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A Systematic Review of Threshold Concepts in Higher Education: Characteristics, Learning Barriers, and Pedagogical Interventions

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Abstract

This systematic review synthesises peer-reviewed empirical and conceptual research on threshold concepts (TC) in higher education published between 2015 and 2025. The review aims to examine how threshold concepts are theorised, operationalised, and empirically investigated across disciplinary contexts, with particular attention to their defining characteristics, associated learning difficulties, and pedagogical implications. Following a rigorous process of database searching, screening, and eligibility assessment, a total of 26 studies were included, comprising 11 peer-reviewed journal articles and 15 articles reporting empirical studies. The analysis integrates qualitative, quantitative, and mixed-methods studies to generate three key contributions: (1) a refined synthesis of TC characteristics as epistemic and, in some cases, ontological turning points in learning; (2) a structured categorisation of learning challenges associated with threshold crossing, including cognitive, affective, and contextual dimensions; and (3) an overview of pedagogical approaches designed to support learners during liminal phases. Findings indicate that TC consistently facilitate transitions from surface understanding to disciplinary ways of knowing, although their forms and manifestations vary across fields. While pedagogical interventions increasingly acknowledge the necessity of learning difficulty, robust longitudinal evidence remains limited. The review concludes with practical indicators for educators, and methodological recommendations, especially the need for longitudinal study, mixed methods design, and clearer operational criteria to strengthen future research and curriculum design.

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INTRODUCTION

Understanding a concept fundamentally requires engaging with abstract ideas that are represented through words or terms with specific meanings. Conceptual understanding therefore goes beyond mere familiarity with terminology; it entails grasping relationships among terms, the structure of meaning, conditions of application, and the conceptual implications that follow (Bae, 2018). Deep conceptual mastery enables learners to generalize

knowledge to new contexts, identify patterns, and select flexible problem-solving strategies (Braithwaite & Sprague, 2021). As such, conceptual understanding not only enhances learning quality but also equips individuals with the cognitive tools required to navigate and address real-world problems (Khodor et al., 2004).

Within higher education, threshold concepts (TC) represent a particular class of concepts that have the potential to transform learners' ways of understanding a discipline. (Meyer & Land, 2005) TC characterize by forms of transformational, integrative, and troublesome. Their transformational nature signifies that once understood, these concepts can prompt significant shifts in perspective, enabling learners to engage with disciplinary knowledge in a more sophisticated manner (Scheja & Pettersson, 2010). Their integrative quality reveals previously hidden interconnections among ideas, fostering a more coherent and comprehensive grasp of disciplinary structures (White, 2023; Wilcox & Leger, 2013). At the same time, their troublesome nature often challenges learners' prior knowledge, intuitions, or assumptions (Deacon, 2020; Roessger, 2010), requiring not only cognitive effort but also critical reflection and epistemic repositioning (Morgan et al., 2019a; Wismath et al., 2015). Successfully traversing a threshold thus opens access to more complex and integrated modes of disciplinary thinking (Townsend et al., 2011).

Although TC have been widely recognized as influential for shaping students' engagement with complex subject matter, significant gaps remain in how the framework is conceptualized, operationalized, and applied across disciplines. Much of the existing literature foregrounds the transformative potential of TC, yet empirical evidence on the effectiveness of pedagogical interventions specifically designed to facilitate threshold crossing remains limited and fragmented (Meyer & Land, 2005). Even in fields where the framework shows strong promise, such as medical education, systematic methodological synthesis explaining how educators can reliably identify and teach TC is still lacking (Jones & Hammond, 2022). Moreover, studies differ considerably in how TC are defined, categorized, and identified, creating inconsistencies that hinder their practical integration into curriculum design. Calls for heightened methodological rigor and clearer reporting standards further underscore the need for consolidation in this research area (Munn et al., 2018). Strengthening the conceptual and methodological foundations of TC research therefore holds substantial implications for advancing both theory and pedagogical practice (Jones & Hammond, 2022; Meyer & Land, 2005).

To address these gaps, this systematic review offers several key contributions. First, it adopts a multi-perspective, multi-method synthesis, integrating qualitative and quantitative studies to produce a holistic picture of the characteristics of the threshold concept, associated learning barriers, and existing pedagogical interventions. Second, it constructs a research map to identify disciplinary and geographic gaps quantitatively, thereby informing priorities for future inquiry (Pinilla & Rubilar, 2024). Third, it develops an empirically grounded taxonomy of learning barriers, distinguishing cognitive, affective, socio-contextual, and linguistic dimensions to support more targeted pedagogical design (Correia et al., 2024; Stopford, 2020). Fourth, the review catalogues and appraises tested pedagogical interventions, evaluating study design, strength of evidence, and effect sizes where available, and synthesizes these insights into a practical framework to guide the identification and teaching of threshold concepts. Fifth, it advances methodological recommendations, including identification criteria, outcome metrics, and longitudinal or experimental designs, to enhance the comparability, validity, and replicability of future research while ensuring systematic integration of student perspectives (Jones & Hammond, 2022; Liljedahl et al., 2022).

