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Review

Uncovering Challenges and Pitfalls in Identifying Threshold Concepts: A Comprehensive Review

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Abstract: The exploration of threshold concepts, which represent a transformed way of understanding, interpreting, or viewing something necessary for a learner's progress, has significantly influenced teaching and learning in higher education, gaining broad acceptance in academic circles. Despite widespread enthusiasm, the scientific development of the field faces obstacles, especially epistemological and ontological uncertainties, directly implying the reliability of identification techniques and, by extension, raising questions about the validity of previous findings. This comprehensive review delves into 60 articles sourced from the Web of Science database to scrutinize the literature on threshold concept identification. The findings confirm the adaptability of threshold concepts across diverse disciplines. However, the fluid definition inherent in these concepts introduces ontological challenges, influencing biases in the identification process. The review highlights the diverse identification methods influenced by knowledge area specificities, community affinities, and research practice traditions. A diagram depicting the methods employed to identify threshold concepts is offered to highlight five central decisions to be considered. Acknowledging professors as pivotal mediators adept at navigating the epistemological and ontological dimensions of threshold concepts while integrating theoretical and applied knowledge, this study enhances our nuanced understanding of threshold concept identification. Emphasizing methodological validity and reliability, it acknowledges the crucial role of experienced educators in this issue and presents future perspectives for advancing current research, fostering the maturation of the field.

Keywords: threshold concept; troublesome knowledge; higher education; learning obstacles; identification methods

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1. Introduction

In the realm of higher education, numerous challenges surround the landscape of learning [1–5]. Students grapple with diverse obstacles, from information overload to the demands of intricate subjects. There is a growing need to reconsider and adapt curricula to accommodate varied learning styles and foster critical thinking [6–8]. The dynamic nature of contemporary knowledge acquisition calls for a shift from traditional teaching approaches, demanding innovations in the formative processes that actively engage students throughout their undergraduate journey [9,10]. The role of university educators is pivotal in navigating this terrain; however, many lack specific pedagogical training. This deficiency can be a barrier to effectively addressing the evolving needs of learners.

Concerning learning difficulties in higher education, [11] identified various forms of 'troublesome knowledge': ritual knowledge, inert knowledge, foreign (or alien) knowledge, conceptually abstract knowledge, and tacit knowledge. Related research conducted by [12] with students experiencing progression difficulties in British universities ultimately revealed a previously undisclosed source of troublesome knowledge: threshold concepts.

The idea of threshold concepts has opened avenues for novel teaching and learning approaches, which are currently in the process of refinement and enhancement yet gaining

widespread acceptance within the academic and teaching communities [13,14]. Among its promising aspects, threshold concepts address solutions for at least three relevant learning issues: firstly, it is designed to map and deal with specific and relevant 'troublesome points' within a disciplinary curriculum [12]. Secondly, the approach acknowledges the critical need to connect theoretical or abstract-conceptual knowledge with background procedural or practical-applied knowledge [15–17]. Thirdly, it adopts a student-focused approach, replacing the teacher-centered or content-centric methodologies and delving into the students' internal processes and latency periods [18].

Despite the speed and enthusiasm with which researchers and educators have embraced the idea of threshold concepts, its theoretical maturation process still faces several obstacles [14]. The approach has sparked academic interest in very diverse areas, resulting in diffuse, poorly organized literature scattered across journals in various distinct fields, with many dispersed contributors. Moreover, doubts persist regarding the reliability of research instruments, which operate with inadequately consolidated and still non-consensual techniques [13]. Finally, epistemological and ontological uncertainties about threshold concepts also endure, compromising the reliability of the techniques used in their identification and the criteria underpinning these techniques [19,20]. Therefore, the research presented in this article aims to address the identified gaps through two key inquiries:

- What are the prevailing themes shaping the organization of academic literature on threshold concepts, and how are they distributed?
- What significant advancements have been made in the techniques employed to identify threshold concepts?

Why Can Threshold Concepts Impact Teaching and Learning Process?

Meyer and Land introduced threshold concepts as a distinct category of ideas that 'can be considered as akin to a portal, opening up a new and previously inaccessible way of thinking about something' ([12], p. 1). They 'represent a transformed way of understanding, interpreting, or viewing something without which a learner cannot progress' ([12], p. 1). A threshold concept is a transformative notion that may manifest itself in various disciplines, and its internalization opens a student's perspective to an integrated understanding of the subject, 'revealing a previously hidden "web" of interrelationships between concepts and other concepts (...) associated with them' ([18], p. 1). This experience has the power to shape the process of the student 'becoming' and 'being' in that setting. Figure 1 contains a concept map to highlight the role that threshold concepts may play in teaching and learning.

Meyer and Land [21] associate threshold concepts with those ideas capable of defining critical, irreversible moments of deep conceptual transformation in learners' educational experiences followed by a significant increase in the ability to comprehend phenomena and interpret reality through that specific lens. The internalization of a threshold concept profoundly transforms how a student uses the ideas of that field because they can integrate this concept into their thinking. This transformed view '... may represent how people "think" in a particular discipline, or how they perceive, apprehend, or experience particular phenomena within that discipline (or more generally)' ([12], p. 1).

Threshold concepts were proposed during the 'Enhancing Teaching-Learning Environments in Undergraduate Courses Project' (ETL project), focusing on high-quality teaching and learning environments in the United Kingdom [22]. Interviews with students and teachers about progression difficulties in higher education led to the recognition of a category of 'considered central' concepts for a full grasp of economics. Meyer and Land extended these insights to four other undergraduate courses which were also investigated, and concluded that in all of them, there was an equivalent category of concepts. This set was named 'threshold concepts', and its characteristics were analyzed, identified, and mapped by the team [12,21].

Davies and Mangan [15] explain threshold concepts by contrasting them to common concepts. A core concept is a simple abstract concept with local transformative effect (such as replacing a term already known and present in everyday language). Core concepts func-

tion as a 'building block' of discipline knowledge, accumulated in overlapping layers. In contrast, the change promoted by a threshold concept has a qualitative nature, articulating core concepts to generate an integrated view of the concepts of a discipline. Davies and Mangan emphasize that this integrated view enables an individual to interpret real-world phenomena from a new theoretical perspective, with interconnected concepts and coherent ideas [15]. Obtaining this capacity qualifies novices as a 'professional,' in the sense of someone who integrates a community of practitioners or users of that knowledge (such as an 'anthropologist' or a 'biologist'). As a result, the individual gains the ability to generate 'appropriate narratives' for that knowledge area, such as understanding a phenomenon, making a consistent argument, or making a well-founded decision [15].

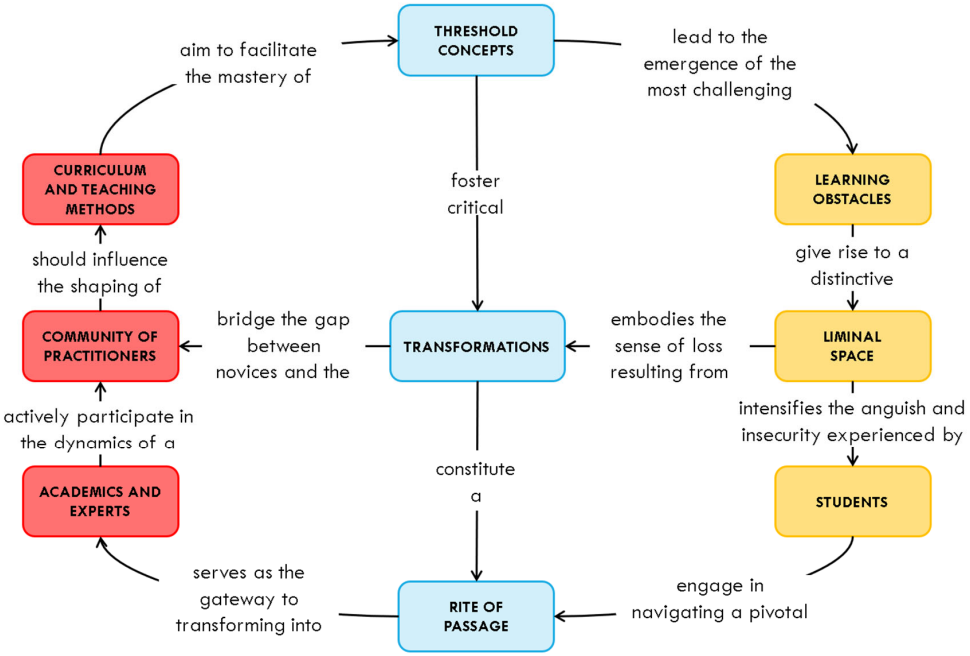

Figure 1. A concept map to answer the following question: How do threshold concepts (in blue) affect learning (in orange) and teaching (in red)?

