Jurnal Pemikir Pendidikan (Journal of Educational Thinkers)
Volume 13, Issue 1, Page Number 49-70, 2025
https://jurcon.ums.edu.my/ojums/index.php/jurnal-pemikir-pendidikan

EXPLORING MAKERSPACES AS TRANSFORMATIVE LEARNING HUBS: A NARRATIVE REVIEW STUDY

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Received: 19 September 2025
Accepted: 04 November 2025
Published: 05 November 2025

To link to this article: https://doi.org/10.51200/jpp.v13i1.6826

ABSTRACT

Makerspaces have emerged globally as transformative environments that blend creativity, technology, and collaboration to cultivate twenty-first-century skills. While their potential in education is widely recognised, research remains fragmented across dimensions such as spatial design, pedagogical activities, inclusion strategies, theoretical underpinnings, and future directions. This fragmentation presents a challenge for scholars and practitioners seeking a holistic understanding of how makerspaces function as learning ecologies. The purpose of this study was therefore to conduct a narrative review to critically synthesise current evidence on makerspaces in formal, informal, and community contexts. Guided by a qualitative thematic analysis, peer-reviewed works published between 2018 and 2025 were systematically identified, screened, and coded according to five analytical dimensions: layout, activities, strategies, learning theories, and emerging trends. The findings reveal that makerspace layouts serve as pedagogical designs shaping collaboration and visibility; activities act as catalysts for both technical competence and socioemotional development; strategies such as recognition, co-design, and sustainability prompts scaffold inclusion; theoretical perspectives extend constructionism through multimodal literacies, capability approaches, and ecosystemic frameworks; and future trends highlight digitalisation, sustainability integration, and innovation ecosystems. Collectively, these insights position makerspaces as ecosystemic hubs that connect education, innovation, and global citizenship. The study concludes that makerspaces are evolving beyond tool-centric spaces into inclusive and sustainability-driven infrastructures for transformative learning, though further longitudinal, cross-cultural, and policy-focused research is required to strengthen evidence of their long-term impact.

Keywords: makerspaces, innovation ecosystems, constructionism, education for sustainable development (ESD)

E-ISSN: 3083-9491

INTRODUCTION

The emergence of the maker movement has significantly influenced education, industry, and community engagement, grounding itself in the principles of hands-on learning and creativity. Traditionally viewed through the lens of technology and innovation, makerspaces represent collaborative environments where individuals come together to create, innovate, and learn through the iterative process of making. Research suggests that these spaces not only foster engagement but also enhance learning outcomes by promoting autonomy and self-efficacy among participants, particularly students (Vongkulluksn et al., 2018). The collaborative nature of makerspaces encourages peer interactions that can develop leadership skills and transformative agency (Leskinen et al., 2020). Furthermore, these environments are not limited to educational contexts; they also extend into community spaces, thereby fostering a culture of lifelong learning and collective creativity across diverse demographics (Shivley et al., 2018).

In this study, a makerspace is conceptualized as a collaborative learning environment where individuals engage in hands-on, project-based creation using diverse tools and materials to design, prototype, and solve problems (Wardrip et al., 2024; Kaar & Stary, 2021). It emphasizes constructionist learning, where learners design and build tangible artifacts that represent their thinking (Yang et al., 2025). Makerspaces can range from low-tech school corners equipped with craft materials to high-tech innovation labs with digital fabrication tools. This study focuses on educational makerspaces that promote creativity, collaboration, and critical thinking in STEM and sustainability contexts (Abdurrahman et al., 2023; Shi & Chen, 2022). For example, Maker Majlis in Qatar integrated human-centered design and sustainability values to nurture global citizenship (Sellami et al., 2025), while the Robot MakerSpace program in Taiwan supported students' problem-solving and programming skills (Chou, 2018).

Despite the burgeoning interest in makerspaces, a comprehensive synthesis addressing their structure, layout design, the types of activities engaged in, strategies for inclusivity and sustainability, pedagogical theories underpinning their frameworks, and evolving trends remains insufficiently explored. The layout of a makerspace is critical as it influences creativity and the overall learning experience; however, empirical discussions on this relationship are sparse (Soomro et al., 2022). Teachers often struggle to integrate making into formal curricula due to limited pedagogical guidance, assessment alignment, and inadequate training (Walan & Brink, 2023).

In addition, sustainability issues persist, as makerspaces can generate high material consumption and waste, creating a gap between environmental awareness and actual practice (Klemichen et al., 2022). In the Malaysian context, resource limitations and a lack of localized frameworks hinder the sustainable and equitable use of makerspaces. Besides, activities defined within makerspaces often emphasize experiential learning, supported by frameworks that encourage learners to engage deeply with materials and tools, yet thorough evaluations of pedagogical strategies are limited (Keune & Peppler, 2018; Strawhacker & Bers, 2018). Additionally, the scaffolding strategies employed for promoting inclusivity and sustaining engagement are essential for ensuring that makerspaces are accessible and beneficial to a diverse population, though evidence of their effectiveness is inconsistent (Andrews & Boklage, 2023; Vinodrai et al., 2021).

E-ISSN: 3083-9491

The purpose of this study is to conduct a narrative review that synthesizes qualitative insights from recent literature on makerspaces, addressing these key areas and bridging identified gaps. The study will explore the following research questions:

(i) how makerspaces are structured in terms of layout and design
(ii) the types of activities defining makerspace learning
(iii) the strategies used to scaffold inclusion and innovation
(iv) the learning theories that underpin makerspace pedagogy
(v) the emerging trends reflecting the future landscape of these innovative spaces

This study aims to contribute valuable insights not only to educators and practitioners involved in shaping makerspace environments but also to policymakers and researchers seeking to understand the broader implications of the maker movement in educational contexts and beyond (Taheri et al., 2019; Kay & Buxton, 2023). Therefore, addressing the diverse elements surrounding makerspaces, which are their design, activities, strategies, and theoretical frameworks, will enhance the effectiveness and potential impact of makerspaces. As the maker movement continues to evolve, understanding these dimensions will be crucial for maximizing both educational and community development outcomes (Moorefield-Lang & Dubnjakovic, 2021).

