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Impact of Classroom Aspect Ratios on Spatial Flexibility and Utilization Efficiency: A Comparative Analysis

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Abstract

The study examines the impact of classroom aspect ratios on spatial flexibility and efficiency by comparing the dominant rectangular classrooms in Egypt with the more semi-square configurations found in England. The research explores how these differing geometries affect the adaptability of teaching spaces, circulation patterns, and the implementation of contemporary, student-centered pedagogies. Through document analysis, evaluation of international case studies, and a practical redesign experiment, the study assesses classroom performance in terms of spatial organization, movement efficiency, and flexibility. Findings reveal that semi-square classrooms offer notable advantages, including enhanced re-configurability of student groups, equitable access to instructional zones, and improved movement dynamics. Quantitatively, redesigned semi-square layouts reduce corridor travel distances and minimize wasted transitional space of total area. These configurations promote inclusive learning by eliminating marginal "shadow zones" and expanding golden and semi-golden zones that facilitate student-teacher contact for optimal interaction and engagement. The study underscores the long-term economic and functional benefits of adaptable classroom designs, particularly in resource-constrained environments. By facilitating modular furnishings and flexible spatial arrangements, semi-square classrooms support diverse teaching styles, improve student interaction, and align with modern educational goals. This research contributes original insights into school design by linking spatial geometry with pedagogical outcomes, offering a practical framework for future educational architecture that prioritizes inclusivity, adaptability, and spatial efficiency.

Keywords

Classroom Aspect Ratio, Efficient Space, Flexible Learning Environments, Pedagogical Adaptability, Educational Space Optimization.

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1. Introduction:

The physical design of educational environments significantly impacts the effectiveness of teaching and learning, with classroom aspect ratios playing a crucial role in shaping spatial efficiency and pedagogical adaptability (Woolner, 2007). The arrangement and proportions of classroom spaces affect how students interact, how teachers deliver instruction, and how various teaching methodologies can be implemented (Barrett P. Z., 2019). Research has shown that classroom configurations influence students' academic performance, engagement levels, and collaborative opportunities, emphasizing the need for an optimal balance between space utilization and flexibility (Blackmore, 2011).

In many Egyptian schools, traditional rectangular classrooms are designed to accommodate large student numbers, often, a rigid educational model based on indoctrination is reinforced. This layout maximizes seating capacity but restricts opportunities for interactive and student-centered learning approaches, such as group work and project-based learning (Dudek, 2015). The conventional design also results in inefficient circulation patterns, limiting movement and engagement among students and teachers (Veloso, 2021). Conversely, classrooms in England increasingly adopt a more square-like aspect ratio, allowing for greater spatial adaptability. These semi-square classrooms support dynamic and interactive learning by enabling varied seating arrangements, optimizing natural sightlines, and facilitating fluid movement between different instructional zones (Cleveland, 2014).

An essential aspect of this study is the evaluation of spatial efficiency in classroom design. The concept of space efficiency encompasses not only the maximization of usable floor area but also the reduction of wasted space, particularly in corridors, transition areas, and circulation paths (Ibrahim, 2013). Efficient classroom layouts contribute to better acoustics, lighting distribution, and ventilation, all of which have been shown to

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enhance learning outcomes (Fisher, 2005). Additionally, adaptable classroom configurations offer long-term economic benefits by allowing schools to modify spaces in response to evolving pedagogical demands without requiring costly renovations (Leiringer, 2011).

The research aims to compare and contrast the spatial characteristics of classrooms to identify best practices in classroom design that optimize both spatial efficiency and pedagogical effectiveness. By examining the implications of aspect ratios on classroom functionality, circulation, and cost efficiency, this study provides logical insights into improving future school design to better align with contemporary educational methodologies and resource constraints.

Research Problem

The issue of the research is the spatial and pedagogical limitations reflected in traditional rectangular classroom layouts, which are most common in Egypt. These traditional classrooms have a tendency to resonate with inherited teacher-centered pedagogy models of teaching, which result in rigid spatial formations that dissuade adaptive use, hinder free movement, and undermine the effective implementation of student-centered learning approaches. Earlier studies have determined that classroom geometry aspect ratio (the ratio of length to width) is one of the most important variables in the determination of the flexibility and functional efficiency of learning spaces. Inflexible layouts can limit the possibilities for interactive group-based collaboration, inclusive participation, and pedagogical innovation, with a knock-on effect on pupil engagement and academic attainment. Accordingly, this research seeks to explore the ways in which classroom size influences spatial layout and flexibility and pedagogical effectiveness, with a view to informing more responsive and effective educational space design.

Main Objective:

This study aims to evaluate how classroom aspect ratios influence spatial flexibility, efficiency, and circulation dynamics by comparing traditional rectangular classrooms in Egypt with semi-square classrooms in England. It seeks to identify spatial configurations that support interactive, student-centered learning by minimizing wasted space, optimizing resource utilization, and enhancing movement within learning environments. Ultimately, the research aims to propose practical design modifications that adapt classroom dimensions to the pedagogical needs of contemporary, flexible, and inclusive educational settings.

Methodology:

To effectively achieve the research objectives and support the pedagogical shift from traditional rote learning to dynamic, student-centered learning environments, this study adopts a structured mixed-methods research design. By integrating both qualitative and quantitative research techniques, the methodology provides a comprehensive analysis of how classroom aspect ratios influence spatial flexibility, efficiency, and movement dynamics. The investigation is organized into three sequential phases, each addressing a specific dimension of classroom design and functionality. The research is guided by the following core questions:

RQ1: What are the prevailing design standards and educational policies influencing classroom aspect ratios in Egypt and England?

