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Inclusive STEM Learning for Enhancing Student Participation: A Bibliometric and Systematic Literature Review

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Abstract: The study aimed to analyze the thematic focus and review the literature on the implementation of inclusive STEM education to enhance student participation in learning, as well as to address four research questions of the STEM education system, inclusive teaching practices, the principles of diversity, equity, and inclusion (DEI), and access to quality education. The particular study integrated bibliometric analysis (BA) and a systematic literature review (SLR). Article metadata from Scopus was extracted on December 7, 2025, and rigorously selected using the PRISMA 2020 protocol. Applying specific inclusion and exclusion criteria to ensure the study's relevance and depth yielded 52 core journal articles that published between 2021 and 2025. The analysis identified four thematic clusters: the STEM learning system, inclusive teaching, diversity, equity, and inclusion (DEI), and access to quality education. The synthesis indicates that students' participation in inclusive STEM learning is shaped by a student-centered, contextual, flexible, and collaborative system design; inclusive pedagogy through differentiation, a safe classroom climate, and equitable formative assessment; the application of DEI principles; and support for access to quality education through institutional support and a transformation of the learning culture.
Keywords: DEI, inclusive, learning participation, science education, STEM.

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INTRODUCTION

STEM (Science, Technology, Engineering, and Mathematics) learning is increasingly being adopted in formal education because of its potential to encourage contextual, integrative, and problem-solving oriented learning that follows the 21st century skills, particularly the 4Cs (critical thinking, creativity, collaboration, and communication) (Böck et al., 2025; Ghazali et al., 2024; Lavi et al., 2021). However, improvements in quality through the STEM approach are not always accompanied by increased participation among all students, as learning designs, classroom interactions, and access to learning resources often favor certain groups (Animashaun et al., 2024; Taylor, 2023). Learning participation is defined as students' involvement in behavioral, cognitive, and emotional dimensions during the learning process, encompassing not only attendance but also meaningful engagement (Fredricks et al., 2004). Therefore, the application of inclusive education principles is a prerequisite for the STEM approach to increase students' participation in learning.

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Inclusive education emphasizes the fulfillment of the right to learn through equality, respect for diversity, collaboration, access, participation, and empowerment of students (Villa & Thousand, 2021). In STEM learning, this principle requires a process that does not assume learners as a homogeneous group, but is designed to be adaptive to variations in prior knowledge, learning styles, special needs, socioeconomic background, language, gender, and social identity (Milanovic et al., 2023). Without integrating these principles, the complexity of STEM activities might become an obstacle, including project-based tasks requiring specific resources, group work reproducing a role of dominance, and assessments reinforcing inequality. As a result, participation in STEM learning may decline due to not inclusive design.

Limitations in the implementation of inclusive STEM learning generally arise through several key mechanisms, such as learning system designs that do not provide room for differentiation, resulting in unequal opportunities for active participation; teaching practices that affect students' sense of security to try and learn openly; and factors of representation and identity recognition that shape perceptions of STEM as an inclusive or exclusive space (Austion, 2023; Estaiteyeh, 2024; Smith, 2025; Taylor, 2023). Therefore, inclusive STEM learning needs to be understood as a system that operates at various levels: micro (classroom—activities and pedagogy), meso (school—internal support and policies), and macro (access to resources, social norms, and opportunities for participation).

Beyond pedagogical challenges, gender bias and social inequality are persistent issues in STEM education, manifested through stereotypes of STEM as a masculine domain, implicit bias in classroom interactions, and the lack of female representation in STEM content and figures (Casad et al., 2021; Cian & Dou, 2024; Park, 2022). Under the framework of inclusive STEM learning, those are viewed as part of the inclusion dimension that directly influences participation in learning. In addition, it is related to the principles of DEI (diversity, equity, and inclusion) and access to quality education, which determine how high students have meaningful opportunities to learn STEM (Basile & Azevedo, 2022; Jamali et al., 2023).

Several studies have examined STEM learning and inclusive education in relation to students' participation in learning. However, these studies remain fragmented, with some focusing on STEM learning design and environments (Edström et al., 2024; Fairhurst et al., 2023; Neher & Ingo, 2023; Patahuddin et al., 2020; Phandini et al., 2023; Roldán et al., 2021; Rusnilawati et al., 2023; Vaiqoh et al., 2021), some emphasize inclusion as a general policy (Neher & Ingo, 2023; Patahuddin et al., 2020; Roldán et al., 2021), and others address gender issues and social inequality as separate themes (Afriana et al., 2016; Edström et al., 2024; Fairhurst et al., 2023; I. Ismail et al., 2016; Neher & Ingo, 2023; Patahuddin et al., 2020; Roldán et al., 2021; Rusnilawati et al., 2023; Vaiqoh et al., 2021). As a result, a comprehensive understanding of inclusive STEM implementation as an ecosystem that shapes learning participation remains limited, leaving an insufficient integrated empirical basis for educators, curriculum developers, and policymakers in designing inclusive STEM interventions. Therefore, a literature review that specifically examines inclusive approaches in STEM education is essential. This review is necessary to synthesize the currently fragmented findings regarding instructional design, pedagogical practices, DEI principles, and access to quality education. Without a comprehensive understanding of these dimensions of inclusivity, the implementation of STEM programs risks failing to address students' diversity fully and may perpetuate disparities in learning participation. Thus, this review aims to provide a more comprehensive foundation for the design and implementation of an inclusive STEM ecosystem.

