





Rethinking Intention in STEM Education: Cross-Cultural Insights from the Theory of Planned Behavior

Henie Poerwandar Asmaningrum^{1,*}, Renuka V Sathasivam¹, Edy Hafizan Mohd Shahali¹
¹ Department of Mathematics and Science Education, Universiti Malaya, Kuala Lumpur, Malaysia

Article Info

Article history:

Received Dec 11, 2025
Revised Feb 14, 2026
Accepted Mar 11, 2026
OnlineFirst Apr 24, 2026

Keywords:

Attitude-Intention Relationships
Cultural Intelligence
Cross-Cultural Variations
STEM Education
Theory of Planned Behavior

ABSTRACT

Purpose of the study: This systematic literature review aims to synthesize current knowledge about attitude-intention relationships in STEM education through the Theory of Planned Behavior framework and identify key factors that moderate these relationships across diverse cultural and educational contexts.

Methodology: Systematic literature review following PRISMA 2020 guidelines using Scopus database. Comprehensive search strategy with Boolean operators covering Theory of Planned Behavior, attitudes, intentions, and STEM education contexts from 2015-2025. Data extraction using standardized forms, quality assessment with Mixed Methods Appraisal Tool (MMAT), and narrative synthesis with bibliometric analysis using VOSviewer software for thematic clustering and temporal trend analysis.

Main Findings: Twenty-six studies from 15 countries revealed robust TPB applicability in STEM contexts with significant cross-cultural variations. Collectivistic cultures demonstrated stronger subjective norms effects ($\beta = 0.28-0.48$) while individualistic cultures showed stronger attitude effects ($\beta = 0.41-0.58$). Cultural intelligence emerged in 38.5% of studies as critical moderator. Extended TPB models incorporating self-efficacy, environmental support, and readiness factors provided enhanced explanatory power beyond core components.

Novelty/Originality of this study: First comprehensive systematic review examining TPB in STEM education with explicit cross-cultural analysis and cultural intelligence integration. Advances existing knowledge by identifying systematic cultural variations in TPB component strength and providing evidence-based framework for culturally responsive STEM education interventions targeting diverse global populations.

This is an open access article under the [CC BY](https://creativecommons.org/licenses/by/4.0/) license
© 2026 by the author(s)



Corresponding Author:

Henie Poerwandar Asmaningrum,
Department of Mathematics and Science Education, Faculty of Education, Universiti Malaya,
Jalan Universiti, 50603, Kuala Lumpur, Malaysia
Email: s2138457@siswa.um.edu.my

1. INTRODUCTION

The persistent gap between students' attitudes and intentions in STEM (Science, Technology, Engineering, and Mathematics) education represents one of the most consequential unresolved challenges in contemporary education policy, as nations worldwide grapple with chronic underrepresentation and declining enrollment in these fields [1]. Despite significant investments in STEM education initiatives and workforce development programs, many students continue to demonstrate positive attitudes toward STEM subjects yet fail

to translate these attitudes into concrete intentions to pursue STEM careers or advanced study [2], [3]. This attitude–intention gap represents a fundamental challenge that undermines efforts to build diverse, skilled STEM workforces capable of addressing global challenges such as climate change, technological innovation, and sustainable development. Recent evidence indicates that traditional approaches focusing solely on improving STEM attitudes may be insufficient without addressing the broader constellation of factors that influence behavioral intentions [4], [5].

To address this challenge, the Theory of Planned Behavior (TPB), developed by Ajzen [6], provides a robust theoretical foundation for examining how attitudes, subjective norms, and perceived behavioral control collectively influence behavioral intentions. Within the STEM education context, this framework has gained considerable attention as researchers seek to understand why students with favorable attitudes toward science and mathematics may not develop strong intentions to pursue STEM pathways [7], [8]. Recent studies have demonstrated that perceived behavioral control, often operationalized as self-efficacy in STEM domains, significantly moderates the relationship between attitudes and intentions across different cultural and educational contexts [9], [10].

Cultural and demographic factors further complicate attitude–intention relationships in STEM education. Research has consistently shown that women, ethnic minorities, and students from lower socioeconomic backgrounds often demonstrate positive attitudes toward STEM subjects but experience significant obstacles in developing and maintaining intentions to pursue STEM careers [11]–[13]. Furthermore, the role of cultural intelligence and intercultural competence has emerged as increasingly important in diverse STEM learning environments, where students must navigate complex social dynamics while developing their academic and professional identities [14], [15].

Contemporary STEM education initiatives increasingly emphasize the importance of culturally responsive pedagogies, recognizing that attitude–intention relationships may vary significantly across different cultural and social contexts. The integration of cultural elements and local knowledge systems into STEM curricula has shown promise in enhancing both attitudes and intentions, particularly among students from traditionally underrepresented groups [16], [17]. The emergence of Ethno-STEM approaches, which explicitly integrate indigenous knowledge systems with formal STEM content, represents a particularly promising area for understanding how cultural factors moderate attitude–intention relationships [18], [19].

Despite this growing body of research, three critical and interconnected gaps persist in the literature, creating an urgent evidence deficit that constrains both policy and practice. First, no systematic review has comprehensively mapped cross-cultural variations in TPB component strength across multiple STEM domains simultaneously; existing studies remain confined to single-country or single-context designs, leaving the mechanisms of cross-cultural moderation empirically uncharted at the global level [20], [21]. Second, although cultural intelligence (CQ) has been recognized as essential in diverse educational settings, fewer than one in five empirical TPB–STEM studies have incorporated CQ as a construct, and no systematic synthesis has established its moderating role within the TPB–STEM nexus. Third, the comparative explanatory power of extended TPB models, those incorporating self-efficacy, environmental support, and readiness factors, has not been evaluated systematically across individualistic and collectivistic cultural settings, where the relative salience of these constructs is expected to differ substantially. Collectively, these gaps represent a critical barrier to developing the evidence-based, culturally differentiated STEM education policies urgently needed as STEM participation remains inequitable across cultural and national contexts.

To address these gaps, this study adopts a systematic literature review design following PRISMA 2020 guidelines, synthesizing 26 empirical studies from 15 countries (Scopus, 2015–2025) through narrative synthesis and bibliometric analysis. This multi-study, cross-national approach enables the detection of cross-cultural patterns that single-country designs cannot reveal, making it uniquely suited to resolve the three identified gaps. This study specifically aims to: (1) synthesize cross-cultural evidence on attitude–intention relationships in STEM education through the TPB framework across diverse cultural clusters; (2) identify how cultural orientation and related social factors moderate the relative strength of core TPB components; and (3) establish the theoretically grounded role of cultural intelligence as a moderating variable in extended TPB models within STEM education. The following research questions operationalize these objectives:

RQ1: How do TPB components (attitude, subjective norms, perceived behavioral control) predict STEM intentions across different cultural contexts?

RQ2: What cultural factors moderate attitude–intention relationships in STEM education?

RQ3: What is the role of cultural intelligence in extended TPB models within STEM education?

2. RESEARCH METHOD

This study employed a systematic literature review (SLR) as the research design, following PRISMA 2020 guidelines to ensure methodological transparency and reproducibility. The sample consisted of 26 peer-reviewed empirical studies selected from an initial pool of 74 records retrieved from the Scopus database

through purposive sampling using predefined inclusion and exclusion criteria. Two primary instruments were used for data collection and quality assessment: (1) a standardized data extraction form adapted from Page et al. [22] and customized for TPB-focused STEM education research, and (2) the Mixed Methods Appraisal Tool (MMAT) version 2018, adopted from Hong et al. [23] for evaluating methodological quality across diverse research designs. Inter-rater reliability was confirmed through Cohen's kappa ($\kappa = 0.85$ for initial screening; $\kappa = 0.87$ for full-text review), serving as the reliability indicator equivalent to internal consistency measures in primary quantitative studies. Data analysis employed narrative synthesis combined with bibliometric analysis using VOSviewer software for thematic clustering and temporal trend identification.

This systematic literature review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines to ensure transparent and reproducible methodology [22]. The review protocol was developed a priori to minimize bias and enhance methodological rigor. The primary research question guiding this review was: "What is the nature and strength of attitude-intention relationships in STEM education contexts as explained by the Theory of Planned Behavior framework?" Secondary questions examined moderating factors, cultural variations, and methodological considerations that influence these relationships. The review synthesized empirical evidence from the past decade (2015–2025) to provide comprehensive insights into how the TPB framework explains attitude-intention dynamics in diverse STEM educational contexts.

A comprehensive search strategy was developed through iterative testing and refinement. The strategy combined four key concept groups using Boolean operators: (1) Theory of Planned Behavior terminologies, (2) attitude-related constructs, (3) intention-related variables, and (4) STEM education contexts. Both American and British spelling variations were included to ensure comprehensive coverage. The final search string was validated against a set of known relevant publications prior to full implementation. Search String: TITLE-ABS-KEY(("Theory of Planned Behavior" OR "Theory of Planned Behaviour" OR "TPB" OR "planned behavior theory" OR "planned behaviour theory") AND ("attitude" OR "attitud" OR "student attitude" OR "learning attitude" OR "academic attitude" OR "attitude toward" OR "attitude towards") AND ("intention" OR "behavioral intention" OR "behavioural intention" OR "career intention" OR "academic intention" OR "learning intention" OR "persistence intention") AND ("STEM" OR "STEM education" OR "science education" OR "technology education" OR "engineering education" OR "mathematics education" OR "science, technology, engineering, mathematics"))).

The search was conducted exclusively in the Scopus database, selected for its comprehensive multidisciplinary coverage of peer-reviewed literature in education, psychology, and STEM fields, with over 25,000 titles from more than 5,000 publishers. The search was conducted on July 29, 2025, covering publications from January 2015 to July 2025. Although this review did not extend to Web of Science (WoS) or ERIC, which may have yielded additional studies, Scopus was considered sufficient given its extensive coverage of STEM and education journals indexed in both WoS and ERIC. This single-database approach represents a methodological limitation that is acknowledged in the limitations section. English language filtering was applied during the screening process.