RQ2: How do different classroom layouts (rectangular vs. semi-square) affect movement dynamics, space utilization, and pedagogical flexibility?

RQ3: What spatial interventions can optimize classroom design to support dynamic and student-centered learning?

1st. A qualitative analysis of school building codes, architectural guidelines, and educational policies from both Egypt and England was conducted. This phase aimed to identify the theoretical and regulatory foundations that influence the design of classroom dimensions and spatial configurations. Key documents were reviewed to discern the underlying principles and standards guiding classroom aspect ratios in both contexts, facilitating a deeper understanding of how national and regional standards shape classroom design.

2nd. A series of case studies were carried out, comparing schools in Egypt and England with differing classroom layouts (rectangular vs. semi-square). This phase involved both qualitative and quantitative data collection:

- **Spatial Organization:** Classroom layouts were evaluated for their ability to accommodate various learning activities. This included the analysis of seating distribution, active zones, and the alignment of space with teaching methodologies.
- **Movement Efficiency:** Detailed observations and tracking of student and teacher movement patterns within classrooms and corridors were conducted. This quantitative data focused on circulation efficiency, identifying potential bottlenecks and wasted space in transitional areas.
- **Flexibility:** A qualitative assessment was performed to evaluate the adaptability of classroom spaces. This focused on how

different layouts supported or hindered dynamic teaching styles, cooperative learning, and reconfiguration of teaching zones.

3rd. An experimental redesign of a rectangular classroom in an Egyptian school into a semi-square layout was carried out as a practical experiment. This design intervention allowed for a direct comparison of the two layout types based on their ability to support interactive, student-centered learning. Data from this experiment were analyzed through descriptive statistics and diagnostic analysis to assess improvements in space utilization, circulation, and flexibility.

The collected data were analyzed using a combination of descriptive and prescriptive analytics. Descriptive analytics provided insights into the current state of classroom layouts, identifying key patterns in space use, movement, and flexibility. Prescriptive analysis helped to develop actionable recommendations for optimal classroom design, based on the strengths and weaknesses identified through the case studies and experimental redesign. This methodological framework ensures a thorough evaluation of the relationship between classroom aspect ratios and educational space efficiency, guiding future school design to better accommodate interactive learning and pedagogical needs.

2. Literature Review

This explores the relationship between classroom aspect ratios and their influence on spatial utilization, flexibility, and functionality, with a particular focus on the distinction between rectangular and semi-square classroom layouts. It also examines the ways in which these layouts align with traditional and modern pedagogical practices, drawing comparisons between educational settings in Egypt and England. By synthesizing key studies, to provide a deeper understanding of how classroom design can support or limit effective learning environments, especially in light of changing educational paradigms.

2.1. Classroom Aspect Ratio and its Influence on Spatial Utilization

Classroom aspect ratio the proportional relationship between length and width plays a crucial role in shaping the spatial efficiency and pedagogical alignment of educational spaces. Well-proportioned classrooms support effective space utilization and accommodate diverse teaching methods. Studies have highlighted that rectangular classrooms, common in traditional educational systems, prioritize seating capacity and linear arrangements, which are suited for teacher-centered instruction but limit flexibility for collaborative or activity-based learning On the other hand, semi-square classrooms, offering symmetrical layouts, provide greater flexibility, enabling a variety of configurations that foster group work and diverse learning activities (Barrett P. Z., 2013). These spaces are seen as conducive to student-centered pedagogies, promoting collaboration and inclusivity.

2.2. Traditional Pedagogical Practices and Rectangular Classrooms

In Egypt, classrooms traditionally prioritize teacher-centered teaching methods, with rectangular layouts designed for dense seating and structured arrangements that support frontal teaching (Elshater, 2017). While these designs work well for rote learning, they limit adaptability for modern pedagogical trends that emphasize student engagement, collaboration, and flexibility. Research suggests that Egypt's classroom designs must evolve to accommodate more interactive learning approaches, requiring spaces that can be easily reconfigured to support diverse teaching styles (Barrett P. Z., 2013).

2.3. Modern Pedagogical Trends and Semi-square Classrooms

In contrast, English schools increasingly favor flexible, student-centered classroom designs that align with progressive pedagogical trends. Semi-square classrooms are more prevalent in these contexts, offering the spatial flexibility necessary for integrating technology, supporting group work, and fostering diverse learning activities (Blackmore, 2011). These spaces, often equipped with flexible furniture and multifunctional layouts, encourage creativity, critical thinking, and collaboration, which are key objectives of contemporary education (Fisher, 2005).

2.4. The Role of Spatial Organization and Travel Efficiency

Efficient spatial organization is critical to minimizing inefficiencies in classrooms and adjacent areas, such as corridors. Poorly designed layouts can lead to excessive travel distances, wasted space, and disruptions to learning. Studies have emphasized the importance of optimizing circulation and reducing transitional space to enhance the overall learning environment (Durán-Narucki, 2008). Flexible spatial arrangements also contribute to better resource utilization and improved educational experiences, especially in schools with limited resources or growing student populations (Barrett P. Z., 2013).

