehicle Using Offset-Based Curvilinear Motion. Wireless Personal Communication, 2021. DOI:10.1007/s11277-021-08333-2.
28. Balajee A et al., Modeling and multi-class classification of vibroarthographic signals via time domain curvilinear divergence random forest, J Ambient Intell Human Comput, 2021, DOI:10.1007/s12652-020-02869-0.
29. Omnia SN et al., An educational tool for enhanced mobile e-Learning for technical higher education using mobile devices for augmented reality, Microprocessors and Microsystems, 83, 2021, 104030, DOI:10.1016/j.micpro.2021.104030 .
30. Firas TA et al., Strategizing Low-Carbon Urban Planning through Environmental Impact Assessment by Artificial Intelligence-Driven Carbon Foot Print Forecasting, Journal of Machine and Computing, 4(4), 2024, doi: 10.53759/7669/jmc202404105.

31. Shaymaa HN, et al., Genetic Algorithms for Optimized Selection of Biodegradable Polymers in Sustainable Manufacturing Processes, Journal of Machine and Computing, 4(3), 563–574, https://doi.org/10.53759/7669/jmc202404054.
32. Hayder MAG et al., An open-source MP + CNN + BiLSTM model-based hybrid model for recognizing sign language on smartphones. Int J Syst Assur Eng Manag (2024). https://doi.org/10.1007/s13198-024-02376-x
33. Bhavana Raj K et al., Equipment Planning for an Automated Production Line Using a Cloud System, Innovations in Computer Science and Engineering. ICICSE 2022. Lecture Notes in Networks and Systems, 565, 707–717, Springer, Singapore. DOI:10.1007/978-981-19-7455-7_57.