Despite the increasing adoption of makerspaces in schools and universities, their implementation still faces several contextual challenges. Teachers often struggle to integrate making into formal curricula due to limited pedagogical guidance, assessment alignment, and inadequate training (Walan & Brink, 2023). In addition, sustainability issues persist, as makerspaces can generate high material consumption and waste, creating a gap between environmental awareness and actual practice (Klemichen et al., 2022). In the Malaysian context, resource limitations and a lack of localized frameworks hinder the sustainable and equitable use of makerspaces. Therefore, this study aims to address these challenges by examining how maker-space-oriented learning can be adapted to promote both creativity and sustainability in educational settings.

THEORETICAL FOUNDATIONS AND ANALYTICAL LENS

This study is based on Constructionism (Papert, 1980) as its core theoretical foundation. Constructionism posits that learners construct knowledge most effectively when they are actively engaged in making tangible artifacts that reflect and externalize their thinking. In the context of makerspaces, this principle translates into the design of learning environments where creation, iteration, and reflection serve as the primary mechanisms for cognitive development. The theory provides the epistemological basis for interpreting making as both a process of individual meaning construction and a participatory act within shared cultural contexts. To deepen this foundation, the study integrates several complementary theoretical lenses that extend Constructionism.

a) Sociocultural Theory (Vygotsky, 1978) situates making within communities of practice, emphasizing mediation, dialogue, and collective problem-solving as central to learning. It bridges individual construction with social interaction.

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b) Multimodal Literacies Theory (Kress, 1997; Cope & Kalantzis, 2009) elucidates how learners express ideas through multiple representational modes, including digital, visual, tactile, and linguistic, thus expanding the communicative scope of constructionist learning.

c) Capability Approach (Sen, 1999; Nussbaum, 2011) reframes makerspaces as environments for expanding learners' freedoms, capabilities, and agency. It complements constructionism by focusing on equity, access, and empowerment.

d) Education for Sustainable Development (ESD) (UNESCO, 2019) and Ecosystemic Theory (Carayannis & Campbell, 2009) extend the constructionist paradigm to include ecological responsibility and interconnected systems of innovation. They re-situate makerspaces as learning ecosystems where human, technological, and environmental dimensions co-evolve.

METHODOLOGY

The research design, sampling strategy, instruments, data collection procedures, and statistical analyses used in this study are discussed in this section. The methodological framework has been designed to ensure transparency, reproducibility, and rigor while addressing the research objectives.

Research Design

This study employed a narrative review methodology to synthesize the diverse and fragmented body of literature on makerspaces, with specific emphasis on their layout, activities, strategies, learning theories, and future trends. A narrative review was selected over systematic or scoping reviews because the research questions are inherently interpretive and exploratory rather than strictly evaluative. Systematic reviews typically prioritize replicability and exhaustive coverage, which can limit their ability to engage with the nuanced and complex interplay of ideas and practices evident within makerspace literature. Conversely, the narrative review approach facilitates the integration of heterogeneous sources, ranging from empirical case studies to conceptual frameworks and intervention reports, allowing for a coherent and critical account that recognizes the diversity of makerspace experiences and innovations. The choice of a narrative review methodology is justified on both epistemological and pragmatic grounds.

Epistemologically, the study's aim is not to measure effect sizes but to interpret and critically connect disparate bodies of evidence, including qualitative insights, conceptual models, and case-based experiences. Narrative reviews are particularly suitable for fields characterized by heterogeneity and conceptual plurality, as is the case with makerspaces, which span education, design, technology, and community development. Pragmatically, narrative review enables the researcher to foreground context, interpretation, and thematic synthesis, aligning with the broader goal of producing insightful findings rather than exhaustive tabulation. The narrative synthesis employed in this study reveals patterns, tensions, and gaps across studies that quantitative aggregation alone cannot adequately capture, providing richer insights into how makerspaces function educationally and socially. Therefore, the narrative

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review contributes to a more comprehensive understanding of the contemporary landscape of makerspaces and their implications for future educational practices.

Materials

The materials for this review were meticulously selected from a range of peer-reviewed journal articles, book chapters, and conference proceedings published between 2018 and 2025, ensuring the inclusion of contemporary research reflective of current practices and trends in makerspaces. The review draws from multiple disciplinary domains, encompassing education, information science, design studies, engineering, and social sciences, thus capturing the multidimensional nature of makerspaces as environments focused on education, social interaction, and innovation (Zhou et al., 2025; Kim & Copeland, 2020). Incorporating both conceptual and empirical works allows for a holistic representation of makerspaces, essential for understanding their varied roles in community and educational contexts (Kim & Copeland, 2020).

Four key criteria guided the selection of sources for this review study (see Table 1). First, relevance was a fundamental criterion; included studies had to explicitly explore makerspaces, maker education, or digital fabrication within educational or community contexts (Moorefield-Lang & Dubnjakovic, 2021). Second, only works published from 2018 to 2025 were selected to ensure that this synthesis reflects the latest developments and innovations in the field. Credibility was ensured by limiting the review to peer-reviewed and scholarly publications, thereby maintaining a rigorous academic standard (Steele et al., 2018). Lastly, diversity of contexts was emphasized to enable a comparative synthesis. This study included studies spanning early childhood education, K–12, higher education, libraries, museums, and community makerspaces.

