



# EVALUATION OF CLASSROOM FURNITURE DESIGN ON POSTURE AND MOBILITY OF ELEMENTARY SCHOOL STUDENTS: A SYSTEMATIC LITERATURE REVIEW

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**Abstract:** This study presents a Systematic Literature Review (SLR) examining the interrelationship between classroom furniture design, postural biomechanics, and the mobility of elementary school students. Guided by the PRISMA framework, from an initial pool of 47 peer-reviewed publications, 14 studies met the inclusion criteria and were analyzed in-depth. The review synthesizes the findings into three core domains: macro-environmental demands, physical mismatch crises at the meso-scale, and cognitive ergonomics deficiencies at the micro-scale. Key findings indicate that the implementation of active learning requires dynamic classroom layouts; however, this is hindered by existing furniture standards that demonstrate an absolute mismatch and possess weights exceeding the safe limits of Manual Material Handling (MMH) for children. Furthermore, the analysis reveals a significant research gap regarding affordances, wherein previous furniture designs overlooked the visual cues necessary to guide safe lifting behaviors among children. This study concludes that future furniture design interventions must integrate cognitive ergonomics to mitigate musculoskeletal injury risks while simultaneously supporting a flexible classroom ecosystem aligned with Sustainable Development Goal 4 (SDG 4).

**Keyword:** Affordances, Cognitive Ergonomics, Flexible Seating, Manual Material Handling, School Furniture.

**Abstrak:** Studi ini menyajikan tinjauan literatur sistematis (Systematic Literature Review/SLR) yang mengkaji interelasi antara desain furnitur ruang kelas, biomekanika postur, dan mobilitas siswa sekolah dasar. Dipandu oleh kerangka PRISMA, dari himpunan awal sebanyak 47 publikasi yang ditelaah sejawat, 14 studi memenuhi kriteria inklusi dan dianalisis secara mendalam. Tinjauan ini mensintesis temuan ke dalam tiga domain inti: tuntutan lingkungan makro, krisis ketidaksesuaian (*mismatch*) fisik pada skala meso, dan defisiensi ergonomi kognitif pada skala mikro. Temuan utama menunjukkan bahwa penerapan pembelajaran aktif menuntut tata letak kelas yang dinamis, namun pelaksanaannya terhambat oleh standar furnitur eksisting yang memiliki tingkat *mismatch* absolut dan bobot yang melampaui batas aman *Manual Material Handling* (MMH) anak. Lebih lanjut, analisis mengungkap adanya celah penelitian yang signifikan pada aspek *affordances*; di mana perancangan furnitur terdahulu mengabaikan petunjuk visual yang diperlukan anak untuk memandu perilaku mengangkat (*lifting behavior*) secara aman. Studi ini menyimpulkan bahwa intervensi desain furnitur masa depan harus mengintegrasikan ergonomi kognitif untuk memitigasi risiko cedera muskuloskeletal, sekaligus mendukung ekosistem ruang kelas yang fleksibel sesuai dengan Tujuan Pembangunan Berkelanjutan (SDG 4).

**Kata Kunci:** Affordances, Ergonomi Kognitif, Furnitur Sekolah, *Manual Material Handling*, Ruang Kelas Fleksibel.

## INTRODUCTION

The global primary education system is currently undergoing a fundamental paradigmatic transition, shifting away from traditional instructional models toward an exclusively student-centered learning approach. The primary foundation of this shift is the adoption of Constructivist pedagogical theory (von Glasersfeld, 1995), wherein students are no longer positioned as passive receptacles of information, but rather as active agents who construct their own

knowledge through exploration, social interaction, and direct engagement with their environment. The logical consequence of this philosophical shift is the emergence of a demand for dynamic classrooms. The implementation of active learning requires teachers and students to constantly modify classroom layouts—transitioning from classical row formats to group discussion formations, circle time, and open communal spaces within the classroom (Satriaji et al., 2025).