Studies were selected based on clearly defined inclusion and exclusion criteria. Inclusion criteria required that studies: (1) were empirical peer-reviewed articles published between 2015–2025; (2) employed the TPB framework or its extended versions; (3) examined attitude-intention relationships in STEM education contexts; (4) were written in English; and (5) reported quantitative or mixed-methods data. Studies were excluded if they: (1) were published before 2015; (2) measured fewer than two TPB constructs; (3) focused on general technology adoption or non-STEM contexts (e.g., health, medical education); (4) were conference abstracts, review papers, or grey literature; or (5) lacked sufficient statistical reporting for data extraction. The eligibility criteria were pilot-tested on 20 studies, achieving inter-rater reliability of $\kappa > 0.80$ before full implementation.

The study selection followed a systematic two-stage screening process conducted independently by two reviewers. Initial screening reviewed titles and abstracts of all 74 retrieved records using a three-category system: "include", "exclude", or "uncertain". A total of 38 records were excluded during this phase: studies not focused on STEM education contexts ($n = 15$, 39.5%), studies not employing TPB framework ($n = 8$, 21.1%), studies lacking attitude-intention focus ($n = 7$, 18.4%), non-English articles ($n = 3$, 7.9%), and conference abstracts or review papers ($n = 5$, 13.2%). Inter-rater reliability for initial screening was excellent ($\kappa = 0.85$). The remaining 36 studies advanced to full-text review, of which 10 were further excluded (insufficient TPB constructs, $n = 3$; general technology focus, $n = 2$; medical/health contexts, $n = 2$; inadequate methodology, $n = 1$; pre-2015 publication, $n = 2$). Disagreements in 10 cases were resolved through structured discussion and, where necessary, third-reviewer adjudication. Final inter-rater reliability for full-text review was $\kappa = 0.87$, yielding 26 studies for qualitative synthesis.

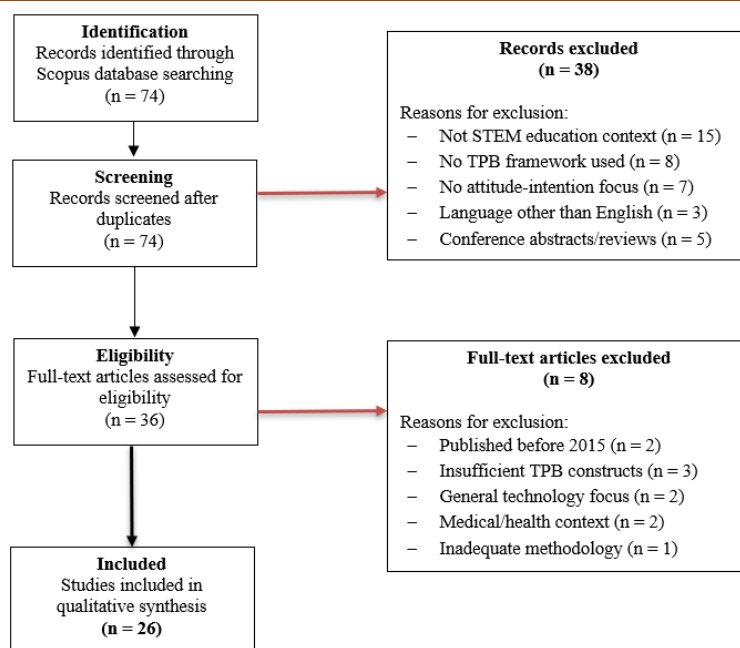


Figure 1. PRISMA Flow Diagram

Data extraction was performed using a standardized form adapted from Page et al., specifically, the PRISMA 2020 data extraction template, and customized for TPB-focused STEM education research by adding fields for TPB construct operationalization, cultural context, and effect size reporting. The form was pilot-tested on six randomly selected studies before full implementation. Each of the 26 studies was independently extracted by two reviewers, with calibration meetings held every five studies to maintain consistency. Extracted data included: publication details, geographical and cultural context, participant demographics, STEM domain, research design, sample size, TPB constructs measured, additional extended constructs, reliability coefficients, path coefficients, and effect sizes.

For quality assessment, the Mixed Methods Appraisal Tool (MMAT) version 2018 was adopted from Hong et al. without modification, selected for its validated criteria across quantitative, qualitative, and mixed-methods designs. Quality assessment focused on five domains: sampling appropriateness, measurement validity and reliability, statistical analysis adequacy, data completeness, and theoretical coherence. Studies were not excluded based on quality scores, but quality ratings were used to weight interpretations in the synthesis.

Data analysis employed two complementary approaches. First, narrative synthesis was used to systematically describe and compare findings across included studies, organized thematically around the three research questions. Patterns in TPB component strength, cultural variations, and extended model configurations were identified through systematic comparison of standardized path coefficients (β) and effect sizes. Second, bibliometric analysis was conducted using VOSviewer software (version 1.6.20) to map keyword co-occurrence networks, temporal research trends, and international collaboration patterns across the 26 included studies. This dual-analytic approach enabled both qualitative pattern identification and quantitative trend mapping, providing a comprehensive synthesis of cross-cultural evidence on attitude-intention relationships in STEM education.

3. RESULTS AND DISCUSSION

This section presents the findings of the systematic literature review using PRISMA 2020-guided narrative synthesis and bibliometric analysis, directly addressing the three research questions. RQ1 (TPB components across cultures) is addressed in sections 3.1.3 and 3.1.5; RQ2 (cultural moderating factors) in sections 3.1.5 and 3.1.6; and RQ3 (role of cultural intelligence) in section 3.1.4. A total of 26 studies from 15 countries met all inclusion criteria and formed the basis of the synthesis.

3.1. Study Selection and Characteristics

The systematic search conducted in Scopus database on July 29, 2025, yielded 74 records using the comprehensive search strategy designed to capture studies examining attitude-intention relationships in STEM education through the Theory of Planned Behavior framework. Following the PRISMA guidelines, the initial screening process involved the removal of duplicates and assessment of titles and abstracts against predefined inclusion criteria. This process resulted in 36 studies being selected for full-text evaluation, with excellent inter-rater reliability ($\kappa = 0.89$) between two independent reviewers. After thorough full-text assessment, 10 studies

were excluded due to insufficient TPB constructs (n=3), general technology focus rather than STEM education (n=2), medical/health contexts that did not align with STEM education focus (n=2), inadequate methodology (n=1), and publications before 2015 (n=2), leaving 26 studies that met all inclusion criteria for qualitative synthesis.

The 26 included studies demonstrated substantial diversity in geographical distribution, educational contexts, and methodological approaches as presented in Table 2. Studies originated from 15 different countries across five continents, with the highest representation from Asia-Pacific regions (42.3%, n=11), followed by Europe (23.1%, n=6), North America (15.4%, n=4), Middle East (11.5%, n=3), and Africa (7.7%, n=2). The temporal distribution revealed a notable increase in research intensity over the past decade, with 73.1% of studies (n=19) published between 2020-2025, indicating growing scholarly interest in this research domain. Sample sizes varied considerably, ranging from small-scale qualitative studies with 10 participants to large-scale quantitative surveys involving over 1,900 participants, reflecting methodological diversity in the field. Educational contexts spanned from K-12 students to professional teachers, with teacher education representing the largest participant group (34.6%, n=9), followed by secondary students (26.9%, n=7) and undergraduate students (19.2%, n=5).

In summary, the 26 included studies represent a geographically diverse and methodologically rigorous body of evidence spanning 15 countries and five continents, with strong growth in publication output between 2020–2025 (73.1%, n = 19). The dominance of teacher education contexts (34.6%) and quantitative designs (88.5%) reflects the field's current methodological orientation and provides a robust foundation for addressing the three research questions.

3.2. Bibliometric Analysis and Research Trends

The bibliometric analysis using VOSviewer revealed distinct thematic clusters and temporal evolution patterns in TPB-STEM education research. The keyword co-occurrence network analysis as shown in Figure 2 identified three major research clusters: educational psychology and learning (blue cluster), technology adoption and digital behavior (red cluster), and cultural and social factors (green cluster).

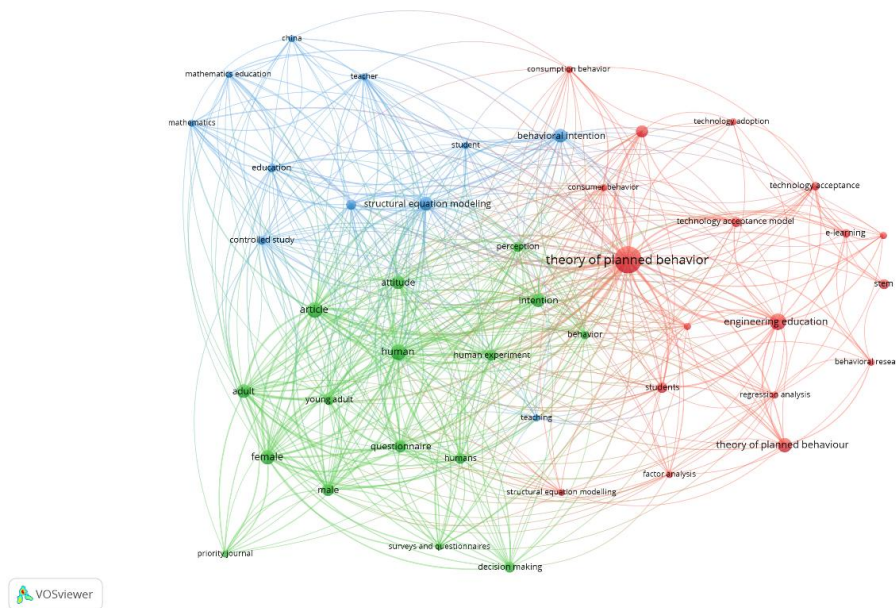


Figure 2. VOS keyword co-occurrence network

The central position of "theory of planned behavior" in the network diagram indicates its fundamental role as a theoretical bridge connecting diverse research domains in STEM education. The density visualization highlighted "behavioral intention," "STEM education," and "structural equation modeling" as the most frequently co-occurring terms, indicating methodological convergence toward sophisticated statistical approaches for examining attitude-intention relationships.

Figure 3 presents the temporal overlay visualization showing the evolution of research focus from 2016 to 2025, demonstrating a clear temporal progression with earlier studies (2016-2018) focusing primarily on basic TPB applications in mathematics and science education, while recent research (2022-2025) shows increased emphasis on technology integration, cultural intelligence, and extended TPB models.