Table 1. Inclusion and Exclusion Criteria

Criteria	Inclusion	Exclusion
Relevance	Studies explicitly addressing makerspaces, maker education, or digital fabrication in educational or community contexts	Articles with only a technical/engineering focus lack an educational dimension
Publication Type	Peer-reviewed journal articles, scholarly book chapters, and academic conference proceedings	Popular press articles, blogs, opinion pieces, and grey literature without peer review
Timeframe	Publications between 2018 and 2025	Publications before 2018, unless foundational to theory
Language	English-language sources	Non-English sources
Content Depth	Empirical findings, conceptual frameworks, or theoretical contributions	Purely descriptive reports without methodological transparency

Exclusion criteria were equally defined. Popular press articles and purely technical reports without educational relevance were omitted to maintain focus on relevant academic discourse, while sources lacking sufficient methodological transparency were also excluded to guard against the inclusion of low-quality research. Thus, by establishing these stringent criteria, the review aims to curate a reliable and informative body of literature that effectively supports the exploration of makerspaces within contemporary educational paradigms.

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Research Instrument

The research instrument for this study was conceptualized as a comprehensive review protocol and thematic coding framework that systematically guided the identification, appraisal, and synthesis of relevant literature on makerspaces. Unlike empirical studies that rely on surveys or experimental tools, the instrument in this study functioned as a structured set of procedures for capturing and interpreting knowledge from published sources (Wannapiroon & Petsangsri, 2020; García-Holgado & García-Peñalvo, 2019).

First, a literature identification protocol was developed, consisting of a search matrix that specified keywords. In this study, the relevant literature was identified from Scopus database using keywords, which are "*makerspace,*" "*maker education*," "*digital fabrication*," "*STEM/STEAM*," "*constructionism*," "*sustainability*," "*learning ecosystem*," and "*innovation hub*", with the boundaries of inclusion criteria (Cuong et al., 2023; Vázquez-Ingelmo et al., 2020). This ensured transparency and replicability in identifying works that represent the current state of knowledge. Second, a screening checklist was employed as a four-criterion instrument, filtering sources by relevance to makerspaces, contextual diversity (Early Childhood Education, K–12, higher education, community, disability settings), scholarly credibility, and analytical richness. Only works satisfying all criteria were included (Jeladze & Pata, 2018; Vázquez-Ingelmo et al., 2020).

A total of 118 articles were retrieved (2010–2025). After title and abstract screening, 75 studies met preliminary inclusion criteria (see Table 2). Following full-text assessment, 20 peer-reviewed journal papers were retained for in-depth analysis based on relevance, methodological rigor, and empirical or theoretical contribution to makerspace education. The selection process is summarized in Figure 1, which shows the flow of the literature search and selection process for makerspace studies (2010–2025).

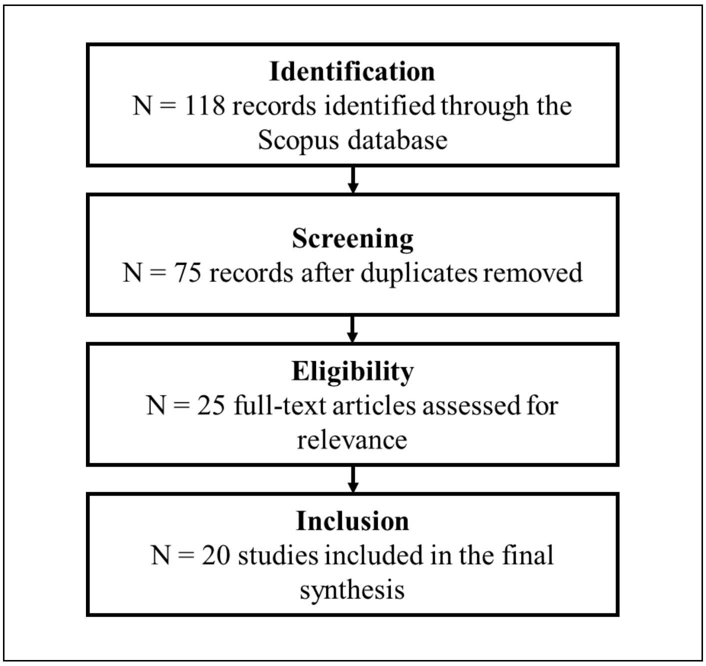

Figure 1. Flow of Literature Search and Selection Process for Makerspace Studies

Third, a thematic coding framework served as the core instrument for qualitative synthesis. Each source was coded against five guiding dimensions derived from the research questions, which were layout, activities, strategies, learning theories, and future trends, allowing iterative identification of cross-cutting themes (Cuong et al., 2023; Pillai et al., 2018). Fourth, to avoid uncritical aggregation, a critical appraisal rubric was applied, rating conceptual clarity, methodological rigor, and transferability on a three-point scale (low, medium, high). This quality filter distinguished robust evidence from tentative claims (Jalil et al., 2022; Soomro et al., 2021). Finally, findings were organized through an integration grid that cross-mapped the five dimensions with different educational levels (early childhood, K–12, higher education, community), enabling comparative synthesis across contexts (Corsini & Moultrie, 2019; Issaro & Piriyasurawong, 2022). Collectively, this layered instrument ensured methodological coherence and enhanced the interpretive depth of the narrative review while mitigating risks of bias and selective reporting (Soledad et al., 2021).

In summary, the use of this research instrument allowed for a rigorous and systematic exploration of the multifaceted dimensions of makerspaces, drawing upon a diverse body of literature to provide a holistic understanding of these innovative learning environments (Pornpongtechavanich & Wannapiroon, 2021; Guo & Ling, 2019). By incorporating both conceptual and empirical works, the study was able to capture the complex interplay between the physical, pedagogical, and social aspects of makerspaces, ultimately contributing to a more nuanced and evidence-based synthesis (García-Holgado & García-Peñalvo, 2018).