3. Designing Active Learning Spaces: Key Considerations

The configuration of learning environments has a profound impact on students' cognitive engagement, collaborative abilities, and overall academic success. With the transition from traditional lecture-based instruction to more

interactive, student-centered learning paradigms, the concept of Active Learning Classrooms (ALCs) has gained significant attention. ALCs are designed to promote mobility, flexibility, and inclusivity, ensuring that both students and instructors can seamlessly transition between various instructional methods. The literature review synthesizes findings from Utrecht University and other related studies to examine the influence of classroom design, furniture configuration, and spatial dynamics on student engagement.

- **Flexibility and Mobility in Learning Spaces:** A well-designed learning space accommodates a variety of instructional methods, allowing students and teachers to transition effortlessly between different learning configurations. Studies suggest that the ability to rearrange classroom furniture supports active learning behaviors by promoting both peer collaboration and instructor-student interaction (Henshaw, 2011).
- **The Role of Classroom Furniture in Active Learning:** Classroom furniture, including chairs and tables, plays a pivotal role in determining the efficiency of a learning environment. Various studies highlight key considerations:
  - **Movable Seating:** Research indicates that classrooms with reconfigurable seating options enable smooth transitions between instructional modes, such as individual work, group discussions, and full-class debates. These configurations support constructivist learning models, where students play an active role in their educational experiences (Park Y. &., 2014).
  - **Ergonomically Designed Chairs and Tables**: Studies emphasize that ergonomics significantly affect student comfort, posture, and concentration levels. Properly designed furniture minimizes physical strain, allowing students to sustain engagement for extended periods (University., 2024).
  - **Clustered Seating Arrangements:** The grouping of desks into clusters facilitates cooperative learning by promoting peer-to-peer discussions and collaborative problem-solving. Research suggests that such arrangements enhance students' ability to synthesize knowledge, engage in critical thinking, and develop teamwork skills (Henshaw, 2011).
- **Teacher Mobility and Classroom Dynamics:** The design of active learning spaces should allow instructors to move freely around the room, eliminating perceived barriers between students and teachers. Studies confirm that unrestricted teacher movement leads to:
  - **Enhanced Student Participation and Motivation:** When instructors can move freely throughout the classroom, they are better positioned to engage students individually, thereby increasing overall participation levels.
  - **Greater Accessibility for Addressing Individual Needs:** Mobile teaching practices allow educators to respond more effectively to students' queries, providing personalized guidance and feedback.
  - **Improved Classroom Management: Unrestricted** movement enhances real-time classroom monitoring, enabling teachers to address distractions promptly and maintain a productive learning environment (Park Y. &., 2014).
- **Impact of Flexible Learning Environments:** A review of literature on mobility in learning spaces (University., 2024)) provides several conclusions:
  - **Increased Student Engagement:** Dynamic seating arrangements and adaptable learning spaces contribute to higher levels of student involvement, as learners can interact with peers and instructors more effectively.
  - **Optimized Utilization of Classroom Space:** The use of multi-functional furniture maximizes the efficiency of learning environments, reducing downtime associated with reconfiguration. This adaptability is particularly valuable in institutions with space constraints.
  - **Accommodation of Diverse Learning Styles:** By offering a variety of seating and interaction options, flexible classrooms cater to different learning preferences, enhancing accessibility and inclusivity. This design approach aligns with contemporary educational theories that emphasize differentiated instruction and student-centered learning.

3.1 The Impact of Seating Arrangements and Polycentric Designs on Active Learning

The transformation of traditional classrooms into active learning spaces requires intentional design strategies that prioritize flexibility, mobility, and inclusivity. Research underscores the importance of adaptable furniture, seamless teacher movement, and fluid transitions between instructional formats in enhancing student engagement.

Classroom seating arrangement significantly affects the performance, participation, and learning

experience of students. It is traditionally believed that good students occupy front seats and bad students take rear seats. However, the literature asserts that seat location itself affects student outcomes rather than merely reflecting students' initial aptitudes. Park and Choi (2014) described two classroom seating areas: the 'golden zone' and the 'shadow zone.' (Park Y. &., 2014)

The 'golden zone' encompasses the most desirable seats, with the best eye contact with the teacher, better concentration and motivation, and a good view of the board and screen. The 'shadow zone' are the worst seating areas due to poor visibility, limited interaction with the teacher, and greater distraction, which negatively impacts learning. Students who occupy front seats exhibit greater engagement, improved communication with instructors, superior motivation, and a reduced likelihood of distraction. Fig. 1.

To mitigate such inequalities, active learning classrooms today incorporate polycentric designs, where multiple foci replace the traditional single-teacher-centered configuration. This setup encourages collaboration, enhances student engagement, and lessens disparities in learning outcomes. Research on these kinds of designs supports their capacities to enhance student participation and learning achievement (Talbert & Mor-Avi, 2019). Accordingly, inclusive classroom design should attempt to minimize shadow zones in order to create equitable learning conditions for everyone.