The urgency of creating this adaptive built ecosystem is not merely a design trend but a global mandate. It is a direct derivative of Sustainable Development Goal (SDG) 4 regarding Quality Education. Specifically, Target 4.a emphasizes the obligation of every institution to build and provide educational facilities that are child-friendly, inclusive, and guarantee safe and effective learning environments (United Nations, 2015). The correlation between the physical quality of a classroom and children's learning success has been empirically proven through the large-scale Holistic Evidence and Design (HEAD) Project. The study concluded that the design of architectural and interior elements in classrooms contributes up to 16% to the variation in students' academic learning progress (Barrett et al., 2015). Furthermore, the freedom of mobility facilitated by the concept of flexible seating has been clinically proven to lower environmental stress levels, reduce anxiety-inducing cognitive load, and holistically enhance the mental health resilience of primary school students (Halidane et al., 2023).

Despite the high macro-level demand for spatial flexibility, its operational realization in the field often encounters fatal obstacles due to a crisis at the meso-scale, namely the design mismatch of the physical classroom facilities themselves. Within the interior design discipline, spatial dynamics are evaluated through the lens of Proxemics theory (Hall, 1966). Furniture layouts in public primary schools are generally still dominated by shared desk configurations with an exceedingly high density. This configuration forces students to constantly remain within each other's personal zones (0.45 - 1.2 m). The limited clearance resulting from this density drastically narrows the students' operational radius. These restrictive spatial conditions are further exacerbated by fundamentally flawed furniture dimensions. As an international benchmark, comparative studies demonstrate that the absolute mismatch between institutional furniture and children's anthropometry is a structural crisis afflicting many countries due to the application of rigid, singular design standards (Castellucci et al., 2010). In Indonesia, this crisis is represented through evaluations of the Indonesian National Standard (SNI) for educational furniture. The SNI parameters, formulated decades ago, fail to accommodate the secular trend—the accelerated physical growth and body proportions of children from generation to generation. Consequently, empirical research consistently finds mismatch rates approaching 100% among early-grade students, where seat height and seat depth dimensions serve as the primary sources of the problem across various regions, ranging from Central Java to urban areas like North Jakarta (Yanto, 2018; Rosyidi et al., 2016; Tarihoran et al., 2021).

The excessively large and rigid physical form of the furniture not only compromises students' passive sitting postures but also creates latent biomechanical hazards when classrooms must be modified. The cycle of adapting classrooms for active learning

methods and daily routines, such as cleaning duties, forces students to routinely engage in Manual Material Handling (MMH) activities, namely lifting and moving chairs onto desks. This moving process is classified as a high-risk MMH task because the construction of standard solid wood chairs possesses a weight that significantly exceeds the safe lifting load tolerance limits for children aged 6-9 years (Purwaningrum et al., 2015). The combination of narrow spatial clearance and excessive material weight forces children to maneuver and lift chairs with their arms extended away from their bodies. Biomechanically, this multiplies the moment force (torque), triggers postural overload in the upper extremities (Batistão et al., 2012), and clinically correlates with a high prevalence of Musculoskeletal Disorders (MSDs) complaints in the cervical (neck) and lumbar (lower back) areas of students (Harahap et al., 2013).

Confronting the paradox between the demand for mobility and the risk of injury, the majority of prior literature offers remedial recommendations in the form of static dimensional reduction or material engineering to make chairs lighter. However, this approach overlooks a crucial variable at the micro-scale: children's cognitive ergonomics. Primary school students are not miniature adults; they are active agents who naturally interact with objects through improvisational, non-standard usage (Knight & Noyes, 1999). Cognitively, children possess limited spatial intuition to evaluate their own postural safety limits without explicit external guidance (Lee & Yun, 2019). Therefore, mere weight reduction of a chair will not eliminate the risk of injury if children continue to grasp the chair at incorrect leverage points.

Herein lies the urgency of the Affordances concept (Gibson, 1979; Norman, 1988)—the visual attributes of an object that intuitively communicate its usage to humans. The physical form of furniture directly dictates the bodily reorientation and movement of children (Furuya & Suzuki, 2023). The absence of affordances—such as the lack of dedicated grip contours on existing school chairs—creates a visual design deficiency. This triggers cognitive confusion, which ultimately causes students to employ grasping patterns in fragile areas or fail to distribute the weight evenly.

To date, systematic literature reviews specifically dissecting the convergence between anthropometric (physical) mismatch and affordance (cognitive) failure in primary school furniture remain highly limited. The majority of previous Systematic Literature Reviews have solely focused on evaluating static dimensional complaints and academic performance (Castellucci et al., 2016). Stemming from this research gap, this systematic literature review is structured with three primary objectives: (1) to map the current trends and escalation of the classroom furniture mismatch crisis; (2) to identify the mechanical impacts of Manual Material Handling activities of furniture on student anatomy; and (3) to evaluate the urgency of transitioning research from static ergonomics toward

dynamic cognitive observations (affordances) in the design of future classroom furniture.