Accordingly, this systematic review pursues three core objectives: (1) to map and synthesize the characteristics of threshold concepts reported across disciplines and geographic contexts; (2) to identify and categorize learning barriers that render these concepts troublesome; and (3) to collect and evaluate pedagogical interventions aimed at supporting threshold crossing. In addition, this study aims to develop a practical framework and methodological guidance to strengthen future research and enhance the utility of TC in curriculum and instructional design. To achieve these aims, the review addresses the following research questions:

1. What are the principal characteristics of TC identified in the higher education literature, and how do these characteristics vary across disciplines and geographic contexts?
2. How does existing research define and identify TC, and to what extent are these procedures consistent or variable?
3. Which learning barriers: cognitive, affective, socio-contextual, and linguistic are most frequently associated with the troublesome nature of TC, and what evidence exists regarding the mechanisms underlying these barriers?
4. What pedagogical interventions have been reported to support threshold crossing, how are they designed, and what empirical evidence exists concerning their effectiveness?
5. Where are the disciplinary, educational-level, and geographic gaps in TC research, and which areas require the most urgent attention?
6. Based on the synthesized evidence, what practical steps and indicators can assist educators in identifying TC, designing appropriate interventions, and evaluating threshold crossing?
7. What methodological approaches and research designs can strengthen the validity, replicability, and comparability of future TC studies?

METHOD

This study employed a systematic review design to synthesize empirical and conceptual research on TC in higher education. A systematic review was selected to ensure transparency, rigor, and reproducibility in the processes of identifying, appraising, and synthesizing evidence across disciplines and methodological traditions. Consistent with the aims of this review, a multi-method synthesis approach was adopted, integrating qualitative studies, quantitative studies, and relevant grey literature to capture both the breadth and depth of research on threshold concepts, associated learning barriers, and pedagogical interventions.

A review protocol was developed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to enhance methodological transparency and reporting quality. The review process comprised four principal stages: (1) literature identification, (2) screening and eligibility assessment, (3) data extraction, and (4) synthesis and analysis.

Sources and search strategy

Literature searches were conducted in multiple bibliographic databases: Scopus, ERIC, PMC, with Google Scholar employed as an additional source. The publication window was set from 2015–2025. Search queries used combinations of keywords such as “threshold concept”, “troublesome knowledge”, “threshold crossing”, “conceptual transformation”, “systems thinking”, “higher education”, and “university teaching”. All search results were exported to a Microsoft Excel spreadsheet to ensure a systematic screening and selection workflow.

Eligibility criteria

Eligibility criteria for this systematic review were structured using a population–concept–context (PCC) framework. The PCC framework is widely recommended for scoping and systematic reviews whose objectives are to map, synthesize, and conceptualize complex and heterogeneous literature sets, particularly when the focus extends to interventions or narrowly defined outcomes.

Population refers to the target groups for this review and includes faculty, instructors, and students at the undergraduate and postgraduate levels (covering multiple disciplines such as medicine, pharmacy, engineering, and pre-service teachers in biology, chemistry, and physics). Studies were considered eligible if they focused on these populations. Studies that explored TC or systems thinking (ST) in primary or secondary education settings were excluded.

The core concepts examined in this review are TC and ST, whether studies addressed them jointly (TC and ST) or investigated them separately. Accordingly, eligible studies were required to treat TC and/or ST substantially and explicitly, to address learning barriers (explicitly or implicitly), and to report pedagogical interventions designed to support crossing TC and/or fostering ST.

The context of interest comprised higher education settings across disciplinary areas and geographic regions, including university-based teaching and professional programs (e.g., medicine, engineering, and education). No restrictions were placed on disciplinary domain or geographic location to capture the global and interdisciplinary scope of research on TC and/or ST. Studies conducted outside higher education contexts were excluded.

Table 1. Mapping of eligibility criteria according to PCC

Aspect	Inclusion	Exclusion
Population	• Studies conducted in higher education involving faculty, instructors, and undergraduate and postgraduate students across disciplines (e.g., medicine, pharmacy, engineering, and pre-service teachers in biology, chemistry, physics, and mathematics).	• Studies addressing TC and/or ST in primary or secondary education or studies whose participants are outside the higher education context.
Concept	• Studies that substantially and explicitly address TC and/or ST. • Studies that consider learning barriers and pedagogical interventions supporting TC and/or ST, whether explicitly or implicitly.	• Studies that mention threshold concepts only in passing without analytical or theoretical engagement. • Publications lacking a clear conceptual framework related to threshold concepts.
Context	• Formal higher education settings, including universities and professional programs. • Discipline-specific and interdisciplinary programs (e.g., medicine, engineering, education).	• Studies located outside the higher education context (e.g., school-based or informal learning environments). • Research without a clear educational context.