2. Research Methods

The investigation followed Creswell's [23] and Gaur and Kumar's [24] approaches to literature reviews, with adjustments made in the coding and thematic categorization stages, which adopted the methodology proposed by Miles, Huberman, and Saldaña [25].

The Web of Science (WoS) database was selected as the source of articles to constitute the research corpus. Established in 1964 as the Science Citation Index, this tool functions as a unified research platform facilitating the acquisition, analysis, and dissemination of information [26]. Encompassing various knowledge fields and subfields, it strictly includes journals achieving high editorial rigor and best practices. The choice of this extensive database aimed to cover undergoing research from diverse knowledge areas.

Concerning the selection criteria, articles available in the WoS database (Core Collection) had to meet the following restrictions:

- Were published in peer-reviewed journals from 2003 (the year when the seminal article on the topic was published) to November 2023 (the last complete month available in the database);
- Included the combination 'THRESHOLD CONCEPT*' in the title, keywords, and/or abstract fields.

The first stage of the preliminary search identified a total of 925 articles. The research corpus for this initial investigation comprised the abstracts of these articles. Each abstract was individually read to identify articles directly related to learning, teaching, and education subjects. Consequently, 507 articles were excluded as they used the term 'threshold

concepts' with divergent meanings (Figure 2). Examples included exercise physiology (referring to lactate blood levels), sustainability studies (referring to the recovery of degraded areas), and computing programming (referring to matrix algebraic operations). Minor occurrences in other knowledge areas were also noted. Following these exclusions, 418 articles remained that aligned with Meyer and Land's definition of 'threshold concept,' [12] and were included in subsequent stages.

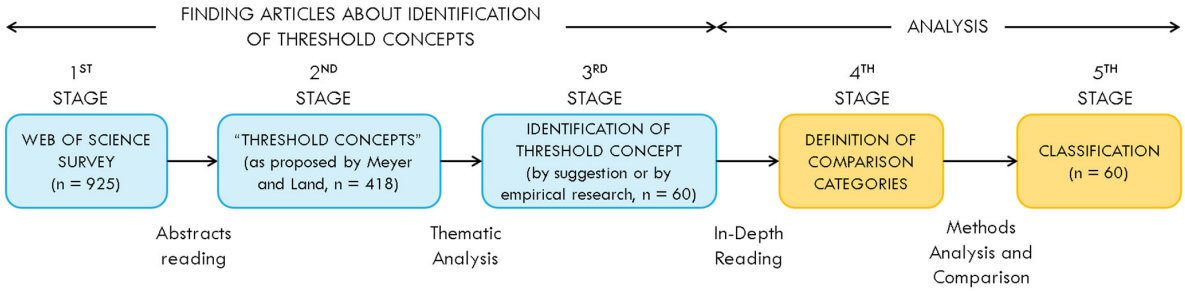

Figure 2. Research procedures organized into stages, with emphasis on survey and selection of articles (in blue) and the creation and validation of categories used in the analysis (in orange).

For the next stage, one of the authors identified and recorded the thematic categories present in [12,21], which are widely recognized as seminal articles in the literature on threshold concepts, using the descriptive coding approach [25]. These thematic categories guided the development of an initial set of codes, along with their provisional descriptions, facilitating the initiation of the extensive database coding work. The generated codes were presented to two other authors, and subsequent discussions allowed for refinement of the descriptions. This approach leveraged the fact that, in the field of threshold concepts, pioneering authors and seminal works are widely acknowledged. Therefore, the study operated under the assumption that the categories presented by these seminal works could effectively be used as a reliable first guidance to the analysis of all subsequent productions.

A preliminary exercise of individual, independent coding was conducted by two of the authors adopting the previously discussed categories as deductive codes. A sample of 50 abstracts was selected, with each paragraph serving as a coding unit. Due to unfamiliarity, specific qualitative analysis software (CAQDAS) was not used, and code occurrences were directly recorded in a separate Microsoft Excel 2019 spreadsheet for each researcher.

The records from the preliminary coding exercise were compared between the two authors for each category and coding unit (i.e., each paragraph of each abstract). Concordance rates ranged from 30% to 83% (weighted average of 54.8%). Since the overall index was considered low, both researchers agreed to review each coding category and its descriptions one by one. It was observed that in about 2/3 of the categories, there were severe inaccuracies in the inclusion and exclusion criteria. These criteria were discussed for each category by the two authors, and after developing a new coding system, the coding exercise was repeated on the same basis. At the end of this process, concordance rates for each category ranged from 60% to 100% (weighted average of 87.3%). The list of codes (codebook) is presented in Appendix A.

The same procedure was adopted for inductive categories, i.e., those categories that emerged directly from the data. After the first round of coding, each researcher presented their proposal for the set of new categories. The categories were compared between the authors, aligned, assigned a label, and characterized (by including a description and inclusion/exclusion conditions). These categories were incorporated into the original coding system and recorded in a separated column in the working spreadsheets (see Appendix A).

The extensive database was coded by two of the authors of this article, with occasional meetings to compare results and identify new emerging categories. At the end of the process, codes and subcodes were grouped by similarity as themes (described in the

Results section). One of these themes, 'Threshold Concepts in Disciplines', allowed for the identification of the subset of 60 articles used in the final phase of the research.

The concluding phase of the analysis involved a qualitative exploration of the methodological practices employed in the identification of threshold concepts. During this final refinement, articles were excluded if they referred to threshold concepts already identified in another article or if they lacked adequate information about the identification methods used. This mapping process identified a subset of 60 articles (Figure 2) with distinctive outcomes related to identifying threshold concepts, either by proposition or empirical research.

Any investigation aiming to identify threshold concepts follows the conventional stages of empirical research: a researcher defines which characteristics of the threshold concept will serve as indicators (properties) for their search, defines a data source believed to inform about these characteristics (such as documents or individuals), selects a strategy for collecting and another for analyzing and interpreting this data, and evaluates the results obtained (in this case, the identified threshold concepts as well as any potential limitations associated with the process). Thus, each of the identification processes reported in the previous 60 articles was categorized according to six groups of variables:

- Reference and cataloging: names of the identified threshold concept and knowledge area;
- The data source: nature of the data source (students, academics, professionals) and characteristics of this source (such as sample size and recruitment criteria used);
- Data collection resources: properties of the adopted threshold concepts ('transformative', 'troublesome', 'integrative', etc.), data collection method (interviews, focus groups, tests, etc.), and posed questions (e.g., 'What do you consider a critical concept in Finance?' or 'Please select the 3 concepts which are the most difficult to learn in Statistics.');
- Interpretation approaches: analysis technique (occurrence counting, content analysis, etc.);
- The overall method design: number of sources used (one or more than one);
- The robustness of the investigative process: limitations reported in the article.