## METHODS

### Research Design and PRISMA Framework

This study is designed utilizing a Systematic Literature Review (SLR) approach. In contrast to traditional narrative literature reviews, which are susceptible to researcher subjectivity bias, an SLR is a methodology that employs structured, planned, and replicable protocols to identify, evaluate, and synthesize all empirical evidence relevant to the research question (Gough et al., 2017). Given that this research operates at the highly complex intersection of three disciplines—namely interior design, physical ergonomics (biomechanics), and cognitive psychology (affordances)—an SLR approach is absolutely necessary to map the common threads among literature scattered across these various scientific domains.

As an operational guideline to ensure validity, this study strictly adopts the updated version of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) reporting framework (Page et al., 2021). The PRISMA protocol was selected as it provides a comprehensive architecture to ensure transparency in every stage of the literature search. The review process in this study is divided into five systematic stages: (1) Formulation of search strategies and protocols, (2) Determination of eligibility criteria (inclusion and exclusion), (3) Execution of literature selection, (4) Study quality appraisal, and (5) Thematic data extraction and synthesis.

**Literature Search Strategy and Protocol** The initial phase of the literature search was conducted in February 2026. To ensure a holistic and comprehensive coverage of publications, the search was conducted across three highly reputable multidisciplinary academic databases: Scopus, ScienceDirect, and Google Scholar. The selection of Scopus and ScienceDirect was based on their prominence in indexing top-tier peer-reviewed journals in the fields of applied ergonomics, product design, and biomechanical engineering. Meanwhile, Google Scholar functioned as a supplementary safety net (secondary net) to capture regional literature from Indonesia as well as high-quality grey literature that might not be indexed in the two primary databases.

The publication timeframe was specifically delimited from 1999 to 2025. This longitudinal boundary was designed to capture the entire evolution of the theory—starting from classic publications that defined children's spatial interaction behaviors (such as the study by Knight & Noyes, 1999) to the most cutting-edge findings regarding post-pandemic flexible classroom layouts (Satriaji et al., 2025). The search process was calibrated using Boolean Operator algorithms (AND, OR) that bound the three main conceptual variables of the study, with the following search string formulation: ("primary school" OR "elementary children" OR "classroom

environment") AND ("school furniture mismatch" OR "classroom ergonomics" OR "manual material handling" OR "biomechanics") AND ("affordances" OR "cognitive ergonomics" OR "visual cues").

### Eligibility Criteria (Inclusion and Exclusion)

To minimize selection bias and ensure the relevance of the data to the research objectives, the literature boundary parameters were established *a priori* prior to the commencement of the screening process. The details of the eligibility criteria, along with their academic justifications, are delineated in Table 1.

**Table 1.** Literature Inclusion and Exclusion Criteria

Eligibility Parameter	Inclusion Criteria	Exclusion Criteria	Methodological Justification
Subject Characteristics	Primary school students (age range 6–12 years).	Preschool (kindergarten) students, secondary school (middle/high school) students, university students, or teachers.	The anthropometric proportions and <i>Manual Material Handling</i> capacities of primary school children are highly specific and occur during a critical phase of skeletal development.
Interaction & Design Focus	Evaluation of physical interaction (dynamic anthropology/MH) and cognitive interaction ( <i>affordances</i> ) with interior elements	Purely medical clinical interventions, academic curriculum evaluations, or school administrative/managerial issues.	To maintain the scope strictly centered on the disciplines of interior design, product interaction, and built environment engineering.
Publication Type	Original empirical research articles (quantitative, qualitative, mixed-methods) from peer-reviewed journals.	Opinion articles, editorials, book reviews, blog articles, or non-peer-reviewed conference proceedings.	To guarantee the internal methodological validity of the studies and the reliability of the findings data, ensuring their suitability as a foundation for design synthesis.
Access Availability	Full-text availability	Paywalled articles	In-depth data

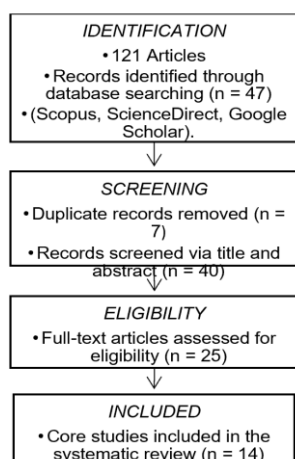
y online, written in English or Indonesian. (abstract only) or those written in foreign languages beyond the researcher's proficiency. extraction regarding visual observation methods necessitates a comprehensive reading of the full manuscript text.