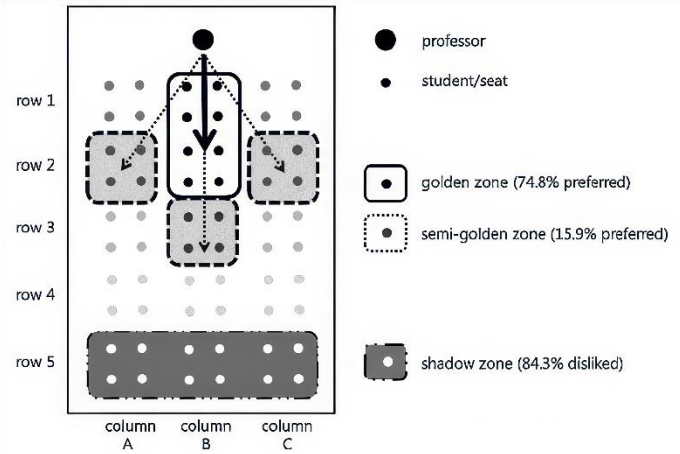


Fig. 1. The Impact of Seating Arrangements and Polycentric Designs on Active Learning (Irmgard Fuchs, 2024)

3.2. Flexibility in Shaping Learning Environments

The flexibility of classroom design plays a fundamental role in fostering dynamic and interactive learning environments. Adaptable spatial configurations, particularly in terms of seating arrangements, enable classrooms to accommodate diverse pedagogical approaches, facilitating seamless transitions between instructional modes. Such flexibility not only supports differentiated teaching methodologies but also enhances student engagement by fostering interaction, collaboration, and mobility within the learning space. Fig. 2.

Empirical research underscores the significance of flexible learning environments in promoting active learning. Henshaw et al. (2011) conducted a study examining the transformation of traditional classroom layouts into Active Learning Classrooms (ALCs) (Henshaw, 2011) and identified three primary benefits of such modifications. First, the reconfiguration of space significantly improved Face-to-Face Interaction among students. The ability to adjust seating arrangements allowed learners to engage in direct eye contact and spontaneous discussions, thereby fostering a more interactive and socially cohesive classroom atmosphere. Second, enhanced Teacher Mobility was observed, as instructors were no longer confined to a fixed position at the front of the room. This increased mobility enabled teachers to navigate the learning space more fluidly, provide individualized support, and maintain higher levels of student engagement and motivation (Park Y. &., 2014). The elimination of rigid front-facing seating structures also encouraged students to participate more actively, ask questions, and engage in meaningful discourse. Lastly, the flexible classroom layout facilitated Smooth Transitions between Instructional Modes, allowing educators to shift effortlessly between lectures, group discussions, and collaborative activities. This adaptability contributed to the optimization of instructional time and reinforced the effectiveness of active learning methodologies. Fig. 3.

By integrating principles of spatial flexibility into educational design, institutions can create learning environments that better align with contemporary pedagogical frameworks, ultimately enhancing student interaction, instructor engagement, and overall learning outcomes.

The findings from these studies emphasize the

importance of flexible learning spaces in fostering student engagement and active participation. The ability to reconfigure classroom spaces to accommodate diverse teaching methods not only supports various learning styles but also contributes to improved academic performance and classroom interactions.

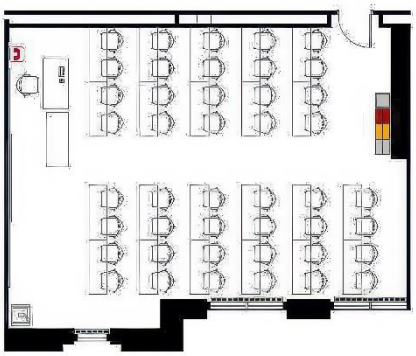


Fig. 2. Traditional learning environments do not meet the needs of contemporary educational frameworks (Irmgard Fuchs, 2024).

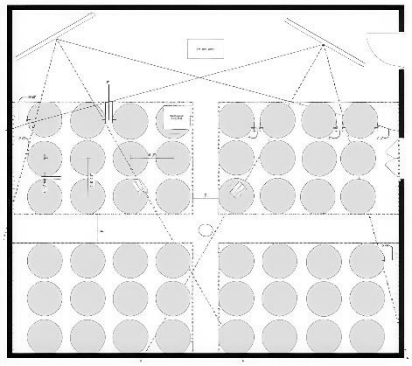


Fig. 3. Learning environments that better align with contemporary pedagogical frameworks (Irmgard Fuchs, 2024).

Research highlights the importance of seating arrangements and adaptable layouts in affecting student performance, engagement, and overall learning experiences. Seat positions have traditionally been linked to students' aptitudes, but research reveals that location in the seats affects learning. The 'golden zone' supports increased interaction and engagement, while the 'shadow zone' inhibits learning due to visibility limitations and distractions. To address these requirements, modern classroom design is moving towards polycentric spaces and flexible seating, which facilitate collaboration, enhance engagement, and allow for seamless transitions between instructional modes. These adaptive spaces make more inclusive spaces, foster stronger teacher-student relationships, and facilitate more equitable, student-centered learning, resulting in improved academic performance. Flexibility and inclusivity in classroom design are therefore essential to support diverse learning needs.

4. A Comparative Analysis of Classroom aspect and Learning Zones

Classroom design plays a critical role in shaping the quality of the learning environment by influencing student interaction, participation, and overall engagement. The spatial arrangement of seating within a classroom has been widely recognized as a key determinant of academic performance, as it directly affects visibility, accessibility, and communication among students and instructors. Empirical research has demonstrated that seat placement significantly impacts students' ability to engage with instructional content and participate in discussions, highlighting the need for equitable spatial distribution to maximize learning opportunities (Park Y. &., 2014); (Talbert, 2019). This applied experiment presents a comparative analysis of two classroom layouts, each occupying the same total floor area but differing in geometric proportions. The study examines the distribution of student seating based on distinct learning zones: the golden zone, which offers optimal visibility and proximity to the instructor; the semi-golden zone, which maintains good access to instructional content but with slightly reduced engagement potential; the regular zone, where interaction and participation levels are moderate; and the shadow zone, which is characterized by limited visibility and reduced engagement.