Based on these gaps, this study aims to analyze the thematic focus and literature studies related to the implementation of inclusive STEM learning in increasing student learning participation and to answer the following research questions (RQ): 1) How is the STEM learning system designed to shape inclusive student learning participation?, 2) How are inclusive teaching practices implemented in STEM learning to shape student learning participation?, 3) How do the principles of diversity, equity, and inclusion (DEI) in STEM learning shape inclusive student learning participation?, and 4) How is access to quality education realized in STEM learning to shape inclusive student learning participation? The findings of the particular study are expected to make conceptual contributions to the ecosystem of inclusive STEM learning implementation and to provide an integrated empirical basis for learning design, teacher training, and policy direction, thereby increasing participation in inclusive STEM learning.

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METHOD

The study was a literature review that integrates bibliometric analysis and systematic literature review (BA-SLR) conducted in sequence. This design was chosen because BA and SLR have complementary functions. BA is effective for mapping a broad knowledge domain, identifying conceptual structures, and displaying clusters of research themes through keyword relationships and links between publications (Jayanti et al., 2024). However, BA is not intended to replace SLR, but rather to complement it by providing an objective mapping foundation for SLR. Therefore, BA is placed in the first stage to determine the focus and boundaries of the data-based review. In contrast, SLR is used in the second stage to thoroughly examine the empirical findings of each formed of thematic cluster (Nuralita et al., 2025). This sequence allows the research not only to map the patterns and themes of the domain but also to substantively explain how the implementation of inclusive STEM learning contributes to student participation.

The data source was the Scopus database, selected for its broad, multidisciplinary journal coverage, and structured bibliographic metadata for bibliometric analysis. The metadata was extracted on December 7, 2025, as the data collection date. The search was conducted using the query: TITLE-ABS-KEY ("STEM education" OR "STEM learning" OR "STEM teaching" OR "integrated STEM") AND TITLE-ABS-KEY ("inclusion" OR "inclusive" OR "equity" OR “diversity”) AND TITLE-ABS-KEY (‘participation’ OR “engagement”). The inclusion and exclusion criteria for the study were set, as shown in Table 1 .

Table 1. Research Inclusion and Exclusion Criteria

No.	Criteria	Inclusion	Exclusion
1.	Publication year	2021 – December 7, 2025	Published before 2021
2.	Publication type	Article	Conceptual papers, book chapter
3.	Source type	Journal	Non-journal
4.	Publication stage	Final	In press or under review
5.	Language	English	Non-English
6.	Discipline	Education	Non-education

The study selection procedure followed the PRISMA 2020 protocol through the identification, screening, eligibility, and inclusion stages. Two independent reviewers screened titles, abstracts, and full texts to minimize selection bias. Any discrepancies regarding article eligibility were resolved through discussion until a consensus was reached. Of the 188 articles identified in the initial search, 52 were selected to proceed to the next stage of analysis. Before synthesis, all selected articles underwent a quality appraisal using the Mixed Methods Appraisal Tool (MMAT) 2018, as the study corpus encompassed quantitative, qualitative, and mixed-methods methodologies (Nha et al., 2018). The appraisal was conducted independently by two reviewers using two initial screening questions and core criteria tailored to each study’s design, which included clarity of the research question, methodological appropriateness, adequacy of data collection, accuracy of analysis, and relevance of findings to the research question. The appraisal results were used to ensure the methodological soundness of the synthesized studies and to support a more careful interpretation of the findings. The flowchart of the study selection process based on the PRISMA 2020 protocol is shown in Figure 1.

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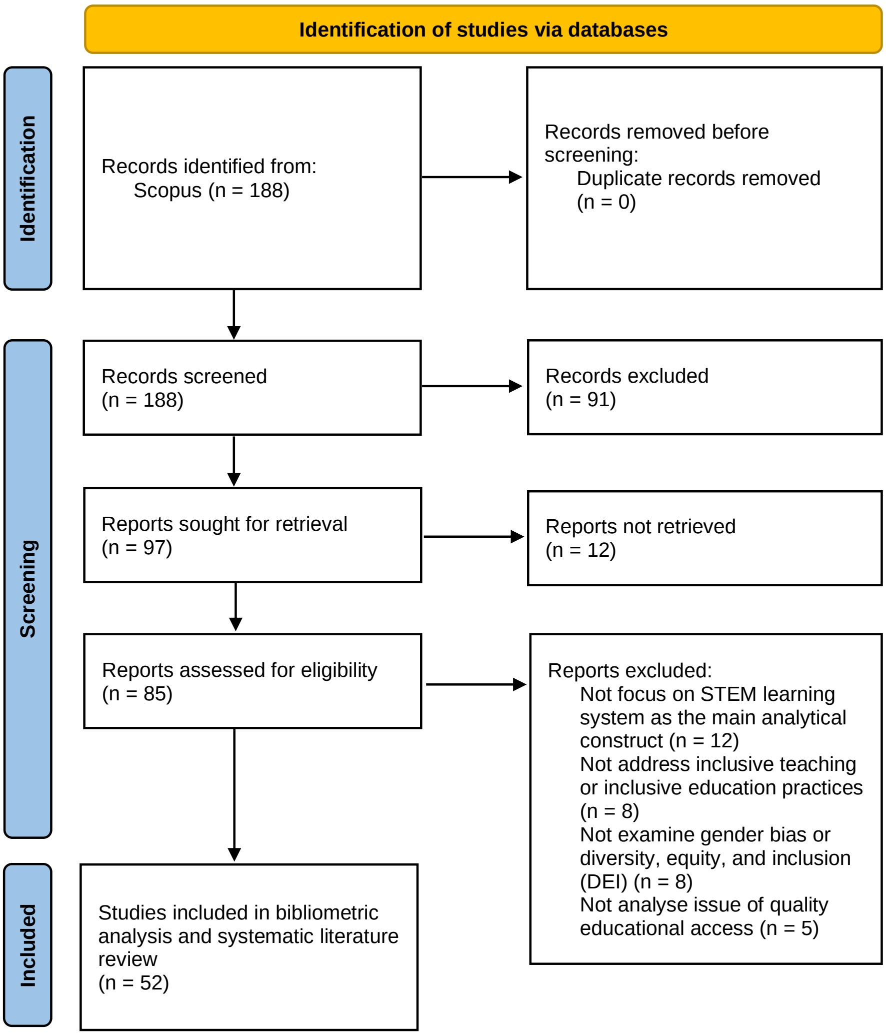