Aspect	Inclusion	Exclusion
	• Implementation at course, curriculum, or program level. • Studies conducted in any geographic region	
Publication	• Publication window between 2015–2025	• Studies outside the publication window 2015–2025
Article type	• Peer-reviewed journal articles and empirical study reports. • Reputable and open-access publications.	• Editorials, opinion pieces, books, book chapters, and book reviews. • Non-systematic reviews, scoping reviews, and meta-analyses. • Non-reputable or closed-access publications.
Language	• English language publications.	• Non-English language publications.

Following a rigorous process of searching, screening, and eligibility assessment, a total of 26 studies were included, comprising 11 peer-reviewed journal articles and 15 articles reporting empirical studies (Figure 1). Data were extracted using a structured charting form capturing study characteristics, disciplinary context, conceptual focus, methodological approach, key findings, and pedagogical intervention (see Appendix 1). This approach facilitated both descriptive mapping of the literature and interpretive integration aligned with the review objectives.

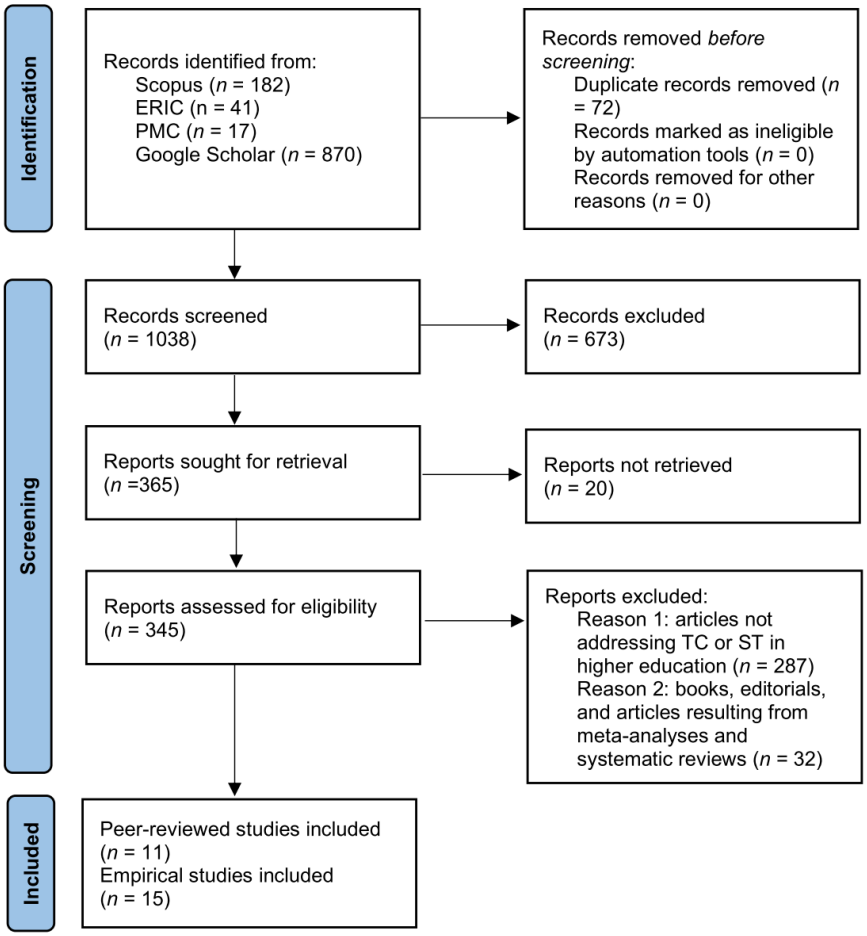

Figure 1. PRISMA flowchart in the study selection process

RESULTS AND DISCUSSION

Results

This section presents the results of the systematic review, organised around the research questions that guided the analysis. Through successive stages of identification, screening, and eligibility assessment, 26 journal articles were included in the review, consisting of 11 peer-reviewed journal articles and 15 empirical studies (see Figure 1 and Appendix 1). Then, the results are presented thematically, with each subsection synthesizing evidence relevant to a particular research question.

RQ1. Principal characteristics of TC across disciplines and geographic contexts

Across disciplines, TC consistently exhibit transformative, integrative, and troublesome characteristics. In STEM fields (biology, chemistry, statistics), thresholds predominantly involve shifts from linear or reductive reasoning to relational or systems-oriented understanding. In professional and applied disciplines (health sciences, writing, teacher education), thresholds more frequently involve ontological change, particularly shifts in learner identity and professional stance.