By systematically evaluating these seating

distributions, the study aims to identify the most effective spatial configuration for fostering an interactive and active learning environment. The findings will contribute to the optimization of classroom design, ensuring that all students, regardless of their seating position, have equitable access to instructional resources and opportunities for meaningful engagement. The results of this study provide valuable insights for architects, educators, and policymakers seeking to enhance learning spaces through evidence-based design principles.

4.1. Comparison framework

The study looks at the transition from traditional rectangular classrooms as shown in the two traditional layouts-odd grouping and paired grouping around the corridor Fig. 4. Spatial logic adheres to traditional hierarchies and axial movement paths, which inadvertently reinforce passive learning and limit flexibility. On the other hand, the semi-square classroom layout supports polycentric, multi-centered learning approaches that facilitate varied learning strategies. Pluralism encourages students to engage in group activities and embraces flexible and diverse learning styles because it provides a place where mobility and interaction are fostered rather than containment.

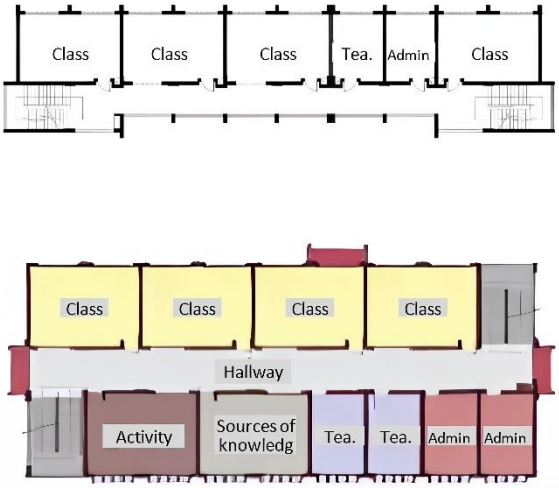


Fig. 4. Typical traditional school design in Egypt, showing the proportions of rectangular classrooms. (El-Zeiny, 2003)

Fig. 5. Typical school design in England, showing the semi-square classroom proportions. (Education, 2014)

Also, as evidenced in the repeated model with differently designed per but having a unified semi-square proportion of the teaching area Fig. 5, this consistency in modularity assures maximizes golden and semi-golden space, and minimizes shadow spaces, thus inviting greater student involvement and face-to-face teacher contact. The arrangement is also changed with polycentric, multi-centered modes of teaching prompting students' cooperative work and accommodating learning styles.

In addition to single-classroom design, the whole school plan also affects space efficiency and performance of learning. Most standardized school plans are based on single-loaded or double-loaded corridor schemes with mixed effects on space utilization, ventilation, and flow of students. Comparative analyses prove that semi-square classrooms form part of enhanced spatial efficiency, reducing travel distances, maximizing

corridor space, and improving emergency evacuation protocols. These innovations not only enhance functional learning environment quality but economic viability in the planning of schools, which are more critically required in urban centers that are faced with severe land shortages.

Current Classroom Arrangement

The existing classroom is characterized by a rectangular layout with a length-to-width ratio of 1 to 1.5 or greater, a common design in traditional educational settings. Prior research has indicated that such elongated layouts tend to reinforce disparities in student participation due to the unequal distribution of learning zones (Montello, 2007). The seating distribution is categorized as follows:

- **Golden Zone:** Positioned at the front and center, accommodating approximately 3 desks. This zone provides optimal visual access, enhanced teacher-student interaction, and higher engagement levels (Park Y. &., 2014).
- **Semi-Golden Zone:** Surrounding the golden zone, containing approximately 6 desks. This zone offers moderate interaction potential and acceptable visual access.
- **Regular Zone:** Located at the periphery of the semi-golden zone, comprising approximately 6 desks. Students in this zone experience minimal interaction and engagement due to their distance from the focal teaching area.
- **Shadow Zone:** Situated at the farthest points from the teacher's desk, encompassing approximately 6 desks. This zone is associated with poor visibility, auditory hindrances, and heightened distractions, which negatively impact student participation and performance (Cheryan, 2014).

4.1.1 Configured Classroom Design

The developed classroom model is informed by contemporary educational design principles advocating for equitable learning spaces and active learning environments (Talbert, 2019). The layout adopts a semi-square geometry with a length-to-width ratio approaching 1 to less than 1.2, maintaining the same total area as the existing classroom. This geometric configuration improves the spatial distribution of seats while enhancing visual and auditory access across the classroom. The seating distribution is restructured as follows:

- **Golden Zone:** Expanded to accommodate 6 desks, significantly increasing the number of students in the most interactive and optimal learning positions.
- **Semi-Golden Zone:** Extended to include 8 desks, providing more students with moderate interaction opportunities.
- **Regular Zone:** Incorporating 8 desks, ensuring that all seats offer acceptable visual and auditory access without major learning hindrances.
- **Shadow Zone:** Completely eliminated, creating an inclusive environment where every student benefits from equitable proximity to the teacher.