Figure 1. Flowchart of Scientific Publication Selection

Data synthesis was conducted using a thematic synthesis approach with a mixed coding strategy, namely deductive and inductive coding. In the initial stage, four cluster labels from the bibliometric analysis (BA) were used as a deductive framework to develop an initial codebook and organize the articles according to thematic focus. Subsequently, two raters conducted repeated full-text readings and applied line-by-line coding to identify new codes emerging from the data, particularly those related to the implementation, challenges, and outcomes of inclusive STEM education. Similar codes were then iteratively grouped into descriptive themes and further developed into analytical themes that explain patterns of relationships among findings and address the four research questions. Any discrepancies in the coding process were discussed until a mutual agreement was reached, and code definitions were adjusted iteratively to ensure the synthesis remained consistent and transparent. Thus, the thematic synthesis does not rely solely on the cluster labels from the BA results but also allows for the emergence of richer, more contextual empirical subthemes derived from the full-text reading.

The BA was conducted using VOSviewer v1.6.20 software to map keyword relationships and identify thematic clusters within the study area. The unit of analysis was a combination of author keywords and indexed keywords, with co-occurrence analysis using the following parameters: 1) full counting as the calculation method, and 2) normalized association strength. The BA results were visualized in network, overlay, and density visualizations to illustrate the thematic structure, temporal dimensions, and density of the research themes. The thematic clusters from the network visualization served as the initial framework for determining the SLR's focus, which was then carried out by grouping articles into clusters and systematically synthesizing empirical findings.

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RESULT AND DISCUSSION

Bibliometric Analysis (BA) using a keyword-related approach was used to map the thematic relationships between STEM learning and inclusive education in the context of inclusive STEM implementation. This analysis was based on 52 Scopus-indexed articles, published between 2021 and December 7, 2025. The analysis results were visualized in three formats: network, overlay, and density. Network visualization was used to map the thematic focus and patterns of relationships between keywords in the literature on STEM learning and inclusive education, as shown in Figure 2.

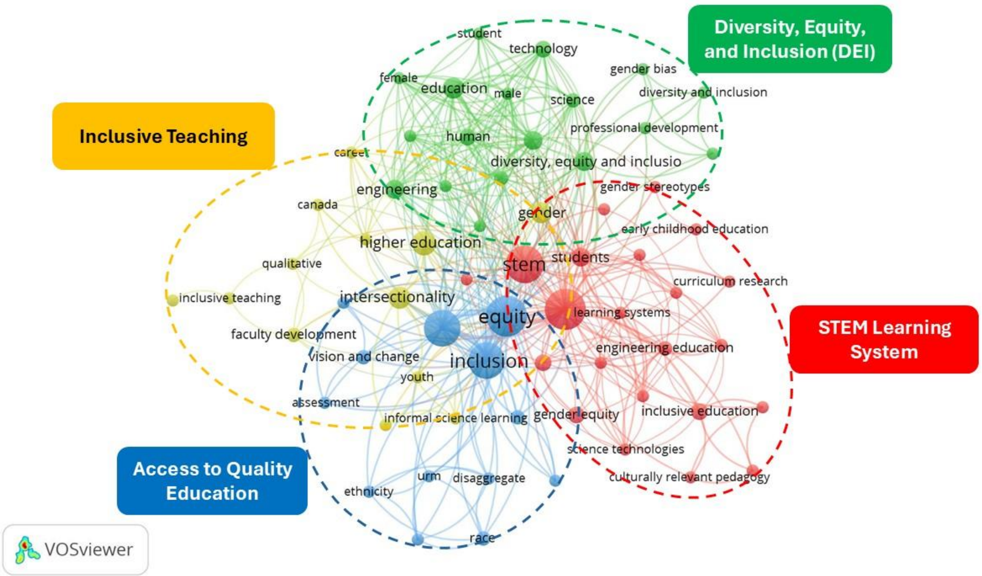

Figure 2. Network Visualization of Keyword Co-occurrence

The visualization results, as shown in Figure 2, show the formation of four thematic clusters: 1) STEM learning system, 2) inclusive teaching, 3) diversity, equity, and inclusion (DEI), and 4) access to quality education. Cluster naming was carried out through qualitative interpretation based on the core keywords in each cluster and the context of the articles (titles and abstracts) that associated with each cluster, aiming to ensure the appropriateness of the theme labels. This approach aims to minimize reliance on visual appearance for cluster labeling and to maintain theme consistency as the basis for analysis in the SLR.

Overlay visualization is used to illustrate the temporal dimension of keyword occurrences in the literature, as shown in Figure 3.