The choice of this set of variables was based on the review conducted by Barradell [13]. It aimed to translate factors that may affect the reliability of the results obtained in a search for threshold concepts.

The analysis of these articles allowed the researchers to group them based on the methodologies employed for identifying threshold concepts. These groups are presented in the Results section. The subsequent analysis of categorizations yielded three second-order analyses, as outlined in the following section:

- A breakdown of each assessed characteristic;
- A compilation of techniques employed at different stages of the identification process;
- A diagram to support decision-making processes essential to investigative procedures.

3. Results and Discussion

The analysis produced three primary outcomes. Firstly, there was a comprehensive and quantitative overview of the key themes discussed in the academic literature on threshold concepts. Secondly, there was a systematization of the various sources of bias that could affect the process of identifying threshold concepts across different knowledge domains. This categorization brings together and organizes several earlier findings scattered throughout the literature on the subject. Lastly, there was a collection of evidence suggesting the potential impact of these biases on previous investigations focused on identifying threshold concepts.

3.1. Charting Current Trends in Academic Research on Threshold Concepts

The Web of Science database presented 418 articles that met the criteria for the 20-year timespan. Table 1 represents the comprehensive results of the analysis of thematic categories

applied to the entire set of 418 abstracts. The left column illustrates relevant thematic categories present in the seminal papers about threshold concepts, offering insight into how the idea was initially introduced to the academic community [12,21]. Thematic categories listed in the right column refer to other significant issues that did not appear in the seminal articles but emerged during the coding process.

Table 1. Categories of seminal and emerging themes from the literature (n = 418) on threshold concepts.

Seminal Themes	Total	Emerging Themes	Total
Best Practices	204	Threshold Concepts in Disciplines	94
Transformative Learning	76	Mechanisms and Mental Models	19
Troublesome Knowledge	58	Metacognitive Issues	11
Ways to Thinking and Practicing	33	Research Methods Development	9
Measurement Techniques	33	Other Applications	8
Threshold Crossing and Liminality	31	Metalearning	3
Theoretical Framework	16	Interface with Concept Maps	2
Student Stuckness	10	Literature Reviews	2
Variation in Student Learning	5		
Epistemological and Ontological Issues	4		
Identification Criteria	4		

Two themes were detailed due to the large number of records. In 'Transformative Learning', we found 'Transformation of Language' (32), 'Construction of Professional Identity' (21), 'Transformation of Understanding' (8), and 'Unspecified' (15). In 'Best Practices,' we found 'Recommendations for Teachers' (81), 'Design of Learning Resources' (40), 'Curricular Design' (41), 'Recommendations for Schools' (20), 'Recommendations for Students' (18), 'Curricular Redesign' (8), and 'Recommendations for Collaborative Practices' (6).

These results offer at least five interesting interpretations:

- The noteworthy number of articles linking threshold concepts and 'troublesome knowledge' (58) reinforces the connection between threshold concepts and learning challenges.
- The prevalence of articles focused on practical applications (linked, for instance, to 'measurement techniques', 33) compared to theoretical or critical articles on these applications ('theoretical framework', 'epistemological/ontological issues', and discussions about criteria for identifying threshold concepts). This aligns with Barradell's observation [13] that the field is still 'in its infancy' and undergoing a phase of theoretical and methodological maturation.
- The substantial amount of research offering recommendations for teachers (81) and direct applications, such as the design of learning resources (40) and curriculum design (31), also underscores the field's strong practical orientation.
- The significant portion of research mentioning specific threshold concepts in various fields of knowledge (94) suggests their dissemination across diverse areas.
- The presence of articles dedicated to understanding the mechanisms and mental models associated with threshold concepts (19), as well as metacognitive (11) and meta-learning (3) questions, were initially unaddressed in the seminal articles but emerged from the field, indicating a refinement towards more specific discussions.

3.2. Identification of Threshold Concepts: Where Are We?

Identifying a threshold concept is crucial for unlocking its potential benefits. However, misidentifying a threshold concept may lead to a lack of focus within the curriculum, directing attention towards misconceived elements or numerous scattered points [15,27]. One of the primary effects of identifying a threshold concept within a curriculum is discerning the portions, points, or ideas critically relevant to learning [12]. Thus, the accurate mapping of the conceptual terrain in any knowledge domain relies on the proper identification of the

threshold concepts present, which, in turn, depends on the methodological care involved in the identification process.

All threshold concepts identified thus far explicitly or implicitly incorporate some of the properties originally proposed by Meyer and Land [12] or a combination thereof. These properties emerged directly from the final phase of the ETL project, serving as the fundamental characteristics of the pioneer threshold concepts identified at the project's conclusion: 'Opportunity Cost' in economics; 'Depreciation' in accounting; 'Signification' in literature; 'Limit' in mathematical analysis; and 'Complex Numbers' in pure mathematics [22]. Since then, these properties have been acknowledged as distinctive indicators of a threshold concept and utilized as criteria for empirical exploration (Table 2). Subsequently, three additional properties were incorporated into the original framework, aiming to enhance methodological rigor in the identification processes [28].

Table 2. Properties (proposed criteria) for the identification of threshold concepts.

Original Properties (2003)		
Property	**Description**	**References**
1. Transformative	Once understood, its potential effect on the student's learning and behavior is to provide a significant change in their perception of the subject.	[12]
2. *'Probably'* irreversible	The change in perspective caused by acquiring a threshold concept is not expected to be forgotten or only forgotten with a significant effort.	[12]
3. Integrative	Exposes previously hidden interrelationships.	[12]
4. *'Very often, but not necessarily always'* bounded	Every conceptual space will always have terminal boundaries, dividing it from threshold concepts in new areas.	[12]
5. *'Potentially, probably inherently'* troublesome	Challenging, counter-intuitive or requiring a suspension of disbelief.	[12,29]
Added Properties (2011)		
6. Liminal	Refers to the transition process where a threshold concept is internalized, and which is like a journey or a 'rite of passage' within a liminal space.	[28,29]
7. Reconstitutive	Relates to a shift in a learner's subjectivity, a transconfiguration of self (identity), promoting an 'ontological shift'.	[28,29]
8. Discursive	An extended use of natural, symbolic, or artificial language characteristic of disciplinary discourses.	[28,29]

This set of five (or eight) properties has rapidly disseminated among researchers from various knowledge domains, but there are some issues concerning threshold concept identification with a low level of consensus and even contested positions. These issues vary in nature and magnitude, but all of them are related to some extent to the various risks of biases associated with these identification processes. Unawareness of these sources of biases may potentially interfere with the final concept obtained, possibly leading to issues of misidentification.

Table 3 systematizes some of these bias sources, moving from more abstract and conceptual issues towards methodological and operational questions. A recurring issue in the literature on threshold concepts, for example, relates to the absence of a formal definition. Instead of a definition, a frequently used quote by scholars describes the threshold concept as 'akin to a portal, opening up a new and previously inaccessible way of thinking about something [12]'. Despite being popular and readily recognized, this analogy does not constitute a definition in itself [19], which has some implications. On the one hand, this allows flexibility for scholars from diverse fields such as architecture or molecular biology to recognize ideas that fit in this description in their respective areas of expertise. On the other hand, it brings potential problems to the identification process, as it

allows scholars from a same field to present two entirely distinct concepts (candidates to being a threshold concept), but both with some level of adequacy to it.

Table 3. Systematization of biases in the identification of threshold concepts.