A semi-square classroom layout creates clear corridors, enabling smooth circulation and communication across seating zones. This design supports polycentric teaching, fostering collaboration, engagement, and reducing learning disparities (Talbert, 2019); (Montgomery, 2008). By removing physical and psychological barriers, it promotes student-centered pedagogy, encouraging active participation and interactive learning experiences.

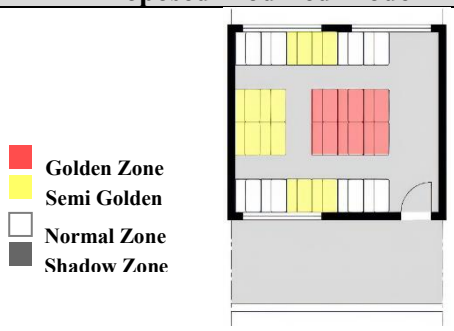
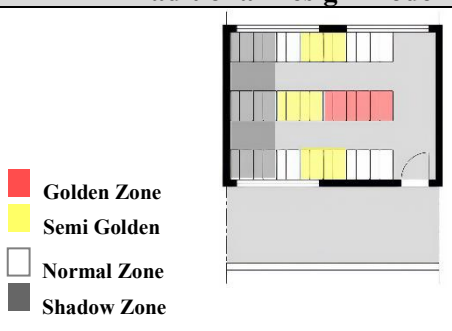
4.2. Classroom Spatial Design and Learning Engagement: A Comparative Analysis

The spatial configuration of classroom environments plays a pivotal role in shaping student engagement, instructional efficacy, and academic performance. Research in environmental psychology and instructional design consistently highlights the impact of physical space on cognitive focus, collaborative interaction, and inclusivity. Comparative analysis reveals significant limitations in traditional rectangular classroom layouts, exemplified by Model A with its rigid 1:1.5 length-to-width ratio. This arrangement enforces a linear, hierarchical orientation that concentrates a large portion of seating within "shadow zones"-areas marked by poor visibility and limited auditory access to the instructor. These conditions contribute to reduced student attention, minimal peer interaction, and passive learning behaviors. Moreover, such spatial marginalization reinforces outdated teacher-centered instruction models that contradict contemporary, student-centered pedagogies promoting active and constructivist learning. The effects are particularly detrimental in overcrowded or under-resourced classrooms, where equitable access to instructional stimuli is already constrained. Table. 1

In contrast, Model B introduces a semi-square spatial configuration that redefines classroom dynamics by eliminating shadow zones and enhancing spatial equity. By employing a near-equivalent length-to-width ratio, this design redistributes seating into the golden and semi-golden zones-areas associated with optimal visual and auditory access. Approximately 50% of students are situated in the golden zone, with an additional 33% in the semi-golden zone, thereby doubling the number of learners fully engaged with the instructional core and eliminating marginalized seating. This model supports polycentric spatial

arrangements with multiple focal points, promoting collaborative work, flexible pedagogy, and active student participation. It facilitates direct teacher-student communication and accommodates diverse learning styles Table. 1. Furthermore, the inclusion of modular learning centers and adaptive circulation paths enhances differentiated instruction, teacher mobility, and real-time feedback. Together, these spatial innovations foster a dynamic, inclusive learning environment aligned with modern pedagogical frameworks and supported by contemporary educational space research. (Cheryan, 2014).

.TABLE I: A Comparative Analysis (Author., 2024)

	Proposed Modified Model	Traditional Design Model
Classroom Spatial Design and Learning Engagement Model		
Learning Engagement Percentage	Learning Zone — percentage of students number Golden Zone — 27.3% Golden Zone — 36.35% Normal Zone — 36.35% Shadow Zone — 00.0%	Learning Zone — percentage of students number Golden Zone — 14.2% Golden Zone — 28.6% Normal Zone — 28.6% Shadow Zone — 28.6%

4.3. A Comparative Study of School Layout Configurations for Spatial Efficiency

School layout designs vary based on ownership structures and regulatory frameworks. Public schools adhere to standardized architectural plans mandated by the General Authority for Educational Buildings, whereas private institutions commission approved engineering firms to develop designs that comply with the same technical specifications. Despite these regulatory consistencies, school layouts generally follow two principal spatial configurations:

Single-Loaded Corridor Layout: Classrooms are arranged along one side of the corridor, optimizing access to daylight and ventilation. However, this configuration requires a larger spatial footprint, which may impact overall site efficiency.

Double-Loaded Corridor Layout: Classrooms are placed on both sides of the corridor, maximizing space utilization but potentially restricting access to natural ventilation and daylight.

4.3.1 Mobility in Classroom Design: Enhancing Interaction and Learning Outcomes

The incorporation of teacher and student mobility within classroom design is increasingly acknowledged as a critical factor in fostering active and student-centered learning environments. Flexible spatial arrangements-enabled through movable furniture and decentralized layouts-support dynamic interaction, minimize hierarchical structures, and enhance inclusivity (Irmgard Fuchs, 2024). Such configurations allow instructors to move freely among students, fostering immediacy and increased engagement, while also enabling students to communicate and collaborate more effectively.

Recent studies demonstrate that spatial mobility directly supports pedagogical adaptability. As classrooms shift between lectures, group work, and discussions, flexible layouts minimize disruptions and encourage transitions between instructional modes (Baepler, 2014) (Irmgard Fuchs, 2024). This results in improved student satisfaction and academic performance.