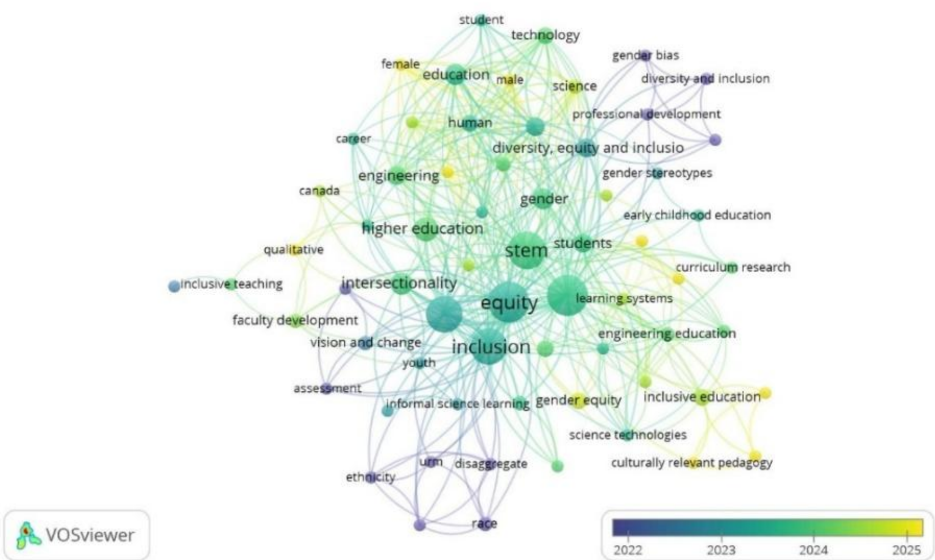

Figure 3. Overlay Visualization of Keyword Co-occurrence

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Dominant keywords in the early publication period (shown in purple) included gender bias, diversity and inclusion, professional development, graduate education, assessment, ethnicity, URM, disaggregated data, and race. In contrast, dominant keywords in the more recent publication period (shown in yellow) included male, female, decision-making, qualitative, figure, early field experience, teacher preparation, culturally relevant pedagogy, and gender equity. Qualitatively, this pattern indicates a shift in focus from issues of structural equity and minority group representation toward learning experiences, pedagogical practices, and context- and identity-based approaches to inclusive STEM learning.

Density visualization displays the density level of keyword occurrences in the literature, as shown in Figure 4.

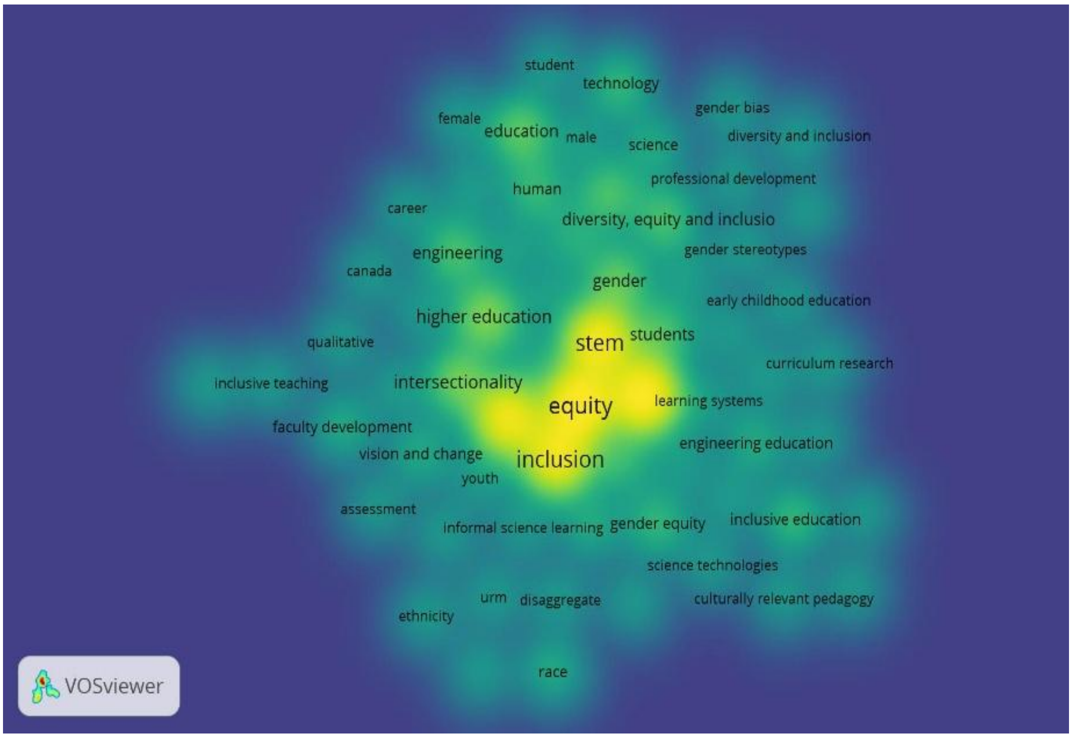

Figure 4. Density Visualization of Keyword Co-occurrence

High-density areas (shown in yellow) include the keywords STEM, equity, inclusion, diversity, higher education, intersectionality, and education. Conversely, lower-density areas (shown in green) are dominated by more specific keywords related to pedagogical practices and the implementation of inclusive STEM learning. This finding suggests that literature remains dominated by core concepts, while studies on practical implementation are scattered and diverse. This situation indicates the need for SLR to deepen its study on the more specific theme of inclusive STEM learning implementation.