While the core characteristics remain stable across regions (Europe, USA, Australia), studies from Nordic and European contexts more explicitly frame thresholds in relation to sustainability, systems thinking, and societal complexity, whereas USA studies more often emphasise assessment and measurement.

RQ2. Definitions and identification of TC

TC are defined through a combination of theoretical criteria (transformative, irreversible, integrative, bounded, troublesome) and empirical indicators (persistent misconceptions, conceptual integration, changes in reasoning patterns). Identification procedures vary substantially, ranging from conceptual analyses and faculty narratives to validated concept inventories and phenomenographic approaches.

The variability in identification procedures highlights limited methodological consensus, though convergence is emerging around the use of longitudinal designs and diagnostic assessments to evidence threshold crossing.

RQ3. Learning barriers underlying troublesomeness

Learning barriers cluster into four interacting categories: cognitive (e.g., linear causality, teleological reasoning), affective (uncertainty, discomfort, identity threat), socio-contextual (disciplinary norms, assessment cultures), and linguistic/representational (ambiguous terminology, misleading diagrams). Evidence suggests that these barriers operate through mechanisms of schema reinforcement and epistemic misalignment rather than simple knowledge deficits.

RQ4. Pedagogical interventions supporting threshold crossing

Effective interventions are deliberately designed to structure liminal learning, rather than eliminate difficulty. Common features include scaffolding, authentic tasks, multiple representations, reflective dialogue, and learner participation. Empirical evidence, particularly from design-based and mixed-methods studies, indicates that such interventions enhance conceptual integration and epistemic awareness, although effect sizes and long-term impacts are unevenly reported.

RQ5. Disciplinary, educational-level, and geographic gaps

Research is heavily concentrated in STEM and teacher education at the undergraduate level, with limited attention to postgraduate education, humanities, and non-Western

contexts. Geographic representation remains skewed toward Europe, USA, and Australia, indicating an urgent need for research in Global South and culturally diverse settings.

RQ6. Practical steps and indicators for educators

The evidence supports a set of practical indicators for identifying threshold concepts, including recurring misconceptions, sudden shifts in explanatory coherence, and affective responses to uncertainty. Pedagogical design should foreground conceptual integration, systems thinking, and reflective practice, while evaluation of threshold crossing benefits from diagnostic tools, longitudinal tracking, and student self-explanation.

RQ7. Methodological directions for future research

Methodological robustness is strengthened through mixed methods designs, longitudinal studies, and the use of validated instruments alongside qualitative approaches. Greater transparency in operationalising threshold crossing and increased cross-study comparability are required to advance cumulative knowledge.

Discussion

This review synthesises evidence from 27 studies to advance a theoretically grounded and analytically coherent account of TC in higher education. Rather than treating TC as isolated curricular topics or lists of difficult ideas, the discussion positions them as epistemic and ontological pivots that reconfigure how learners know, practise, and identify within disciplines. Drawing on seminal and contemporary scholarship, the discussion develops five interrelated arguments: (1) TC as mechanisms of epistemic access, (2) disciplinary and geographic variation in threshold characteristics, (3) the multi-dimensional nature of learning barriers, (4) pedagogy as the intentional design of liminal learning, and (5) methodological implications for advancing TC research.

TC as mechanisms of epistemic and ontological transformation

In line with the foundational work of Meyer and Land (2005), the studies reviewed reaffirm that TC are not merely cognitively demanding ideas but represent irreversible points of epistemic transformation. Subsequent scholarship has extended this view by emphasizing that crossing a threshold involves a shift in learners' relationships with knowledge, including how knowledge claims are constructed, justified, and enacted within disciplinary practice (Land et al., 2014). Across the reviewed literature, TC function as gateways to disciplinary ways of thinking, marking a transition from surface engagement to participation in the epistemic practices valued by a given discipline (Göransson et al., 2020; Tibell & Harms, 2017).

This synthesis further indicates that crossing TC often entails ontological transformation, particularly in professional and applied fields. Studies in health sciences, teacher education, and academic writing highlight shifts in learners' identities, such as coming to see themselves as practitioners, researchers, or legitimate participants within disciplinary communities (Basgier & Simpson, 2020; Morgan et al., 2019a; Smart, 2023). This is in line with the mission of higher education, that learning in higher education cannot be reduced only to the acquisition of concepts but must also be understood as a process of forming epistemology and identity (Barnett, 2004).

Disciplinary and geographical variation in threshold characteristics

Although the core characteristics of threshold concepts—transformative, integrative, and troublesome, remain remarkably stable across contexts, their manifestations vary by discipline and geographical setting. In STEM disciplines, particularly biology, chemistry, and statistics, TC are frequently associated with shifts from linear and reductionist reasoning

toward relational, probabilistic, or systems-based understanding (Kalinowski et al., 2016; Talanquer, 2015; Tibell & Harms, 2017). These thresholds are often linked to specific conceptual obstacles, such as randomness, variation, or dynamic regulation, which resist assimilation into learners' prior cognitive schemas (Batzli et al., 2016; Göransson et al., 2020; Talanquer, 2015; Tibell & Harms, 2017).

