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Core concept identification in STEM and related domain education: a scoping review of rationales, methods, and outputs

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Core concepts—fundamental, enduring, and discipline-specific ideas—are essential for enhancing comprehension and facilitating knowledge acquisition for STEM and health-related learners. Since the 1990s, many articles have been published in STEM and health-related domains explaining the need and/or the value of identifying and utilizing core concepts in education. However, little research has explored the reasons for and methods for identifying the core concepts that may be useful to curriculum designers, course coordinators, instructors and assessment specialists in STEM and health sciences faculties. This scoping review examines the research on core concept identification within the context of STEM and Health-related domains of education with three objectives: (1) to describe the rationale for identifying core concepts; (2) to identify the study designs and research approaches employed; and (3) to present key outputs about core concept identification across domains. Using scoping review methodology aligned with Arksey and O'Malley's framework, eligible studies addressing core concept identification with a methodological description of how these concepts were identified for formal education in a STEM or health-related domain were identified through Medline ALL and Scopus database, complemented with backward citation of all included full-text references. Thirty research publications were identified, and data was systematically extracted and analyzed according to the review objectives. The review identified seven rationales for core concept identification, the most common being content prioritization, which addresses the need to identify essential teaching content within expanding knowledge bases. Mixed methods were the predominant research approach (n = 20), with various data collection and analysis methods, most of which are aligned with pragmatic philosophical worldviews, strongly emphasizing expert-driven techniques. These findings provide valuable insights for educators and researchers engaging in core concept identification, offering guidance for methodology selection and implementation while highlighting areas requiring further development in the field.

KEYWORDS

core concept, stem education, health science education, scoping review, concept identification, mixed methods, content prioritization, big ideas

1 Introduction

Core concepts are the big ideas that are essential to the understanding and practice of a discipline, the mastery of these concepts resulting in enduring understanding and the ability to address novel problems across that discipline (McFarland and Michael, 2020). These core concepts help learners develop appropriate structures for understanding and organizing discipline-specific knowledge; retain key concepts long after specific details are forgotten; solve discipline-specific problems, and transfer learning across different areas of a field (Michael et al., 2017). These concepts have underpinned education for decades, particularly in Science, Technology, Engineering, Mathematics (STEM), and health-related fields. Identifying core concepts in education is crucial as they provide a structured framework for organizing knowledge, facilitating deeper understanding, and establishing consistency across disciplines, thereby enhancing the application of learning across various contexts. These big ideas are considered central to a discipline and help in transferring learning beyond rote memorization. The value of core concepts is realized not only in their identification but also in how they are applied and integrated with other active learning strategies.

In STEM education, core concepts have gained prominence for their ability to support the structuring of information into coherent patterns and establish common vocabulary frameworks (Bacon, 1979; D'Avanzo, 2008; Chen et al., 2022). Their implementation streamlines knowledge acquisition by focusing on fundamental ideas rather than overwhelming students with excessive facts, which is particularly important given the rise in disciplinary knowledge explosion (Michael et al., 2017). Research demonstrates that core concepts enhance student learning and comprehension (Wood, 2008; Koba and Tweed, 2009), support curriculum development (Ball, 2023; Barrett et al., 2023), and improve assessment practices (Libarkin and Ward, 2011). When integrated into classroom instruction, these interventions effectively improve students' "big picture" understanding (Schaefer and Hannah, 2023).For health professionals, core concepts help educators prioritize and benchmark their curriculum, facilitate integration with other disciplines, and improve the application of knowledge to professional contexts like safe prescribing practices (Guilding et al., 2023). They have also been used as a framework to link student learning to program objectives in undergraduate medical education (Averill et al., 2022).

The identification and application of core concepts in education are grounded in several complementary theoretical perspectives. Ausubel's theory of meaningful learning(Ausubel, 1966; Ausubel, 2012) provides a fundamental foundation, distinguishing between rote and meaningful learning. Learning becomes meaningful when new information integrates into existing cognitive structure, and reorganized or transformed to create desired outcomes or discover relationships. Core concepts, the "big ideas" of a domain serve as cognitive anchors for this integration process. Building on Ausubel's work, concept mapping(Novak and Cañas, 2008) demonstrates how educators can help students develop mental models and conceptual frameworks to make meaning of new content. This approach supports the paradigm shift from teaching isolated facts to shaping conceptual understanding through Concept-Based Curriculum and Instruction (CBCI), where topics, facts, and skills become tools for understanding deeper conceptual structures (Erickson et al., 2017). Core concepts also facilitate transfer of learning—applying knowledge across contexts—which is central to the Understanding by Design framework (Wiggins and McTighe, 2005) commonly used in curriculum development. These theoretical perspectives converge to establish core concepts as pedagogically powerful tools grounded in principles of human learning, supporting the movement from transmitting isolated facts toward developing conceptual understanding and adaptive expertise.

In light of this, educational researchers in various fields have sought to identify and characterize the core concepts within their domains. Many STEM domains—contextualized here as disciplines or fields of knowledge — have identified, selected, and applied these concepts to their educational practice (Gray et al., 2019). However, despite these efforts, few publications describe the methods for identifying these core concepts, and no comprehensive resource exists to guide researchers in this process. Such guidance could save researchers time and effort, potentially enhancing the process, quality, and application of core concepts in education. This is particularly important because developing these core concepts has been reported to be intellectually demanding and time-consuming for educators, who have numerous competing professional endeavors (Mitchell et al., 2017).

A knowledge synthesis of how and why core concepts are identified would be helpful for educators including program directors, curriculum committees, course coordinators, faculty, instructors and assessment specialists embarking on this process. Several scholars who have launched into core concept identification for their domain provide rich and relevant literature reviews in their publications, albeit always focused on the specifics of their domain (McFarland and Michael, 2020; White et al., 2021; Chen et al., 2022). A mini-review further advances the STEM education literature by comparing how physiology and neuroscience developed their core concepts, revealing that effective concept identification must consider disciplinary context, implementation challenges, and educational goals while also providing a framework for other STEM fields to develop their core concepts through documented lessons and identified research needs (Schaefer and Michael, 2024). While these reviews offer valuable insights, they do not fully illustrate the broader context of core concept identification within STEM and health-related fields. This scoping review article aims to understand core concept identification, focusing on the rationale, methodologies, and key outcomes across STEM and health-related domains.

2 Methods

2.1 Methodological justification

The frameworks proposed by Munn and colleagues that provides guidance for authors when choosing between a systematic or scoping review approach (Munn et al., 2018) and Arksey and O'Malley's methodological framework for scoping studies were selected as they align with our research needs by focusing on identifying available evidence, clarifying key concepts, examining research methods, and analyzing knowledge gaps---objectives that are central to our review. The framework (Arksey and O'Malley, 2005) comprises six stages: (1) identifying the research question, (2) identifying relevant studies, (3) applying predetermined criteria to select studies, (4) charting relevant data, and (5) collating, summarizing, and reporting the results. We excluded the optional consultation exercise since it was irrelevant to our review.

In line with the first stage of the framework, the primary research question was framed using the PICo (Phenomena of Interest, Context) framework (McArthur et al., 2015): "What methodological approaches have previous studies used to identify core concepts [Phenomenon of

Interest] within STEM and health-related educational fields [Context]?" To address this question, our research objectives are:

1. To identify the rationale for core concept identification, focusing on the reasons or factors driving the process.
2. To identify the research design used for core concept identification, including the specific methods employed.
3. To present key outputs about core concept identification across structured domains, including the number, examples, and reported intentions of the core concepts identified.

2.2 Protocol and reporting

This scoping review protocol was guided by the methodological framework developed by Arksey and O'Malley, revised by all research team members, and registered prospectively on Open Science Framework (Etukakpan et al., 2024). The Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) was used to guide reporting (Tricco et al., 2018).

2.3 Eligibility criteria

The specific eligibility criteria used to guide the identification and selection of sources of evidence are summarized in Table 1. Studies were included if they aligned with the operational definition of core concepts (i.e., fundamental, enduring, useful, and discipline-specific ideas that underpin a field of knowledge). We focused on studies within STEM and health-related domains that pertained to formal education, defined as institutionalized, intentional and planned through public or recognized private bodies (Schneider, 2013), including primary, secondary, and post-secondary education. To ensure comprehensive coverage of relevant literature, only studies published in English were considered, and no date restrictions were applied.

2.4 Information sources

Prior to database selection, we conducted a preliminary assessment using a predetermined gold-set of articles(Quirk et al., 2024; Nosratzadeh et al., 2025) that met our inclusion criteria as a means to test the search strategy's sensitivity (ability to identify relevant studies) and specificity (ability to exclude irrelevant studies; Hub, 2025). This step helped identify the most appropriate databases for our review. Relevant studies were identified using two primary electronic databases: Medline(R) ALL via Ovid and Scopus. These databases were chosen because they provided the highest yield of articles from our gold set of articles, demonstrating optimal coverage of our target literature.

2.5 Search strategy

The search strategy focused on three main concepts: (1) core concepts and related synonyms, (2) STEM and health-related domains using an exhaustive list of STEM and health-related domains, and (3) the educational context, using "education" and related synonyms. The search strategy was developed iteratively in consultation with an experienced librarian and refined by testing various combinations of terms across the databases.