**Literature Selection Procedure and PRISMA Flow**

The execution of the literature selection was conducted sequentially in accordance with the four phases of PRISMA: Identification, Screening, Eligibility, and Inclusion. In the Identification phase, the search utilizing the query string yielded 47 potential articles from the three databases. All search results were subsequently exported to reference management software for the deduplication process, wherein 7 duplicate articles were automatically removed.

Entering the Screening phase, the 40 remaining articles were manually evaluated based on the relevance of their titles and abstracts. At this stage, 15 articles were promptly excluded as they explicitly deviated from the criteria; for instance, examining adult office chair designs or evaluating classroom ergonomics from the perspective of visual/lighting comfort rather than physical interaction.

The Eligibility testing stage constitutes the most critical phase, where the full texts of the 25 remaining articles were downloaded and comprehensively reviewed. A total of 11 articles had to be eliminated during this phase due to highly specific limitations. The majority of these excluded articles merely presented tables of static body measurement dimensions without any reference to lifting behavior, or entirely neglected the aspect of visual cognitive interaction. Following this rigorous filtration process, the Inclusion phase secured a final corpus of 14 core papers that comprehensively fulfilled all eligibility parameters for synthesis. This literature reduction flow is visually illustrated in Figure 1.



**Figure 1.** PRISMA Flow Diagram of the Literature Selection Process  
**Study Quality Appraisal**

To ensure that the 14 included core articles possess strong methodological integrity and are free from publication bias, a quality appraisal was conducted. Because the included studies comprise diverse methodologies—ranging from qualitative observational studies and quantitative measurements to mixed-methods approaches—this research adapted evaluation principles from the Mixed Methods Appraisal Tool (MMAT) (Hong et al., 2018). Each article was evaluated based on five critical criteria: the clarity of the research question, the appropriateness of data collection instruments (e.g., the use of motion capture or the Standardized Nordic Questionnaire/SNQ), the representativeness of the student sample, the control of confounding variables, and the accuracy of the result interpretation. All 14 included articles were confirmed to meet the highest methodological eligibility standards to serve as the foundation for design arguments.

**Data Extraction and Thematic Analysis**

Data from the 14 core literature sources were extracted into an instrument matrix encompassing variables such as study identity, unit of analysis scale, methodological design (e.g., freeze-frame video recording), mismatch dimension percentages, and identification of research gaps.

Given the high heterogeneity in the measurement instruments utilized by previous studies, pooling data using statistical meta-analysis methods was not feasible. Instead, this study employed the Narrative Synthesis method with Thematic Analysis (Braun & Clarke, 2006). The coding process was conducted inductively to summarize specific findings (such as the phenomenon of torso twisting during classroom cleaning duties or children's confusion when searching for grip points) into central themes. Through this iterative process, the entire spectrum of issues was reconstructed into three conceptual domains serving as its framework: (1) Macro Domain (pedagogical and environmental demands); (2) Meso Domain (static anthropometric crisis and MMH biomechanics); and (3) Micro Domain (cognitive ergonomics and affordance design).

**RESULTS AND DISCUSSION**

Through PRISMA screening process, 14 core articles were extracted and evaluated. Based on the inductive thematic analysis, the primary school furniture design crisis has proven not to be a unidimensional problem. The design failures of these facilities are rooted in the collision between environmental demands, physical realities, and object-level cognitive deficiencies. To provide a comprehensive overview of the positioning of each study, Table 2 maps the 14 core articles into the three primary conceptual domains that serve as the foundation for the synthesis in this research.