By contrast, studies focusing on sustainability education, higher education studies, and professional programs more explicitly emphasize the integrative and value-laden nature of threshold concepts. ST, in particular, emerges as a powerful integrative threshold that enables learners to connect disciplinary knowledge with broader societal, environmental, and institutional concerns (Kinchin, 2022; Loring, 2020; Palmberg et al., 2017). Notably, European and Nordic studies tend to situate TC within discourses of sustainability, complexity, and social responsibility, whereas American research more frequently emphasizes assessment, measurement, and instructional design. These patterns suggest that while TC are theoretically robust across contexts, their pedagogical enactment is shaped by regional educational priorities and traditions.

Learning barriers as multidimensional and interactive mechanisms

A major contribution of this review lies in its synthesis of learning barriers associated with threshold concepts as multidimensional mechanisms rather than isolated cognitive difficulties. Cognitive barriers, such as reliance on linear causality, teleological reasoning, or procedural approaches are well documented in STEM-focused studies (Fiedler et al., 2017; Talanquer, 2015; Walck-Shannon et al., 2019). However, the evidence also underscores the critical role of affective barriers, including discomfort, uncertainty, and anxiety, which often accompany liminal states (Land et al., 2014; Wismath et al., 2015).

Socio-contextual barriers further complicate the process of crossing thresholds. Disciplinary norms, assessment practices, and institutional cultures shape which forms of knowledge are valued and how learners interpret difficulty (Basgier & Simpson, 2020). In several studies, linguistic and representational barriers, such as ambiguous terminology or misleading diagrams, reinforced misconceptions and delayed conceptual integration (Villafañe et al., 2021; Wernecke et al., 2018). Collectively, these findings suggest that difficulty is not an inherent property of concepts alone but an emergent outcome of interactions among learners, knowledge structures, and educational contexts.

Pedagogy as the deliberate design of liminal learning

Within the reviewed literature, effective pedagogical responses to threshold concepts do not seek to eliminate difficulty but rather to design for productive engagement with liminality. Interventions that support threshold crossing share several recurring features: explicit support for conceptual integration, opportunities for reflection and dialogue, the use of multiple representations, and engagement with authentic disciplinary practices (Couch et al., 2015; Olaniyi, 2020; Villafañe et al., 2021). Design-based and participatory approaches further indicate that learner agency and collaboration play crucial roles in sustaining engagement during the liminal phase (Hubbard et al., 2017).

This pedagogical orientation closely aligns with higher education context emphasis on teaching as a form of scholarly design work rather than mere content transmission. By making epistemic structures visible and legitimizing uncertainty as an integral part of learning, educators can support students in navigating threshold concepts without prematurely resolving productive tensions. Consequently, this synthesis reinforces the argument that pedagogy for TC is inherently relational and context-sensitive, requiring ongoing adaptation rather than fixed instructional prescriptions.

Methodological implications for advancing threshold concept research

This review also reveals substantial methodological diversity in threshold concept research, ranging from conceptual analyses and phenomenography to mixed methods approaches and instrument validation studies. Whereas early work relied heavily on the theoretical identification of threshold concepts, more recent studies increasingly employ validated diagnostic tools and longitudinal designs to substantiate threshold crossing (Kalinowski et al., 2016; Walck-Shannon et al., 2019).

For TC research to develop as a cumulative research program, greater transparency is needed in how thresholds are operationalized and measured. Integrating qualitative insights into learners' experiences with quantitative indicators of conceptual integration offers a promising way forward, particularly when aligned with cross-disciplinary frameworks that enable comparison.

Overall, these findings position TC as epistemic pivots that mediate learners' access to disciplinary knowledge and practices. ST emerges as a particularly salient example of an integrative threshold capable of reshaping understanding across domains. Crucially, the evidence indicates that learning barriers and liminal experiences are not obstacles to be eliminated but essential features of higher education learning that require thoughtful pedagogical and methodological responses.

LIMITATIONS

Several limitations of this review should be acknowledged, both to contextualise the findings and to guide interpretation. First, although the review draws on studies published across a wide temporal span (2015–2025) and multiple databases, the geographic distribution of the literature remains uneven. Most studies originate from Europe, North America, and Australia, with limited representation from the Global South. As a result, the synthesis may underrepresent culturally and institutionally diverse conceptions of threshold concepts, learning barriers, and pedagogical practices. This limitation constrains the generalisability of the findings to higher education systems operating outside Western epistemological traditions.