The science education literature and recent STEM reform proposals consistently employ several related terms: *concepts*, *core concepts*, *concept learning*, and *foundational concepts*, which appear throughout discussions across all STEM fields (Michael et al., 2017). This observation necessitated the development of our operational definition of core concepts as fundamental, enduring, useful, and discipline-specific ideas underpinning a field of knowledge to support the identification and selection of studies.

A search log was maintained throughout this process to track details such as the date, time, search terms, and databases used. The final search string (see Supplementary material 1), which yielded the most comprehensive capture of our gold set articles, was implemented for this review on March 1st, 2024. All search results and citations were imported into EndNote (Version 20, Clarivate Analytics, Philadelphia, PA, United States) for an initial deduplication process. The deduplicated library was then transferred to Covidence (Covidence, Melbourne, VIC, Australia) systematic review software, where a secondary deduplication process was performed before the screening process.

2.6 Selection of sources of evidence

The evidence selection process involved two stages: Title with abstract and full-text screening. A complete dual review approach (Stoll et al., 2019) was followed, where two independent reviewers, AUE and AKN, screened each title and abstract against the predetermined inclusion and exclusion

TABLE 1 Inclusion and exclusion criteria.

Criterion	Included	Excluded
Phenomenon of interest	Studies that Align with the operational definition of core concepts AND Provide a methodological description of how the core concepts were identified	Studies that Do not align with our operational definition AND / OR Do not have a methodological description of how the core concepts were identified
Context	Formal education AND STEM/health-related field	Non-formal education AND/OR Non-STEM/health-related field
Publication Type	Peer-reviewed publications, including original research and conference proceedings.	Publications lacking methodological descriptions, such as opinion pieces, commentaries, and articles focused on the authors' personal views, were excluded.

criteria. A third independent reviewer, PJW, resolved conflicts. During the full-text screening, two reviewers (from the pool of co-authors AUE, TA, MW, and KJ) independently assessed each article, documenting reasons for exclusion. A third reviewer (PJW) resolved conflicts at this stage. The search was complemented with backward citation searching of identified full-text publications.

2.7 Data charting process

Data extraction was conducted for all 30 included publications to obtain key study characteristics, such as the citation, country of authors, domain (field of knowledge), and aims/purpose. Subsequent extractions were organized according to the three main research objectives of the scoping review. For each review objective, specific data extraction approaches were implemented:

For review objective 1, AUE conducted a content analysis (Morse, 2008) of the reasoning behind core concept identification, as presented in the background sections of the included publications. Initial coding involved assigning summative words or short phrases to specific text segments that captured the essence of the authors' reasoning for core concept identification. These coded text segments were extracted from the publications and organized using Excel (Microsoft Corporation, Redmond, WA) and Miro (RealtimeBoard Inc., San Francisco, CA). Following the initial coding, repetitive or consistent patterns in the codes (occurring more than twice in the data) were identified and grouped together (Wolgemuth et al., 2024). These patterns were then consolidated into broader categories, each representing a distinct rationale for core concept identification. This enabled identifying and describing categories as rationales for core concept identification.

For review objective 2, which focused on the research design used for core concept identification and the specific methods employed, data was extracted from the methods sections of the included studies. Key methodological characteristics were charted to enhance understanding of the research designs. This included:

- Participant types, i.e., the study participants or groups selected for the research.
- Criteria for core concepts, including examples of criteria used across publications and how they were applied in the research methods.
- Methods were charted into two categories: (a) methods used for candidate concept identification (approaches for gathering an initial/preliminary list of concepts) and (b) methods used for concept refinement (approaches for further developing the initial list of concepts).
- Research design, combining methods from both procedural categories
- The utilization of research frameworks, particularly if any theoretical and/or conceptual frameworks were employed and
- The utilization of a pilot study

For review objective 3, which focused on presenting findings about core concept identification across domains, data was extracted from the results and discussion sections. This included the total number of core concepts identified in each study, examples of these concepts, the format in which they were presented, and any reported practical intentions for the concepts.

3 Results

3.1 Selection of sources of evidence

Figure 1 shows the flow diagram for the selection of evidence. From an initial pool of 3,447 records (3,429 from database searches and 18 from citation searching), 522 duplicates were removed through Endnote and Covidence

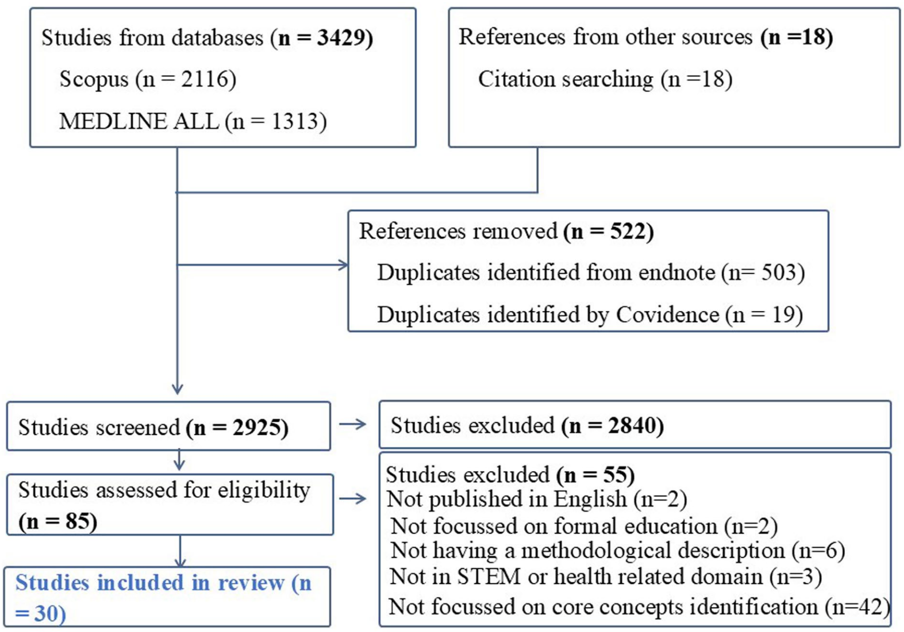

FIGURE 1
Flow diagram for study identification, screening, and inclusion.

screening. Of the remaining 2,925 records screened at the title and abstract stage, 85 were selected for the full-text screening phase. During this phase, 55 records were eliminated primarily because they did not focus on core concepts identification (n = 42), had insufficient methodological description (n = 6), were from non-STEM/health disciplines (n = 3), were non-English language publications (n = 2), or did not focus on formal education (n = 2). This resulted in a final selection of 30 publications for inclusion in the review.

3.2 General characteristics of included publications

The review included 30 research publications on core concept identification for formal education in STEM and health-related domains (see Table 2). The publications span diverse domains, with biochemistry and molecular biology, nursing, pharmacology, psychology, and neuroscience each contributing two publications, while 17 other STEM and health-related domains contributed one. For Neuroscience, the most recent and comprehensive publications for neuroscience were included as multiple papers covered the same research (Chen et al., 2022; Chen et al., 2023). All included publications were post-secondary school level and peer-reviewed except for one report from a professional organization in plant biology (American Society of Plant, 2011). Supplementary material 2 shows an overview of these 30 included publications.

The geographical distribution of research on core concept identification reveals important patterns in the field. The United States dominates the research landscape, contributing 19 out of 30 publications (63.3%), followed by Australia (including

TABLE 2 Geographic and domain distribution of included publications.

Country	Domain	Number of Publications	Citations
United States of America	Biochemistry and Molecular Biology	2	Tansey et al. (2013); Wright et al. (2013)
	Biological Sciences	1	Michael (2007)
	Comparative vertebrate anatomy and morphology	1	Danos et al. (2022)
	Cybersecurity	1	Parekh et al. (2018)
	Digital libraries for the scientific domain (Plate Tectonics, Weather and Climate, and Biological Evolution)	1	Foster et al. (2012)
	Digital logic within computer science and engineering	1	Herman and Loui (2012)
	Evolutionary Developmental Biology	1	Hiatt et al. (2013)
	Evolutionary medicine	1	Grunspan et al. (2018)
	Genetics	1	Hott et al. (2002)
	Interdisciplinary environmental and sustainability (IES)	1	Horne et al. (2024)
	Microbiology	1	Merkel (2012)
	Neuroscience	1	Chen et al. (2023)
	Nursing	2	Valiga and Bruderle (1994); Giddens and Brady (2007)
	Physiology	1	Michael and McFarland (2011)
	Plant Biology	1	American Society of Plant (2011)
	Psychology	2	Boneau (1990); Zechmeister and Zechmeister (2000)
	Thermal and transport science	1	Streveler et al. (2003)
	Toxicology	1	Gray et al. (2019)
	Traffic signals engineering	1	Hurwitz et al. (2013)
Australia	Biochemistry	1	Rowland et al. (2011)
	Dietetics	1	Tweedie et al. (2020)
	Physiology	1	Tangalakis et al. (2023)
Australia and New Zealand	Pharmacology	1	White et al. (2021)
China	Chemistry	1	Qian et al. (2023)
International collaboration*	Pharmacology	1	White et al. (2022)
New Zealand	Electromagnetics	1	Smaill et al. (2008)
United Kingdom	Behavioral and social sciences in medicine	1	Peters and Livia (2006)
Total Publication		30	

*International Collaboration includes Australia, UK, USA, Ireland, Canada, India, China, Brazil, Sweden, Malta, Qatar, Lebanon, Colombia, Nigeria, and Japan.

joint work with New Zealand) with 4 publications. Other countries (UK, China, New Zealand) have minimal representation with 1 publication each. One notable international collaboration involved 14 countries, potentially signaling an emerging trend toward global cooperative efforts (White et al., 2022).