Potential Source of Bias	Remarks and Inquiries	References
Epistemological	Lack of a formal definition; indirect description by characterizing properties.	[12,20,30,31]
Ontological	What are the essential (non-negotiable) characteristics of a threshold concept?	[13,19,32]
Nature of properties/criteria	Different natures of the properties/characteristics; two distinct subsets of properties.	[20]
Political uses	Relations of 'entrenched power dynamics'.	[20,30,33]
Researcher's subjectivity	How does the researcher interpret the idea of a threshold concept? How does the researcher interpret each of the properties? How does the researcher select the most relevant characteristics? How does the researcher define data sources? How does the researcher interpret the collected data?	[13,19,20]
Interviewee's subjectivity	How does the interviewee interpret the properties? How does the interviewee perceive these properties?	[13,19,20]
Data analysis methods	Which criteria influence the choice of data analysis approaches?	[13,20]
Data gathering methods	Which criteria influence the choice of field-data-gathering instruments?	[13,20]
Intended output format	What is the most suitable format to express, document, and communicate a threshold concept given a specific knowledge area?	[32,34]

Another consequence of the absence of a formal definition is that the characterization of a threshold concept becomes dependent on indirect means, such as properties and markers with indicative functions. In the case of threshold concepts, there is a natural choice in the form of a popular framework (Table 2). However, discussions on the five originally proposed properties are ongoing regarding the completeness or exhaustive nature of their set. For instance, there is an ongoing debate about whether a threshold concept needs to meet all five properties simultaneously, most of them, or just one of them [20]. In the case of meeting only one (or some of them), technical questions automatically arise about different degrees of relevance among these properties (in the form of weights or gradations) when they function as criteria or about negotiable (with non-mandatory occurrence) or non-negotiable (with mandatory occurrence) characteristics [13]. For some researchers, the inclusion of three additional properties [28] has intensified this discussion [13]. Another more sophisticated debate suggests that within these sets of properties, two subsets coexist: some properties are related to the role that a threshold concept plays in the epistemic conceptual field (which is more easily perceived by academics and practitioners), while other properties relate to effects produced by a threshold concept on the learning process (which is more easily perceived by students and teachers) [20].

Beyond strictly epistemological issues, another current discussion is the use of threshold concepts as instruments of power within a community. For instance, in curriculum building, different (and sometimes conflicting) interests and worldviews converge. Some researchers acknowledge that labeling a concept as 'the threshold concept of that knowledge area' is subject to interference from (and caters to) 'entrenched power dynamics' [20,30,33].

There are also other documented sources of bias intrinsic to any research process (especially well known in qualitative traditions). These sources are associated with the implicit subjectivity of the involved agents, whether acting as researchers (making methodological choices) or as participants (providing the data to be collected). These bias sources are more readily acknowledged for experienced researchers and consequently (at least theoretically) simpler to control.

A final source of bias concerns the format that a researcher expects from a threshold concept, i.e., how this threshold concept is expressed, documented, and communicated. The threshold concepts firstly reported in academic literature corresponded to highly abstract concepts, formulated as a single word or a combination of a few words (such as 'opportunity cost' or 'caring') [35]. However, some authors suggest that the use of short phrases can better translate and communicate the essence of a threshold concept

as a semantic resource (such as 'System analysis involves an interplay between time and frequency' instead of 'Frequency Response') [34]. Some authors speculate that knowledge areas from different domains (for example, engineering or writing studies) may have a greater affinity with one or the other of these two formats [34]. Other threshold concepts which were reported adopted the format of 'big ideas' in a knowledge field ('Poverty' [36]), stances ('Motivational Engagement' [37]), or key skills for professional practice in the area ('Developing new ways of knowing', 'Constructing researcher and writer identity', and 'Positioning within the nursing search' [38]).

Regarding the impact of these bias sources on the methods employed in identifying threshold concepts, Barradell warns that '...the rapid acceptance of something that is still emerging... means that aspects of the discussion around threshold concepts have not necessarily been conducted with the rigor they should have,' and that 'a number of important questions remain unanswered' ([13], p. 266). After a literature review on the identification of threshold concepts, she reveals other findings, such as the wide variety of techniques used, the predominance of qualitative research approaches, and a widespread lack of rigor (with respect to what the interviewees understand as a 'threshold concept'). She concludes with two recommendations [13]:

- The need for more robust methodologies that incorporate consensus-building rounds (such as the Delphi technique or the Nominal Group Technique);
- The inclusion of non-academic experts, with a focus on the professional and applied use of discipline knowledge and the 'ways of thinking and practicing' mentioned by Meyer and Land [12].

Two more recent articles report the results of literature reviews on methods for identifying threshold concepts. Nicola-Richmond and colleagues conducted an interesting and comprehensive analysis, but it was oriented toward measurement techniques for crossing the threshold rather than specifically addressing identification issues [14]. Hendrawati et al. provided a commented comparison of methods, but they limited their analysis to the field of science education [39].

To the best of our knowledge, there is no systematic review that provides a quantitative overview of the production related to the identification of threshold concepts or that has systematized this production in the form of an articulated body of research methods.

3.3. Criteria to Identify Threshold Concepts

Regarding the properties chosen as identification criteria, Table 4 describes the number of articles in which each property was triggered in the identification process of threshold concepts [12,28]. In some articles, the methodology did not make it clear whether a particular property was adopted or not. In such cases, a record of 'implicitly adopted' was generated.

Overall, there are four approaches that have been adopted for surveys:

- Questions that request the identification of 'a highly relevant concept', 'a central (fundamental) concept', or 'the most important concept(s) in the discipline'.
- Questions that request the indication of 'an essential concept for a professional in the field.'
- Questions that directly address the identification of a 'threshold concept' (after providing some usually simple explanation about the idea of a threshold concept).
- Questions that address one or more properties of the analytical framework, such as 'What do you consider a difficult concept in the discipline?' or 'Has any concept in the discipline changed your view of the discipline? Which one?'

These statistics, however, support Barradell's perception that 'troublesome' and 'transformative' are recurrent choices for three reasons: the emphasis given to them by Meyer and Land [12] in their seminal article, the greater ease of their measurement, and their probable status as the most determining factors for the success or failure of learning [13]. The data also confirmed the modest effect promoted by the expansion of the identification

framework from five to eight properties [28]; the properties that were included at that time remain among the four least effectively adopted.

Table 4. Utilization frequencies of threshold concept properties for identification purposes.

Property	Explicitly Adopted	Implicitly Adopted	Total	% (n = 60)
Transformative	39	10	49	81.7
Troublesome	40	5	45	75.0
Integrative	31	7	38	63.3
Irreversible	30	5	35	58.3
Liminal	8	6	14	23.3
Bounded	12	1	13	21.7
Reconstitutive	5	4	9	15.0
Discursive	4	3	7	11.7

In the absence of a formal definition for what constitutes a threshold concept, the discussion on its properties becomes central in debates about identification methods, as these properties are naturally adopted as criteria for such identification [19]. Thus, questions about which properties are non-negotiable, how many of these properties (and which ones) should be observed [20], and the existence of 'canonical' threshold concepts (in the sense of simultaneously exhibiting all properties) occupy a central (perhaps the most central) role in any discussion about identification method. Defining this set of criteria has implications for subsequent methodological decisions that need to be made and articulated.

For example, the definition of the criteria significantly influences the choice of information sources for the researcher. An undergraduate student, particularly at the beginning of a course, may find it challenging to grasp the notion that the conceptual framework of each knowledge area revolves around a specific threshold concept. Likewise, an academic who is not actively involved in teaching is likely to depend solely on their individual experience, such as recalling concepts that had 'transformative' or 'troublesome' effects on their own learning journey.