Second, the disciplinary coverage is uneven, with a strong concentration in STEM fields (particularly biology, chemistry, and statistics) and teacher education. Humanities, arts, and social science disciplines, where epistemic practices and language use differ substantially, remain comparatively underexplored. Consequently, the identified characteristics of threshold concepts and associated learning barriers may reflect disciplinary norms prevalent in science-oriented contexts rather than the full diversity of higher education knowledge practices.

Third, there is considerable methodological heterogeneity across the included studies. TC are identified using varied approaches, ranging from conceptual analyses and faculty narratives to phenomenography and validated concept inventories. While this diversity reflects the exploratory nature of the field, it also limits direct comparability across studies. In particular, the absence of shared operational definitions of "threshold crossing" makes it difficult to assess the relative effectiveness of pedagogical interventions or to synthesise outcomes quantitatively.

Fourth, many empirical studies rely on short-term or course-bound data, offering limited insight into the durability and irreversibility of threshold crossing over time. Longitudinal evidence demonstrating sustained epistemic or ontological transformation remains scarce. As such, claims regarding irreversibility should be interpreted cautiously and understood as provisional rather than definitive.

CONCLUSION

This systematic review shows that TC act as epistemic pivots in higher education, enabling learners to move from superficial engagement to disciplinary ways of knowing. ST emerges as a salient integrative threshold capable of reorganising knowledge across disciplinary and institutional boundaries. Learning difficulties associated with TC should not be treated as anomalies but as necessary liminal phases that can and should be anticipated, intentionally designed for, and pedagogically supported.

Building on these claims, this review advances three overarching conclusions. First, threshold concepts provide a powerful analytical lens for understanding learning in higher education as a process of epistemic and ontological transformation, rather than one of incremental knowledge accumulation. By foregrounding moments of conceptual disruption and integration, TC illuminate how learners gain access to disciplinary ways of knowing, practising, and being an issue central to contemporary higher education research.

Second, the prominence of ST across multiple disciplines underscores the importance of identifying cross-cutting threshold concepts that transcend individual subject boundaries. As an integrative threshold, ST supports learners in engaging with complexity, non-linearity, and interdependence features that increasingly characterise both academic knowledge and the societal challenges universities are expected to address. This finding suggests that some TC operate at a meta-disciplinary level, with implications for curriculum design and institutional learning agendas.

Third, the synthesis demonstrates that pedagogical effectiveness in relation to threshold concepts does not lie in simplifying content or removing difficulty, but in designing learning environments that work productively with liminality. Learning difficulties associated with TC are best understood as signals of epistemic transition rather than failure. Consequently, effective pedagogy anticipates these transitions, legitimises uncertainty, and provides sustained scaffolding to support learners as they navigate conceptual thresholds (CT) over time.

IMPLICATIONS AND RECOMENDATIONS

Taken together, the findings of this systematic review highlight the practical and scholarly significance of threshold concepts as a framework for understanding learning as a process of epistemic transformation rather than incremental knowledge accumulation. The implications extend across pedagogical practice, curriculum design, and future research, underscoring the need for intentional alignment between how learning challenges are anticipated, supported, and evaluated.

For educators, the findings suggest three practical imperatives: (1) identify TC by attending to recurring misconceptions, epistemic bottlenecks, and affective responses to uncertainty; (2) design pedagogical interventions that foreground integration, reflection, and systems-oriented reasoning; and (3) evaluate threshold crossing using diagnostic and longitudinal approaches rather than single-point assessments.

At the curriculum level, TC provide a principled basis for prioritising depth over breadth. Academic developers can use threshold concepts to support curriculum redesign, professional learning, and cross-disciplinary dialogue, particularly around systems thinking and sustainability.

For researchers, the review highlights the need for greater disciplinary diversity, attention to postgraduate and non-Western contexts, and methodological convergence. Future research should prioritise longitudinal designs, transparent operationalisation of threshold crossing, and comparative studies that enable cumulative knowledge building.

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The authors have sufficiently contributed to the study, and have read and agreed to the published version of the manuscript.

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Appendix 1:
The result of the study identification and selection process