Table 2. Research Instrument Framework for the Narrative Review

Component	Description	Purpose
Literature Identification Protocol	• Search matrix with keywords (“makerspace,” “maker education,” “digital fabrication,” “STEM/STEAM,” “constructionism,” “sustainability,” “learning ecosystem,” “innovation hub”) • Scopus database • Timeframe (2018–2025) • Filters (peer-reviewed, English-language, full-text)	Ensures transparency and replicability in selecting contemporary sources.
Screening Checklist	Four-criteria filter: a) Relevance to makerspaces b) Contextual diversity (Early Child Education, K–12, HE, community) c) Scholarly credibility d) Analytical richness	Identifies studies with direct relevance, rigour, and interpretive value.
Thematic Coding Framework	Five dimensions: a) Layout b) Activities c) Strategies d) Learning theories e) future trends Applied iteratively with allowance for emergent themes.	Provides structured synthesis across studies while capturing cross-cutting patterns.

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Component	Description	Purpose
Critical Appraisal Rubric	Three-point scale (low/medium/high) across: a) Conceptual clarity b) Methodological rigor c) Transferability	Distinguishes robust findings from tentative claims; mitigates overgeneralization.
Integration Grid	Cross-maps five dimensions (layout, activities, strategies, theories, trends) against educational levels (ECE, K–12, HE, community, adult learning).	Enables comparative synthesis across contexts; highlights gaps and overlaps.

Data Analysis Procedure

The data analysis employed in this narrative review was guided by a qualitative thematic synthesis approach that enabled the identification and interpretation of patterns across heterogeneous bodies of literature. Following the selection of eligible sources, each study was systematically examined using a pre-determined coding framework comprising five analytical dimensions: makerspace layout, activities, strategies, learning theories, and future trends. This framework was applied iteratively, allowing the emergence of additional themes such as multimodal literacies, equity practices, and sustainability-driven innovation.

To enhance the depth of interpretation, a process of constant comparative analysis was adopted, moving between within-study insights and across-study comparisons to highlight convergences, divergences, and contextual variations. An integration grid was also employed to cross-map themes with educational levels, for example, early childhood, K–12, higher education, and community contexts, facilitating a multi-layered synthesis of evidence. Each study was further appraised for conceptual clarity, methodological rigor, and transferability, ensuring that thematic interpretations were weighted in proportion to the robustness of the evidence presented. Through this recursive and critically reflective process, fragmented findings from diverse contexts were transformed into emerging themes and higher-order interpretations, offering a synthesized account of makerspaces as transformative learning ecologies.

Ethical Consideration

As this study adopted a narrative review methodology, it did not involve direct interaction with human participants or the collection of primary data, thereby minimizing ethical risks commonly associated with empirical research. Nevertheless, ethical integrity was upheld through a rigorous commitment to academic honesty, transparency, and responsible scholarship. All sources were drawn exclusively from peer-reviewed and reputable academic publications, ensuring the credibility and reliability of evidence. Proper attribution and citation were applied consistently in accordance with academic standards, safeguarding against plagiarism and misrepresentation of authors' contributions.

The review process was conducted with sensitivity to the contextual origins of the studies, acknowledging the cultural, institutional, and geographical diversity embedded in the literature. Moreover, findings were synthesized and presented with an emphasis on fair representation and balance, avoiding selective reporting that might privilege particular perspectives. In line with best practices for secondary research, this study adhered to the

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principles of integrity, respect for intellectual property, and transparency in methodology, thereby ensuring that the synthesis of knowledge contributes responsibly to the ongoing discourse on makerspaces as transformative learning ecologies.

RESULTS

Evolution of Makerspace Research (2010–2025)

The qualitative synthesis of the reviewed studies showed that the global makerspace movement has evolved through three identifiable phases over the past decade and a half. This chronological overview situates the current review historically and conceptually. While earlier syntheses, such as Halverson and Sheridan (2014) and Martin (2015), focused on educational adoption, this study aims to extend the discourse by integrating sustainability, inclusion, and ecosystemic perspectives to show how makerspace scholarship has matured from tool-oriented practices toward socio-ecological transformation. Figure 2 shows the evolution of makerspace research (2010–2025).

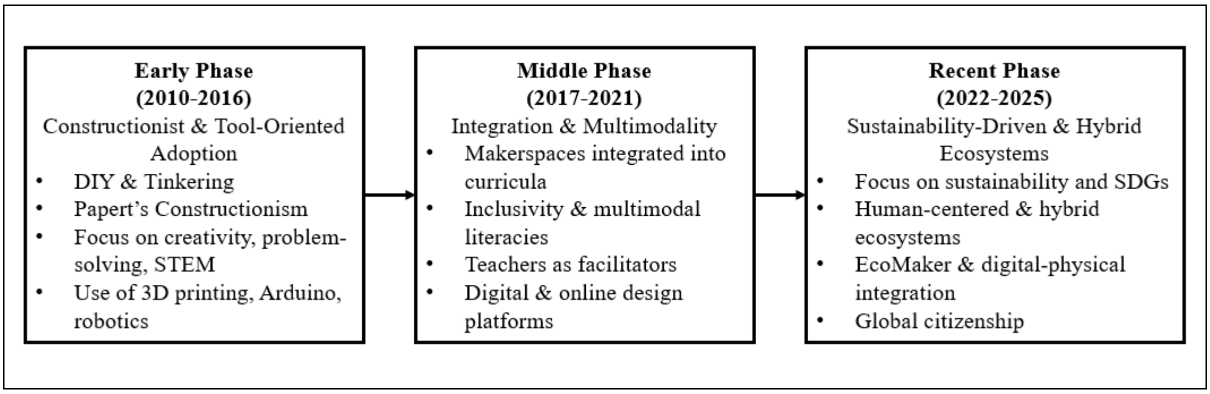

Figure 2. The Evolution Of Makerspace Research (2010-2025)