Figure 3 represents this correspondence between sources and criteria, positioning different actors in a space with two axes. The x-axis represents the opposition between the two different dimensions of threshold concepts. On the left is the epistemological dimension, referring to the set of concepts in a knowledge area, how these concepts are organized, and the prominent position of a threshold concept within this set (for example, integrating the meanings of various core concepts) [15]. On the right is the ontological dimension related to the various transformative processes that a student must undergo in his formative process, characterizing the promotion from a novice to an expert as s/he overcomes a liminality process. The y-axis, in turn, represents the continuum between theoretical-abstract knowledge (associated with network-like concept structures) and applied-procedural knowledge (associated with linear concept structures) [16,17].

This representation offers three contributions that can enhance the comprehension of identification methods:

- Different actors perceive different manifestations of threshold concepts, whether at the abstract level of concept organization in a knowledge field or at the subjective level of experiences lived by students in their formative processes, with varying degrees of precision.
- The integrative property of a threshold concept encompasses not only the ability to integrate other concepts with it and among themselves but also its role in connecting theoretical-abstract concept structures ('thinking') with applied-procedural concept structures ('practicing') [27], fostering structures that articulate theory and practice [16,17].
- Third, the professor occupies a position that allows individuals in this role to bring together the perceptions of different actors as mediators for all perspectives.

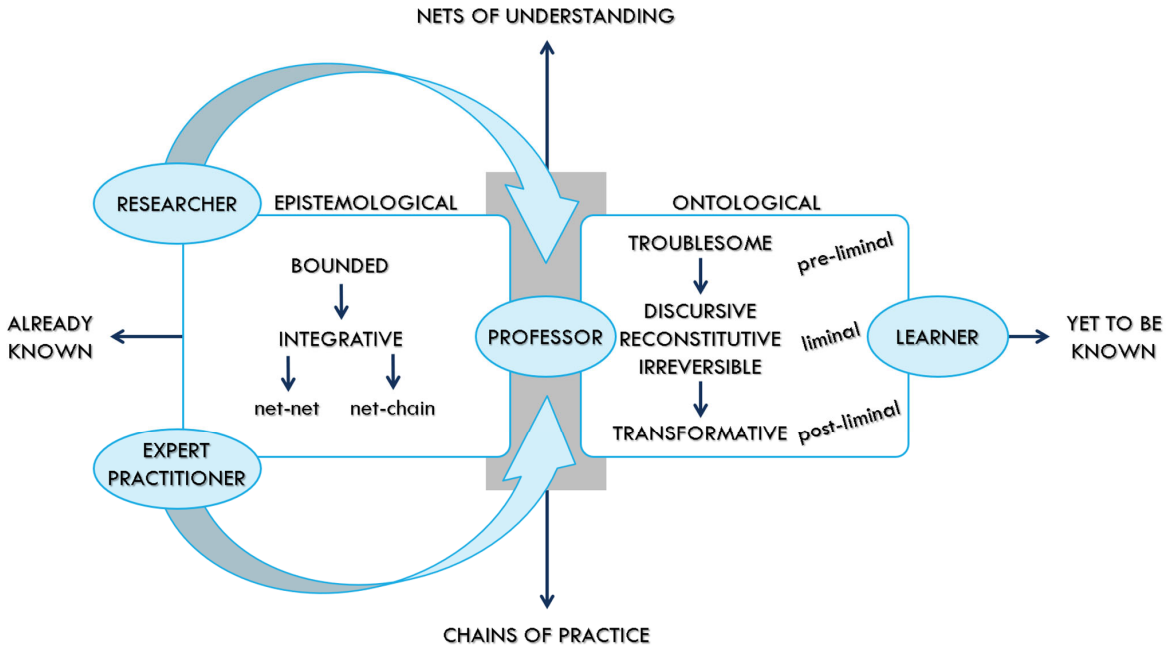

Figure 3. Framework for organizing the characteristics of threshold concepts considering knowledge structures and the teaching and learning process. It highlights the epistemological and ontological domains (white boxes) and the professor's role in bridging the gap (grey box) that separates these domains.

The framework outlined in Figure 3 also clarifies the interrelation among the eight indicative properties of a threshold concept, originating from their diverse natures. Some scholars posit that the 'bounded' property is arguably the most characteristic and pertinent feature of a threshold concept [27]. This stems directly from the epistemological evolution within each knowledge area. Addressing real-world issues, a community of practitioners develops and consolidates its knowledge through practices, values, and beliefs continually shared, matured, and formalized within the community. These understandings are solidified in an organized body, typically referred to as 'ways of thinking and practicing' [12], wherein theory and practice are naturally interconnected through a mutual process of signification. Within this knowledge structure, the threshold concept assumes a unique position, articulating and guiding the meaning of other concepts in the field by integrating theory and practice [15–17].

The dissociation of these two elements (e.g., in a less contextualized or excessively abstract learning process) tends to render this knowledge counterintuitive and, consequently, lacking in meaning. Consequently, facing the unusual nature of the threshold concept can elicit an initial reaction of estrangement in the student's mind, activating the early stages of a liminality process. This peculiar nature can also trigger feelings of insecurity, uncertainty, and discomfort. Thus, the first visible manifestation (from the student's perspective) is troublesome knowledge, taking the form of a very specific learning obstacle that poses challenging for the student.

The troublesome condition is navigated throughout the entire liminality process across its three main dimensions: cognitive (via the reordering of cognitive structure and re-establishment of semantic relationships), affective (through the acquisition of metacognitive skills and threshold capabilities [40]), and social (via acceptance into a community of practitioners after the appropriate rites of passage). Following the overcoming of liminality, the post-liminal phase is characterized by a shift in discourse capability, a change in worldview within the knowledge area and self (reconstitutive) [28]. This marks the culmination of the extensive transformation process. Due to the extent of the transformation and its intertwined levels, it is reasonable to assume that this transformation is most likely irreversible.

3.4. Comparison of Methods for Identifying Threshold Concepts

The final research reported in this article aimed to produce a systematic review of articles focused on identifying threshold concepts. The methods described in 60 articles (reporting threshold concepts identification processes) were compared using ten characteristics. This analysis revealed that the broad variation in techniques already reported in the literature [13] revolves around the following key aspects:

- The overarching strategy adopted (the 'general design' of a methodological approach);
- The selection of how many and which properties of a threshold concept were chosen for the identification process;
- The nature of the selected information source (e.g., whether teachers, academics, experts, undergraduates, or postgraduate students);
- The data gathering instrument used, the method of analyzing, and the method of interpreting the generated data;
- The expected format (presentation form) for the threshold concept.

A researcher engaged in empirical work and mindful of these aspects can make more suitable and informed decisions regarding the selected methods, critically assess the validity of the results obtained, and pinpoint areas for improvement in these processes. Conversely, an inquiry that neglects these aspects may introduce biases to varying degrees, potentially resulting in the misidentification of threshold concepts [41].

The extensive variation in techniques likely stems from three main factors. Firstly, the absence of a formal definition for a threshold concept prompts researchers to resort to well-known properties of these concepts (integrative, transformative, troublesome, etc.). In empirical research, a subset of these properties serves as markers, indirectly indicating the presence of a threshold concept. Secondly, despite being widely disseminated and known among researchers, these properties themselves also contend with fluctuating definitions and some degree of imprecision in their description [19,20]. Consequently, researchers are likely to select as criteria the subset of properties most correlated with their understanding of a threshold concept. Thirdly, the idea of a threshold concept has rapidly proliferated, engaging scholars in various fields in a decentralized process [13]. The diverse backgrounds of researchers are reflected in the different methodological resources with which they are familiar.