Author (year)	Country	Discipline	Design/ Method	Participants	Leraning Barrier	Key Finding	Pedagogical Intervention
Stopford (2020)	UK	Higher education studies	Conceptual analysis	—	Epistemic uncertainty around "troublesomeness" and certainty.	Reconceptualises troublesomeness as productive epistemic disruption rather than deficit.	Critical reflexivity; reframing uncertainty as learning resource.
Kennie-Kaulbach & Janke (2025)	Canada	Pharmacy/ health professions education	Narrative review/ integrative review	—	Professional identity elements as internal barriers (difficulty linking professional practice to the concept of threshold).	Threshold concepts help explain the process of professional identity formation; they are both transformative and troublesome in the formation of pharmacy practice.	Threshold concepts-based curriculum: integrate professional reflection, structured practice assignments and mentoring to support crossing the-threshold.
Batzli et al. (2016)	USA	Biology education	Conceptual essay	—	Understanding of variation (biological variation) is often a misconception; it is counter-intuitive for students.	Biological variation is defined as a candidate threshold concept: integrative, transformative, and often troublesome; requiring explicit teaching.	Use case studies of variation, real-world data, exploratory discussions, and assessments that assess evolutionary reasoning to encourage crossing.
Claus et al. (2023)	USA	Chemistry/ analytical chemistry	Commentary/ conceptual mapping	—	Molecular interactions and equilibrium are often understood superficially by chemistry students.	Proposes three threshold concepts for analytical chemistry (statistics, molecular interactions, chemical equilibria); emphasizes the need for teaching context	Integrate statistics in the lab, conceptual molecular representations, and real-world context approaches to equilibrium; practice stock & flow concepts.
Talanquer (2015)	USA	Chemistry education	Conceptual analysis	—	The role of implicit schemas in causing misconceptions in chemistry.	Shows that threshold concepts in chemistry are closely related to implicit schemas that shape students' understanding; suggests a cognitive analysis.	Instructional design that exposes and challenges implicit schemas (e.g., visual representations, analogies, and comparison tasks).
Tibell and Harms (2017)	Sweden	Biology education	Conceptual analysis	—	Understanding natural selection requires mastery of several threshold concepts (randomness, variation, fitness).	Outlining candidate threshold concepts to understand natural selection and how they are related.	Model-based learning, population simulation, and stock and flow representation tasks to support appropriate mental construction.
Momsen et al. (2022)	USA	Biology education	Essay (conceptual synthesis)	—	Many biology courses are fragmentary students have difficulty seeing systemic relationships.	Systems thinking is proposed as a unifying framework for biology; it encourages dynamic thinking, interconnectedness, and emergentism.	Curriculum recommen-dations: use systems diagrams, stocks and flows, dynamic models, and authentic assessments to build systemic skills.
Loring (2020)	Canada	Environmental studies	Conceptual review	—	Contested definitions of	Identifying several threshold concepts	Interdisciplinary teaching, real case

Author (year)	Country	Discipline	Design/ Method	Participants	Leraning Barrier	Key Finding	Pedagogical Intervention
					sustainability; students and teachers struggle to map key concepts that are transformative.	for sustainability (complexity, no-panaceas, collaborative institutions) and epistemic tension.	studies, cross-disciplinary project-based learning to address ambiguity and complexity.
Kinchin (2022)	UK	Educational development	Theoretical/ conceptual review	—	Institutional dynamics and pedagogical continuity confuse educators in applying the threshold concept.	Introduces the idea of the university as an adaptive ecosystem; emphasizes the dynamic process of sustaining transformational pedagogy.	Continuous professional development, strengthening intra-institutional networks, and designing learning spaces that support pedagogical experimentation.
Smart (2023)	Ireland	Physiotherapy education	Conceptual review	—	Pain science is counterintuitive; students hold biomedical reductionist views that hinder holistic understanding.	Pain science can serve as a threshold concept that transforms clinical practice and student reasoning.	Integration of clinical cases, interprofessional reflection, and simulation-based learning to facilitate crossing.
Polley et al. (2025)	Australia	Environmental education	Literature analysis and assessment policy	—	Identifying difficulties in linking field experiences to formal conceptual constructs	Presenting an instrument/ framework for assessing threshold crossing in outdoor education.	Use of reflective rubrics, practical portfolios, and field-based integrative assignments.
Fiedler et al. (2017)	Germany	Biology education	Design-based research (instrument development and validation)	Biology students, pre-service biology teachers	Randomness and probability concepts are counterintuitive; students tend to make simple causal attributions.	Demonstrates weaknesses in understanding randomness in the context of evolution; proposes assessment items to evaluate.	Explicit teaching of probability in biological contexts, random simulation activities, and problem-based learning.
Couch et al. (2015)	USA	Molecular, cellular, and developmental biology	Developmental research	Biology students	Fragmentation of molecular concepts and difficulty integrating conceptual levels.	Developing a capstone assessment tool to measure upper-level conceptual understanding.	Implementation of capstone assessments, portfolios, and integrative assignments that require knowledge synthesis.
Zuckerman and Lo (2022)	USA	Mathematics and science education	Qualitative (Phenomenog-raphy)	University student in cognitive science, psychology, and health sciences	Varied perceptions of what makes a successful researcher; professional misconceptions.	Identifying categories of researchers' conceptions of success and their relationship to learning experiences.	Research-based learning, mentoring, and reflective assignments to broaden students' understanding of research practices.
Göransson et al. (2020)	Sweden/ Germany	Behavioural sciences and learning	Qualitative (content analysis)	Biology students	Item context effects: the context of the question influences whether students apply the threshold concept.	Indicates that the context of the item can reveal or hide the threshold crossing indication.	Designing diverse evaluation contexts, using multiple representations, and ongoing formative assessment.
Walck-Shannon et al. (2019)	USA	Biology education	Mixed method	Biology students	Challenges in measuring crossing (operationalization).	Develop quantitative and qualitative indicators to assess whether students cross the threshold.	Use mixed assessment (interviews and concept inventories) and crossing rubrics for learning evaluation.
Gilissen et al. (2020)	Netherlands	Biology education	Qualitative	Biology teachers, pre-service biology teachers	Teachers rarely include systems thinking in their teaching practices.	Teachers recognise systems thinking as threshold for learners.	Professional development, modular resources, and the gradual