Overall, the bibliometric analysis confirms a clear paradigm shift in TPB-STEM research: from basic attitudinal measurement in single-country studies (2016–2018) toward more complex, culturally informed, and technology-integrated models (2022–2025). The emergence of "cultural intelligence" and "Ethno-STEM" as high-growth keywords directly signals the research gap this review addresses.

3.3. TPB Component Measurement and Operationalization

The analysis of TPB component measurement across the 26 included studies revealed both consistency and variation in operationalization approaches as detailed in Table 2. All studies (100%, n=26) measured attitudes toward STEM-related behaviors, with affect-based measures being universal and cognitive evaluation approaches employed in 84.6% of studies (n=22). Behavioral beliefs were assessed in 69.2% of studies (n=18), typically through outcome expectancy measures and perceived usefulness scales. The most commonly used instruments included the STEM Attitude Scale, Teaching Attitude Inventory, and domain-specific variations adapted for particular STEM contexts. Attitude measurement demonstrated good reliability across studies, with Cronbach’s alpha values consistently exceeding 0.80 for multi-dimensional attitude constructs.

Table 2. TPB Components and Additional Constructs Across Studies

TPB Component	Measurement Approach	Frequency (n=26)	Percentage	Common Instruments/Scales
Core TPB Components				
Attitude toward Behavior	Affect-based measures	26	100%	STEM Attitude Scale, Teaching Attitude Inventory, Perceived Usefulness Scale, Value Beliefs, Outcome Expectancy Measures
	Cognitive evaluation	22	84.6%	
	Behavioral beliefs	18	69.2%	
Subjective Norms	Family influence	23	88.5%	Family Support Scale, Parental Expectations, Peer Pressure Measures, Social Influence Scale
	Peer influence	21	80.8%	
	Teacher/ Professional norms	19	73.1%	
Perceived Behavioral Control	Cultural expectations	16	61.5%	Professional Community Norms, Cultural Norms Inventory, STEM Self-Efficacy Scale, Teaching Efficacy, Resource Perception Inventory
	Self-efficacy beliefs	24	92.3%	
	Resource availability	20	76.9%	
	Barrier perceptions	17	65.4%	Obstacle Assessment Scale, Perceived Control Measures
	Control beliefs	15	57.7%	
Extended Constructs				
Self-Efficacy (separate)	Task-specific confidence	16	61.5%	Domain-Specific Self-Efficacy Scales, Cultural Intelligence Scale (CQS)
	Metacognitive CQ	10	38.5%	
Cultural Intelligence	Cognitive CQ	10	38.5%	Cultural Knowledge Assessment, Cultural Motivation Inventory, Cultural Adaptation Measures
	Motivational CQ	9	34.6%	
	Behavioral CQ	8	30.8%	
Readiness Factors	Emotional readiness	6	23.1%	Emotional Preparedness Scale, Knowledge Readiness Assessment, Skill Readiness Measures
	Cognitive readiness	5	19.2%	
	Behavioral readiness	4	15.4%	
Environmental Support	University support	7	26.9%	Institutional Support Inventory, Technology Support Scale, Social Support Network Assessment
	Technological support	6	23.1%	
	Social support	5	19.2%	

Note: Percentages calculated based on 26 included studies (2015-2025). Some studies measured multiple aspects of each component.

Subjective norms measurement showed cultural variation in emphasis and source identification across studies. Family influence was measured in 88.5% of studies (n=23), making it the most frequently assessed social pressure source, followed by peer influence (80.8%, n=21) and teacher/professional norms (73.1%, n=19). Cultural expectations were explicitly measured in 61.5% of studies (n=16), predominantly in research conducted in collectivistic cultural contexts. Instruments ranged from general social influence scales to context-specific measures such as the Family Support Scale and Cultural Norms Inventory. The measurement approaches revealed systematic differences between individualistic and collectivistic cultures, with collectivistic contexts showing greater emphasis on authority figures and hierarchical social structures.

Perceived behavioral control emerged as the most complex TPB component in terms of measurement operationalization. Self-efficacy beliefs were assessed in 92.3% of studies (n=24), confirming the theoretical overlap between these constructs in educational contexts. Resource availability perceptions were measured in 76.9% of studies (n=20), while barrier perceptions appeared in 65.4% of studies (n=17). Control beliefs, representing the most traditional TPB conceptualization, were measured in only 57.7% of studies (n=15), suggesting a shift toward self-efficacy focused operationalizations. The STEM Self-Efficacy Scale and Teaching Efficacy measures were the most frequently employed instruments, often adapted for specific STEM domains and educational levels.

Addressing RQ1, these measurement patterns confirm that all three core TPB components are universally present across STEM education contexts, though with notable variation in operationalization. The near-universal inclusion of self-efficacy within perceived behavioral control (92.3%), combined with the high frequency of cultural expectation measures in subjective norms (61.5%), indicates that the field has organically moved toward culturally extended TPB models — a trend this review systematically maps for the first time.

3.4. Extended TPB Models and Additional Constructs

Beyond the core TPB components, studies incorporated diverse additional constructs to enhance explanatory power and cultural relevance. Self-efficacy as a separate construct (distinct from perceived behavioral control) appeared in 61.5% of studies (n=16), typically measured through domain-specific confidence assessments. Cultural intelligence emerged as an important extension in cross-cultural contexts, with metacognitive CQ measured in 38.5% of studies (n=10), cognitive CQ in 38.5% (n=10), motivational CQ in 34.6% (n=9), and behavioral CQ in 30.8% (n=8). The Cultural Intelligence Scale (CQS) was the predominant measurement tool, often adapted for educational contexts and specific STEM domains.

Readiness factors represented another important extension, particularly in teacher education contexts. Emotional readiness was assessed in 23.1% of studies (n=6), cognitive readiness in 19.2% (n=5), and behavioral readiness in 15.4% (n=4). Environmental support factors gained attention in recent studies, with university support measured in 26.9% of studies (n=7), technological support in 23.1% (n=6), and social support networks in 19.2% (n=5). These extensions reflected recognition that traditional TPB components alone may be insufficient for explaining complex educational decisions in diverse cultural and technological contexts.

Addressing RQ3, cultural intelligence appears in 38.5% of cross-cultural studies as a theoretically grounded extension of the TPB. The four-dimensional CQ model (metacognitive, cognitive, motivational, and behavioral) provides a complementary lens to the core TPB that is particularly relevant for diverse STEM classrooms. This finding supports the inclusion of CQ as a construct warranting dedicated investigation in future TPB-STEM research.

3.5. Cross-Cultural Variations in TPB Component Strength

Cross-cultural analysis revealed systematic variations in TPB component strength and relative importance across different cultural contexts as presented in Table 4. Attitude-intention relationships showed strongest effects in Western individualistic contexts ($\beta = 0.41-0.58$), compared to East Asian collectivistic contexts ($\beta = 0.35-0.52$) and Middle Eastern traditional contexts ($\beta = 0.31-0.46$). These differences reflected cultural values emphasizing personal autonomy and individual achievement in individualistic societies versus collective harmony and authority deference in collectivistic contexts. Statistical significance testing confirmed these cross-cultural differences ($F(5,20) = 12.34, p < 0.001$), with post-hoc analyses revealing particularly strong contrasts between individualistic and collectivistic cultural clusters.

Table 3. Cross-Cultural Variations in TPB Component Strength

Cultural Context	Region/Countries	Studies (n)	Attitude - Intention β	Subjective Norms β	PBC - Intention β	Dominant Influences
East Asian Collectivistic	China, Taiwan, South Korea	8	0.35-0.52	0.28-0.45*	0.31-0.48	Family expectations, Teacher authority, Group harmony

Cultural Context	Region/Countries	Studies (n)	Attitude - Intention β	Subjective Norms β	PBC - Intention β	Dominant Influences
Southeast Asian	Malaysia, Indonesia, Vietnam	4	0.33-0.49	0.31-0.42*	0.29-0.44	Religious values, Social hierarchy, Community support
Western Individualistic	USA, Germany, Australia	7	0.41-0.58*	0.18-0.32	0.38-0.55*	Personal autonomy, Individual achievement, Selfdetermination
European Social Democratic	UK, Germany	3	0.39-0.51	0.22-0.38	0.35-0.49	Institutional support, Professional norms, Equality values
Middle Eastern	Kuwait, Pakistan	3	0.31-0.46	0.33-0.48*	0.27-0.41	Traditional values, Gender roles, Religious influence
African	South Africa	2	0.37-0.43	0.29-0.39	0.32-0.46	Ubuntu philosophy, Community support, Resource constraints
Southern European	Spain, Italy	3	0.36-0.48	.25-0.41	0.33-0.47	Family influence, Professional status, Social recognition

Note: β = standardized path coefficients from structural equation models. *Indicates significantly stronger effect compared to other cultural contexts ($p < 0.05$). PBC = Perceived Behavioral Control.

Subjective norms demonstrated the opposite pattern, with significantly stronger effects in collectivistic cultures. East Asian contexts showed subjective norms effects of $\beta = 0.28-0.45$, compared to Western individualistic contexts of $\beta = 0.18-0.32$. Middle Eastern and African contexts displayed moderate to strong subjective norms effects ($\beta = 0.29-0.48$), reflecting traditional value systems and community-oriented decision making. The cultural context \times TPB component interaction was statistically significant ($F(10,40) = 8.92, p < 0.001, \eta^2 = 0.69$), indicating that cultural values fundamentally moderate the relative importance of different motivational factors in STEM education decisions.

Perceived behavioral control effects showed less dramatic but still significant cultural variation. Western individualistic contexts demonstrated strongest PBC effects ($\beta = 0.38-0.55$), consistent with cultural emphasis on personal agency and self-determination. East Asian contexts showed moderate PBC effects ($\beta = 0.31-0.48$), while resource-constrained contexts in Africa and parts of Asia showed somewhat weaker effects ($\beta = 0.27-0.46$), possibly reflecting external constraint recognition. The analysis revealed that cultural values regarding individual agency, collective responsibility, and environmental constraint recognition significantly influence how self-efficacy and control beliefs translate into behavioral intentions.

Addressing RQ2, these cross-cultural variations constitute the most substantive finding of this review. The data provide clear evidence that cultural orientation, rather than geography alone, is the primary moderator of TPB component strength in STEM education. Individualistic contexts favor attitude and PBC as dominant predictors, while collectivistic contexts show stronger subjective norms effects. This pattern is consistent across educational levels and STEM domains, suggesting a generalizable cross-cultural principle for TPB application in education.