The four thematic clusters derived from the BA served as an initial framework for the SLR to select, group, and synthesize research findings following the research questions (RQs). In the SLR, the cluster framework was used as an initial structure, which was then developed into subthemes through full-text reading. As the result, the synthesis was not limited to cluster labels but provided a deeper understanding of the mechanisms by implementing inclusive STEM learning to shapes students' participation in learning.

The same 52 articles used for the BA were then further analyzed in the SLR stage. These articles were published between 2021 and December 7, 2025. The publication distribution shows an increasing trend from year to year, as shown in Figure 5. The number of publications was relatively limited in the initial period and increased significantly in 2023 and 2025.

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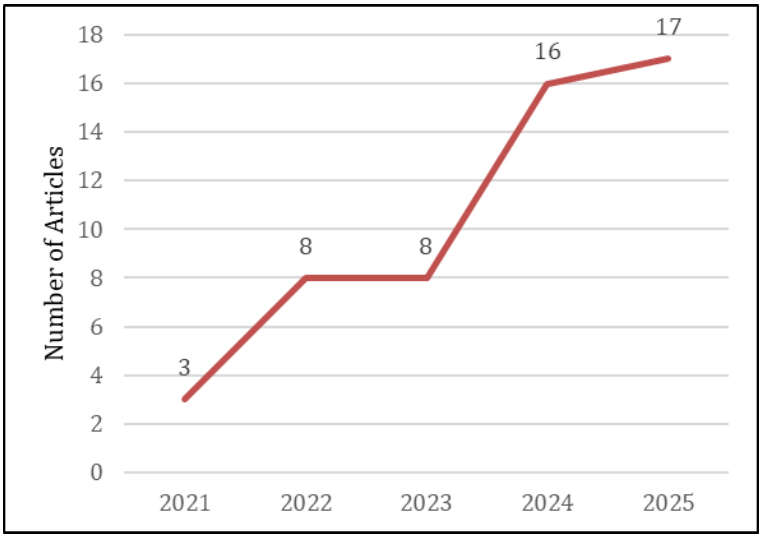

Figure 5. Distribution of Number of Articles by Year of Publication

Next, the articles were grouped into four thematic clusters based on the BA's network visualization. The distribution of articles by cluster, discussion focus, and related references is presented in Table 2.

Table 2. Focus on SLR Discussion

Cluster	Focus Discussion	Reference
STEM Learning System	Student-centered learning	Guss, Lim, et al., (2024); Mgambi et al., (2025); Sunasee, (2023); Wang, (2024)
	Integration of contextual issues	Karpudewan, (2024); Raman et al., (2025); Vásquez-chaux et al., (2025)
	Flexibility of learning structures	Estaiteyeh et al., (2024); Felipe et al., (2024); Guss, Clements, et al., (2024); Leonard et al., 2023)
	Inclusive multidisciplinary collaboration	Brancaccio-taras et al., (2022); Estaiteyeh & DeCoito, (2024); Fink et al., (2024); Kier, (2025)
Inclusive Teaching	Instructional differentiation	Estaiteyeh & Decoito, (2023)
	A safe and supportive classroom climate	Goodman et al., 2024; Hill et al., (2025); Lee & Rodriguez, (2022); Raphael et al., (2025); Sherard & Russo, (2025)
	Fair formative assessment	Knezz et al., (2022); Parmaxi et al., (2024); Singh et al., (2023)
Diversity, Equity, and Inclusion (DEI)	Gender stereotypes	Guo et al., (2024; Kamran et al., 2025; Szczesny & Salazar, 2025)
	Unequal access for women	Bhatti, (2021); El et al., (2025); Gámez et al., (2022); Nazari, (2025); Rahman, (2024); Reznik et al., (2023); Stefani et al., (2024)
	Women's representation	Ana & De, (2023); Kube et al., (2024); Nguyen & Riegle-Crumb, (2021); Osés &s Lafuente, (2025)

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Access to Quality Education	Identity validation and representation	Avent, (2025); Cardullo & Burton, (2025); Mkhize, (2023)
	Systemic barriers and provision of support	Marshall et al., (2022); Tatapudy et al., (2025); Tremaine et al., (2022); Tripon, (2025)
	Institutional cultural transformation	Miles et al., (2024); Pearson et al., (2022); Wu et al., (2023)

STEM learning system

Based on the SLR synthesis, the STEM learning system cluster puts the learning system as a systemic design that includes the structure of activities, the sequence of learning experiences, forms of support, and arrangements for collaboration and assessment. An inclusive STEM learning system is not only determined by the selection of learning models, but also the design of a classroom ecosystem that consciously provides access to students' participation with diverse initial abilities, needs, and backgrounds. Moreover, studies in this cluster show that inclusive system design shapes learning participation through four components: 1) students-centered learning orientation, 2) integration of contextual issues, 3) flexibility of structure and assessment, and 4) inclusive multidisciplinary collaboration.

The synthesis results show that inclusive STEM learning systems are designed with the assumption that students are not a homogeneous group. This student-centered orientation is manifested through a variety of activities and media, as well as adjustments to cognitive demands and material depth to be responsive to differences in student's characteristics (Guss, Lim, et al., 2024; Mgambi et al., 2025; Sunasee, 2023; Wang, 2024). This design increases participation opportunities by offering diverse entry points for STEM exploration without relying on a single, uniform learning path. Also, the findings of Aini et al. (2025) and Liu et al. (2024) show the implementation of student-centered learning through a variety of activities, a variety of media, and active learning involving behavioral, cognitive, and social dimensions increase student motivation, curiosity, and learning participation in science learning.