3.3 Results for review objective one: rationale for identifying core concepts

The results of content analysis of the background sections from the 30 included publications are shown in Table 3. From this analysis, seven categories of rationales for core concepts identification in STEM and health-related domains emerged. These are content prioritization, conceptual assessment, educational reform, ontological understanding, learning-centric approaches, curriculum design, and resource optimization—spanning from the need to identify essential teaching content within expanding disciplinary knowledge through to optimizing resources to address educational resource constraints. Table 3 presents these categories along with their descriptions, supporting citations, and illustrative examples from the literature. The findings show that these rationales frequently overlap across studies, demonstrating the complex interplay of factors that drive core concept identification across different domains.

3.4 Results for review objective two: research design for identifying core concepts

Table 4 presents a mapping of methodological characteristics found in the core concept identification publications with a focus on the participant types, criteria for core concepts, research frameworks, and the utilization of pilot studies. The findings for criteria for core concepts are organized to highlight those that appeared in three or more instances.

Table 5 maps methodological procedures employed in core concept identification studies across two main phases: candidate identification and candidate refinement. This phase-wise process begins with candidate identification to generate preliminary terms/concepts from participants and documents, followed by candidate refinement to develop and validate the initial list. Various methods are applied individually and/or in combination throughout these phases. Findings revealed that various methods were used in each phase, with expert group techniques and document analysis dominating the identification phase. In contrast, surveys and expert group techniques were prominent in the refinement phase. By examining the combination of methods used across both phases, we identified the underlying research designs, which were predominantly mixed methods approaches, even when not explicitly stated in the original publication. This methodological breakdown offers a view of how researchers identified and validated core concepts for education in their domains.

3.5 Results for review objective three: key outputs with a focus on the number of core concepts, concept format, and intention for practical use

Table 6 presents two key outputs of core concepts across domains: the number of core concepts and their presentation format. Core concepts ranged from 3 to 352 across studies, with most disciplines having fewer than 10 concepts ($n = 12$). The concepts were primarily presented as terms ($n = 21$), with fewer studies using statements ($n = 7$) or hybrid formats ($n = 2$). These patterns suggest varying approaches to organizing and expressing disciplinary knowledge across fields.

Table 7 shows four primary intended uses for core concepts across domains. Most studies emphasized these concepts as guiding rather than prescriptive resources, with many reporting multiple intended applications. This suggests that core concepts are expected to serve diverse practical purposes in academic fields, from curriculum planning to establishing common frameworks.

4 Discussion

Adopting a scoping review methodology, this review examined 30 publications on core concept identification within STEM and health-related educational domains to highlight the rationale, the research approaches, and key outputs. Figure 2 shows an overview of the findings of this review in the context of the rationale, process, and outputs of core concept identification in STEM and Health-Related Education Domains.

4.1 The rationale for core concepts identification

Core concept identification within formal education in STEM and health-related fields is motivated by a complex interplay of factors, revealed through the analysis of 30 publications as seven distinct categories of rationales (see Table 3). These findings demonstrate the diverse motivations driving researchers' pursuit of core concept identification in their respective domains.The identification of core concepts is driven mainly by the need to prioritize essential content within expanding knowledge bases of domains (White et al., 2021; White et al., 2022; Chen et al., 2023). This includes lacking of existing core concepts (American Society of Plant, 2011; Grunspan et al., 2018; Parekh et al., 2018; Danos et al., 2022), establishing core knowledge (Boneau, 1990), clarifying key concepts (Valiga and Bruderle, 1994), standardizing domain vocabulary (Zechmeister and Zechmeister, 2000), and aligning core concepts with learning objectives in the educational curricula (Tangalakis et al., 2023).

Complementary to this is the learning-centric rationale for identifying core concepts, where developing conceptual frameworks (Zechmeister and Zechmeister, 2000), strengthening conceptual understanding (Rowland et al., 2011; Qian et al., 2023), and addressing students' misconceptions (Streveler et al., 2003; White et al., 2021) all come together to enhance learning. This rationale aligns with Ausubel's theory of meaningful learning (Ausubel, 2012), where learning becomes meaningful when new information is

TABLE 3 Rationales for core concepts identification in STEM and health-related domains.

Categories	Description	Supporting citation	Illustrative quote
Content prioritization	Envelopes the rationale for identifying core concepts based on the need to prioritize essential teaching content, particularly within an expanding knowledge base. This includes establishing a core knowledge base, clarifying critical curriculum concepts, addressing the lack of consensus on core vocabulary and concepts, developing conceptual frameworks, and ensuring alignment between existing core concepts and learning objectives in content-rich curricula.	Boneau (1990); Valiga and Bruderle (1994); Zechmeister and Zechmeister (2000); Hott et al. (2002); American Society of Plant (2011); Herman and Loui (2012); Hurwitz et al. (2013); Grunspan et al. (2018); Parekh et al. (2018); Gray et al. (2019); White et al. (2021); Danos et al. (2022); White et al. (2022); Chen et al. (2023); Tangalakis et al. (2023)	"The need for community-derived core concepts is pressing, because both the pace of research and number of neuroscience programs are rapidly expanding"(Chen et al., 2023)
Conceptual assessment	Encompasses rationale related to the need for educational aids that support educators in developing concept inventories and assessing conceptual attainment.	Streveler et al. (2003); Michael (2007); Smaill et al. (2008); Michael and McFarland (2011); Hiatt et al. (2013); Hurwitz et al. (2013); Tansey et al. (2013); White et al. (2021); Horne et al. (2024)	"……….. but the lack of such validated and reliable assessment tools has certainly impeded research about the learning of biology and, specifically, physiology." (Michael, 2007)
Educational reforms	Reflects rationale driven by calls for educational reforms, specifically the shift toward student-centered learning and conceptual understanding rather than rote memorization.	Merkel (2012); Gray et al. (2019); Danos et al. (2022); Chen et al. (2023)	"In light of the recommendations coming from the national reports, the Education Board of the American Society for Microbiology decided to revisit the microbiology curriculum guidelines as a strong statement of support for embracing ASM's recommendations for concept-based, student-centered learning." (Merkel, 2012)
Ontological	Reflects rationale for identifying core concepts based on the inherent nature of how knowledge emerges and is represented within the domain, particularly in contexts with multidisciplinary and interdisciplinary roots.	Wright et al. (2013); Parekh et al. (2018); White et al. (2021); Horne et al. (2024)	"The multi-disciplinary nature of pharmacology, with roots in biology, chemistry, and physics, and the enormous body of knowledge in this field means that educators struggle to decide what to teach and assess." (White et al., 2021)
Learning centric	Covers rationale focused on facilitating meaningful learning connections. This includes developing conceptual knowledge frameworks, enhancing learners' conceptual understanding, and identifying and addressing misconceptions or alternative conceptions of learning.	Zechmeister and Zechmeister (2000); Streveler et al. (2003); Rowland et al. (2011); White et al. (2021); Qian et al. (2023)	"to help students develop a set of key understandings in biochemistry that would enrich their understanding of other courses in their programs of study and be useful to them in the long term, regardless of their career ambitions." (Rowland et al., 2011)
Curriculum design	Envelopes rationale related to various curriculum development contexts, including informing the curriculum design process, addressing curricular variability, and adopting concept-based curricula.	Peters and Livia (2006); Giddens and Brady (2007); Tweedie et al. (2020)	"The process for developing a concept-based curriculum starts with an identification of the core (foundational) concepts of the discipline and their definitions followed by the development of exemplars that best illustrate the concept" (Tweedie et al., 2020)
Resources optimization	Encompasses rationales driven by the need to optimize inadequate educational resources, including selection of resources, course development materials, and management of limited training time	Foster et al. (2012); Gray et al. (2019); White et al. (2021); White et al. (2022)	"No pharmacology program, however well-resourced, has sufficient time to teach students all the knowledge in the discipline." (White et al., 2021)

intentionally integrated into existing cognitive structures rather than memorized in isolation as facts. Core concepts function as cognitive anchoring points that allow learners to incorporate new knowledge into their existing mental frameworks. When educators identify and emphasize core concepts, they are essentially providing students with the cognitive infrastructure necessary for this integration

TABLE 4 Methodological characteristics: focus on participant types, criteria for core concepts, utilization of research frameworks, and pilot studies for core concept identification.