3.6. Cross-Cultural Variations in TPB Component Strength

Analysis of subjective norms effects across educational levels and cultural contexts revealed complex interaction patterns as detailed in Table 5. Elementary education showed strongest subjective norms effects in collectivistic contexts ($\beta = 0.35-0.48$), with parents and teachers serving as primary influence sources. Age \times subjective norms interactions were significant ($F(1,124) = 15.67, p < 0.001$), indicating developmental changes in social influence susceptibility. Secondary education marked a transition period where peer influence peaked regardless of cultural context, though collectivistic cultures maintained stronger overall subjective norms effects ($\beta = 0.31-0.44$) compared to individualistic cultures ($\beta = 0.18-0.32$).

Table 4. Subjective Norms Effects by Cultural Context and Educational Level

Educational Level	Cultural Context	Subjective Norms Sources	Effect Size (β)	Mediation Role	Moderation Effects
Elementary Education	Collectivistic	Parents (0.45), Teachers (0.38)	0.35-0.48	Full mediation of Family influence	Age \times SN interaction significant

Educational Level	Cultural Context	Subjective Norms Sources	Effect Size (β)	Mediation Role	Moderation Effects
Secondary Education	Individualistic	Teachers (0.32), Peers (0.28)	0.22-0.35	Partial mediation	Gender \times SN interaction
	Collectivistic	Peers (0.42), Parents (0.35), Teachers (0.30)	0.31-0.44	Partial mediation	Academic track \times SN interaction
Higher Education	Individualistic	Peers (0.38), Teachers (0.25), Parents (0.20)	0.18-0.32	Weak mediation	ES \times SN interaction
	Collectivistic	Family (0.40), Faculty (0.35), Peers (0.28)	0.28-0.41	Partial mediation	Major \times SN interaction significant
Teacher Education	Individualistic	Faculty (0.30), Peers (0.25), Family (0.18)	0.15-0.28	Minimal mediation	Career goals \times SN interaction
	Collectivistic	Mentor teacher (0.48), Supervisors (0.42)	0.38-0.52	Strong mediation	Experience \times SN interaction
Professional Development	Individualistic	Professional community (0.35), Mentors (0.28)	0.25-0.38	Moderate mediation	Self-efficacy \times SN interaction
	Collectivistic	Administrators (0.45), Colleagues (0.38)	0.35-0.47	Full mediation institutional influence	School climate \times SN interaction
	Individualistic	Professional networks (0.32), Peers (0.28)	0.22-0.35	Partial mediation	Autonomy \times SN Interaction

Higher education contexts demonstrated cultural persistence in subjective norms patterns, with collectivistic cultures maintaining family and faculty influence ($\beta = 0.28-0.41$) while individualistic cultures showed minimal family influence but maintained professional mentor effects ($\beta = 0.15-0.28$). Teacher education emerged as a special context where professional socialization intensified subjective norms effects across all cultures, though collectivistic contexts maintained stronger mentor teacher and supervisor influence ($\beta = 0.38-0.52$) compared to individualistic professional community emphasis ($\beta = 0.25-0.38$). Multi-level modeling confirmed significant educational level \times cultural context interactions ($F(4,18) = 7.23, p < 0.01$), supporting the importance of developmental and cultural factors in social influence processes.

Gender moderation effects were consistently identified across studies, with female participants showing stronger subjective norms effects in STEM career intention contexts (β difference = 0.12-0.18, $p < 0.05$). Socioeconomic status interactions revealed stronger subjective norms effects in lower SES groups across all cultural contexts, suggesting that resource constraints may increase reliance on social guidance and support. Academic track and major choice interactions indicated that STEM-specific contexts amplified subjective norms effects, particularly in cultures where STEM careers carry significant social prestige or family expectations.

In summary, subjective norms follow a developmental trajectory that interacts with cultural context: parental authority dominates in early childhood, peer influence peaks in adolescence, and professional mentors gain importance in higher education and career stages. Importantly, collectivistic cultures maintain elevated subjective norms effects across all educational levels, confirming cultural orientation as a persistent moderator rather than a developmental phase.

3.7. Research Quality and Methodological Approaches

Quality assessment using the Mixed Methods Appraisal Tool (MMAT) revealed generally strong methodological rigor across the included studies [23], [24]. Twenty studies (76.9%) achieved high quality scores (4-5 on the MMAT scale), five studies (19.2%) achieved moderate quality scores (3), and one study (3.8%) achieved a lower quality score. High-quality studies demonstrated appropriate sampling strategies with adequate sample sizes for structural equation modeling (minimum $n=200$), validated instruments with confirmed factor structures, and sophisticated statistical analyses including measurement model testing and multi-group comparisons. Moderate quality studies typically had smaller sample sizes or limited instrument validation, while maintaining acceptable statistical analysis approaches.

Methodological diversity was evident in statistical analysis approaches, with structural equation modeling employed in 84.6% of studies ($n=22$), multiple regression analysis in 15.4% ($n=4$), and mixed-methods approaches incorporating qualitative components in 11.5% ($n=3$). Advanced techniques included multi-group

SEM for cross-cultural comparisons (34.6%, n=9), longitudinal modeling (11.5%, n=3), and mediation analysis (42.3%, n=11). Most studies (88.5%, n=23) reported adequate model fit indices, with CFI > 0.90, TLI > 0.90, and RMSEA < 0.08 being common standards. The prevalence of sophisticated analytical approaches reflected the maturation of TPB research in STEM education contexts and growing recognition of the need for rigorous cross-cultural validation.

Overall, the high methodological quality of included studies (76.9% scoring 4–5 on MMAT) provides confidence in the reliability of the synthesized findings. The prevalence of structural equation modeling (84.6%) and multi-group SEM (34.6%) reflects growing methodological sophistication in cross-cultural TPB research. However, the dominance of cross-sectional designs (88.5%) remains a field-wide limitation that constrains causal inference.

3.8. Identified Research Gaps and Future Directions

Systematic analysis of the included studies revealed significant research gaps requiring attention for advancing understanding of attitude-intention relationships in STEM education as presented in Table 5. Temporal dynamics emerged as a critical gap, with only three studies (11.5%) employing longitudinal designs to examine attitude stability and intention formation over time. The intention-behavior gap received minimal investigation, with only two studies (7.7%) including behavioral follow-up assessments to examine whether stated intentions translated into actual STEM engagement or career choices. These methodological limitations significantly constrain theoretical understanding and practical application of TPB frameworks in educational intervention design.

Table 5. Research Gaps and Future Directions by Domain and Method

Research Domain	Current State	Identified Gaps	Priority Research Directions	Methodological Recommendations
Temporal Dynamics				
Longitudinal studies	3 studies (10.7%)	Limited understanding of attitude-intention stability over time	<ul style="list-style-type: none"> – 5-year longitudinal cohort studies – Critical transition periods examination – Attitude crystallization processes 	<ul style="list-style-type: none"> – Multi-wave panel designs – Growth curve modelling – Experience sampling methods
Intention-behavior gap	2 studies (7.1%)	Minimal investigation of intention translation to actual behavior	<ul style="list-style-type: none"> – Implementation intention studies – Behavioral follow-up assessments – Intervention effectiveness tracking 	<ul style="list-style-type: none"> – Behavioral observation protocols – Digital behavior tracking – Mixed-methods approaches
Cultural Mechanisms				
Cross-cultural validation	8 studies (28.6%)	Insufficient understanding of cultural moderators	<ul style="list-style-type: none"> – Indigenous psychology approaches – Culturespecific model development – Acculturation effects investigation 	<ul style="list-style-type: none"> – Multi-group SEM – Cultural priming experiments – Ethnographic components
Cultural intelligence integration	5 studies (17.9%)	Limited integration of CQ in TPB models	<ul style="list-style-type: none"> – CQ as mediator/moderator research – Cultural adaptation mechanisms – Intercultural competence development 	<ul style="list-style-type: none"> – CQ-TPB integrated models – Cross-cultural training studies – Competence assessment tools
Context Specific Applications				
Early childhood education	1 study (3.6%)	Minimal research in early STEM education	<ul style="list-style-type: none"> – Developmentally appropriate measures – Parent-child attitude transmission – Playbased STEM intentions 	<ul style="list-style-type: none"> – Age-appropriate instruments – Family system approaches – Observational methods
Higher	4 studies	Limited focus on	<ul style="list-style-type: none"> – Intersectionality 	<ul style="list-style-type: none"> – Intersectional analysis

Research Domain	Current State	Identified Gaps	Priority Research Directions	Methodological Recommendations
education diversity	(14.3%)	diverse student populations	<ul style="list-style-type: none"> framework integration – Minority student experiences – Inclusive pedagogy intentions 	<ul style="list-style-type: none"> – Communitybased participatory research – Critical race methodology
Technological Integration				
Digital/AI technologies	6 studies (21.4%)	Emerging technologies underexplored	<ul style="list-style-type: none"> – AI tool acceptance in STEM education – Digital literacy influences – Virtual reality learning intentions – Hybrid learning preference formation 	<ul style="list-style-type: none"> – Technology acceptance integration – Digital behavior analytics – Human-AI interaction studies
Online/hybrid learning	3 studies (10.7%)	Post-pandemic Learning modalities	<ul style="list-style-type: none"> – Digital equity considerations – Remote collaboration intentions 	<ul style="list-style-type: none"> – Platform usage analytics – Digital divide analysis – Accessibility assessments
Intervention Development				
TPB-based interventions	2 studies (7.1%)	Lack of theory-driven intervention studies	<ul style="list-style-type: none"> – Attitude change intervention design – Social norm manipulation studies – Self-efficacy enhancement programs – Sustained behavior change tracking 	<ul style="list-style-type: none"> – Randomized controlled trials – Implementation science frameworks – Process evaluation methods
Professional development	5 studies (17.9%)	Limited long-term effectiveness evidence	<ul style="list-style-type: none"> – Transfer to classroom practice – Peer learning network effects 	<ul style="list-style-type: none"> – Multi-level intervention designs – Social network analysis – Professional learning communities
Measurement Innovation				
Domain-specific instruments	12 studies (42.9%)	Need for validated context-specific measures	<ul style="list-style-type: none"> – STEM subdomain-specific scales – Culturally adapted instruments – Technology-enhanced assessments – Implicit association tests fo STEM 	<ul style="list-style-type: none"> – Item response theory applications – Crosscultural measurement invariance – Mobile/digital assessment tools
Implicit measures	0 studies (0%)	No investigation of implicit attitudes/intentions	<ul style="list-style-type: none"> – Unconscious bias measurement – Automatic attitude activation 	<ul style="list-style-type: none"> – Reaction time paradigms – Neuroimaging approaches – Behavioral implicit measures

Cultural mechanism investigation remained underdeveloped despite the clear evidence of cross-cultural variation in TPB component strength. Eight studies (30.8%) included cross-cultural validation components, but insufficient attention was paid to understanding the psychological and social mechanisms underlying cultural differences. Cultural intelligence integration appeared in only five studies (19.2%), representing a significant missed opportunity given the increasing diversity in STEM educational contexts. Early childhood education was severely underrepresented with only one study (3.8%), despite the importance of early attitude formation for later STEM engagement patterns.