Early Phase (2010–2016): Constructionist and Tool-Oriented Adoption

During this period, research primarily emphasized constructionist learning and the do-it-yourself (DIY) ethos of making. Inspired by Papert's (1980) constructionism, early studies conceptualized makerspaces as open, informal learning environments where learners explored physical and digital materials through tinkering and experimentation (Sheridan et al., 2014; Chou, 2018). The focus was largely on hands-on fabrication and technology adoption, such as 3D printing, Arduino, and robotics, with learning outcomes centered on creativity, problem-solving, and engineering skills.

Middle Phase (2017–2021): Integration and Multimodality

From 2017 onward, makerspaces moved into formal education systems. Research in this stage addressed curricular integration, multimodal literacy, and inclusivity (Keune & Peppler, 2019; Walan & Brink, 2023). Scholars highlighted how fostering collaboration, communication, and cross-disciplinary learning within classrooms and universities (Wardrip & Brahms, 2015). This

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phase also saw an expansion of digital makerspaces, blending physical tools with online design platforms.

Recent Phase (2022–2025): Sustainability-Driven and Hybrid Ecosystems

Contemporary studies reflect a shift toward ecological, digital, and social sustainability. Makerspaces are now examined as part of hybrid ecosystems that merge human-centered design, global citizenship, and sustainable development goals (SDGs). For example, Klemichen et al. (2022) explored ecoMaker practices addressing the attitude–behavior gap in sustainability. Sellami et al. (2025) examined the Maker Majlis in Qatar as a localized, human-centered digital makerspace promoting global citizenship. Shi and Chen (2022) conceptualized makerspaces as multi-agent knowledge ecosystems driving innovation and value co-creation.

Emerging Themes of Makerspaces

The qualitative synthesis of the reviewed studies revealed five emerging themes that collectively characterize the pedagogical, social, and sustainability dimensions of makerspaces, answering the research questions. Within each theme, subthemes illustrate how different contexts shape practices and outcomes. Table 3 shows the emerging themes and their subthemes.

Table 3. Emerging Themes and Subthemes

Emerging Theme	Subthemes	Description / Evidence	Representative Studies
Theme 1: Makerspace Layout as Pedagogical Design	1.1 Flexible and open zones	Early childhood layouts encourage exploration and engineering play.	Wardrip (2024); Walan & Brink (2023); Soomro et al. (2021); Georgiev & Nanjappan (2023)
	1.2 Structured workstations	Museums/libraries use visible stations for observation and assessment.	
	1.3 Innovation hubs	Universities integrate fabrication labs and entrepreneurial spaces.	
	1.4 Digital/hybrid configurations	Hybrid models (for example, Maker Majlis) extend beyond physical spaces.	
Theme 2: Activities as Catalysts for Learning and Creativity	2.1 Early childhood STEM play	Robotics, block-based making, and socioemotional growth.	Soomro et al. (2021); Georgiev & Nanjappan (2023); Abdurrahman et al. (2023); Chou (2018)
	2.2 K–12 curriculum projects	Renewable energy and STEM-EDP are integrated into lessons.	
	2.3 Informal/community practices	Toy hacking, crafts, and critical cultural making.	
	2.4 Higher education innovation	Prototyping, additive manufacturing, entrepreneurship.	
Theme 3: Strategies for Inclusion,	3.1 Recognition of identities	Public display of artifacts legitimizes women's STEM participation.	Soomro et al. (2021); Georgiev & Nanjappan (2023);

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Emerging Theme	Subthemes	Description / Evidence	Representative Studies
Recognition, and Sustainability	3.2 Co-design of learning tools	Educators/researchers develop assessment instruments collaboratively.	Klemichen et al. (2022); Boccardi et al. (2022); Yang et al. (2025)
	3.3 Structured digital scaffolding	Roadmaps and learning contracts guide fabrication projects.	
	3.4 Sustainability interventions	EcoMaker prompts and nudges embed eco-conscious practices.	
Theme 4: Learning Theories Underpinning Makerspaces	4.1 Constructionism	Learning through making and artifact creation remains central.	Abdurrahman et al. (2023); Chou (2018); Yang et al. (2025); Boccardi et al. (2022)
	4.2 Maker literacies & multimodality	Material/visual literacies transcend reliance on language.	
	4.3 Sociocultural/capability approach	Makerspaces empower diverse learners, including people with disabilities.	
	4.4 Knowledge ecosystem models	Quintuple Helix positions makerspaces as orchestrators of innovation.	
	4.5 Education for Sustainable Development (ESD)	Embedding global citizenship and sustainability in pedagogy.	
Theme 5: Future Trends of Makerspaces	5.1 Digitalisation/hybridisation	COVID-19 accelerated digital and hybrid participation.	Kaar & Stary (2021); Shi & Chen (2022); Walan & Brink (2023); Wardrip (2024)
	5.2 Sustainability embedding	Bio-based prototyping and eco-design integration.	
	5.3 Assessment innovations	Self-assessment and co-designed tools to capture informal learning.	
	5.4 Localisation & global citizenship	Spaces grounded in cultural traditions fostering global values.	
	5.5 Innovation ecosystems	University makerspaces as 4IR incubators.	