Methodological characteristics	Description	Citations
Participant types	Categories of individuals involved in the core concept identification process	
Domain educators (n = 12)	Teaching faculty actively involved in student training, instruction and curriculum delivery	Zechmeister and Zechmeister (2000); Hott et al. (2002); Peters and Livia (2006); Michael (2007); Foster et al. (2012); Herman and Loui (2012); Merkel (2012); Tansey et al. (2013); Wright et al. (2013); White et al. (2021); White et al. (2022); Tangalakis et al. (2023)
Domain experts (n = 11)	A mix of domain specialists with theoretical and practical knowledge, including educators, professionals, researchers, and textbook authors	Boneau (1990); Streveler et al. (2003); Michael (2007); Smaill et al. (2008); Rowland et al. (2011); Hiatt et al. (2013); Hurwitz et al. (2013); Grunspan et al. (2018); Parekh et al. (2018); Gray et al. (2019); Chen et al. (2023)
Others (n = 6)	Additional stakeholders including educational program leaders, professional association members, and students	Valiga and Bruderle (1994); American Society of Plant (2011); Rowland et al. (2011); Danos et al. (2022); Qian et al. (2023); Horne et al. (2024)
No participant (n = 1)	The study relies solely on document analysis without human participants	Tweedie et al. (2020)
Criteria for core concepts	Standards/characteristics used to support what qualifies as a core concept within the domain	
Importance (n = 12)	The concept holds fundamental significance to the domain	Boneau (1990); Zechmeister and Zechmeister (2000); Hott et al. (2002); Streveler et al. (2003); Smaill et al. (2008); Foster et al. (2012); Herman and Loui (2012); Hiatt et al. (2013); Grunspan et al. (2018); Parekh et al. (2018); Qian et al. (2023); Horne et al. (2024)
Teaching Inclusion (n = 3)	The concept is frequently included in educational programs	Valiga and Bruderle (1994); Giddens and Brady (2007); Hiatt et al. (2013)
Difficult and challenging (n = 3)	The concept requires special attention due to its complexity	Streveler et al. (2003); Parekh et al. (2018); White et al. (2021)
Enduring and timeless (n = 3)	The concept maintains relevance over time	White et al. (2021); White et al. (2022); Chen et al. (2023)
Criteria application in data collection	Approach by which use of criteria was implemented in the study	
Explicit application (n = 16)	Clear, documented use of criteria in research instruments (surveys) as well as analysis process	Boneau (1990); Valiga and Bruderle (1994); Hott et al. (2002); Peters and Livia (2006); Giddens and Brady (2007); Smaill et al. (2008); Michael and McFarland (2011); Herman and Loui (2012); Hiatt et al. (2013); White et al. (2021); White et al. (2022); Chen et al. (2023); Qian et al. (2023)
Non-explicit application (n = 4)	Implicit use of criteria in conceptualization	Zechmeister and Zechmeister (2000); Michael (2007); Hurwitz et al. (2013); Horne et al. (2024)
Research frameworks Use of Conceptual Framework (n = 6)	Use of apriori structure organizing research/ existing core concepts frameworks from related domains	Giddens and Brady (2007); American Society of Plant (2011); Merkel (2012); Tansey et al. (2013); Gray et al. (2019); Tangalakis et al. (2023)
Pilot study utilization Publications reported conducting a pilot (n = 10)	Preliminary testing of research methods to validate approaches and instruments	Boneau (1990); Valiga and Bruderle (1994); Hott et al. (2002); Hurwitz et al. (2013); Tweedie et al. (2020); White et al. (2021); White et al. (2022); Chen et al. (2023); Horne et al. (2024)

process, facilitating the development of enduring understanding. This learning-centric rationale for core concepts identification also intersects with pedagogical content knowledge (PCK) in that core concept identification precedes PCK application, where establishing the fundamental knowledge structures of the domain will subsequently support teaching and learning approaches (Loewenberg Ball et al., 2008). Ultimately, this connects to the conceptual assessment rationale, where educators require valid tools to measure deeper conceptual understanding rather than mere recall(Streveler et al., 2003; Michael, 2007; Smaill et al., 2008; Michael and McFarland, 2011; Hiatt et al., 2013; Hurwitz et al., 2013; Tansey et al., 2013; White et al., 2021; Horne et al., 2024). These assessment needs reflect the broader challenge of evaluating authentic conceptual understanding across various knowledge dimensions.

The educational reform rationale reflects a paradigm shift toward student-centered learning and conceptual understanding, moving away from traditional rote memorization approaches (Merkel, 2012; Gray et al., 2019; Danos et al., 2022; Chen et al., 2023). For instance, in physiology education, the initiative was driven by a broader educational transformation that aimed to move beyond simple memorization toward conceptual understanding, with the specific goal of helping

TABLE 5 Methodological characteristics: focus on procedures, methods, and research design for core concept identification.

Methodological characteristics*	Description	Citation
1. Procedures for core concept identification		
A. Candidate Identification Phase		
Expert group techniques (n = 13)	A collaborative and iterative collection of methods that leverages the collective knowledge of individuals identified as knowledgeable and/or experienced in a subject matter to identify, evaluate, and refine core concepts in that domain	See below for specific corresponding methods
Discussions/workshops ($n = 6$)	Structured group interactions with clear objectives	Hott et al. (2002); Giddens and Brady (2007); Michael (2007); American Society of Plant (2011); Merkel (2012); Tansey et al. (2013); Wright et al. (2013)
The first round of Delphi ($n = 5$)	First round of Delphi process (subsequent rounds reported in the candidate refinement phase)	Streveler et al. (2003); Hurwitz et al. (2013); Grunspan et al. (2018); Parekh et al. (2018); Tangalakis et al. (2023)
Brainstorming ($n = 2$)	Open-ended ideas generation activities	Hiatt et al. (2013) Danos et al. (2022)
Document analysis (n = 8)	Analysis of domain textbooks, curriculum materials, learning syllabi, learning outcomes and outlines, competency standards, and guidelines	See below for specific corresponding methods
Content analysis ($n = 7$)	Non-automated analysis of the domain-relevant textual resources	Boneau (1990); Zechmeister and Zechmeister (2000); Peters and Livia (2006); Smaill et al. (2008); Gray et al. (2019); Tweedie et al. (2020); Qian et al. (2023)
Text mining ($n = 1$)	Automated analysis of textbooks to extract keywords	White et al. (2022)
Other methods	Methods used that are less the 5 instances across all studies	See below for specific corresponding methods
Open-ended surveys ($n = 5$)	Using a research instrument that asks participants questions without providing predetermined response options.	Michael and McFarland (2011); Rowland et al. (2011); White et al. (2021); White et al. (2022); Chen et al. (2023)
literature reviews ($n = 4$)	A comprehensive analysis of existing academic research, publications and scholarly works to support the core concept identification process	Valiga and Bruderle (1994); Hiatt et al. (2013); White et al. (2021); Horne et al. (2024)
Interviews ($n = 1$)	A structured, semi-structured, or unstructured conversation with participants to gather in-depth information regarding core concepts	Qian et al. (2023)
Algorithm application ($n = 1$)	Using an automated systematic set of rules or procedures to extract concepts	Foster et al. (2012)
B. Candidate Refinement Phase		
Surveys ($n = 14$)	Using research instruments that ask participants to respond through various formats	Boneau (1990); Valiga and Bruderle (1994); Zechmeister and Zechmeister (2000); Hott et al. (2002); Peters and Livia (2006); American Society of Plant (2011); Michael and McFarland (2011); Merkel (2012); Hiatt et al. (2013); Wright et al. (2013); White et al. (2021); Chen et al. (2023)
Expert group techniques ($n = 12$)	A collaborative and iterative collection of methods that leverages the collective knowledge of individuals identified as knowledgeable and/or experienced in a subject matter to identify, evaluate, and refine core concepts in that domain	See below for specific corresponding methods
Discussions/workshops/consultations ($n = 5$)	Structured interactions with participants in groups or individually	Merkel (2012); Gray et al. (2019); White et al. (2021); Danos et al. (2022); Chen et al. (2023)
Subsequent rounds of Delphi ($n = 7$)	Subsequent Delphi rounds used for candidate refinement	Streveler et al. (2003); Herman and Loui (2012); Hurwitz et al. (2013); Grunspan et al. (2018); Parekh et al. (2018); White et al. (2022); Tangalakis et al. (2023)
Other methods	Methods used that are less than 5 instances across all studies	See below for specific corresponding methods
Document analysis ($n = 2$)	Analysis of domain textbooks, curriculum materials, learning syllabi, learning outcomes and outlines, competency standards, and guidelines	Hott et al. (2002); Horne et al. (2024)

(Continued)

TABLE 5 (Continued)

Methodological characteristics*	Description	Citation
Machine learning techniques (*n* = 1)	Specific computational method that enables systems to learn patterns from data and make predictions or decisions for core concept identification	Foster et al. (2012)
2. Research design	A combination of methods used in candidate identification and concept refinement	
Mixed methods (*n* = 20)	Combined qualitative and quantitative approaches	Boneau (1990); Zechmeister and Zechmeister (2000); Streveler et al. (2003); Giddens and Brady (2007); Smaill et al. (2008); American Society of Plant, 2011; Michael and McFarland (2011); Rowland et al. (2011); Foster et al. (2012); Herman and Loui (2012); Merkel (2012); Hiatt et al. (2013); Hurwitz et al. (2013); Grunspan et al. (2018); Parekh et al. (2018); White et al. (2021); White et al. (2022); Chen et al. (2023); Qian et al. (2023); Tangalakis et al. (2023)
Multimethod (*n* = 3)	Multiple methods of the same type, either qualitative or quantitative, but not both	Hott et al. (2002); Gray et al. (2019); Danos et al. (2022)
Quantitative (*n* = 2)	Predominantly quantitative approaches	Boneau (1990); Valiga and Bruderle (1994)
Qualitative (*n* = 5)	Predominantly qualitative approaches	Michael (2007); Tansey et al. (2013); Wright et al. (2013); Tweedie et al. (2020); Horne et al. (2024)

*Main categories are shown in bold. Procedures for Core Concept Identification encompass both the Candidate Identification and Concept Refinement phases in italics. *n* = number of publications using each method.

students transfer their learning across different topics (Schaefer and Michael, 2024). This educational reform reason for core concepts identification approach aligns with the paradigm shift in education from teaching isolated facts toward shaping the conceptual mind. When educators identify and teach through concepts, they enable students to move beyond surface-level memorization to a deeper understanding of the transferable principles that organize a domain facilitating students' ability to see patterns, connections, and relationships between seemingly disparate facts and examples—precisely the kind of cognitive integration that strengthens conceptual understanding and addresses misconceptions (Erickson et al., 2017). The ontological rationale for identifying core concepts is particularly evident in interdisciplinary fields like pharmacology (White et al., 2021), where knowledge's inherent and underlying nature necessitates careful consideration of content organization and presentation. This rationale acknowledges the unique challenges posed by fields that integrate multiple disciplinary perspectives and knowledge frameworks.