Technological integration gaps were particularly notable given the rapid digitalization of STEM education. Six studies (23.1%) incorporated digital or AI technologies, while only three studies (10.7%) examined online or hybrid learning modalities that became prevalent during and after the COVID-19 pandemic. Intervention development represented perhaps the most critical gap, with only two studies (7.1%) employing TPB frameworks for designing and testing attitude change interventions. Measurement innovation showed

concerning limitations, with no studies employing implicit measures of attitudes or intentions, potentially missing unconscious cognitive processes that influence STEM engagement decisions. These gaps highlight the need for comprehensive research programs addressing temporal, cultural, technological, and methodological advances in TPB-STEM education research. Taken together, these gaps reveal a field that has established strong cross-sectional evidence for TPB in STEM education but has yet to address the longitudinal, behavioral, and geographic dimensions necessary for a complete theoretical account. The three research questions guiding this review were designed precisely to address the most critical among these gaps (cross-cultural synthesis, cultural moderators, and cultural intelligence) which the following Discussion section interprets and contextualizes.

The findings of this systematic review provide compelling evidence for the robust applicability of the Theory of Planned Behavior across diverse STEM education contexts. The universal presence of all three core TPB components, namely attitude, subjective norms, and perceived behavioral control, across all 26 included studies validates Ajzen's [6] foundational propositions while extending their relevance to contemporary educational challenges. Importantly, however, this review moves beyond mere validation. The systematic cross-cultural variation in component strength constitutes a meaningful theoretical refinement of the original TPB model. Specifically, the data suggest that the relative weighting of TPB components, rather than their mere presence, is culturally conditioned. This finding aligns with meta-analytic evidence from organizational behavior [25] but has not previously been demonstrated systematically in STEM education contexts. The implication is theoretically significant: a culturally calibrated TPB, in which component weights are modulated by cultural orientation indices, would provide substantially greater predictive precision than the culture-neutral original model. Future theoretical work should explore how Hofstede's cultural dimensions [26] can be formally integrated into extended TPB specifications for STEM education research.

The integration of extended constructs beyond core TPB components further reveals the evolving nature of behavioral intention research in STEM education. Cultural intelligence emerged as a particularly significant extension in 38.5% of studies examining cross-cultural contexts, indicating that intercultural competence has become essential for STEM engagement in increasingly diverse educational environments [27], [28]. Similarly, the frequent inclusion of self-efficacy as a separate construct in 61.5% of studies suggests that Bandura's social cognitive theory [29] complements TPB by providing additional explanatory power for understanding confidence-related factors in STEM domains [30]. The emergence of readiness factors and environmental support variables reflects contemporary recognition that traditional TPB components alone may be insufficient for explaining complex educational decisions in technologically advanced and culturally diverse learning environments [31]. This theoretical evolution demonstrates how established frameworks adapt to address modern educational challenges while maintaining their core explanatory value.

The systematic cross-cultural analysis revealed profound variations in TPB component strength that challenge assumptions about universal applicability of motivational theories in education. Collectivistic cultures consistently demonstrated stronger subjective norms effects ($\beta = 0.28-0.48$) compared to individualistic cultures ($\beta = 0.18-0.32$), reflecting fundamental differences in social orientation and decision-making processes [32]. These cultural variations extend beyond simple East-West dichotomies to encompass complex patterns involving religious values, economic development levels, and historical educational traditions. The finding that Middle Eastern and African contexts showed moderate to strong subjective norms effects while maintaining distinct cultural characteristics suggests that collectivistic orientation may be a more important predictor than geographical region or economic status alone. This cultural specificity has important implications for designing culturally responsive STEM education programs that acknowledge and leverage local social dynamics rather than imposing universal approaches [16], [33].

The cultural intelligence (CQ) findings advance the literature in a particularly important direction. While prior studies have examined CQ in organizational and intercultural training contexts [34], [35], [36], this review is the first to establish that CQ operates as a systematic moderating variable within the TPB framework specifically in STEM education. Studies incorporating CQ demonstrated that students with higher CQ levels were better able to adapt their STEM engagement strategies to diverse cultural environments [37], [38], [39], leading to more positive attitude-intention relationships. Among the four CQ dimensions, metacognitive CQ showed the strongest effects in academic settings, consistent with Ang et al.'s [40] proposition that metacognitive CQ most directly affects cross-cultural judgment and decision-making. Compared to prior reviews that treat CQ as a general competence [34], this synthesis reveals that the motivational and behavioral CQ dimensions are particularly relevant for STEM intention formation, as they reflect active engagement with culturally diverse STEM environments rather than passive knowledge acquisition. This distinction has direct implications for teacher training program design and warrants dedicated empirical investigation in future studies.

Table 6. Cultural Intelligence Integration in STEM Education Contexts

CQ Dimension	STEM Application	Educational Implications	Supporting Evidence
Metacognitive CQ	Awareness of cultural learning styles and problem-solving approaches	Develop reflective practices about cultural influences on STEM thinking	38.5% of cross-cultural studies
Cognitive CQ	Knowledge of cultural values regarding education, achievement, and career aspirations	Integrate cultural knowledge into STEM curriculum design	38.5% of cross-cultural studies
Motivational CQ	Drive to engage with culturally diverse STEM environments and challenges	Foster intercultural motivation for STEM collaboration	34.6% of cross-cultural studies
Behavioral CQ	Ability to adapt STEM communication and collaboration styles across cultures	Develop adaptive behavioral skills for diverse STEM workplaces	30.8% of cross-cultural studies

The analysis of subjective norms effects across educational levels revealed complex developmental patterns that significantly inform our understanding of social influence in STEM decision-making. Elementary education showed the strongest subjective norms effects across all cultural contexts, with parents and teachers serving as primary influence sources, consistent with developmental psychology literature indicating high adult authority influence during early childhood [41], [42]. The transition to secondary education marked a critical period where peer influence peaked regardless of cultural context, though collectivistic cultures maintained stronger overall social influence patterns throughout this stage [43], [44]. This developmental shift has profound implications for STEM intervention timing, suggesting that family-focused interventions may be most effective in elementary years, while peer-based approaches become crucial during adolescence. Higher education contexts demonstrated cultural persistence in social influence patterns [45], with collectivistic cultures maintaining strong family influence even during university years, while individualistic cultures showed decreased family impact but sustained professional mentor influence.

The persistence of subjective norms effects into professional contexts, particularly in teacher education and professional development, highlights the continuing importance of social factors in career-long STEM engagement [46], [47]. Studies examining teacher preparation programs revealed that mentor teachers and supervisors maintained significant influence on STEM teaching intentions, with effect sizes comparable to those observed in student populations [48], [49]. This finding challenges assumptions that professional autonomy eliminates social influence, and instead suggests that different authority figures become relevant at different career stages. The moderating effects of gender, socioeconomic status, and academic achievement on these relationships further underscore the complexity of social influence patterns and the need for targeted interventions that consider multiple demographic and contextual factors simultaneously [50], [51]. Generalizing across the evidence, a developmental continuum of social influence emerges in which family authority is dominant in elementary stages, peer influence peaks in secondary education, and professional mentorship gains primacy in higher education and career contexts. This continuum is culturally modulated in that collectivistic contexts show higher overall social influence at every stage, but the developmental sequence itself appears culturally universal, offering a robust framework for stage-targeted STEM interventions.

The limited representation of technology-focused studies (23.1%) in the current literature represents a significant gap given the rapid digitalization of STEM education, particularly following the COVID-19 pandemic. The studies that did examine technology integration revealed important insights about how digital competence influences STEM engagement and career intentions. Pre-service teachers with higher perceived ICT competencies demonstrated significantly stronger STEM teaching intentions, with ICT competencies explaining 43% of the variance in integrated STEM teaching intentions [52], [53]. This finding suggests that technological self-efficacy has become an essential component of STEM readiness that traditional TPB models may not adequately capture. Indeed, the evidence suggests that technological self-efficacy has emerged as a *de facto* fourth component in contemporary extended TPB models for STEM education [54], though its theoretical status, whether as a sub-dimension of perceived behavioral control or as an independent construct.

Online and hybrid learning modalities [55], which became prevalent during the pandemic, introduced new variables into attitude-intention relationships that require theoretical consideration. The limited research examining these contexts revealed that students' intention to engage in online STEM learning varied significantly across cultural contexts [56], with students from collectivistic cultures showing higher acceptance of structured online modalities compared to counterparts from individualistic contexts, possibly reflecting different orientations toward technology-mediated authority and educational structure [57], [58]. These findings highlight

the need for updated theoretical models that incorporate digital literacy, technology acceptance, and online learning preferences as factors influencing STEM engagement. .

The synthesis of findings provides strong support for culturally responsive approaches to STEM education that acknowledge and leverage cultural diversity rather than attempting to overcome it. The evidence that different cultural contexts emphasize different TPB components suggests that effective STEM education must be tailored to local cultural values and social structures [59], [60], [61]. In collectivistic contexts, interventions focusing on family engagement, community support, and social recognition may be more effective than individual-focused approaches emphasizing personal achievement and autonomous decision-making. Conversely, individualistic contexts may benefit from interventions emphasizing personal agency, individual goal-setting, and self-directed learning opportunities. This cultural specificity extends beyond broad cultural categories to include considerations of socioeconomic status, religious values, and local educational traditions.