Theme 1: Makerspace Layout as Pedagogical Design

Based on Table 3, the analysis of the literature indicates that makerspace layouts function as pedagogical designs rather than neutral spatial arrangements, shaping how learners collaborate, create, and are assessed. In early childhood settings, makerspaces are typically organized as flexible and open zones, enabling free exploration, block-based construction, and early engineering play, thereby foregrounding accessibility, mobility, and unstructured creativity. By contrast, museums and libraries often adopt structured workstation layouts that prioritize visibility and documentation, allowing educators and researchers to observe, assess, and co-design tools for capturing learning evidence. At the university level, makerspaces increasingly evolve into innovation hubs, blending digital fabrication laboratories with entrepreneurial incubation areas and collaborative meeting zones, thereby linking hands-on making with research and enterprise ecosystems. Beyond the physical, many initiatives demonstrate the rise

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of digital and hybrid configurations, where platforms extend spatial boundaries to facilitate global collaborations and virtual mentoring. Taken together, these diverse configurations show that makerspace layouts are strategic pedagogical environments, where they not only provide access to tools but also mediate collaboration, mentoring, and knowledge visibility across educational levels and contexts.

Theme 2: Makerspace Activities as Catalysts for Learning and Creativity

The findings reveal that makerspace activities operate as powerful catalysts for learning and creativity, adapting to developmental stages and institutional contexts while balancing technical competence with 21st-century skills. In early childhood education, activities such as hands-on making, robotics, and block play nurture foundational STEM thinking skills while simultaneously supporting socioemotional growth through collaboration and play-based exploration. At the K–12 level, makerspaces are increasingly integrated into curriculum-based projects, with renewable energy units and STEM-Engineering Design Process (STEM-EDP) activities embedding sustainability issues into science learning, thereby fostering both minds-on and hands-on engagement. In informal and community contexts, activities like toy hacking, craft-making, and sustainability-focused projects empower learners to interrogate cultural narratives, express agency, and engage in social justice-oriented design. Higher education makerspaces, in contrast, prioritize innovation-driven practices such as rapid prototyping, additive manufacturing, and entrepreneurial product development, which cultivate advanced problem-solving, creativity, and innovation capacity aligned with the demands of the Fourth Industrial Revolution. Taken together, these activity patterns highlight that makerspaces do more than provide access to tools: they function as transformative learning ecologies where learners of all ages develop technical knowledge, critical creativity, and collaborative dispositions that extend far beyond conventional pedagogy.

Theme 3: Strategies for Inclusion, Recognition, and Sustainability

The study highlights that makerspaces thrive not only on tools and activities but also on strategies deliberately designed to foster inclusion, recognition, and sustainability. One prominent approach is the recognition of maker identities, where the public display and circulation of learners' artifacts validate their expertise, particularly supporting women's trajectories into STEM by legitimizing their contributions and cultivating long-term interest. Another strategy is co-design, evident in museums and libraries where educators and researchers collaboratively create observation and assessment tools to systematically capture learning outcomes while ensuring pedagogical relevance. In higher education and advanced fabrication contexts, structured digital scaffolding, which, through learning contracts, project roadmaps, and iterative guidance, supports learners in managing complex additive manufacturing processes without stifling creativity. Complementing these approaches are sustainability-oriented interventions, such as the ecoMaker framework, which embeds eco-design prompts and design nudges into making practices, thereby encouraging learners to adopt environmentally responsible mindsets. Collectively, these strategies demonstrate that makerspaces are not merely neutral learning settings but intentional pedagogical and social constructs, where structured scaffolding is interwoven with recognition, inclusion, and ecological responsibility to create equitable and future-oriented learning ecosystems.

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Theme 4: Learning Theories Underpinning Makerspaces

The finding highlights that makerspaces are deeply grounded in diverse but complementary learning theories that collectively explain their pedagogical power. At the foundation lies constructionism, which positions learning as the process of creating personally meaningful artifacts; this philosophy remains the anchor for hands-on experimentation across educational levels. Extending beyond this foundation, scholars emphasize multimodal and maker literacies, which challenge the dominance of language-based learning by valuing material, visual, and gestural forms of expression, thereby enabling more inclusive meaning-making. A further theoretical strand draws from sociocultural and capability perspectives, framing makerspaces as environments of empowerment where marginalized learners, including individuals with disabilities, gain agency and autonomy through active participation. At a systemic scale, makerspaces are increasingly theorized through knowledge ecosystem models, such as the Quintuple Helix, which situate them as orchestrators of innovation linking academia, industry, government, civil society, and the environment. Finally, the lens of ESD integrates global citizenship, ethical responsibility, and ecological awareness into maker pedagogy, aligning making with broader social and planetary goals. Taken together, these theoretical perspectives converge on the principle of learning-by-doing and collaboration, while diverging in emphasis, from literacy and inclusion to systemic innovation and sustainability, thereby enriching the conceptual foundation of makerspaces as transformative learning ecologies.

Theme 5: Future Trends of Makerspaces

The literature collectively points to a set of future trends that signal the ongoing evolution of makerspaces into integrative and ecosystemic hubs. First, the acceleration of digitalization and hybridization, intensified by the COVID-19 pandemic, has expanded makerspaces beyond their physical confines, enabling virtual collaboration, global participation, and remote mentoring through online platforms. Second, there is a growing emphasis on embedding sustainability, with initiatives such as ecoMaker frameworks and bio-based prototyping practices emerging to address the persistent “attitude–behavior gap” between environmental awareness and actual eco-friendly making. Third, the need for robust assessment tools is increasingly recognized, with co-designed observation instruments and digital self-assessment platforms being developed to provide credible evidence of learning in informal and formal contexts. Fourth, future-oriented makerspaces are being framed as vehicles for localization and global citizenship, simultaneously grounding practices in cultural traditions while nurturing values of empathy, equity, and civic responsibility on a global scale. Finally, in higher education and innovation policy contexts, makerspaces are rapidly expanding as innovation ecosystems and incubators of the Fourth Industrial Revolution, linking universities, governments, and industries to support entrepreneurship, technological advancement, and societal problem-solving. Together, these trends suggest that the makerspace of the future will no longer be defined merely as a “room with tools” but as a dynamic, hybrid, and sustainability-driven ecosystem that bridges education, industry, and community in pursuit of inclusive and transformative learning.