From these categories of rationales and their emerging domains, we posit that a strong disciplinary focus, responding to the unique challenges and epistemological structures of each domain, is at the nucleus of these reasons for identifying core concepts. This aligns with existing literature, as the adoption of core concepts approaches in STEM teaching varies significantly across disciplines, with each field implementing this strategy to meet distinct disciplinary needs (Schaefer and Michael, 2024). Supporting this assertion for instance we see in pharmacology (White et al., 2021) emerged across five rationale categories, reflecting its interdisciplinary roots, nature, and complex knowledge integration challenges, while Neuroscience (Chen et al., 2023) were inherently both content prioritization and educational reforms, responding to its rapidly expanding knowledge base. Chemistry, on the other hand (Qian et al., 2023), focuses on learner-centric approaches to address the challenges of conceptual understanding, which can be peculiar to teaching abstract concepts. Perhaps, these disciplinary differences extend to epistemological structures where systems-focused disciplines like physiology (Michael, 2007) prioritize strategies for assessing the attainment of conceptual understanding. Hence, the rationale for core concept identification responds to discipline-specific needs, with each discipline's approach appearing tailored to its unique knowledge structures, pace of knowledge evolution, professional requirements, and student learning challenges—reinforcing that core concept identification is fundamentally a discipline-contextualized practice.

4.2 Methods for core concepts identification

There is a clear preference for mixed methods approaches (see Table 5), reflecting a pragmatic worldview that prioritizes practical solutions over strict methodological adherence (Creswell, 2015). This choice aligns well with the rigorous process of core concept identification, which requires integrating and triangulating multiple perspectives and data, enhancing the reliability of the research-driven core concept identification outputs. The identification process typically followed a two-phase approach: an initial candidate concept identification phase followed by a subsequent concept refinement phase. This process aligns with a sequential exploratory design, where qualitative exploration precedes quantitative validation (Fetters et al., 2013), allowing researchers to generate potential core concepts and subject them to rigorous validation. Exploratory methods like document analysis and expert group techniques—discussions, workshops, and initial Delphi rounds—dominated the candidate identification phase (See Table 5). In contrast, surveys and expert group techniques—subsequent Delphi rounds and consultations — were prevalent in the refinement phase, suggesting systematic progression from broad exploration to focused validation of the concepts.

TABLE 6 Key outputs with a focus on the number of core concepts and their presentation formats across domains.

Key findings characteristics	Description	Domain and citation
Number of core concepts	Sixteen publications identified 3 to 10 core concepts	Biochemistry (Rowland et al., 2011), Biochemistry and molecular biology (Tansey et al., 2013; Wright et al., 2013), Biological sciences (Michael, 2007), Comparative vertebrate anatomy and morphology (Danos et al., 2022), Digital logic (Herman and Loui, 2012) Electromagnetics (Smaill et al., 2008), Evolutionary developmental biology (Hiatt et al., 2013), Genetics (Hott et al., 2002), Interdisciplinary environmental and sustainability (Horne et al., 2024), Microbiology (Merkel, 2012), Neuroscience (Chen et al., 2023) Physiology (Michael and McFarland, 2011; Tangalakis et al., 2023), Toxicology (Gray et al., 2019) Traffic signals engineering (Hurwitz et al., 2013)
	Five publications identified 10 to 50 concepts core concepts	Evolutionary medicine (Grunspan et al., 2018), Pharmacology(White et al., 2021; White et al., 2022), Plant Biology (American Society of Plant, 2011), Thermal and transport science (Streveler et al., 2003)
	Nine studies identified more than 50 core concepts	Behavioral and social sciences in medicine (Peters and Livia, 2006), Chemistry (Qian et al., 2023), Cybersecurity (Parekh et al., 2018), Dietetics (Tweedie et al., 2020), Digital libraries (Foster et al., 2012), Nursing (Valiga and Bruderle, 1994; Giddens and Brady, 2007), Psychology (Boneau, 1990; Zechmeister and Zechmeister, 2000)
Concept format: The structural presentation and organization of core concepts, reflecting different approaches to expressing disciplinary knowledge.		
Concept format	Terms—a word or group of words ($n = 21$) E.g., "cognition" in psychology and "homeostasis" in physiology	Behavioral and social sciences in Medicine (Peters and Livia, 2006), Biochemistry (Rowland et al., 2011) Biochemistry and Molecular Biology(Tansey et al., 2013), Chemistry (Qian et al., 2023), Comparative vertebrate anatomy and morphology (Danos et al., 2022), Cybersecurity (Parekh et al., 2018), Dietetics (Tweedie et al., 2020), Digital logic (Herman and Loui, 2012), Electromagnetics (Smaill et al., 2008), Interdisciplinary environmental and sustainability (Horne et al., 2024), Nursing (Valiga and Bruderle, 1994; Giddens and Brady, 2007), Pharmacology (White et al., 2021; White et al., 2022) Physiology (Michael and McFarland, 2011; Tangalakis et al., 2023), Psychology (Boneau, 1990; Zechmeister and Zechmeister, 2000), Thermal and transport science (Streveler et al., 2003), Toxicology (Gray et al., 2019), Traffic signals engineering (Hurwitz et al., 2013)
	Statement---a sentence or assertion ($n = 7$) E.g. in evolutionary medicine, "Sexual selection shapes traits that result in different health risks between sexes"	Biochemistry and Molecular Biology (Wright et al., 2013), Biological Sciences (Michael, 2007), Digital Libraries (Foster et al., 2012), Evolutionary Developmental Biology (Hiatt et al., 2013), Evolutionary medicine (Grunspan et al., 2018), Genetics (Hott et al., 2002), Microbiology (Merkel, 2012)
	Hybrid ---Use of both terms and/or statements ($n = 2$)	Plant biology (American Society of Plant, 2011), Neuroscience (Chen et al., 2023)

A crucial methodological finding is the predominance of a collection of similar research methods termed *expert group techniques*, described in previous research publications as techniques that involve group members engaged in a series of collaborative iterations (Ralph and Walker, 2014) and have been used to develop a set of guidelines in the context of health professionals (Skirton et al., 2014). Based on its use in the core concepts identification publications within this review, we operationally define expert group techniques as a collaborative and iterative collection of methods that leverages the collective knowledge of individuals identified as knowledgeable and/or experienced in a subject matter to identify, evaluate, and refine core concepts in that domain. This was employed in 29 of 30 studies, drawing on domain experts, including textbook authors, educators, professionals, and researchers (see Tables 4, 5). This finding shows that core concept identification has relied heavily on the collective judgment of individuals identified as experts to define core disciplinary knowledge, aligning with established practices in educational research (de Villiers et al., 2005; Laughlin et al., 2006; Hakkarainen et al., 2016).

We surmise that the expert group techniques have important elements for researchers to consider in core concept identification. Participant selection criteria may or may not be determined *a priori* (Streveler et al., 2003; Herman and Loui, 2012; Hurwitz et al., 2013; Grunspan et al., 2018; Parekh et al., 2018; White et al., 2022; Tangalakis et al., 2023), composing mainly of educators, professionals, researchers, and other stakeholders in education (See Table 4). The strategic selection of experts across disciplines reveals important core concept identification methodology insights. While studies have employed various expert profiles—from textbook authors in psychology (Boneau, 1990) to dual-role teacher-researchers in evolutionary biology(Hiatt et al., 2013), the common thread is a balance between theoretical knowledge and practical application expertise. This balanced approach to expert selection appears intentional rather than incidental, suggesting that researchers recognize that effective core concept identification requires both deep disciplinary expertise in the context of knowledge, understanding and experience. The significance of this pattern is particularly evident in recent studies (Chen et al., 2023; Qian et al., 2023), where diverse stakeholder perspectives were deliberately integrated into their core

TABLE 7 Key outputs with focus on intended use of identified core concepts.