**Table 2.** Thematic Mapping of Core Literature Based on Analytical Domains

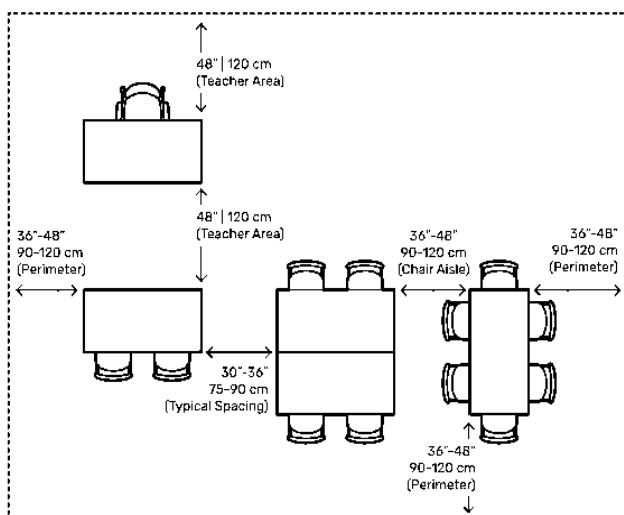
Analytical Domain	Research Focus	Primary Reference Literature

Macro Domain	Demands of active learning, flexible seating, and classroom adaptation cycles	Satriaji et al. (2025); Halidane et al. (2023)
Meso Domain	Evaluation of anthropometric mismatch, Manual Material Handling loads, and Musculoskeletal Disorders (MSDs) risks	Yanto (2018); Tarihoran et al. (2021); Rosyidi et al. (2016); Castellucci et al. (2016); Harahap et al. (2013); Purwaningrum et al. (2015); Batistão et al. (2012)
Micro Domain	Cognitive ergonomics, limitations of children's intuition, affordances, and visual mapping methods (freeze-frame)	Furuya & Suzuki (2023); Lee & Yun (2019); Gonçalves & Arezes (2012); Domljan et al. (2010); Knight & Noyes (1999)

modify the classroom layout or perform the routine task of lifting chairs onto desks (Manual Material Handling/MMH), students lack the necessary space to establish an ergonomic stance. Consequently, this spatial density architecturally coerces students into adopting improper lifting postures—such as asymmetrical spinal twisting or lifting loads with arms extended away from the body's center of gravity—even before the physical interaction with the furniture itself occurs.

**Meso Domain: The Paradox of Dimensional Standards and Biomechanical Tolerance Limits**

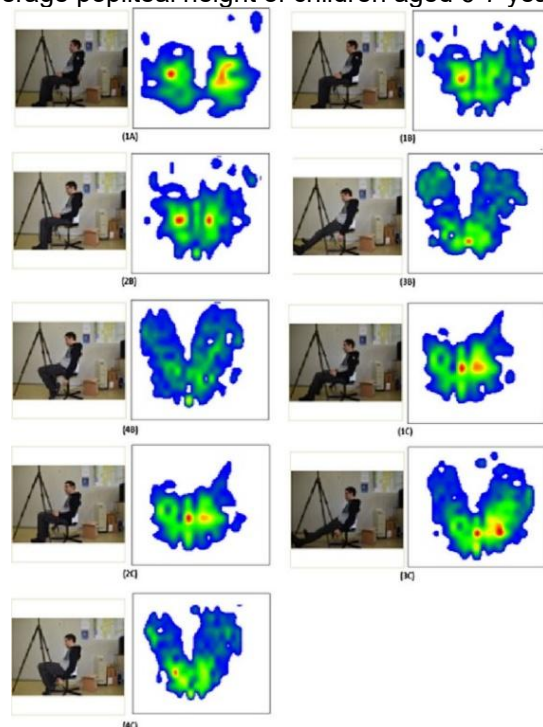
The postural strain induced by classroom density within the macro domain is significantly compounded by furniture design failures at the meso scale. Literature evaluations indicate that the fundamental furniture crisis lies in the dimensional mismatch between product specifications and user anthropometry. As a global benchmark, Castellucci et al. (2016) reported high mismatch rates across various nations that employ mass manufacturing standards without accounting for childhood demographic variability. In Indonesia, this phenomenon is not only prevalent but has reached an alarming level of escalation. A critical evaluation of the Indonesian National Standard (SNI) for elementary school wooden chairs reveals that these standards are obsolete, failing to account for the secular trend—the acceleration of physical growth from generation to generation. Large-scale anthropometric studies conducted by Yanto (2018) in Jakarta, cross-validated by Tarihoran et al. (2021) and Rosyidi et al. (2016), identified an absolute mismatch rate of 100% among early-grade students. Specifically, the minimum seat height of 37 cm mandated by the SNI significantly exceeds the average popliteal height of children aged 6-7 years.