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Interconnection of Themes

The five themes identified in this narrative review are not discrete silos but interconnected dimensions of makerspaces as transformative learning ecologies. Layout serves as the structural foundation that enables activities to flourish, providing spatial and digital configurations that either facilitate or constrain collaboration, creativity, and visibility. Activities, in turn, are the pedagogical drivers that activate the potential of the layout, transforming physical and digital resources into meaningful learning experiences. Strategies operate as the bridging mechanisms, aligning layout and activities with learner needs through scaffolding, recognition, and sustainability interventions. Learning theories provide the conceptual scaffolds that explain why layouts, activities, and strategies work, anchoring them in constructionism, multimodal literacies, capability approaches, and ecosystem models. Finally, future trends emerge as the forward-looking synthesis of all preceding themes: hybrid layouts, sustainability-driven activities, inclusive strategies, and theory-informed practices converge to shape the trajectory of makerspaces as integrative hubs for education, innovation, and global citizenship. Together, these themes form a dynamic system, where each element reinforces the others to cultivate inclusive, sustainable, and future-ready learning environments.

Table 4. Interconnections of Themes

Theme	Role	Interconnections with Other Themes
Layout	Provides structural and digital foundations for makerspaces.	Shapes the kinds of activities possible; influences the implementation of strategies; embodies theoretical ideas
Activities	Act as pedagogical drivers of learning and creativity.	Depend on layout for feasibility; require strategies for support; reflect learning theories in practice; evolve into innovative models highlighted in future trends.
Strategies	Serve as bridging mechanisms, aligning pedagogy with learner needs.	Operationalize theories in practice; optimize layout use; scaffold activities; anticipate sustainability and inclusion priorities emphasized in future trends.
Learning Theories	Provide conceptual scaffolds explaining why and how makerspaces work.	Ground the rationale for layout designs, activity types, and strategies; inform the direction of future trends.
Future Trends	Represent the convergence of layout, activities, strategies, and theories in forward-looking trajectories.	Hybrid layouts, sustainability-driven activities, inclusive strategies, and theory-informed models coalesce to redefine makerspaces as ecosystemic hubs.

DISCUSSION

This study shows that makerspaces function as transformative learning ecologies, where layout, activities, strategies, learning theories, and future trends interconnect to shape holistic learning. The findings advance existing discourse by extending the conceptualization of makerspaces beyond tool-filled rooms into ecosystemic hubs of creativity, sustainability, and inclusion. Earlier studies have positioned makerspaces primarily as sites of hands-on engagement, but this study shows that layouts are pedagogical designs that actively shape collaboration and

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learning. For example, early childhood settings emphasize flexible, play-based zones (Keune et al., 2019), while higher education integrates innovation hubs and digital fabrication laboratories (Kruger & Steyn, 2024; Kaar & Stary, 2021), reflecting how space mediates epistemic practices. This aligns with constructionism, which highlights the centrality of environments in enabling artifact creation, but extends it through ecosystem theories such as the Quintuple Helix, positioning makerspaces as orchestrators of multi-actor knowledge systems (Shi & Chen, 2022).

The review further reveals that activities in makerspaces act as catalysts for learning and creativity, embedding both technical competence and twenty-first-century skills. While previous research has highlighted the link between making and problem-solving (Chou, 2018), our synthesis demonstrates that activities also integrate sustainability-oriented content, such as renewable energy design (Abdurrahman et al., 2023), and nurture socioemotional growth in early childhood contexts (Keune et al., 2019). These insights expand the scope of constructionist practice by aligning with Education for ESD frameworks, situating making as a means to address climate change, renewable energy, and global citizenship (Sellami et al., 2025). Importantly, informal and community-based activities such as toy hacking and cultural making highlight that makerspaces also serve as sites of social critique and agency, echoing Rowsell et al. (2024) and Marsh et al. (2024)'s emphasis on "*languageless literacies*" that disrupt traditional educational hierarchies.

Equally significant are the strategies adopted to scaffold inclusion and sustainability. Prior research has shown that recognition of learners' expertise legitimizes participation, particularly for women in STEM (Keune et al., 2019), while co-design of tools empowers educators to meaningfully capture evidence of learning (Wardrip et al., 2024). These findings align with sociocultural theories of learning, which stress the co-construction of knowledge through recognition and dialogue. Moreover, sustainability frameworks such as ecoMaker projects (Klemichen et al., 2022; Georgiev & Nanjappan, 2023) show promise in embedding eco-design practices, yet the persistence of the "*attitude–behavior gap*" highlights a limitation that future interventions must address. This gap underscores the need for strategies that go beyond awareness campaigns toward systemic behavioral change in sustainable making.

The findings also found that learning theories underpinning makerspaces are pluralistic. While constructionism remains central (Chou, 2018), its explanatory power is complemented by multimodal literacies (Rowsell et al., 2024), the capability approach in assistive technology contexts (Boccardi et al., 2022), and systemic ecosystem frameworks (Shi & Chen, 2022). This theoretical convergence suggests that makerspaces should be conceptualized as ecologies of learning where individual meaning-making, inclusion, and systemic innovation intersect. Importantly, the integration of ESD frameworks positions makerspaces as powerful platforms for operationalizing sustainability in education, reinforcing their global significance in addressing the United Nations Sustainable Development Goals (Abdurrahman et al., 2023; Sellami et al., 2025).