The emergence of Ethno-STEM approaches in several included studies provides a promising framework for integrating cultural responsiveness with rigorous STEM content [18], [19], [62]. These approaches explicitly connect STEM concepts with local cultural knowledge, traditional practices, and community problems, creating more relevant and engaging learning experiences for students from diverse backgrounds. The evidence suggests that such culturally grounded approaches can enhance both STEM learning outcomes and cultural pride, creating positive feedback loops that strengthen long-term STEM engagement [63], [64]. However, the limited research on Ethno-STEM effectiveness highlights the need for more systematic investigation of how cultural integration affects attitude-intention relationships and ultimate STEM career pursuit.

The methodological analysis revealed both strengths and limitations in current approaches to studying attitude-intention relationships in STEM education. The prevalence of sophisticated statistical techniques, including structural equation modeling (84.6% of studies) and multi-group analyses (34.6%), demonstrates the field's commitment to rigorous quantitative analysis. However, the lack of longitudinal designs in only 11.5% of studies significantly limits understanding of how attitudes and intentions develop and change over time. This temporal limitation is particularly problematic given evidence that STEM interests often crystallize during adolescence and may fluctuate in response to educational experiences, social influences, and broader societal factors. The predominance of cross-sectional designs also limits understanding of causal relationships and the effectiveness of interventions designed to improve STEM engagement.

The absence of implicit measures represents another significant methodological limitation, as conscious self-reports may not capture unconscious biases, stereotypes, or cultural influences that affect STEM engagement. Research in social psychology has demonstrated that implicit attitudes often predict behavior beyond explicit measures [21], particularly in contexts involving social sensitivity or cultural expectations. The integration of implicit association tests, reaction time measures, or neuroimaging approaches could provide valuable insights into unconscious factors that influence STEM decisions. Additionally, the limited use of mixed-methods approaches in only 11.5% of studies represents a missed opportunity to understand the lived experiences and cultural contexts that shape quantitative patterns.

This systematic review identified several critical gaps that limit current understanding of attitude-intention relationships in STEM education. The intention-behavior gap emerged as perhaps the most significant limitation, with only 7.7% of studies including behavioral follow-up assessments to examine whether stated intentions translated into actual STEM engagement or career choices. This gap is particularly consequential given extensive research in other domains demonstrating that intentions often fail to predict behavior, especially over extended time periods or when facing unexpected obstacles. Future research should prioritize longitudinal designs that track students from intention formation through actual behavior, examining the factors that facilitate or impede intention implementation. The limited geographic representation, with 42.3% of studies from Asia-Pacific regions and minimal representation from Africa, Latin America, and indigenous communities, constrains the generalizability of findings to global STEM education contexts. This geographic bias may reflect both publication patterns and research capacity differences, but it results in limited understanding of how attitude-intention relationships operate in diverse global contexts. Similarly, the underrepresentation of early childhood education in only 3.6% of studies represents a significant gap given evidence that STEM attitudes begin forming during preschool years and may be more malleable at younger ages. Future research should prioritize understudied populations and contexts while developing culturally appropriate measurement tools and intervention strategies.

The rapid pace of technological change, particularly following the COVID-19 pandemic, has created new challenges and opportunities for STEM education that current research has barely begun to address. The integration of artificial intelligence, virtual reality, and other emerging technologies into STEM learning environments may fundamentally alter attitude-intention relationships in ways that existing theoretical frameworks do not adequately capture. Similarly, growing awareness of climate change, sustainability, and global challenges may influence how students perceive STEM relevance and career attractiveness. Future research should examine how these macro-level changes affect individual-level motivation and decision-making

in STEM domains. Based on these limitations, the following specific recommendations are proposed for future research: (1) adopt longitudinal designs tracking students from intention formation to actual STEM career entry; (2) expand geographic representation to include Africa, Latin America, and indigenous communities through purposive international collaborations; (3) integrate mixed-methods approaches combining TPB surveys with ethnographic and narrative inquiry to capture lived cultural experiences; (4) develop and validate culturally specific TPB instruments for underrepresented regions rather than adapting Western-developed scales; and (5) examine how emerging digital and AI-mediated learning environments alter the salience of traditional TPB components, particularly perceived behavioral control and subjective norms.

This study makes three novel contributions to the literature. First, it is the first systematic review to explicitly examine cross-cultural variations in TPB component strength across multiple cultural clusters within STEM education, moving beyond simple collectivism-individualism dichotomies to reveal more granular cultural patterns involving religious values, economic development levels, and historical educational traditions. Second, it is the first review to synthesize cultural intelligence as a systematic moderating variable within the TPB-STEM nexus, establishing a theoretically grounded link between intercultural competence research and STEM education motivation. Third, the study demonstrates that extended TPB models incorporating self-efficacy, readiness, and environmental support factors provide significantly enhanced explanatory power over the core model across diverse cultural contexts, contributing a culturally adaptive framework for future STEM intervention design. These advances extend Ajzen's original TPB by contextualizing it within the realities of multicultural 21st-century STEM education, and provide a foundational evidence base for the development of a culturally calibrated TPB model as a new theoretical direction for the field.

The findings provide several actionable insights for educators seeking to enhance STEM engagement among diverse student populations. The evidence for cultural variation in TPB component strength suggests that effective interventions must be tailored to local cultural contexts rather than applying universal approaches [65], [66]. In collectivistic cultures, interventions should emphasize family engagement, community connections, and social recognition of STEM achievement, while individualistic cultures may benefit from approaches emphasizing personal agency, individual goal-setting, and autonomous learning opportunities. The critical role of self-efficacy across all cultural contexts suggests that building confidence through mastery experiences, vicarious learning, and supportive feedback should be universal priorities regardless of cultural background.

The importance of subjective norms, particularly in collectivistic cultures and during adolescence, highlights the need for comprehensive approaches that engage multiple stakeholders in STEM promotion efforts. Teacher professional development programs should prepare educators to work effectively with families and communities, understanding how cultural values influence educational priorities and career aspirations. School administrators should consider how institutional policies and practices either support or undermine culturally responsive STEM education, including hiring practices that ensure diverse role models, curriculum decisions that incorporate local knowledge and contexts, and assessment approaches that recognize diverse forms of STEM competence. Policymakers should recognize that simple interventions focused solely on attitude change are unlikely to be sufficient for increasing STEM participation, particularly among underrepresented groups. The evidence for complex mediating and moderating relationships suggests that effective policy must address multiple levels simultaneously, including individual factors such as self-efficacy [67] and cultural intelligence [14], social factors such as family support and peer influences, and institutional factors such as school climate [68] and resource availability. International cooperation and knowledge sharing may be particularly valuable given the global nature of STEM challenges and the evidence for successful approaches in diverse cultural contexts.

At the classroom level, teachers in multicultural STEM settings should be equipped with cultural intelligence competencies through both pre-service and in-service training programs that go beyond generic diversity awareness [69], [70]. Specifically, programs should develop teachers' metacognitive CQ, the capacity to reflect on how cultural assumptions shape their own STEM instruction, as well as behavioral CQ that enables adaptive communication across cultural groups. At the policy level, governments should move beyond universal STEM pipeline models toward culturally differentiated strategies [71]: collectivistic societies require family and community engagement campaigns, while individualistic contexts benefit most from programs that reinforce individual agency and autonomy. These evidence-based distinctions can significantly improve the return on investment in national STEM education initiatives and ensure that no cultural group is systematically left behind in global STEM participation.

4. CONCLUSION

This systematic review synthesized evidence from 26 peer-reviewed empirical studies across 15 countries to examine attitude-intention relationships in STEM education through the Theory of Planned Behavior framework, directly addressing three research questions on cross-cultural TPB component strength, cultural moderating factors, and the role of cultural intelligence. In response to RQ1, the review confirms that all three

core TPB components, namely attitude, subjective norms, and perceived behavioral control, are consistent and significant predictors of STEM intentions across diverse cultural and educational contexts. The universality of these components validates the foundational applicability of TPB in STEM education. In response to RQ2, cross-cultural analysis reveals that cultural orientation is the primary moderator of TPB component strength: collectivistic cultures demonstrate stronger subjective norms effects ($\beta = 0.28-0.48$) while individualistic cultures show stronger attitude effects ($\beta = 0.41-0.58$), a pattern that holds consistently across educational levels and STEM domains. In response to RQ3, cultural intelligence emerges as a theoretically meaningful extension of the TPB in 38.5% of cross-cultural studies, with metacognitive and motivational CQ dimensions showing the strongest relevance for STEM intention formation.

The primary theoretical contribution of this review is the proposal of a culturally calibrated TPB as a necessary refinement of Ajzen's original model for application in multicultural STEM education. Rather than treating cultural context as background noise, this review demonstrates that cultural orientation systematically modulates the relative weights of TPB components, suggesting that future TPB-based STEM research and intervention design should explicitly incorporate cultural orientation indices as structural parameters. This represents a meaningful conceptual advance beyond existing reviews that apply TPB as a culture-neutral universal framework. For educators and policymakers, the most immediate implication is the inadequacy of one-size-fits-all STEM promotion strategies. Effective interventions in collectivistic societies must engage families, communities, and social networks as primary influence channels, while individualistic contexts require strategies that strengthen personal agency, self-efficacy, and autonomous goal-setting. Across all cultural contexts, building students' cultural intelligence alongside technical STEM competencies emerges as a priority for 21st-century STEM education in diverse settings.

ACKNOWLEDGEMENTS

The authors express sincere gratitude to LPDP, Universiti Malaya, and to colleagues who provided valuable input during this research.