Author (year)	Country	Discipline	Design/ Method	Participants	Leraning Barrier	Key Finding	Pedagogical Intervention
							integration of systems thinking into existing courses.
Palmberg et al. (2017)	Nordic countries	Teacher education	Mixed method (survey and interview)	Student teachers	The relationship between species biodiversity and sustainability is often invisible to prospective teachers or isolated views of biodiversity.	Systems thinking can clarify relationships and encourage ongoing understanding.	Integration of field teaching, cross-curricular projects, and pedagogical reflection.
Kalinowski et al. (2016)	USA	Biology education	Developmental research (develop and validate instruments)	Undergraduate biology students	Natural selection misconceptions persist; assessment challenges	Developing and validating the conceptual assessment of natural selection (CANS) to measure in-depth understanding.	Use assessment data to inform instructional design, evolutionary case-based learning.
Villafañe et al. (2021)	USA	Biology education	Developmental research (develop and validate instruments)	Undergraduate students in biochemistry courses	Dynamics and regulation of metabolic pathways are abstract and difficult to visualize.	CANS validated as an evolutionary concept assessment tool.	Utilization of CANS for learning design.
Basgier and Simpson (2020)	USA	Writing Studies	Qualitative (narrative inquiry and focus group discussions)	Lecturers and faculty staff	Expressing trouble in crossing threshold in writing (argumentation structure, voice).	Identifying threshold concepts in academic writing as transformational and contextual.	Co-development of curriculum materials, structured assignments, and writing course design.
Hubbard et al. (2017)	UK	Plant science	Participatory action research (PAR)	Undergraduate students	Traditional practical formats limit engagement and ownership (pedagogical barrier).	Student co-production enhances engagement, reflection, and conceptual understanding.	Co-creation of lab materials, peer-teaching, and iterative design cycles in early practicums.
Beitelmal et al. (2022)	USA	Introductory statistics/ engineering education	Exploratory mixed methods	University students	Abstractness of probability and inference; math anxiety as a barrier	Applying threshold concepts theory clarifies persistent barriers in intro statistics and suggests pedagogical shifts.	Proposed curriculum redesign guided by identified threshold concepts ("statistics rainbow" framework), targeted scaffolding, introducing threshold theory to students, and using findings to redesign syllabi and teaching activities.
Morgan et al. (2019)	New Zealand	Health professions education	Mixed-methods interpretive study	Undergraduate students and clinical educators	Disciplinary silos, role uncertainty and limited integrative reasoning that constrain collaborative, patient-centred practice.	Identified interprofessional thresholds: (a) broadening perspectives on health practice; (b) navigating collaborative roles; (c) team-based practice through active learning/learning-by-doing; and (d) integrative professional practice for holistic, patient-centred care; transformation is	Recommend scaffolded, cumulative interprofessional placements and student-led clinical experiences with structured facilitation, reflection and debrief to support threshold crossing

Author (year)	Country	Discipline	Design/ Method	Participants	Leraning Barrier	Key Finding	Pedagogical Intervention
						cumulative across collaborative experiences.	
Kallia and Sentence (2021)	UK	Computer programming education	Qualitative interpretative phenomenological analysis (IPA)	Interprofessional students	Students' troublesome knowledge around parameters, parameter passing, return values, and procedural decomposition, conceptual/practical barriers to understanding 'functions'.	Parameters, passing parameters and return values together likely form a threshold conception; procedural decomposition constitutes a procedural threshold/skill; teachers' experiences support framing these as thresholds with implications for curriculum.	Recommendations for explicit scaffolding, worked examples, progressive tasks, diagnostic checks, and teacher professional development to address these threshold conceptions/skills.
Olaniyi (2020)	Nigeria	Physics education	Action research design	Physics students	Thermodynamics and other counter-intuitive physics topics identified as troublesome threshold knowledge; low self-efficacy and limited meta-learning.	Flipped classroom format with interactive videos, pre/post testing and structured in-class active tasks improved students' understanding and self-efficacy; students requested more interactive videos and valued guided in-class application.	Proposed a concrete flipped-lesson format for threshold concepts: pre-class interactive videos with embedded questions, in-class active learning tasks, pre- and post-tests for self-assessment, guided reflection and peer feedback.