Reported intention for the practical uses	Illustrative quote	Citation
Curriculum development	"Neuroscience core concepts are intended for use by neuroscience educators, including program directors, department chairs, and instructional faculty in neuroscience higher education. The core concepts can be used to inform curricular and course development, as well as curricular and programmatic assessment, given that they represent input from a diverse group of neuroscience educators." (Chen et al., 2023)	Valiga and Bruderle (1994); Giddens and Brady (2007); American Society of Plant (2011); Hurwitz et al. (2013); Grunspan et al. (2018); Gray et al. (2019); Tweedie et al. (2020); White et al. (2021); White et al. (2022); Chen et al. (2023); Tangalakis et al. (2023)
Teaching and learning	"Based on results of surveys and interviews with students, we suggest that teaching core concepts (CCs) within a framework that integrates supporting concepts (SCs) from both evolutionary and developmental biology can improve evo-devo instruction." (Hiatt et al., 2013)	Zechmeister and Zechmeister (2000); Hott et al. (2002); Rowland et al. (2011); Herman and Loui (2012); Merkel (2012); Hiatt et al. (2013); Parekh et al. (2018); White et al. (2022)
Assessment and evaluation	"Results from the Delphi processes lay a foundation for improving cybersecurity teaching and learning by helping educators design better assessment tools, learning materials, and curricula." (Parekh et al., 2018)	Streveler et al. (2003); Michael (2007); Smaill et al. (2008); Michael and McFarland (2011); Hiatt et al. (2013); Hurwitz et al. (2013); Tansey et al. (2013); Wright et al. (2013); Parekh et al. (2018); White et al. (2021); Danos et al. (2022); Chen et al. (2023); Qian et al. (2023)
Standardization and common framework	"Defined partially by their explanatory breadth and importance to the field, core principles also provide a framework to organize research. The framework of core principles provided here can help clarify connections between ongoing research that may be based on larger ideas and not on topics or methodology." (Grunspan et al., 2018)	Boneau (1990); Peters and Livia (2006); Foster et al. (2012); Tansey et al. (2013); Grunspan et al. (2018); Danos et al. (2022); Qian et al. (2023); Tangalakis et al. (2023); Horne et al. (2024)

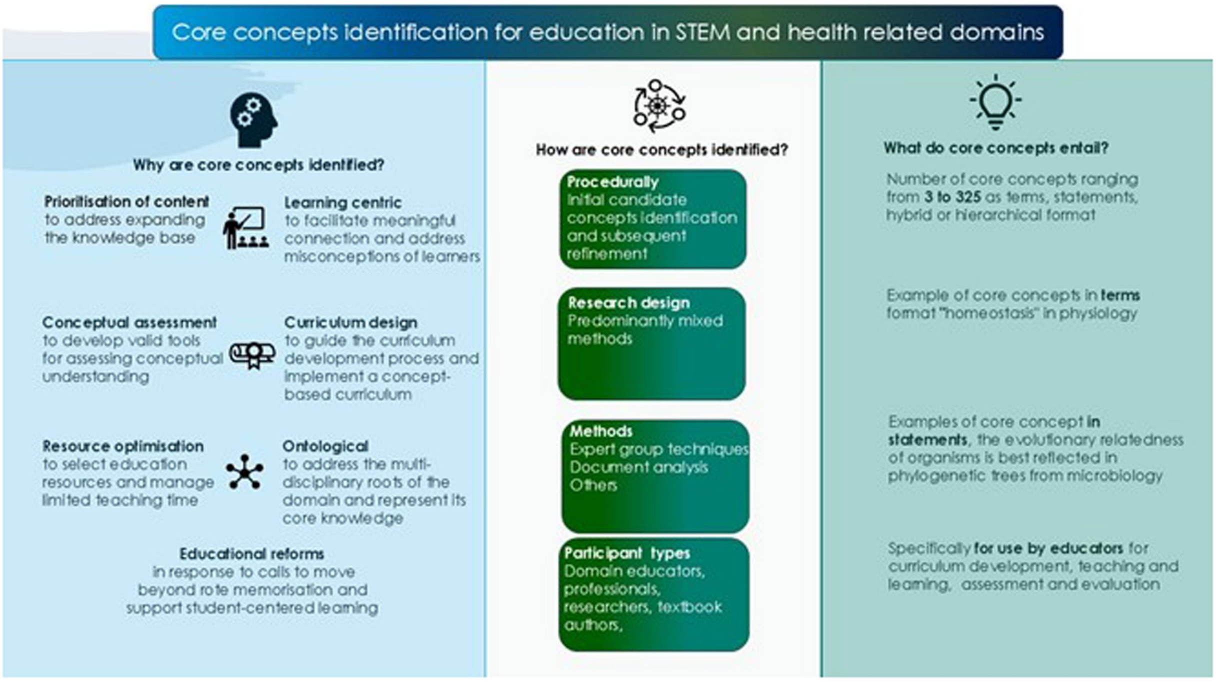

FIGURE 2
Rationale, process, and outputs for core concepts identification.

concepts identification work compared to earlier studies, which focused on one education stakeholder. This suggests a growing interest in inclusive expert selection strategies that incorporate theory and practice.

Establishing clear initial goals is essential, though iterative adjustments may occur. Methodological flexibility enables using varied formats and activities suited to specific disciplinary needs. The expert group techniques complement other methods, incorporating robustness into identifying the domain's core concept.

The methodological approaches to core concept identification require careful consideration, particularly regarding research frameworks and pilot testing of data collection and analysis processes. The absence of theoretical frameworks across all included publications highlights that core concept identification is driven more by pragmatic focus than theoretical concerns. This pragmatic emphasis may limit the development of robust methodological approaches, potentially sacrificing methodological rigor (Morgan, 2007; Tracy, 2010). The limited use of pilot testing (see Table 4) raises concerns about rigor, as piloting is crucial for validating research instruments and procedures, addressing concerns of methodological reliability and verification (Morse et al., 2002; Van Teijlingen and Hundley, 2002). Additionally, while several criteria were used for core concept identification (See Table 4), their inconsistent application in data collection and analysis across publications suggests that more standardized concept evaluation approaches are needed.

4.3 Key outputs of core concepts identification

A core concepts approach to teaching STEM disciplines is increasingly evident with intention to solve different problems in different disciplines (Schaefer and Michael, 2024).The outputs of core concept identification vary in terms of the number of these core concepts, their presenting formats, and their intended use. This striking variation reveals important differences in what constitutes a 'core' concept across disciplines. The scope and complexity of different domains clearly influence the quantity of identified core concepts. Digital Logic, an introductory course (Herman and Loui, 2012), features just three core concepts, while Digital Libraries, a broad scientific field (Foster et al., 2012), encompasses over 352. This difference likely reflects both the inherent complexity of these domains and differing approaches to concept granularity across them, presenting that core concepts can be identified at varying levels of a domain such as micro level at a single/ course level through to macro level being the of the domain. Also, the Biological sciences often identify fewer core concepts, typically between 5 and 15 (Michael, 2007; American Society of Plant, 2011; Michael and McFarland, 2011; Merkel, 2012; Gray et al., 2019; Danos et al., 2022; Chen et al., 2023). In contrast, health-related fields such as Dietetics (Tweedie et al., 2020) and Nursing (Valiga and Bruderle, 1994; Giddens and Brady, 2007) tend to identify more concepts. Perhaps, these disciplinary differences stem from a combination of pedagogical requirements, domain complexity, and varying philosophical approaches to what constitutes the 'core' in each domain. The format of the core concept presentation varied widely. While most studies listed concepts as discrete terms, others used statements or hierarchical formats (see Table 6), reflecting diverse pedagogical needs and disciplinary preferences. Some studies used hierarchical structures (Hott et al., 2002; Merkel, 2012; Hiatt et al., 2013; Wright et al., 2013), suggesting the interconnected nature of core concepts within the domain's conceptual structure. Core concepts were intended to be used by educators as a guide in curriculum development, teaching and learning improvement, assessment, and standardization (See Table 7). This suggests that core concept identification is largely driven by pedagogical and educational goals rather than theoretical aims. Emphasis on curriculum and assessment development indicates a shift towards structured, evidence-based educational approaches across disciplines.

4.4 Implications

Based on the findings from this scoping review, several implications emerge for enhancing core concept identification in education. Developing standardized protocols and quality criteria for expert group techniques would strengthen methodological rigor and consistency across domains. Establishing clear guidelines for methodological reporting, particularly regarding pilot testing and validation procedures, would improve transparency and reproducibility. The observed variations in core concept identification suggest a need for standardized criteria to guide this process. Moving forward, future research should focus on developing comprehensive methodological guidelines for expert group techniques, providing research frameworks to guide identification efforts, and establishing clear criteria for determining how "core" is a concept for a domain. These developments would effectively advance the identification and validation of core concepts across different domains. Additionally, investigating the relationship between different presentation formats of core concepts and their educational effectiveness would provide valuable insights for pedagogical practice.

4.5 Limitations

The operational definition of core concepts as "fundamental, enduring, useful, and discipline-specific ideas that form the foundation of a field of knowledge" may have limited the scope of our search. While this definition provided our common understanding and supported study selection, it may have excluded studies that explored similar concepts under different terminology. Including only articles published in English may have limited the diversity of studies analysed in this review. However, this criterion was only applied in the final screening phase and resulted in exclusion of only 2 studies. Also, the involvement of multiple reviewers in the full-text review phase may have introduced the potential for varying interpretations of the inclusion criteria; however, reviewer training and using a third independent reviewer to mitigate this concern. The research team published and followed an *a priori* protocol but made methodological adaptations by modifying the extraction template in response to the unanticipated volume and complexity of data. Although this adaptation enabled more precise data extraction for each research objective, deviating from the original protocol's single extraction template represents a limitation in terms of protocol adherence.

5 Conclusion

This scoping review synthesizes research on core concepts in STEM and health-related domains, providing valuable insights into the rationales for their identification, methodological approaches, and key outputs. The findings highlight the predominance of expert-driven approaches and the need for more standardized methodological frameworks. Recognizing that core concept development is intellectually demanding and time-consuming, this review provides a valuable resource for educators and researchers to adopt this evidence-based approach.