Looking toward the future, the study highlights emerging trends that reshape the role of makerspaces. The digitalization and hybridization of makerspaces extend access and collaboration (Sellami et al., 2025), while sustainability-driven innovations and bio-based prototyping embed ecological responsibility into making (Georgiev & Nanjappan, 2023). At the same time, the growing demand for robust assessment tools highlights the importance of evidence-based practice, particularly in informal and hybrid contexts (Wardrip et al., 2024;

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Walan & Brink, 2018). These findings suggest that the next generation of makerspaces will converge around hybrid inclusivity, sustainability, and ecosystemic innovation, redefining the meaning of making in education and society.

Implications and Significance

Theoretically, this study expands the discourse by integrating constructionism with multimodal literacies, sociocultural theory, the capability approach, and ecosystemic models, offering a conceptualization of makerspaces as dynamic learning ecologies. Practically, the findings aim to help educators and policymakers: layouts must be designed to align with pedagogical goals, activities should embed sustainability and socioemotional learning, and strategies such as recognition and co-design can democratise participation. Although technology offers great opportunities for collaborative and immersive learning, effective pedagogical integration requires adequate training and support for educators (Bih Ni et al., 2025). Socially, makerspaces emerge as inclusive and civic spaces, empowering marginalized learners, for example, women and individuals with disabilities (Keune et al., 2019; Boccardi et al., 2022) and nurturing global citizenship (Sellami et al., 2025). These implications highlight the broader significance of makerspaces as engines of educational transformation, social equity, and sustainable innovation.

Limitations and Recommendations

While this study aims to offer a comprehensive synthesis of makerspace research, several limitations remain that correspond to key thematic domains and provide directions for future inquiry. First, the dimension of inclusion is constrained by the geographical and contextual scope of existing studies. The majority of research originates from Western, urban, or technologically privileged environments, with limited attention to rural, early-childhood, and marginalized populations. Consequently, future investigations should prioritize culturally responsive and community-based makerspace models that reflect the socio-economic diversity of global educational contexts.

Second, about sustainability, few empirical studies have systematically examined the long-term environmental impact of makerspace initiatives or assessed how eco-Maker practices translate awareness into measurable outcomes. This gap underscores the need for longitudinal and mixed-method research that evaluates material use, waste reduction, and the cultivation of environmental literacy within maker-oriented curricula.

Third, the evidence on hybridization, which is the integration of physical and digital making, remains exploratory and fragmented across studies. As digital tools increasingly mediate collaboration, future research should examine hybrid pedagogies that harmonize online co-creation with embodied, hands-on learning to ensure equitable and authentic participation. Addressing these interrelated limitations will strengthen the theoretical and methodological foundations of the field, enabling a more inclusive, sustainable, and interconnected trajectory for makerspace scholarship and practice.

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CONCLUSION

This study synthesized research on makerspaces across diverse educational and community contexts, revealing their role as transformative learning ecologies that extend beyond technical skill-building into inclusive, sustainable, and innovation-oriented practices. The findings highlighted five interconnected themes: layouts as pedagogical designs, activities as catalysts for learning and creativity, strategies that scaffold inclusion and sustainability, pluralistic learning theories, and future trends of digitalization, sustainability, and ecosystemic integration. Collectively, these themes illustrate that makerspaces are not static environments but dynamic systems where physical and digital spaces, pedagogical practices, and social strategies converge to support holistic development.

The significance of this study lies in reframing makerspaces from being tool-centric "*rooms with equipment*" to being ecosystemic hubs that link education, innovation, and global citizenship. Theoretically, the review extends constructionism by incorporating multimodal literacies, sociocultural and capability perspectives, and ecosystemic models, providing a richer framework to understand maker pedagogy. Practically, it demonstrates how deliberate alignment of layout, activities, and strategies can cultivate creativity, sustainability, and equity across age groups and learning contexts. Socially, the study affirms the capacity of makerspaces to democratise participation, empower marginalized learners, and contribute to broader societal goals such as the United Nations Sustainable Development Goals.

Nevertheless, the study recognizes its limitations: the interpretive nature of narrative synthesis, the reliance on context-specific case studies, and the limited availability of longitudinal evidence. Future research should address these gaps by conducting cross-cultural and long-term studies, developing robust and scalable assessment frameworks, and examining how makerspaces can serve as policy instruments for sustainable innovation and inclusive education. In conclusion, makerspaces are evolving as critical infrastructures for twenty-first-century learning, where creativity, collaboration, and civic responsibility intersect. By situating them within broader educational and social ecosystems, this study underscores their transformative potential to reshape pedagogy, empower communities, and contribute to sustainable futures.

Conflict of Interest: The authors have no conflicts of interest to declare.

Author Contributions: Goh Kok Ming wrote the manuscript. The author has read and agreed to the published version of the manuscript.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this review are available on request from the corresponding author.

Acknowledgement: The author would like to express their deepest gratitude to the scholars and practitioners whose work on makerspaces, digital fabrication, and STEM education provided the foundation for this review. Sincere appreciation is extended to the research

E-ISSN: 3083-9491

supervisors and colleagues who offered constructive feedback and intellectual guidance throughout the development of this study. The author also acknowledges the institutions and databases that facilitated access to scholarly materials, enabling a comprehensive and critical synthesis of the literature. Finally, heartfelt thanks are given to the broader educational and maker communities, whose ongoing innovations and practices continue to inspire research into inclusive, sustainable, and transformative learning ecologies.

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E-ISSN: 3083-9491

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E-ISSN: 3083-9491