The second component is the integration of authentic and contextual problems. Synthesis results show that presenting problems rooted in students' social, cultural, and environmental contexts increases the perceived relevance of STEM learning, thereby eliminating a focus solely on technical procedures (Karpudewan, 2024; Raman et al., 2025). This relevance encourages sustained engagement because students can identify the social and practical value of STEM activities. Furthermore, contextual problems provide a more equitable space for participation due to contributions based on diverse experiences and knowledge, not only on high STEM technical skills (Vásquez-chaux et al., 2025). Supported by Adanur-sönmez & Aydın-ceran (2025), the use of contextual problems in learning, including context-based STEM, increase learning engagement, conceptual understanding, and the relevance of learning to students' daily lives.

The third component emphasizes flexibility as a characteristic of an inclusive STEM learning system, encompassing the sequence of activities, duration, individual and group work patterns, and a variety of assessment methods. The synthesis suggests that flexibility does not mean the absence of structure, but rather a learning structure that adapted without sacrificing learning outcomes (Estaiteyeh et al., 2024; Felipe et al., 2024). In terms of assessment, flexibility is manifested through various ways for students to express their understanding, such as written reports, presentations, or simulations, so that students with limitations in language, confidence, device access, or learning needs, still have equal access to participation (Guss, Clements, et al., 2024; Leonard et al., 2023). Systemically, this flexibility helps reduce physical, cognitive, and social barriers to participation. Research by Callaghan et al. (2023) and N. R. Fadillah et al. (2024) revealed that flexibility in learning and assessment, such as differentiated learning, varied tasks, and collaborative assessment, increase student engagement and reduce barriers to participation by offering various ways to express understanding.

The fourth component is a multidisciplinary collaborative design that ensures each student makes a meaningful contribution. Synthesis results show that inclusive collaboration is not only related to group formation but also to the design of complementary roles and responsibilities (positive interdependence) (Brancaccio-Taras et al., 2022; Estaiteyeh & DeCoito, 2024). Through structured role

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allocation, students with diverse academic backgrounds can contribute according to their strengths, thereby minimizing dominance by a few students (Fink et al., 2024; Kier, 2025). Group success is determined by each member's contributions, which strengthen equal social interactions and broaden participation for students who were previously underserved in competitive STEM practices. Findings by Ismail et al. (2025) and Zhou & Colomer (2024) show that collaborative learning with clear and complementary role allocation enhance social interactions, individual responsibility, and participation through the principles of positive interdependence and individual accountability.

Inclusive teaching

The inclusive teaching cluster puts teaching practices as a classroom-level mechanism that determines the STEM system designs are accessible to diverse students. The synthesis suggests that the implementation of inclusive teaching in STEM learning shapes learning participation through three interconnected core practices: 1) instructional differentiation, 2) the creation of a safe and supportive classroom climate, and 3) equitable and continuous formative assessment. These three practices complement each other, with differentiation expanding access to learning, a safe classroom climate strengthen students' courage to engage, and equitable formative assessment maintaining continued participation through feedback and opportunities for development.

Instructional differentiation is a key practice in inclusive STEM teaching, implemented through adjustments in learning methods, variations in concept representations, flexibility in learning activities, and adjustments in academic support levels to different students' needs (Estaiteyeh & Decoito, 2023). This practice allows students to access STEM content through various activities, such as problem-based explorations, visual media, or simulations, so that students with certain academic strengths do not dominate participation. In the context of learning participation, differentiation expands students' behavioral, cognitive, and affective engagement. The findings of Syarida et al. (2025) and Mart et al. (2023) confirm that implementing differentiation through variations in methods, activities, and concept representations following the students' needs increase access to learning and expand behavioral, cognitive, and emotional engagement in the learning process.

Synthesis results indicate that inclusive teaching practices place a psychologically safe and supportive classroom climate as a condition for participation in STEM learning. This climate is reflected in learning norms that value diverse opinions, provide constructive feedback, and recognize mistakes as part of the learning process (Goodman et al., 2024; Hill et al., 2025; Lee & Rodriguez, 2022). Support is realized through ongoing academic support, facilitation of collaborative interactions, and adaptive teacher responses to student needs (Raphael et al., 2025; Sherard & Russo, 2025). These conditions contribute to reduced academic anxiety and increased courage to try, ask questions, express ideas, and join in STEM learning as indicators of inclusive participation. Findings by Papademetriou et al. (2022) suggest that a psychologically safe classroom climate, characterized by respect for diverse opinions, constructive feedback, and ongoing academic support, increase student engagement and the courage to participate, while actively reducing academic anxiety.

Also, inclusive teaching practices are supported by fair and ongoing formative assessment. Fairness is demonstrated through openly communicated assessment criteria from the outset. Then, students understand learning expectations and guide their learning efforts (Knezz et al., 2022). Sustainability is demonstrated through the provision of diverse learning evidence, varying task complexity, and feedback-based improvement opportunities (Parmaxi et al., 2024). In the context of participation, formative assessment broadens the scope for contribution because a one-time assessment does not limit students; instead, they are encouraged to engage incrementally through feedback and performance improvement (Singh et al., 2023). This context is crucial in STEM learning, which often involves complex projects. Meanwhile, opportunities for revision and diverse learning evidence contribute to increased equitable participation. Research by Parastika et al. (2024) and Schildkamp et al. (2020) demonstrates that transparent, ongoing formative assessment, communicated through criteria, constructive feedback, and opportunities for improvement, increase student's engagement and participation.