Author contributions

AE: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing. MW: Conceptualization, Investigation, Methodology, Supervision, Writing – review & editing. KJ: Conceptualization, Investigation, Methodology, Supervision, Writing – review & editing. AN: Investigation, Writing – review & editing. TA: Conceptualization, Investigation, Writing – review & editing. PW: Conceptualization, Funding acquisition, Investigation, Methodology, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted without any commercial or financial relationships that could potentially create a conflict of interest.

Generative AI statement

The author(s) declare that no Gen AI was used in the creation of this manuscript.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2025.1547994/full#supplementary-material

References

American Society of Plant. (2011) ASPB – BSA Core concepts and learning objectives in plant biology for undergraduates. Available at: https://aspb.org/wp-content/uploads/2016/05/ASPB-BSA-CoreConcepts.pdf

Arksey, H., and O'Malley, L. (2005). Scoping studies: towards a methodological framework. *Int. J. Soc. Res. Methodol.* 8, 19–32. doi: 10.1080/1364557032000119616

Ausubel, D. P. (1966). "Meaningful reception learning and the acquisition of concepts" in Analyses of concept learning. eds. H. J. Klausmeier and C. Harris (New York: Academic Press), 157–175.

Ausubel, D. P. (2012). The acquisition and retention of knowledge: A cognitive view: Springer Science & Business Media. Dordrecht: Springer Netherlands.

Averill, D., Waite, G. N., Sharma, P., Mamillapalli, S., and Carbe, C. (2022). Core concepts as a framework to assess the progression of student learning in a Ume curriculum. *FASEB J.* 36:5831. doi: 10.1096/fasebj.2022.36.S1.R5831

Bacon, R. S. (1979). Building a curriculum in introductory human geography through core concepts. *J. Geogr.* 78, 152–156. doi: 10.1080/00221347908979974

Ball, K. L. (2023). Foundations in physiology: an introductory course using the core concepts. *Adv. Physiol. Educ.* 47, 501–507. doi: 10.1152/advan.00135.2022

Barrett, T., Jacob, S. R., and Likes, W. (2023). Development of a concept-based curriculum. *Teach. Learn. Nurs.* 18, 330–334. doi: 10.1016/j.teln.2022.06.002

Boneau, C. A. (1990). Psychological literacy: a first approximation. *Am. Psychol.* 45, 891–900. doi: 10.1037/0003-066X.45.7.891

Chen, A., Phillips, K. A., Schaefer, J. E., and Sonner, P. M. (2022). The development of core concepts for neuroscience higher education: from beginning to summer virtual meeting satellite session. *J. Undergrad. Neurosci. Educ.* 22, A160–A164. doi: 10.59390/GHOR4737

Chen, A., Phillips, K. A., Schaefer, J. E., and Sonner, P. M. (2023). Community-derived core concepts for neuroscience higher education. *CBE Life Sci. Educ.* 22:ar18. doi: 10.1187/cbe.22-02-0018

Creswell, J.W. (2015) Revisiting mixed methods and advancing scientific practices Oxford handbooks online. Oxford Handbook of Multimethod and Mixed Methods Research Inquiry, Oxford Library of Psychology. eds. S. N. Hesse-Biber and R. Burke Johnson doi: 10.1093/oxfordhb/9780199933624.013.39

Danos, N., Staab, K. L., and Whitenack, L. B. (2022). The Core concepts, competencies, and grand challenges of comparative vertebrate. *Anat. Morphol. Integ. Organ. Biol.* 4:19. doi: 10.1093/iob/obac019

D'Avanzo, C. (2008). Biology concept inventories: overview, status, and next steps. *Bioscience* 58, 1079–1085. doi: 10.1641/b581111

de Villiers, M. R., de Villiers, P. J. T., and Kent, A. P. (2005). The Delphi technique in health sciences education research. *Med. Teach.* 27, 639–643. doi: 10.1080/13611260500069947

Erickson, H. L., Lanning, L. A., and French, R. (2017). "Chapter 2: the structures of knowledge and process" in Concept-based curriculum and instruction for the thinking classroom. eds. D. A. Bartlett, K. Irwin and K. E. Taylor (Thousand Oaks, California: Corwin, A sage company).

Etukakpan, A., Janke, K., Waldhuber, M., Angelo, T., and White, P.J. (2024) Methodological approaches to identifying Core concepts in STEM and health education: A scoping review protocol, Available online at: https://doi.org/10.17605/OSF.IO/VTF74 [Accessed March 14].

Fetters, M. D., Curry, L. A., and Creswell, J. W. (2013). Achieving integration in mixed methods designs—principles and practices. *Health Serv. Res.* 48, 2134–2156. doi: 10.1111/1475-6773.12117

Foster, J.M., Sultan, M.A., Devaul, H., Okoye, I., and Sumner, T. (2012). "Identifying core concepts in educational resources." in Proceedings of the ACM/IEEE joint conference on digital libraries. pp. 35–42.

Giddens, J. F., and Brady, D. P. (2007). Rescuing nursing education from content saturation: the case for a concept-based curriculum. *J. Nurs. Educ.* 46, 65–69. doi: 10.3928/01484834-20070201-05

Gray, J. P., Curran, C. P., Fitsanakis, V. A., Ray, S. D., Stine, K. E., and Eidemiller, B. J. (2019). Society of Toxicology develops learning framework for undergraduate toxicology courses following the vision and change Core concepts model. *Toxicol. Sci.* 170, 20–24. doi: 10.1093/toxsci/kfz090

Grunspan, D. Z., Nesse, R. M., Barnes, M. E., and Brownell, S. E. (2018). Core principles of evolutionary medicine: a Delphi study. *Evol. Med. Public Health* 2018, 13–23. doi: 10.1093/emph/eox025

Guilding, C., Kelly-Laubscher, R., Netere, A., Babey, A. M., Restini, C., Cunningham, M., et al. (2023). Developing an international concept-based curriculum for pharmacology education: the promise of core concepts and concept inventories. *Br. J. Clin. Pharmacol.* 13:13. doi: 10.1111/bcp.15985

Hakkarainen, K., Hytönen, K., Makkonen, J., and Lehtinen, E. (2016). Extending collective practices of doctoral education from natural to educational sciences. *Stud. High. Educ.* 41, 63–78. doi: 10.1080/03075079.2014.914910

Herman, G.L., and Loui, M.C. (2012). Identifying the core conceptual framework of digital logic ASEE annual conference and exposition, conference proceedings. Available online at::https://peer.asee.org/identifying-the-core-conceptual-framework-of-digital-logic (Accessed 8 April, 2025)

Hiatt, A., Davis, G. K., Trujillo, C., Terry, M., French, D. P., Price, R. M., et al. (2013). Getting to Evo-devo: concepts and challenges for students learning evolutionary developmental biology. *CBE Life Sci. Educ.* 12, 494–508. doi: 10.1187/cbe.12-11-0203

Horne, L., Manzanares, A., Babin, N., Royse, E. A., Arakawa, L., Blavascunas, E., et al. (2024). Alignment among environmental programs in higher education: what food-energy-water Nexus concepts are covered in introductory courses? *J. Geosci. Educ.* 72, 86–103. doi: 10.1080/10899995.2023.2187680

Hott, A. M., Huether, C. A., McInerney, J. D., Christianson, C., Fowler, R., Bender, H., et al. (2002). Genetics content in introductory biology courses for non-science majors: theory and practice bioscience 52, 1024–1035. doi: 10.1641/0006-3568(2002)052[1024:GCIIBC]2.0.CO;2

Hub, A.L. (2025). ACAP library pathfinder: Systematic searching for a review. Available online at: https://libguides.navitas.com/systematic-searching/scoping-gold-sets

Hurwitz, D.S., Brown, S.A., Islam, M.R., and Daratha, K. (2013) Mental models of students and practitioners in the development of an authentic assessment instrument for traffic signal engineering ASEE annual conference and exposition, conference proceedings. Available online at: https://peer.asee.org/mental-models-of-students-and-practitioners-in-the-development-of-an-authentic-assessment-instrument-for-traffic-signal-engineering (Accessed 7 April, 2025).

Koba, S., and Tweed, A. (2009). Hard-to-teach biology concepts: A framework to deepen student understanding. *1st* Edn. Arlington, VA: National Science Teachers Association.

Laughlin, P. R., Hatch, E. C., Silver, J. S., and Boh, L. (2006). Groups perform better than the best individuals on letters-to-numbers problems: effects of group size. *J. Pers. Soc. Psychol.* 90, 644–651. doi: 10.1037/0022-3514.90.4.644

Libarkin, J. C., and Ward, E. M. G. (2011). The qualitative underpinnings of quantitative concept inventory questions. Geological Society of America eBooks [Preprint].

Loewenberg Ball, D., Thames, M. H., and Phelps, G. (2008). Content knowledge for teaching:what makes it Special? *J. Teach. Educ.* 59, 389–407. doi: 10.1177/0022487108324554

McArthur, A., Klugárová, J., Yan, H., and Florescu, S. (2015). Innovations in the systematic review of text and opinion. *JBI Evid. Implement.* 13, 188–195. doi: 10.1097/xeb.0000000000000060

McFarland, J. L., and Michael, J. A. (2020). Reflections on core concepts for undergraduate physiology programs. *Adv. Physiol. Educ.* 44, 626–631. doi: 10.1152/advan.00188.2019

Merkel, S. (2012). The development of curricular guidelines for introductory microbiology that focus on understanding. *J. Microbiol. Biol. Educ.* 13, 32–38. doi: 10.1128/jmbe.v13i1.363

Michael, J. (2007) Conceptual assessment in the biological sciences: a National Science Foundation-sponsored workshop. Advances in Physiology Education.