Thus, a researcher aiming to identify a threshold concept in their field can employ two strategies. The first is to adapt an investigative approach (methods) already familiar in their empirical practice (likely from existing research in that field) but now with the specific goal of identifying a threshold concept in their knowledge area. Another strategy is to adapt an approach previously used to identify threshold concepts but applied in another knowledge area. In this second case, researchers engage in some interaction (mediated by academic literature), but this exchange occurs only at the level of techniques and methods, as the results of these investigations (the identified threshold concepts themselves) are usually not shareable across areas. Thus, in most fields, each researcher initiates this research in their field without previous results to build on given that empirical research on threshold concept identification is still in the process of structuring and consolidating in most fields. In each field, the maturity of identification varies. In some, the discussion has advanced to comparisons of adopted methods and results; however, in most areas, the outcomes reflect the efforts of isolated researchers with limited capacity for dialogue.

The concern about biases in the identification of a threshold concept is crucial in any empirical inquiry, but it significantly affects investigations that do not employ some form of verification. One way to address this is through negotiation among the actors involved in the learning process (such as professors, students, academics, and experts) or directly through the outcomes obtained from different searches in the same knowledge area. In this regard, Table 5 presents a hierarchy of the five different general methodological designs adopted in the set of analyzed articles. As a criterion for ordering, the reported sequence considers the adoption of precautions to ensure the validity and reliability of

the results, considering bias control by using checks, verification steps, and triangulation among different sources of evidence.

Table 5. Overarching method designs and implied challenges and pitfalls.

Groups	Description of the Method	Total	References
Group 1	Personal reflection by the researcher, occasionally involving informal consultation with other academics (e.g., personal exchanges of communications but without following a declared research protocol). • Challenges: *Lack of support in pre-existing results in the specific literature, limited access to peers familiar with the idea of threshold concepts, and uncertainty regarding the validity of results obtained through reflection.* • Pitfalls: *The absence of experienced peers with the idea may lead to the impression of little rejection and challenge, 'enchantment' with the idea of threshold concepts may suggest the non-necessity of result validation, and the lack of a counterpoint may imply the existence of a singular view on the knowledge area.*	23 (38.3%)	[36,42–63]
Group 2A	Personal reflection, as in the previous case, but preceded by some structured method of validating the results of these reflections (e.g., focus group with other academics or students, verification through questionnaires, or analysis of exam results). • Challenges: *The need to 'translate' the idea of threshold concepts for a non-initiated audience, difficulty in recognizing the personal biases involved in the initial proposition of the threshold concept, difficulty in recognizing biases related to the non-initiated audience, the need to select an appropriate audience (e.g., students or academics), the need to select suitable data collection methods (e.g., identification criteria) for the chosen audience, the need to adapt research methods existing in the literature to their own knowledge area.* • Pitfalls: *Proposing a specific idea to a non-initiated audience can lead to an induction of their opinions, the audience's perception of the researcher may interfere with the audience's inclination to accept/reject the proposition of the threshold concept, and the use of a validation form tends to hide biases hidden in the validation process itself.*	4 (6.6%)	[64–67]
Group 2B	Personal reflection followed by validation methods, as in the previous case, but also allowing for the suggestion or emergence of new threshold concepts beyond those initially proposed. • Challenges: *The same as the previous case.* • Pitfalls: *The same as the previous case (aggravated by the fact that threshold concepts will also be suggested by an audience probably not initiated into the idea), and threshold concepts suggested by the audience also need some form of validation.*	2 (3.3%)	[68,69]
Group 3A	Open-ended single-stage approaches where threshold concepts are directly suggested by the individuals researched without prior suggestions by the researcher. • Challenges: *Selecting appropriate data collection strategies for the audience (such as focus groups, questionnaires, or consensus generation techniques like Delphi), choosing collection strategies suitable for the academic or disciplinary area, crafting suitable collection instruments (e.g., discussion prompt questions, questionnaire items), defining how the idea of a threshold concept will be presented (the idea itself or through which descriptive properties), setting criteria for consensus generation, and facilitating mediations between participants in the collection.* • Pitfalls: *The idea of threshold concepts is challenging even for researchers experienced with the topic, let alone for non-initiated audiences. Surveys, even when conducted in groups, may mask the need for subsequent validations.*	19 (31.6%)	[37,38,70–86]

Table 5. *Cont.*

Groups	Description of the Method	Total	References
	Open-ended multiple-stage approaches where threshold concepts are initially suggested through some survey and then assessed by some other method (e.g., a group of students suggests a preliminary list of results, and then a group of academics discusses and evaluates these results, or vice versa).		
Group 3B	• Challenges: *Use of multi-stage techniques, definitions of data sources (and the sequence of stages), and definition of criteria for cross-referencing results between stages*. • Pitfalls: *Threshold concept identifications are not definitive and can be refined (in terms of validity, reliability, and final presentation form)*.	13 (21.7%)	[87–99]

Group 1 refers to articles with the simplest methodological design reported in the literature involving a researcher (or a small group of researchers) identifying threshold concepts in their area as a direct result of introspection. Usually, researchers analyze the most relevant concepts pertaining to a specific knowledge area, consider a subset of threshold concept properties, and chooses which concepts 'fit that set', justifying their reasons. Eventually, this identification process is followed (or preceded) by some literature review on the topic [43,51]. Propositions grounded solely in personal reflections are subject to various personal biases related to the researcher (e.g., their understanding of what threshold concepts are and how they perceive the various concepts in their field). However, in some cases, the scarcity of dialogue partners in a specific area makes this the only available option.

Group 2A refers to articles with the same starting point (i.e., a researcher proposing threshold concepts after a personal process of introspection) but with the additional care of formally including a verification step. This step involves confronting the result with a second source of opinions. For example, a concept may be characterized as a threshold concept in an area by a researcher, but this proposition is subsequently validated through focus groups with students [64], workshops with academics, or questionnaires [69]. Other articles report a similar methodological design (Group 2B), relying on a subsequent validation step but allowing for the possibility that new concepts may be identified as threshold concepts in this same step. Generally, these articles explain that this second source (e.g., students) must be informed about what a threshold concept is to make an appropriate assessment of the concept proposed by the researcher. As a second effect of this clarification, they become capable of expressing their own impressions. In both cases, the supplementary verification step tends to minimize the effect of the researcher's personal biases; on the other hand, it opens the door for biases from this second source to be introduced. For example, how this second source interprets what threshold concepts are also starts to interfere in the process, with the potential drawback that this second source is probably less familiar with the idea of threshold concepts than the original researcher.

In Groups 3A and 3B, the researcher refrains from directly proposing a threshold concept, choosing instead to conduct a survey with a broader audience for this purpose. Generally, the idea of a threshold concept or some of its characteristics (such as being integrative, transformative, or problematic) is presented and explained to this audience (e.g., academics, students) to enable them to minimally recognize a threshold concept. Data can then be gathered from interviews [73], focus groups [37,70], participant observation [71], action research [80], or questionnaires [86], and content analysis is usually selected as a standard following step, although some researchers adopt more structured techniques (for example, grounded theory [82,89] or phenomenological approaches [75]). Next, the results of this survey are organized and analyzed by the researcher, who applies some criteria to arrive at a definitive threshold concept (or a shortlist of threshold concepts), as in Group 3A. In articles in Group 3B, the evaluation of the results of this preliminary survey is carried out by a second source (e.g., other academics or professionals experienced in the field). In every case, a round of consensus generation may be required, such as Delphi [87,90] or nominal group technique [91] approaches. Again, involving more sources tends to contribute to reducing

the biases intrinsic to the isolated researcher but introduces new possible biases related, for example, to the understanding that students and other academic colleagues have about what a threshold concept is or how they decode labels like 'integrative' or 'transformative'. Compared to the process centered on an isolated researcher (Group 1), these new sources of bias have a less uniform, more diffuse nature and can imply subtle effects on the results of identification.