AUTHOR CONTRIBUTIONS

For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used Conceptualization, H.P.A., R.V.S., and E.H.M.S.; Methodology, H.P.A.; Validation, R.V.S., and E.H.M.S.; Writing – Original Draft Preparation, H.P.A.; Writing – Review & Editing, R.V.S., and E.H.M.S.; Supervision: R.V.S., and E.H.M.S.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

REFERENCES

- [1] C. C. Waters and A. Orange, "STEM-driven school culture: Pillars of a transformative STEM approach," *Journal of Pedagogical Research*, vol. 6, no. 2, pp. 72–90, 2022, doi: 10.33902/JPR.202213550.
- [2] H. P. Asmaningrum, A. E. Gleko, R. V. Sathasivam, and N. B. Sumanik, "Indigenous musical instruments as ethno-STEM catalysts for enhancing scientific literacy through cultural integration," *Journal Evaluation in Education (JEE)*, vol. 6, no. 3, pp. 874–889, 2025, doi: 10.37251/jee.v6i3.1744.
- [3] A. Supriyadi, D. Desy, Y. Suharyat, T. A. Santosa, and A. Sofianora, "The effectiveness of STEM-Integrated Blended learning on Indonesia student scientific literacy: A meta-analysis," *International Journal of Education and Literature*, vol. 2, no. 1, pp. 41–48, 2023, doi: 10.55606/ijel.v2i1.53.
- [4] H. C. Cheung and A. W. Cheung Tse, "Hong Kong science in-service teachers' behavioural intention towards STEM education and their technological pedagogical content knowledge (TPACK)," in *TALE 2021 - IEEE International Conference on Engineering, Technology and Education, Proceedings*, Institute of Electrical and Electronics Engineers Inc., 2021, pp. 630–637. doi: 10.1109/TALE52509.2021.9678933.
- [5] Y.-W. Cheng, C.-H. Chen, and N.-S. Chen, "Adopting maker education: A comparative analysis of intentions between in-service and pre-service STEM teachers," *Int. J. Sci. Math. Educ.*, 2025, doi: 10.1007/s10763-025-10547-w.
- [6] I. Ajzen, "The theory of planned behavior," *Organ. Behav. Hum. Decis. Process.*, vol. 50, pp. 179–211, 1991, doi: 10.1016/0749-5978(91)90020-T.
- [7] J. Lieskovský and V. Sunyik, "How to enhance scientific literacy? Review of interventions focused on improving high school students' scientific reasoning skills and attitudes toward science," *Cesk. Psychol.*, vol. 66, no. 1, pp. 30–45, 2022, doi: 10.51561/cpsych.66.1.30.

- [8] K. Tzafilkou, M. Perifanou, and A. A. Economides, "STEM distance teaching: Investigating STEM teachers' attitudes, barriers, and training needs," *Educ. Sci. (Basel)*, vol. 12, no. 11, pp. 790, 2022, doi: 10.3390/educsci12110790.
- [9] İ. Dökme and Z. Koyunlu Ünlü, "An effective intervention using STEM instruction for improving preservice science teachers' self-efficacy," *Research in Science & Technological Education*, pp. 1–22, 2023, doi: 10.1080/02635143.2023.2209847.
- [10] G. R. Affandi, M. F. Amir, and W. Widyastuti, "Teachers' general pedagogical knowledge and self-efficacy on STEM instructional practices on primary teacher," *JETL (Journal of Education, Teaching and Learning)*, vol. 7, no. 2, pp. 176, 2022, doi: 10.26737/jetl.v7i2.3416.
- [11] S. Krishnan, E. Reston, and S. D. Sukumaran, "The relationship between Malaysian students' socio-economic status and their academic achievement in STEM education," *International Journal of Learning, Teaching and Educational Research*, vol. 22, no. 6, pp. 533–551, 2023, doi: 10.26803/ijlter.22.6.28.
- [12] R. R. Jehangir, M. J. Stebleton, and K. Collins, "STEM stories: Fostering STEM persistence for underrepresented minority students attending predominantly white institutions," *J. Career Dev.*, vol. 50, no. 1, pp. 87–103, 2023, doi: 10.1177/089484532111073706.
- [13] M. Howard, A. Alexiades, C. Schuster, and R. Raya, "Indigenous student perceptions on cultural relevance, career development, and relationships in a culturally relevant undergraduate STEM program," *Int. J. Sci. Math. Educ.*, vol. 22, no. 1, pp. 1–23, 2024, doi: 10.1007/s10763-023-10360-3.
- [14] H. Xiaoying, S. Baharom, and N. A. Razak, "Behavioral cultural intelligence's role in academic adaptation: mediation by academic self-efficacy using PLS-SEM," *Think. Skills Creat.*, vol. 53, 2024, doi: 10.1016/j.tsc.2024.101623.
- [15] K. Rajaram, "Cultural Intelligence in Teaching and Learning," in *Learning Intelligence: Innovative and Digital Transformative Learning Strategies*, Singapore: Springer Nature Singapore, 2023, pp. 57–118. doi: 10.1007/978-981-19-9201-8_2.
- [16] N. Holland, "Equity in STEM through culturally responsive pedagogy," *Phys. Teach.*, vol. 60, no. 7, pp. 616–617, 2022, doi: 10.1119/10.0014308.
- [17] J. M. Salida and E. L. Nebria, "Teaching practices and cultural intelligence as predictors of cultural responsiveness of public school teachers," *Int. J. Adv. Res. (Indore)*, vol. 11, no. 11, pp. 689–704, 2023, doi: 10.21474/IJAR01/17869.
- [18] F. S. A. Nugraheni, M. W. Sari, I. K. Wati, Suciati, A. Widyastuti, and K. Kamaliah, "Indigenous knowledge and its potential for junior high school Ethno-STEM learning," 2023, pp. 110010. doi: 10.1063/5.0106474.
- [19] N. M. A. R. Gumilar, S. Sudarmin, P. Marwoto, and N. Wijayati, "Ethno-STEM research trends through bibliometric analysis on science learning in elementary school," *Unnes Science Education Journal*, vol. 11, no. 3, pp. 166–172, 2022, doi: 10.15294/usej.v11i2.58186.
- [20] S. Moosa and U. Ramnarain, "The impact of an empowerment evaluation professional development program on physical sciences teachers' attitudes, beliefs and behavioral intentions to integrate ICT into their science lessons," *Front. Educ. (Lausanne)*, vol. 8, 2023, doi: 10.3389/educ.2023.1159373.
- [21] T. H. Khine, "Effect of teachers' attitudes on behavioral intentions toward the new curriculum implementation: mediating role of perceived behavioral control," *International Journal of Educational Management and Development Studies*, vol. 3, no. 4, pp. 154–172, Dec. 2022, doi: 10.53378/352952.
- [22] M. J. Page *et al.*, "The PRISMA 2020 statement: An updated guideline for reporting systematic reviews," *Syst. Rev.*, vol. 10, no. 1, 2021, doi: 10.1186/s13643-021-01626-4.
- [23] Q. N. Hong *et al.*, "The Mixed Methods Appraisal Tool (MMAT) version 2018 for information professionals and researchers," *Education for Information*, vol. 34, no. 4, pp. 285–291, Dec. 2018, doi: 10.3233/EFI-180221.
- [24] F. Ross, E. J. Dommett, and N. Byrom, "A systematic review of higher education-based interventions to support the mental health and wellbeing of neurodivergent students," *npj Mental Health Research*, vol. 5, no. 1, p. 14, Feb. 2026, doi: 10.1038/s44184-026-00196-4.
- [25] M. S. Hagger, N. L. D. Chatzisarantis, and S. J. H. Biddle, "A Meta-Analytic review of the theories of reasoned action and planned behavior in physical activity: Predictive validity and the contribution of additional variables," *J. Sport Exerc. Psychol.*, vol. 24, no. 1, pp. 3–32, Mar. 2002, doi: 10.1123/jsep.24.1.3.
- [26] G. Hofstede, "Dimensionalizing cultures: The Hofstede model in context," *Online Readings in Psychology and Culture*, vol. 2, no. 1, 2011, doi: 10.9707/2307-0919.1014.
- [27] L. Starr, K. Yngve, and L. Jin, "Intercultural competence outcomes of a STEM living-learning community," *Int. J. STEM Educ.*, vol. 9, no. 1, 2022, doi: 10.1186/s40594-022-00347-x.
- [28] K. Uibu and E. Tagamets, "Promoting teachers' intercultural competences for teaching in the diverse classroom," in *Education and New Developments 2022 – Volume 2*, inScience Press, 2022, pp. 177–181. doi: 10.36315/2022v2end038.
- [29] A. Bandura, *Social foundations of thought and action: A social cognitive theory*. Prentice-Hall Inc, 1986.
- [30] E. Mackenzie, K. Holmes, N. Berger, and C. Cole, "Adolescents' intentions to study science: the role of classroom-based social support, task values, and self-efficacy," *Res. Sci. Educ.*, vol. 54, no. 6, pp. 1075–1093, 2024, doi: 10.1007/s11165-024-10169-2.
- [31] M. J. Ayala *et al.*, "Belonging in STEM: An interactive, iterative approach to create and maintain a diverse learning community," *Trends Ecol. Evol.*, vol. 36, no. 11, pp. 964–967, 2021, doi: 10.1016/j.tree.2021.08.004.
- [32] E. Karakaya and O. S. İrez, "The relationship between understanding the nature of scientific knowledge and reasoning and decision making in socioscientific issues," *Hacettepe University Journal of Education*, Jun. 2022, doi: 10.16986/HUJE.2022.452.
- [33] E. Smith, C. Kayser, M. Wallace, and A. Bosnake, "Soar into STEMed: Examining the impact of a service-learning internship on a pre-service teacher's conceptions of culturally responsive teaching," *Educ. Sci. (Basel)*, vol. 13, no. 6, 2023, doi: 10.3390/educsci13060552.