Michael, J., Cliff, W., McFarland, J., Modell, H., and Wright, A. (2017). "Reforming science education/reforming physiology education" in The Core concepts of physiology: A new paradigm for teaching physiology. eds. J. Michael, W. Cliff, J. McFarland, H. Modell and A. Wright (Springer New York: New York, NY), 3–18.

Michael, J., and McFarland, J. (2011). The Core principles ("big ideas") of physiology: results of faculty surveys. *Adv. Physiol. Educ.* 35, 336–341. doi: 10.1152/advan.00004.2011

Mitchell, I., Keast, S., Panizzon, D., and Mitchell, J. (2017). Using 'big ideas' to enhance teaching and student learning teachers and teaching. *Theory Pract.* 23, 596–610. doi: 10.1080/13540602.2016.1218328

Morgan, D. L. (2007). Paradigms lost and pragmatism regained: methodological implications of combining qualitative and quantitative methods. *J. Mixed Methods Res.* 1, 48–76. doi: 10.1177/2345678906292462

Morse, J. M. (2008). Confusing categories and themes. *Qual. Health Res.* 18, 727–728. doi: 10.1177/1049732308314930

Morse, J. M., Barrett, M., Mayan, M., Olson, K., and Spiers, J. (2002). Verification strategies for establishing reliability and validity in qualitative research. *Int J Qual Methods* 1, 13–22. doi: 10.1177/160940690200100202

Munn, Z., Peters, M. D. J., Stern, C., Tufanaru, C., McArthur, A., and Aromataris, E. (2018). Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. *BMC Med. Res. Methodol.* 18, 1–7. doi: 10.1186/s12874-018-0611-x

Nosratzadeh, H., Bhowmick, D., Ríos Carmona, A. B., Thompson, J., Thai, T., Pearson, L., et al. (2025). A scoping review of the design and characteristics of e-bike financial incentives. *Transp. Rev.* 45, 149–171. doi: 10.1080/01441647.2024.2419884

Novak, J.D., and Cañas, A.J. (2008). The theory underlying concept maps and how to construct and use them. Technical Report IHMC CmapTools 2006-01 Rev 01-2008, Florida Institute for Human and Machine Cognition. Available at: http://cmap.ihmc.us/Publications/ResearchPapers/TheoryUnderlyingConceptMaps.pdf

Parekh, G., DeLatte, D., Herman, G. L., Oliva, L., Phatak, D., Scheponik, T., et al. (2018). Identifying Core concepts of cybersecurity: results of two Delphi processes. *IEEE Trans. Educ.* 61, 11–20. doi: 10.1109/TE.2017.2715174

Peters, S., and Livia, A. (2006). Relevant behavioural and social science for medical undergraduates: a comparison of specialist and non-specialist educators. *Med. Educ.* 40, 1020–1026. doi: 10.1111/j.1365-2929.2006.02562.x

Qian, Y., Wang, Y., Wen, J., Wu, S., and Zhang, J. (2023). One hundred Core concepts in chemistry and upper-secondary school Teachers' and Students' chemistry conceptual structures. *J. Balt. Sci. Educ.* 22, 493–505. doi: 10.33225/jbse/23.22.493

Quirk, S. E., Koivumaa-Honkanen, H., Honkanen, R. J., Mohebbi, M., Stuart, A. L., Heikkinen, J., et al. (2024). A systematic review of personality and musculoskeletal disorders: evidence from general population studies. *Front. Psychol.* 15:15. doi: 10.3389/fpsyt.2024.1288874

Ralph, E., and Walker, K. (2014). The potential of adaptive mentorship: experts' perspectives. *Open J. Soc. Sci.* 2, 77–86. doi: 10.4236/jss.2014.28013

Rowland, S. L., Smith, C. A., Gillam, E. M., and Wright, T. (2011). The concept lens diagram: a new mechanism for presenting biochemistry content in terms of "big ideas". *Biochem. Mol. Biol. Educ.* 39, 267–279. doi: 10.1002/bmb.20517

Schaefer, J., and Hannah, R. (2023). Core concepts intervention was more effective for improving student "big picture" understanding when accompanied by embedded core concept instruction. *Physiology* 38:5796123. doi: 10.1152/physiol.2023.38.S1.5796123

Schaefer, J. E., and Michael, J. (2024). Core concepts: views from physiology and neuroscience. *Front. Educ.*:9. doi: 10.3389/feduc.2024.1470040

Schneider, S. L. (2013). "The international standard classification of education 2011" in Class and stratification analysis. ed. G. Elisabeth Birkelund (Leeds, England: Emerald Group Publishing Limited), 365–379.

Skirton, H., Goldsmith, L., Jackson, L., Lewis, C., and Chitty, L. (2014). Offering prenatal diagnostic tests: European guidelines for clinical practice [corrected]. *Eur. J. Hum. Genet.* 22, 580–586. doi: 10.1038/ejhg.2013.205

Smaill, C.R., Rowe, G.B., and Fink, F.K. (2008). A software tool for the web-based delivery and analysis of concept-based diagnostic tests proceedings of 36th European society for engineering education, SEFI conference on quality assessment, Employability and Innovation. Available at: https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=1ef9453f1430ca306cdde10d6585fa386d71a8b2

Stoll, C. R. T., Izadi, S., Fowler, S., Green, P., Suls, J., and Colditz, G. A. (2019). The value of a second reviewer for study selection in systematic reviews. *Res. Synth. Methods* 10, 539–545. doi: 10.1002/jrsm.1369

Streveler, R.A., Olds, B.M., Miller, R.L., and Nelson, M.A. (2003). Using a Delphi study to identify the most difficult concepts for students to master in thermal and transport science Proceedings of the annual conference of the American Society for Engineering Education.

Tangalakis, K., Lexis, L., Hryciw, D. H., Towstoless, M., Bakker, A. J., Beckett, E., et al. (2023). Establishing consensus for the core concepts of physiology in the Australian higher education context using the Delphi method. *Adv. Physiol. Educ.* 47, 419–426. doi: 10.1152/advan.00140.2022

Tansey, J. T., Baird, T. Jr., Cox, M. M., Fox, K. M., Knight, J., Sears, D., et al. (2013). Foundational concepts and underlying theories for majors in "biochemistry and molecular biology". *Biochem. Mol. Biol. Educ.* 41, 289–296. doi: 10.1002/bmb.20727

Tracy, S. J. (2010). Qualitative quality: eight "big-tent" criteria for excellent qualitative research. *Qual. Inq.* 16, 837–851. doi: 10.1177/1077800410383121

Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K. K., Colquhoun, H., Levac, D., et al. (2018). PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. *Ann. Intern. Med.* 169, 467–473. doi: 10.7326/M18-0850

Tweedie, J., Palermo, C., Wright, H. H., and Pelly, F. E. (2020). Using document analysis to identify core concepts for dietetics: the first step in promoting conceptual learning. *Nurs. Health Sci.* 22, 675–684. doi: 10.1111/nhs.12712

Valiga, T. M., and Bruderle, E. (1994). Concepts included in and critical to nursing curricula: an analysis. *J. Nurs. Educ.* 33, 118–124. doi: 10.3928/0148-4834-19940301-07

Van Teijlingen, E., and Hundley, V. (2002). The importance of pilot studies. *Nurs. Standard* 16, 33–36. doi: 10.7748/ns.16.40.33.s1

White, P. J., Davis, E. A., Santiago, M., Angelo, T., Shield, A., Babey, A. M., et al. (2021). Identifying the core concepts of pharmacology education. *Pharmacol. Res. Perspect.* 9:e00836. doi: 10.1002/prp2.836

White, P. J., Guilding, C., Angelo, T., Kelly, J., Gorman, L., Tucker, S., et al. (2022). Identifying the core concepts of pharmacology education: a global initiative. *Br. J. Pharmacol.* 180, 1197–1209. doi: 10.1111/bph.16000

Wiggins, G., and McTighe, J. (2005). Understanding by design, Ascd.

10.3389/feduc.2025.1547994

Wolgemuth, J. R., Guyotte, K. W., Shelton, S. A., and Saldaña, J. (2024). An introduction to themeing the data. *In Expanding Approaches to Thematic Analysis.* United Kingdom: Routlege, Taylor & Francis Group. 11–26. doi: 10.4324/9781003389149-2

Wood, W. B. (2008). Teaching concepts versus facts in developmental biology. *CBE Life Sci. Educ.* 7, 10–11. doi: 10.1187/cbe.07-12-0106

Wright, A., Provost, J., Roecklein-Canfield, J. A., and Bell, E. (2013). Essential concepts and underlying theories from physics, chemistry, and mathematics for "biochemistry and molecular biology" majors. *Biochem. Mol. Biol. Educ.* 41, 302–308. doi: 10.1002/bmb.20728

Zechmeister, J. S., and Zechmeister, E. B. (2000). Introductory textbooks and Psychology's Core concepts. *Teach. Psychol.* 27, 6–11. doi: 10.1207/S15328023TOP2701_1