The developed classroom model transitions from a traditional to an interactive learning environment by integrating contemporary educational design principles that emphasize equity, flexibility, and student-centered learning. Utilizing a semi-square layout with a near 1:1 length-to-width ratio, the new configuration retains the original floor area while optimizing seat distribution for improved visual and auditory accessibility. The redesign expands the most effective learning zones-the Golden and Semi-Golden Zones-by 50% and 33%, respectively, while entirely eliminating the Shadow Zone, thereby ensuring equitable learning conditions for all students.

This spatial transformation supports polycentric teaching and smooth circulation, facilitating active participation and collaborative learning. Flexible, reconfigurable furniture enables dynamic instructional modes, aligning with constructivist pedagogy and promoting engagement, critical

thinking, and peer collaboration. Furthermore, increased teacher mobility enhances personalized instruction, classroom management, and overall inclusivity. Together, these features foster an interactive, adaptable, and inclusive learning environment that addresses diverse student needs and supports contemporary educational goals. Fig. 6.

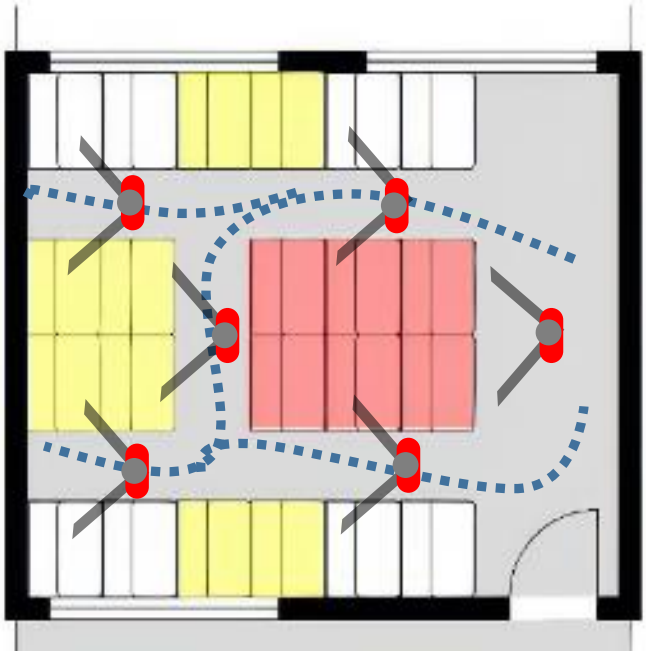


Fig. 6. Enhancing Equity, Accessibility, and Active Learning through Spatial Reconfiguration. (Author., 2024)

The Student-Centered Active Learning Environment with Upside-down Pedagogies (SCALE-UP) and similar active learning classroom (ALC) models exemplify how physical design influences learning. Circular table arrangements and reconfigurable furnishings increase instructor-student interaction and foster peer learning through visual and spatial accessibility (Beichner, 2014)

Mobility within classroom environments is not merely a design preference but a pedagogical necessity, facilitating interactive learning, inclusivity, and instructional flexibility in contemporary education.

4.3.2. Comparative Insights into Semi-Square Classroom Configurations:

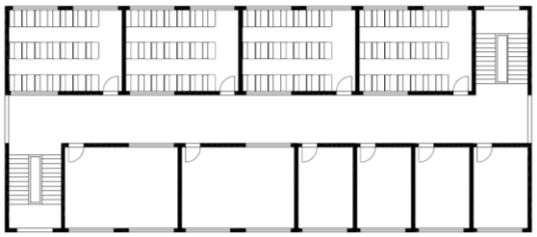
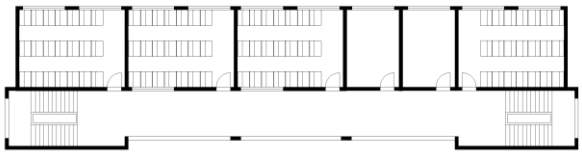
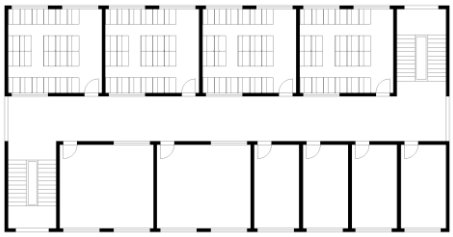
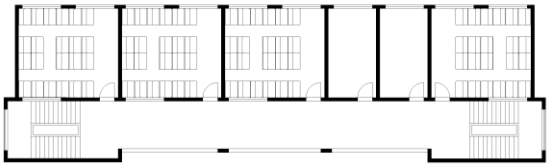
- Travel Distance Efficiency: The semi-square classroom arrangement reduces travel distances along corridors by 8.60% to 13.00%. This improvement enhances student mobility and facilitates safer and more efficient evacuation procedures in emergency situations. The compact spatial footprint of semi-square classrooms minimizes the distance between classrooms, emergency exits, and designated assembly areas. Table. 2
- Space Optimization and Economic Viability: By minimizing wasted corridor space, the optimized layout achieves space savings ranging from 8.44% to 13.70% of the total corridor space area. These efficiencies contribute to cost reductions in school construction and align with broader objectives of economic sustainability in educational infrastructure.
- Reduction in Total Building Length: The reconfiguration of corridors results in an 8.30% to 9.71% decrease in total building length, making the design particularly advantageous for high-density urban areas where land availability is limited. Table. 2
- The polycentric nature of the semi-square design supports student-centered learning by creating multiple focal points that encourage collaborative group activities and diverse instructional methodologies. The optimized corridor layout reduces travel distances by up to 13.0%, improving both mobility and emergency preparedness. Additionally, the design achieves a reduction of up to 10.1% in total building length, making it a viable solution for space-constrained urban settings. Table. 2

This study emphasizes the benefits of transitioning from traditional rectangular classrooms to semi-square configurations, which enhance space efficiency, facilitate active learning, and provide equitable educational access. By optimizing the distribution of the learning areas expanding golden

and semi-golden zones and eliminating shadow zones the semi-square configuration strengthens the engagement of students and enables teachers to interact more effectively.