Diversity, equity, and inclusion (DEI)

The diversity, equity, and inclusion (DEI) cluster identifies gender bias and the marginalization of social groups as factors influencing student participation in STEM learning. The SLR synthesis results indicate that inclusive participation is influenced by: 1) gender stereotypes and implicit biases that influence self-confidence and role-taking, 2) unequal access for women to STEM learning experiences

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that shape their readiness and inclination to engage, 3) representation and female figures that influence self-identification and belonging in STEM, and 4) validation of the identities of marginalized social groups.

The synthesis results show that stereotypes associating STEM with masculine characteristics create biased expectations from both the learning environment and students, which impact their confidence and willingness to engage in STEM activities. This impact is found in activities that require visible participation, such as discussions, group work, experiments, and presentations, in which female students are often marginalized or play less central roles (Guo et al., 2024). Bias mitigation is achieved through collaborative strategies with clear, equal role allocation and rotation, so that opportunities to perform, lead, and make decisions are not dominated by one gender (Kamran et al., 2025; Szczesny & Salazar, 2025). This more equitable participation structure minimizes the reproduction of stereotypes in group work. The findings of Demalata et al. (2024) and Zúñiga-mejías (2024) showed that gender stereotypes reduce female students' confidence and participation, which need to foster the collaborative strategies with equal role allocation and rotation in learning participation.

Findings from this cluster suggest that gender bias is evident in unequal access to STEM learning experiences, including lower engagement in advanced projects, limited support tools, and reduced participation in extracurricular activities (Bhatti, 2021; El et al., 2025; Gámez et al., 2022). These inequalities affect cognitive readiness, the development of practical competencies, and successful experiences, all of which are crucial for maintaining participation in STEM. Within the DEI framework, this issue is understood as an equity issue, and expanding STEM experiences must be achieved through activity designs that provide more equitable support and access to learning resources, projects, and practical experiences (Nazari, 2025; Rahman, 2024; Reznik et al., 2023; Stefani et al., 2024). The implementation is found through project-based assignments and providing adequate learning tools and time. Research by M. A. Fadillah et al. (2024) and Hernández-Pérez et al. (2024) confirmed that gender bias is associated with differences in access to learning experiences, which directly affect students' participation and readiness in STEM.

Inequality in participation is also related to the low representation of women in STEM learning content and the limited presence of female teachers in STEM fields (Ana & De, 2023; Kube et al., 2024). This lack of representation lead to symbolic exclusion, hindering self-identification and making it difficult for female students to see STEM as a field that aligns with their identity. Within the DEI framework, representation is an inclusion strategy that strengthens a sense of belonging and expands opportunities for participation, both learning and decisions about pursuing studies in STEM fields (Nguyen & Riegle-Crumb, 2021; Osés & Lafuente, 2025). Therefore, it needs to provide more balanced gender representation in STEM materials, case studies, and narratives, and present relevant female teacher figures to reduce stereotypes. Research by McCance et al. (2025) and Tamba & Ling (2024) shows that greater gender equality increases female students' sense of belonging and participation in STEM.

Findings from this cluster indicate the students' participation in learning from marginalized groups increases when their identities are recognized and represented in STEM learning (Cardullo & Burton, 2025). Identity validation is manifested through the presentation of inclusive STEM content and narratives, such as figures, case studies, or representations that reflect diverse social backgrounds, thereby making STEM more relevant to students' identities (Avent, 2025). Furthermore, structured, intentional mentoring practices, such as academic mentoring, regular guidance, progress monitoring, and reflective feedback, serve to strengthen belonging and provide emotional and academic support. At the end, it contributes to increased participation in STEM learning (Mkhize, 2023). Findings from Adinda et al. (2025) and Atkins et al. (2020) provide additional evidence that learning participation of students from underrepresented groups in STEM increases when their identities are recognized through inclusive representation and supported by structured academic mentoring practices, which reinforce a sense of belonging, emotional support, and engagement in learning activities.

Access to education

The access to education cluster puts an adequate education as a structural and cultural condition that determines whether students, especially those from marginalized groups, have equal opportunities to access, persist in, and participate meaningfully in STEM learning. The results of the SLR synthesis suggest the access to quality education can be achieved through two mechanisms: 1) reducing systemic

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barriers through equitable institutional support, and 2) transforming institutional culture that changes exclusionary norms within the STEM ecosystem.

Barriers to participation in inclusive STEM learning primarily are from systemic issues when educational institutions fail to provide equitable support for diverse learning needs. These barriers are evident in the unequal distribution of resources, limited support tools, and learning designs (Marshall et al., 2022; Tatapudy et al., 2025). As a result, opportunities for participation, especially in technology-based activities, are reduced. Therefore, reducing systemic barriers requires equitable institutional support through responsive learning resources, the use of educational technology, strengthened academic services, and expanded access to inclusive learning communities (Tremaine et al., 2022; Tripon, 2025). The findings of Beribe et al. (2024) and Pettalongi et al. (2024) confirm that an equity-based approach is needed to expand participation in learning.

The synthesis indicates that increasing participation in inclusive STEM learning might not be achieved solely through administrative reform or increasing numerical representation without substantive changes to learning practices and institutional culture (Miles et al., 2024). The main challenge lies in the institutional culture that continues to reproduce knowledge hierarchies, gender bias, and exclusionary norms within the STEM ecosystem (Wu et al., 2023). Therefore, social equity requires cultural transformation through a critical review of learning values, policies, and practices at the leadership, governance, and professional levels of educators. Accountable leadership, equity-based recruitment, and educator professional development are crucial to building an inclusive and participatory STEM learning climate (Pearson et al., 2022). Findings by Monigir et al. (2024) confirm that increasing the participation of underrepresented groups requires institutional transformation that encompasses academic culture, pedagogical practices, and evaluation systems.