Figure 4 presents a diagram to show that essentially every process of identifying threshold concepts involves five central decisions. The first decision is about the overall design of the research concerning how the threshold concept will be generated. The simplest design is through the researcher's personal reflection (Group 1), but there is an option to test the suitability of this threshold concept through assessors, such as academic and non-academic experts, education experts, and different groups of students. This can be a 'closed list' test (where only the proposed concepts are assessed for their suitability or not, Group 2a) or an 'open list' test (where new threshold concepts can be suggested and added to the list, Group 2b). In these cases, in addition to defining the test group, it is also necessary to define the data collection method (questionnaires, individual interviews, and focus groups are the most common choices, but options like workshops, analyses of tests, and observations of class behavior are available), statements (conveying the chosen criteria), and criteria for generating consensus (voting, counting, or the Delphi technique, for example). Bolder designs involve surveys of threshold concepts where the researcher goes into the field with the expectation that respondents will suggest their concepts. In this case, the process can be carried out in a single stage (Group 3a) or in multiple stages, which tends to add greater robustness to the process (Group 3b) by incorporating different perspectives on the same phenomenon. Barradell [13], for example, notes that professors tend to observe more abstract characteristics like 'Integrative' and 'Bounded', while students are likely to focus on experiential characteristics such as 'Troublesome' and 'Transformative'.

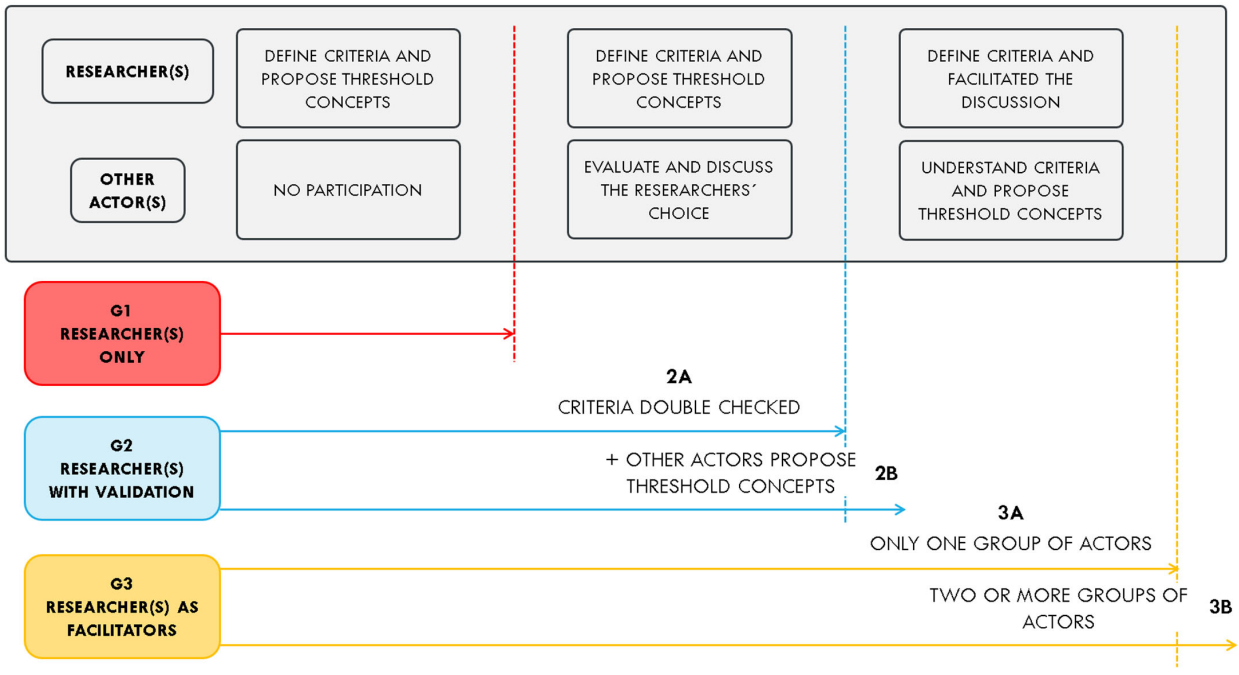

Figure 4. Diagram depicting the methods employed to identify threshold concepts considering their respective strengths and weaknesses.

4. Conclusions, Prospects, and Limitations

This comprehensive review revealed that academic production has expanded on various fronts. The results indicate that threshold concepts find advocates in various disciplines, suggesting that the idea can be adapted to the demands of different academic areas. This flexibility facilitates the exchange of ideas, practices, and findings in a shared space, explain-

ing why the literature on threshold concepts is scattered across disciplinary fields. However, this fluid definition inherent to threshold concepts implies ontological challenges with methodological consequences. The imprecision directly affects the processes of identifying threshold concepts in each knowledge area, serving as an inherent bias source.

The methods for identifying threshold concepts are selected according to the specificities of each knowledge area and are associated with affinities and traditions in each research community. This practice is also influenced by different interpretations that each community has regarding what a threshold concept is, its nature, and the format that best represents its essence. The wide variety of techniques resulting from this conjunction of factors is neither inherently suitable nor unsuitable for threshold concept identification practices, but each method choice brings challenges to overcome and pitfalls to avoid.

A critical challenge is recognizing that threshold concepts are not readily identifiable by a single absolute technique extendable to all areas, as there are specificities in each area that cause threshold concepts to manifest with significant variations in each context. Each combination of techniques is related to a different degree of rigor (from a scientific perspective) and, consequently, a greater or lesser consideration for the various sources of biases that affect these identification processes. Thus, the systematization of these bias sources can serve three functions: allowing researchers in each area to critically review the threshold concepts identified so far, contributing to guiding methodological choices in future identification work (towards designs that are not necessarily more robust but more aware), and highlighting the strategic role that the experienced teacher plays in these identification studies. The teacher can freely navigate between epistemological and ontological dimensions and access the background theoretical and applied knowledge in their area of expertise. Thus, they can act as the 'necessary mediator' between the perceptions of various stakeholders (other teachers, academics, students, professional experts).

A final aspect worth highlighting is the proposition that the results of identifications (the 'threshold concepts' of each area) can be generated through an incremental process with increasingly accurate and valid results. The set of threshold concepts in a disciplinary area can be refined through the adoption of more suitable techniques (in terms of more coherent methodological designs), more robust techniques (in terms of greater care with data collection instruments, for example), or by adopting formats more suitable for that knowledge area (in terms of the form and presentation of these threshold concepts).

The prospects for advancing current research in the field necessitate careful consideration:

- Promoting the widespread dissemination of intra-area threshold concept debate to elucidate their potential benefits and applications. This endeavor aims to foster increased engagement of researchers and heightened productivity in each specific field, working towards a critical mass that facilitates meaningful discourse among peers.
- Broadening the scope of academic discourse on threshold concepts through the establishment of continuous interdisciplinary forums. These forums will address limitations in usage and promote the sharing of best practices related to identification methods.
- Redirecting the discourse surrounding the identification of threshold concepts by emphasizing the imperative to review the underpinning epistemological and ontological foundations. Many pertinent issues arising in empirical practice within the identification field directly result from the impasses inherent in these foundations.

The present paper should be viewed considering the following study limitations:

- The authors chose to use a specific database (Web of Science). Results may vary when using other databases.
- The categories employed in deductive coding were formulated by a single researcher, relying on their interpretation of seminal articles [12,21]. This decision introduces a significant degree of subjectivity, albeit informed by well-established articles in the field. Furthermore, the coding process itself was subjective, despite the participation of two researchers and a verification process.
- The results presented in this review do not provide solutions to the ontological issues related to threshold concepts. Until this matter is more comprehensively addressed,

all empirical findings reported in the literature (including our review) possess relative value and will require further analysis in the future.