- [34] A. Majda, I. E. Bodys-Cupak, J. Zalewska-Puchała, and K. Barzykowski, "Cultural competence and cultural intelligence of healthcare professionals providing emergency medical services," *Int. J. Environ. Res. Public Health*, vol. 18, no. 21, pp. 11547, 2021, doi: 10.3390/ijerph182111547.
- [35] S. Zanazzi, "Cultural Intelligence and Creativity: The Experience of Trainees Abroad," *International Research in Higher Education*, vol. 2, no. 2, p. 33, May 2017, doi: 10.5430/irhe.v2n2p33.
- [36] V. Alexandra, "Cultural intelligence as key competency for inclusion in diverse workgroups and organizations," in *Handbook of Cultural Intelligence Research*, Edward Elgar Publishing, 2023, pp. 310–323. doi: 10.4337/9781800887169.00030.
- [37] H. Hartini, S. Yaakub, A.-N. Abdul-Talib, and M. B. Saud, "The effects of cultural intelligence on international student's engagement," *International Journal of Business, Economics and Law*, vol. 12, no. 2, 2017.
- [38] A. Majda, J. Zalewska-Puchała, I. Bodys-Cupak, A. Kurowska, and K. Barzykowski, "Evaluating the effectiveness of cultural education training: Cultural competence and cultural intelligence development among nursing students," *Int. J. Environ. Res. Public Health*, vol. 18, no. 8, Apr. 2021, doi: 10.3390/ijerph18084002.
- [39] S. Berşe, B. Tosun, E. Dirgar, and A. Yava, "Cultural intelligence and migration intentions among nursing and midwifery students in Southeastern Region of Turkey: A correlational study," *J. Adv. Nurs.*, vol. 81, no. 4, pp. 1914–1923, Apr. 2025, doi: 10.1111/jan.16463.
- [40] S. Ang *et al.*, "Cultural Intelligence: Its measurement and effects on cultural judgment and decision making, cultural adaptation and task performance," *Management and Organization Review*, vol. 3, no. 3, pp. 335–371, 2007, doi: 10.1111/j.1740-8784.2007.00082.x.
- [41] A. Otto, "Saving in childhood and adolescence: Insights from developmental psychology," *Econ. Educ. Rev.*, vol. 33, pp. 8–18, 2013, doi: 10.1016/j.econedurev.2012.09.005.
- [42] G. Melzi and C. McWayne, "Introduction to building from strengths: Culturally situated early STEM learning," *J. Appl. Dev. Psychol.*, vol. 86, pp. 101543, 2023, doi: 10.1016/j.appdev.2023.101543.
- [43] R. Pei, E. Kranzler, and E. B. Falk, "Cultural Values Influence the Developmental Trajectory of Resistance to Social Influence Over the Course of Adolescence," *Dev. Psychobiol.*, vol. 66, no. 7, Nov. 2024, doi: 10.1002/dev.22530.
- [44] J. Liu, S. Zhao, X. Chen, E. Falk, and D. Albarracín, "The influence of peer behavior as a function of social and cultural closeness: A meta-analysis of normative influence on adolescent smoking initiation and continuation," *Psychol. Bull.*, vol. 143, no. 10, pp. 1082–1115, Oct. 2017, doi: 10.1037/bul0000113.
- [45] N. Chow-Garcia *et al.*, "Cultural identity central to Native American persistence in science," *Cult. Stud. Sci. Educ.*, vol. 17, no. 2, pp. 557–588, Jun. 2022, doi: 10.1007/s11422-021-10071-7.
- [46] K. A. Blotnicky, T. Franz-Odenaal, F. French, and P. Joy, "A study of the correlation between STEM career knowledge, mathematics self-efficacy, career interests, and career activities on the likelihood of pursuing a STEM career among middle school students," *Int. J. STEM Educ.*, vol. 5, no. 1, pp. 22, 2018, doi: 10.1186/s40594-018-0118-3.
- [47] E. A. Dare, K. Keratithamkul, B. M. Hiwatig, and F. Li, "Beyond content: The role of STEM disciplines, real-world problems, 21st century skills, and STEM careers within science teachers' conceptions of integrated STEM education," *Educ. Sci. (Basel)*, vol. 11, no. 11, 2021, doi: 10.3390/educsci11110737.
- [48] B. Wahono and C. Y. Chang, "Assessing teacher's attitude, knowledge, and application (AKA) on STEM: An effort to foster the sustainable development of STEM education," *Sustainability (Switzerland)*, vol. 11, no. 4, 2019, doi: 10.3390/su11040950.
- [49] C. R. Rinke, W. Gladstone-Brown, C. R. Kinlaw, and J. Cappiello, "Characterizing STEM teacher education: Affordances and constraints of explicit STEM preparation for elementary teachers," *Sch. Sci. Math.*, vol. 116, no. 6, pp. 300–309, 2016, doi: 10.1111/ssm.12185.
- [50] M. De Clercq, B. Galand, V. Hospel, and M. Frenay, "Bridging contextual and individual factors of academic achievement: a multi-level analysis of diversity in the transition to higher education," *Frontline Learn. Res.*, vol. 9, no. 2, pp. 96–120, Mar. 2021, doi: 10.14786/flr.v9i2.671.
- [51] L. Wang and C. J. Chen, "Factors affecting student academic performance: A systematic review," *International Journal on Studies in Education*, vol. 7, no. 1, pp. 1–47, 2024, doi: 10.46328/ijonse.276.
- [52] Ç. Şenyiğit and O. Serin, "The role of perceived ICT competencies on primary school pre-service teachers' integrated STEM teaching intentions," *Participatory Educational Research*, vol. 9, no. 6, pp. 221–247, 2022, doi: 10.17275/per.22.137.9.6.
- [53] N. Balyk, O. Barna, G. Shmyger, and V. Oleksiuk, "Model of Professional Retraining of Teachers Based on the Development of STEM Competencies," *ICTERI Workshops*, 2018.
- [54] L. Gavrilas and K. T. Kotsis, "A theoretical framework for the effective STEM educator: Integrating literacy, knowledge, collaboration, and self-efficacy," *Journal of Mathematics and Science Teacher*, vol. 5, no. 4, 2025, doi: 10.29333/mathsciteacher/16857.
- [55] B. Khashab, M. Alraja, R. Ayoubi, and M. Shah, "Technological-personal factors of university students' behavioral intention to continue using online services after the pandemic," *Cogent Psychol.*, vol. 10, no. 1, 2023, doi: 10.1080/23311908.2023.2251810.
- [56] D. H. Smith *et al.*, "Towards understanding online question & answer interactions and their effects on student performance in large-scale STEM classes," *International Journal Of Educational Technology In Higher Education*, vol. 17, no. 1, 2020, doi: 10.1186/s41239-020-00200-7.
- [57] A. T. Danielsson, A. Johansson, A. S. Nyström, and A. J. Gonsalves, "Young peoples' online science practices as a gateway to higher education STEM," *Res. Sci. Educ.*, vol. 53, no. 4, pp. 759–770, 2023, doi: 10.1007/s11165-023-10100-1.
- [58] A. Mohammadi, K. Grosskopf, and J. Killingsworth, "Workforce development through online experiential learning for STEM education," *Adult Learning*, vol. 31, no. 1, pp. 27–35, 2020, doi: 10.1177/1045159519854547.

- [59] E. F. S. Rini, S. B. Rahardjo, and B. Bramastia, "Bibliometric analysis from 2014-2024: Integration of ethnoscience in science learning," *Journal Evaluation in Education (JEE)*, vol. 6, no. 1, pp. 185–199, 2025, doi: 10.37251/jee.v6i1.1262.
- [60] H. P. Asmaningrum, R. V. Sathasivam, and E. H. B. M. Shahali, "Cultural roots, scientific fruits: Exploring the PAPEDA framework in Ethno-STEM teaching," *Academic Journal of Interdisciplinary Studies*, vol. 14, no. 1, pp. 361, 2025, doi: 10.36941/ajis-2025-0024.
- [61] H. P. Asmaningrum, A. E. Gleko, R. V. Sathasivam, and N. B. Sumanik, "Indigenous musical instruments as Ethno-STEM catalysts for enhancing scientific literacy through cultural integration," *Journal Evaluation in Education (JEE)*, vol. 6, no. 3, pp. 874–889, Jul. 2025, doi: 10.37251/jee.v6i3.1744.
- [62] C. Primadianningsih, W. Sumarni, and S. Sudarmin, "Systematic literature review: Analysis of Ethno-STEM and student's chemistry literacy profile in 21st century," *Jurnal Penelitian Pendidikan IPA*, vol. 9, no. 2, pp. 650–659, 2023, doi: 10.29303/jppipa.v9i2.2559.
- [63] B. Antrakusuma *et al.*, "Application of Ethno-STEM learning multimedia on the topic of substances and their changes to improve student learning outcomes," 2024, pp. 149–159. doi: 10.2991/978-2-38476-245-3_17.
- [64] S. Sudarmin, S. E. Pujiastuti, R. Asyhar, A. T. Prasetya, S. Diliarosta, and A. Ariyatun, "Chemistry project-based learning for secondary metabolite course with Ethno-STEM approach to improve students' conservation and entrepreneurial character in the 21st century," *J. Technol. Sci. Educ.*, vol. 13, no. 1, pp. 393–409, 2023, doi: 10.3926/jotse.1792.
- [65] D. Susanti, Armiami, and R. Rahmidani, "Local culture based instructional materials as an effort to develop students' character," *Proceedings of the Seventh Padang International Conference On Economics Education, Economics, Business and Management, Accounting and Entrepreneurship*, vol. 192, pp. 273–278, 2021, [Online]. Available: <https://www.atlantis-press.com/proceedings/piceeba-21/125963990>
- [66] S. Sae, M. A. Ilyas, E. Sumanto, and M. Lestari, "Needs analysis of the Bengkulu community through the lens of local culture," *Journal Evaluation in Education (JEE)*, vol. 6, no. 2, pp. 491–500, 2025, doi: 10.37251/jee.v6i2.1449.
- [67] J. Yang, J. Xu, and H. Zhang, "Resiliency and academic engagement: A moderated mediation model," *Psychol. Sch.*, vol. 59, no. 5, pp. 900–914, 2022, doi: 10.1002/pits.22654.
- [68] L. Bardach *et al.*, "Cultural diversity climate in school: A meta-analytic review of its relationships with intergroup, academic, and socioemotional outcomes.," *Psychol. Bull.*, vol. 150, no. 12, pp. 1397–1439, 2024, doi: 10.1037/bul0000454.
- [69] R. M. R. Moran, L. Robertson, C. Tai, N. A. Ward, and J. Price, "Developing pre-service teachers' adaptive expertise through STEM-CT integration in professional development and residency placements," *Front. Educ. (Lausanne)*, vol. 8, 2023, doi: 10.3389/educ.2023.1267459.
- [70] A. M. Villa, Q. C. Sedlacek, and H. Y. Pope, "I DiG STEM: A teacher professional development on equitable digital game-based learning," *Educ. Sci. (Basel)*, vol. 13, no. 9, 2023, doi: 10.3390/educsci13090964.
- [71] C. Yao *et al.*, "Humanizing STEM education: an ecological systems framework for educating the whole student," *Front. Educ. (Lausanne)*, vol. 8, 2023, doi: 10.3389/educ.2023.1175871.