Overall, the results of the SLR synthesis indicate an increasing of students' participation in inclusive STEM learning is not driven by a single variable but rather by the integration of four core elements that synergize (Figure 6).

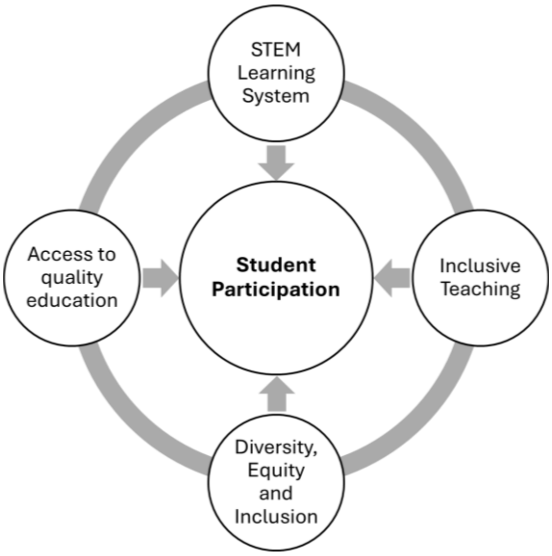

Figure 1. Conceptual Framework of Student Learning Participation in Inclusive STEM Learning

The STEM learning system is designed as an ecosystem with diverse entry points, contextual relevance, and flexible learning processes. Then, the system design is operationalized directly in the classroom through inclusive teaching. Through instructional differentiation, a safe classroom climate, and formative assessment, teachers ensure that the system operates optimally to maintain student learning participation. Furthermore, the effectiveness of the pedagogy is highly dependent on a commitment to the principles of diversity, equity, and inclusion (DEI). Reducing stereotypes, strengthening women's representation, and validating the identities of marginalized social groups are essential prerequisites for bridging the gap in access to quality education. This equality culminates in efforts to overcome systemic barriers at the institutional level. Therefore, these four elements do not operate in isolation but rather shape a cohesive ecosystem cycle. In line with Astutik (2020), Simpson et al. (2023), Vaiqoh et al. (2021), and Valenzuela (2025), learning participation is formed through

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synergy among system design, inclusive pedagogy, reducing gender bias, and DEI principles, as well as equity-oriented institutional support to ensure fair access and learning opportunities.

Although this synthesis identifies four main pillars of inclusive STEM learning, it should be noted that the strength of evidence across studies is not entirely consistent. The reviewed literature remains dominated by small-scale qualitative studies (Guss, Clements, et al., 2024; Leonard et al., 2023) and self-reported studies (Lee & Rodriguez, 2022), while large-scale longitudinal quasi-experimental studies that directly measure the long-term impact on learning participation relatively limited. This situation indicates some of the findings are stronger in explaining the processes, experiences, and perceptions of implementation than providing causal evidence of long-term effectiveness. Additionally, the synthesis reveals conflicting findings regarding certain aspects of implementation. For example, while the flexibility of instructional design is viewed as supporting inclusivity by opening space for more diverse participation (Wang, 2024). Also, it leads to disorientation and reduce participation among students with low prior abilities if not accompanied by adequate pedagogical scaffolding (M. Ismail et al., 2025). Similarly, collaborative strategies do not always result in equitable participation; without clear role assignments and adequate supervision of interactions, group work can reproduce social hierarchies and gender dominance within small groups (Osés & Lafuente, 2025). Thus, these findings confirm that the effectiveness of inclusive STEM learning depends not only on the presence of inclusive elements but also on the quality of pedagogical design and its implementation mechanisms in the classroom.

The findings have important theoretical and practical implications. Theoretically, the particular study demonstrates that learning participation in inclusive STEM education should be understood as the result of an ecosystem that connects instructional design, inclusive pedagogy, DEI principles, and institutional access support—rather than merely as a single pedagogical issue. Practically, the results of this synthesis provide a foundation for educators to design a more responsive learning to student with diverse backgrounds through instructional differentiation, inclusive interaction management, and efforts to reduce gender bias. For policymakers and institutional leaders, these findings provide an empirical evidence for strengthening institutional support, reviewing exclusive cultures, and directing resource allocation more equitably to expand opportunities for learning participation.

CONCLUSION

This study goes beyond a descriptive literature review to offer an analytical understanding that increasing student participation in STEM learning cannot be achieved through the isolated application of a single teaching method. The synthesis suggests that inclusive participation stems from an interconnected learning ecosystem, where STEM system design, inclusive pedagogy, the principles of diversity, equity, and inclusion (DEI), and institutional access support must operate tandem and reinforce one another. In other words, the effectiveness of inclusive STEM learning is determined not only by the presence of each of these elements but by the integration of their relationships in learning practice.

However, this synthesis indicates the success of an ecosystem strongly depends on the quality of its implementation. Flexible learning and collaborative interventions, for example, do not always lead to more inclusive participation unless they are accompanied by pedagogical scaffolding, role-setting, and adequate support for interaction. Within the conditions, interventions intended to expand participation may actually reinforce existing inequalities. Furthermore, because the available literature is largely based on small-scale qualitative studies and perception-based research, broader empirical studies—including longitudinal and quasi-experimental designs—are still needed to more convincingly test the effectiveness of inclusive STEM interventions across diverse student contexts and educational environments.

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