**Figure 2.** Spatial Clearances and Proxemic Distances in Classroom Desk Configurations.

This figure illustrates the standard spatial clearances and proxemic zones essential for maintaining optimal circulation and functional learning environments within a classroom. It details the precise metric and imperial measurements required between various seating arrangements, specifically highlighting paired (double desk) and clustered configurations. By establishing a typical interpersonal spacing of 75-90 cm between student workspaces and maintaining perimeter aisles of 90-120 cm, the layout effectively accommodates both the students' personal boundaries and the social distances necessary for unhindered teacher mobility. Adhering to these proxemic parameters is critical for mitigating spatial crowding, respecting student territoriality, and fostering a psychologically and ergonomically supportive educational setting.

This limited clearance deprives students of a sufficient operational radius. When instructed to



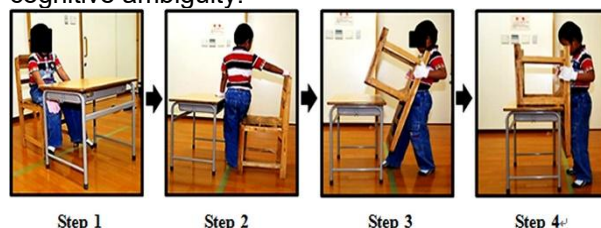
**Figure 3.** Seat Pressure Mapping (Heatmaps) Demonstrating the Biomechanical Impact of Postural Alterations on Rigid School Chairs.

Empirical evidence regarding the impact of mismatched furniture on postural behavior is robustly supported by seat pressure mapping analyses. As demonstrated by Naddeo et al. (2018), the interaction between a seated subject and a rigid school chair involves a complex interplay of human body posture, interface pressure, and load distribution. When subjects are forced to sit on non-adjustable or improperly sized seats, their posture dynamically alters, which is visually quantifiable through varying pressure distribution maps. Multivariate analysis in their study revealed a significant negative correlation between the human-seat contact area and peak pressure ( $P_{\max}$ ); as the contact area decreases—often a direct consequence of adopting compensatory stances on mismatched furniture—the peak pressure heavily concentrates on specific anatomical points. Furthermore, this phenomenon triggers two distinct distress mechanisms: while concentrated interface pressure primarily induces physiological and tactile discomfort on the skin and soft tissues, the resulting alteration in load distribution disrupts the overall equilibrium of bodily forces, thereby triggering severe physical and biomechanical postural discomfort. Ultimately, the availability of such quantitative frameworks for describing comfort perception provides a critical design-path for mitigating these ergonomic crises. By integrating biomechanical evaluations and pressure distribution models into the early stages of product development, designers can proactively predict and improve comfort performance before the furniture is manufactured. In the context of elementary education, this empirical evidence mandates a decisive paradigm shift away from obsolete, mass-manufactured dimensional standards. It highlights the urgent need for anthropometrically responsive school furniture that not only safeguards vulnerable students from cumulative musculoskeletal strain, but also ensures that the physical classroom environment actively facilitates, rather than hinders, their daily academic focus.

#### Micro Domain: The Gap in Cognitive Ergonomics Literature and the Urgency of Affordances

In addressing the aforementioned physical load paradox, literature synthesis within the micro domain demonstrates that merely reducing the weight of the chair is insufficient to eliminate injury risks. A substantial literary void exists concerning how children perceive and intuitively interact with objects prior to the actual exertion of muscular force. Elementary school children are not mere miniature adults equipped with mature risk assessment capabilities. Observational research by Knight and Noyes (1999) underscores that children act as active agents, frequently employing furniture in improvised, non-standard manners. This behavioral trait is corroborated by Lee and Yun's (2019) experimental study, which demonstrated that elementary students exhibit limited spatial intuition, often failing to adopt safe postural interactions in the absence of explicit instructions.