Moreover, these findings accentuate the primary role played by responsive classroom design in the creation of adaptable, inclusive, and future-proof learning environments. By pairing spatial efficiency with pedagogical flexibility, the semi square form thereby represents a strategic innovation in contemporary school design, aligning with best practices in educational design and sustainable development.

TABLE 2: Comparative Insights into Semi-Square Classroom Configurations (Author., 2024)

	Double-Loaded Corridor Layout	Single-Loaded Corridor Layout
Traditional Design Model		
	Total Layout Area: 524.50 m2 Total Layout Length: 35.0 m Hallway Area Adjacent to Classrooms: 110.30 m2 Hallway Length Adjacent to Classrooms: 34.50 m	Total Layout Area: 383.65 m2 Total Layout Length: 40.70 m Hallway Area Adjacent to Classrooms: 101.70 m2 Hallway Length Adjacent to Classrooms: 30.40 m
Proposed Modified Model		
	Total Layout Area: 519.00 m2 Total Layout Length: 32.10 m Hallway Area Adjacent to Classrooms: 101.00 m2 Hallway Length Adjacent to Classrooms: 31.55 m	Total Layout Area: 366.90 m2 Total Layout Length: 36.75 m Hallway Area Adjacent to Classrooms: 88.10 m2 Hallway Length Adjacent to Classrooms: 26.45 m

4.3.3. Enhancing Interactive Learning: The Spatial Advantages of Semi-Square Classroom Layouts

Classroom models designed with semi-square proportions offer significant advantages in terms of spatial flexibility and interactive learning dynamics. The near-equal length and width dimensions allow for multiple seating arrangements, facilitating various group-based configurations that support collaborative learning. This adaptability ensures that student seats can be efficiently distributed in clusters, enhancing peer interaction and engagement. As shown in Fig 7.

Furthermore, the semi-square layout integrates intermediate circulation paths, enabling seamless movement for both teachers and students. These pathways enhance direct communication between the instructor and all student groups, fostering a dynamic learning environment where feedback and interaction are continuous. The improved accessibility also strengthens peer-to-peer collaboration, reinforcing the principles of active and interactive education.

Additionally, this design optimizes spatial communication zones by incorporating golden, semi-golden, and regular interaction areas, ensuring equitable access to teacher support and collaborative engagement. Importantly, it eliminates shadow zone, which are often associated with distraction and disengagement. By ensuring that all students remain within active learning zones, the semi-square classroom layout promotes focus, participation, and an inclusive educational experience.

Fig. 7. Spatial Advantage Alternatives to Semi-Square Classroom Layouts (Author., 2024)

Conclusion:

The comparative analysis highlights the dramatic effect of classroom aspect ratios on spatial efficiency, pedagogical flexibility, and fair learning achievement. The transition from the traditional rectangular classrooms in Egyptian schools to semi-square geometry yields significant gains in different aspects of performance. The semi-square design maximizes learning space utilization by maximizing golden and semi-golden spaces and reducing shadow spaces, hence fostering an inclusive and equitable learning environment.

- One of the primary advantages of the semi-square classroom system is its capacity to foster student communication and interaction. The expanded golden zone comprises 50% of the seating, effectively doubling the number of students with optimal visual and auditory access to the instructor. Additionally, the semi-golden zone increases seating by 33%, eliminating shadow areas entirely and ensuring equitable access to learning across the entire classroom. This spatial configuration supports multi-centered layouts with several focal points, enabling collaborative activities and encouraging active engagement. Such design principles align with modern student-centered pedagogical approaches that emphasize active learning and peer-to-peer dialogue over conventional teacher-led instruction.
- The study also demonstrates that semi-square classrooms optimize space use and circulation. The corridor travel distances are reduced by 8.6% to 13.0%, which improves evacuation safety during emergencies and maximizes overall movement dynamics. Furthermore, the optimized corridor design reduces wasted space, which corresponds to space savings from 8.44% to 13.70% of the total corridor space area. The efficiency not only maximizes performance but also reduces construction and operation costs needed by schools that are working in an environment of scarcity of resources.
- The inclusion of flexible, ergonomic furniture further enhances the benefits of semi-square classrooms. Modular workstations and flexible seating enable instant reassignment of spaces, enabling multiple instruction modes from frontal instruction to group work. Flexibility enables multiple teaching styles and multiple student learning styles, as well as greater teacher mobility, enabling greater student interaction, and the inclusion of real-time feedback variables with higher student motivation and engagement.
- Besides, elimination of shadow zones renders the learning space more inclusive in the sense that all students, regardless of where they are seated, enjoy equal visibility, auditory access, and engagement with the instructor. Such a design principle supports contemporary educational needs for closing achievement gaps and addressing diverse learning needs.

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