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Appendix A. List of Codes for Thematic Analysis (Codebook)

Deductive Codes	Description	Inclusion and Exclusion Criteria	Subcodes

Best Practices	This passage presents, exemplifies, or evaluates the use of some pedagogical practice involving threshold concepts (TCs). It can be the presentation of a didactic activity (e.g., an online learning resource), guidance to the teacher (e.g., paying attention to the learning difficulties that may occur in contact with TCs), or guidance for academic managers (e.g., restructuring the curriculum of a discipline to include the learning of TCs).	- Consider evaluations and analyses made on practices presented in other articles.
		- Disregard the mere nominal mention of practices presented in other articles.
		- Disregard generic and unspecific guidance ('TCs can collaborate with the learning process').
			For schools
			For teachers
			For (undergraduate) students
			For (graduate) students
			For collaborative practices
			Curriculum (re)design
			Design of learning resources
			Evaluation of learning resources

Transformative Learning	This passage presents, describes, or explains some personal transformation related to the student and associated with the learning of a threshold concept. It can be a change in the understanding of a concept/idea or a shift in worldview, in a disciplinary field, or about oneself. It can also refer to manifestations of acquiring threshold concepts, such as an enhanced language/discourse ability and skill acquisition. It can also relate to the development of a professional identity.	- Disregard the mere mention of transformations (without specifying what it is and who undergoes the transformation). - Disregard transformations of other kinds than those manifested through individuals (for example, a curriculum change).	- Transformation of understanding - Transformation of language - Construction of professional identity - Other (unspecified)
Troublesome Knowledge	This passage refers to problematic knowledge and learning difficulties in a broad sense (inert, tacit, counterintuitive, alien/foreign), that is, learning barriers. It does not address the behavioral and emotional reactions of students in the liminality process, which are discussed in other categories.	- Disregard mentions of behavioral reactions resulting from contact with this knowledge. - Disregard mentions of liminality resulting from contact with this knowledge.	-

Deductive Codes	Description	Inclusion and Exclusion Criteria	Subcodes
Ways of Thinking and Practicing	This passage mentions the idea of a practice (or a set of practices) that is shared by a community of users. It is also related to the idea that for a medical student to become a doctor, it is necessary for them to 'think like a doctor,' (and not only to know the necessary theoretical knowledge). It may refer to ways of thinking, values, beliefs, and expectations that characterize professionals in that community.	- Consider references to 'academic tribes' (such as postgraduate students or researchers). - Disregard mentions of illustrative examples that do not develop new ideas. - Situations that deal with the student's way of thinking (in contrast to the professional's way of thinking) but emphasize the transition between these modes fall under 'Transformative Learning.'	-
Threshold Crossing and Liminality	This passage mentions, describes, or analyzes the phenomenon of liminality, that is, the long non-linear process that connects the student in formation to the professional in the field. It may refer to cognitive issues (change in understanding), affective aspects (anxieties, distress, insecurity), or social aspects (rejection or acceptance by a community of professionals). Issues related to insecurity, self-esteem, and confidence are also addressed here.	- Consider situations that intersect with the 'Transformative Learning' code. - Consider situations that intersect with the 'Ways to Thinking and Practicing' code. - Disregard simple mentions of the phenomenon, only for illustrative or intentional purposes. - Disregard mentions of the phenomenon that do not develop new ideas ('this project aims to reduce the known negative effects of liminality').	- Liminality: cognitive issues - Liminality: emotional issues - Liminality: social issues
Measurement Techniques	This passage presents, explains, analyzes, or mentions the use of a technique specifically developed to detect threshold crossing, that is, the process of acquiring understanding of a threshold concept by students. It could be an assessment, an activity, or any other approach created to capture evidence that this transition has occurred.	-	- Proposed instrument - Instrument analysis

Deductive Codes	Description	Inclusion and Exclusion Criteria	Subcodes
Theoretical Framework	This passage refers to theoretical aspects related to TCs, for example, the relationship between TCs and learning theories or between TCs and pedagogical approaches. It can also address the idea of TCs but from a purely theoretical perspective. In general, it refers to more abstract works with a theoretical orientation (rather than practical).	- Consider references to theories from other fields (such as communication, psychology, neuroscience). - Disregard direct references to foundational works in TC but only for illustrative purposes aiming to situate the audience ('this work is based on the theoretical framework proposed by Meyer and Land').	-
Student Stuckness	This passage directly mentions the sensations of disorientation experienced by students during the liminality process. Typically, it refers to a feeling of uncertainty (about 'not knowing where to go', 'not knowing how to get out', or 'not understanding what is happening').	- Consider situations that intersect with the 'Threshold Crossing and Liminality' code. - Disregard situations where insecurity is not directly related to the contact with TC.	-
Variation in Student Learning	This passage mentions the specific term 'Variation in Learning,' which refers to the different outcomes that a learning process can have (promotion through expected learning, promotion through apparent learning/mimesis, retention, dropout).	- Consider only explicit mentions of the terms (or very close synonyms, such as 'Learning Outcomes').	-
Epistemological and Ontological Issues	This passage mentions evidence and/or inquiries about the actual existence of TCs and questions linked to the foundations of science (related to the validity of the phenomenon). These are essentially theoretical reflections.	-	- Ontological issues - Epistemological issues
Identification Criteria	This passage criticizes or analyzes the criteria used in the identification of TCs (transformative, integrative).	- Disregard the mere mention of the criteria without developing novel ideas related to them.	-

Inductive Codes (Emerged from the Field)	Description	Inclusion and Exclusion Criteria	Subcodes
Threshold Concepts in Disciplines	This passage identifies the use of threshold concepts in a specific knowledge area (e.g., medicine, PhD, law, chemistry) and names the threshold concept in question. It also includes excerpts and articles where threshold concepts are identified in a specific knowledge area.	- Consider graduate-level skills within this group (such as research skills, academic reading, and writing skills) as if it were a discipline. - Consider uses of any kind (approaches, learning resources, curriculum design). - Disregard mentions made solely for illustrating or presenting the idea of threshold concepts.	- Report of identification process - Non-report of identification process
Mechanisms and Mental Models	This passage explains, illustrates, or proposes how individual student processes work related to the acquisition of threshold concepts operating strictly at the mental and/or cerebral level (i.e., through pathways related to neuroscience). It also includes processes related to meaning attribution and the construction of meaning structures.	- Disregard mere mentions of this idea that do not elaborate on it.	-
Metacognitive Issues	This passage associates the acquisition of threshold concepts by the student with the development of specific personal skills not directly related to the discipline itself (which pertains to cognitive knowledge). It refers to self-awareness skills that enable access to self-regulation abilities.	- Disregard mere mentions of states of confidence and wellbeing (they fall under 'Threshold Crossing and Liminality').	-
Research Methods Development	This passage mentions, describes, questions, or analyzes empirical research methods related to threshold concepts (for example, proposes or questions techniques related to the identification of threshold concepts).	- Consider excerpts describing methodologies (techniques) adopted in empirical research, provided the research is reported in the same article. - Disregard excerpts that only describe sample characteristics/research corpus or merely report research results. - Disregard generic citations to empirical practice (without specifying or naming the cited techniques).	-

Inductive Codes (Emerged from the Field)	Description	Inclusion and Exclusion Criteria	Subcodes
Meta-learning	This passage explicitly refers to the meta-learning ability (i.e., the ability to 'learn about one's own learning process').	- Disregard quotations that do not delve into or develop the idea.	-
Literature Reviews	This passage is part of a literature review article.	- Use the code 'Literature Review' ONLY ONCE per article.	-
Interface with Concept Maps	This passage illustrates some explicit association of TCs with Concept Maps.	-	-
Other Applications	This passage presents other applications of TCs beyond those originally envisaged (curricular redesign; activity redesign; and guidance for use in courses, classes, and activities).	-	-

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