This highlights the critical urgency of integrating the theory of Affordances (Gibson, 1979; Norman, 1988) into educational furniture design. Affordances refer to the visual and physical design features that intuitively communicate an object's intended use. As Furuya and Suzuki (2023) observed, the specific morphology of furniture silently dictates a child's movement and interaction trajectory. Currently, existing school chairs in Indonesia suffer from a severe lack of gripping affordances (a handle-less paradigm). In the absence of ergonomic indentations or visual cues—such as color-coding—to guide proper hand placement, students are subjected to cognitive ambiguity.



**Figure 4.** Heat Map Analysis of Children's Grasping Patterns and Contact Points during Manual Material Handling of Handle-less School Chairs.

This cognitive ambiguity compels children to improvise their grasping patterns. Consequently, many students instinctively grasp the uppermost edge of the backrest (top rail) due to its high visual prominence. However, gripping the chair from this topmost area creates the longest leverage arm relative to the object's center of gravity. Mechanically, this significantly amplifies—potentially tripling—the rotational force (torque) exerted on their spinal column. This upper backrest surface, which deceptively appears to be an intended handling point despite its biomechanical hazards, is classified as a *False Affordance* (a misleading visual cue). To evaluate this cognitive failure, this review identifies the necessity for a methodological paradigm shift towards dynamic recording techniques, such as precision freeze-frame analysis (Gonçalves & Arezes, 2012). Such methods are essential to capture naturalistic cognitive interaction behaviors and extract the children's exact grasping areas into spatial mappings.

#### Synthesis of Findings: Flexible Classroom Furniture Design Interaction Model

Based on the review of the three aforementioned domains, this systematic review synthesizes a novel conceptual framework indicating that furniture-related issues in elementary schools constitute a causal chain reaction. The implementation of active learning (Macro domain) necessitates mobility, which directly clashes with the realities of excessive weight and SNI dimensional mismatches (Meso domain). Because these objects present biomechanical hazards, the furniture requires visual guidance or affordances (Micro domain) to ensure children lift them at the correct center of gravity. Consequently, the primary research gap identified in this Systematic Literature Review (SLR) is the absence of empirical studies mapping children's intuitive grasping patterns on school chairs to be extracted into interior design

criteria. Future design interventions must evolve beyond merely seeking static dimensional precision toward creating communicative visual features to guide safe lifting behavior.

## CONCLUSION

The furniture design crisis in elementary schools represents a causal chain that is vastly more complex than mere issues of material dimensions or static sitting discomfort. This systematic literature review of 14 core studies concludes that the contemporary educational ecosystem is currently trapped in an operational paradox. On one hand, the implementation of constructivist pedagogy and the mandate of the Sustainable Development Goals (SDG Goal 4) demand the creation of flexible classrooms that necessitate high mobility. On the other hand, these mobility demands are hindered by physical facilities that fundamentally fail to support students' dynamic interactions.

This review demonstrates that this failure is rooted in the collision of three intersecting domains. At the meso scale, manufacturing standards (such as SNI) trigger absolute mismatches and mandate the use of solid wood materials that exceed the safe limits of children's Manual Material Handling (MMH). This forces students to maneuver within densely packed classrooms using overextended postures, which clinically induces Musculoskeletal Disorders (MSDs). Furthermore, at the micro scale, furniture design suffers from cognitive ergonomics deficiencies. The absence of affordances (visual cues) causes cognitive ambiguity, compelling students to improvise grasping patterns at incorrect leverage points, which ultimately multiplies the rotational torque on the spine. Interventions focusing solely on material weight reduction will be ineffective in mitigating injury risks unless accompanied by a redesign of the object's visual communication features.

Based on these conclusions, this study recommends three strategic domains of intervention. First, for design practitioners and the industry, future classroom furniture design must integrate cognitive ergonomics principles by injecting explicit affordances—such as providing gripping indentations calibrated as closely as possible to the chair's Center of Gravity—to guide safe lifting behaviors. Second, for academia, classroom ergonomics research must evolve from merely evaluating static anthropometric metrics toward employing dynamic visual-spatial observation methods (such as freeze-frame and motion capture analyses) to empirically generate Heat Maps of children's interactions. Third, for policymakers and the National Standardization Agency (BSN), regulations regarding school furniture standards must be urgently revised to accommodate the secular trend of children's physical growth, and must incorporate clauses for ergonomic interaction safety testing and MMH load limits before products are distributed to public educational institutions.

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