

# Research Trends in Competency-Based Education and Training: A Data-Driven Historical Analysis

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**Abstract**—This systematic review employs topic modeling techniques to delve into the Competency-Based Education and Training (CBET) research landscape, comprehensively exploring this domain's prevalent themes and subjects. The study scrutinizes a dataset of over 4000 records from the Web of Science, spanning 1998 to 2024, encompassing journal articles, books, book chapters, and conference papers. The analysis discerns distinct clusters of topics in CBET research: discipline-specific applications, emerging technologies, pedagogical approaches, assessment frameworks, and behavioral intervention. This paper highlights key challenges and opportunities.

**Keywords**—competency-based, education and training, systematic review, topic modeling

## I. INTRODUCTION

Competency-Based Education and Training (CBET) is becoming a popular learning method where students focus on skill and knowledge mastery rather than a set curriculum [1]. This instructional strategy is defined by its emphasis on quantifiable learning outcomes. There's a rising number of peer-reviewed articles on CBET within fields like health, medicine, social work, business, and STEM [2–4]. This paper examines CBET research trends, aiming to share insights on its evolution, approaches, and new themes. It reviews selected articles to guide educators, policymakers, and researchers on CBET's progress and potential for education.

In the evolving education landscape, CBET represents a paradigm shift from traditional time-based models to a focus on developing and demonstrating skills and competencies [5]. The inception of CBET has brought a fundamental change in educational strategies, aligning learning outcomes with the dynamic requirements of the workforce and societal needs. This pedagogical approach emphasizes the acquisition of competencies—specifically, the application and creation of knowledge—as opposed to the mere passage of time or completion of courses [5, 6].

As the CBET model matures, examining the breadth and depth of research within this field is critical to understanding its trajectories and transformations. The infusion of data-driven analytical methods in historical research allows for a novel exploration of CBET's progression, shedding light on its past, delineating its present status, and envisioning its future implications.

Successful implementation of CBET usually requires strong and supportive institutional leadership, appropriate curriculum design, implementation and management, resource dedication, proper faculty development, and faculty commitment to making these changes [7].

This manuscript, therefore, presents a historical analysis of CBET by harnessing a data-driven approach to map the trends in research within this domain. We dissect peer-reviewed literature spanning several decades to identify patterns, peaks, and pivots in CBET research. We endeavor to uncover the underpinnings of the field's expansion, adaptation in various applied disciplines, and evolution of central themes.

The aim is to offer a comprehensive overview that is both retrospective and forward-looking, providing scholars, educators, and decision-makers with a robust foundation to understand CBET's impacts and to inform policy and practice. By synthesizing and analyzing vast quantities of scholarly data, this work charts CBET's course and forecasts its potential to revolutionize the educational landscape.

## II. LITERATURE REVIEW

### A. Historical Development of CBET

While the history of CBET is now more than five decades old, recent recognition of its utility in demystifying educational processes by linking learning to measurement has brought CBET increasingly to the forefront. It provides a fresh look at learning by shifting the focus from seat time as a passive activity to the active and intentional demonstration of learning [1]. When CBET was first documented in the 1950s, the field of education was influenced by behaviorism. It is a psychological theory that focuses on observable behaviors and measurable outcomes. This behavioral approach to learning laid the groundwork for later developments in competency-based education. Behaviorism emphasizes defining clear learning objectives and assessing students based on their demonstrated skills and competencies. Benjamin Bloom, a prominent educational psychologist, introduced the concept of mastery learning in the 1960s, which can be seen as a precursor to CBET. Mastery learning emphasizes that students should master a particular concept or skill before moving on to the next, challenging the traditional notion of fixed timelines for learning. CBET has historically been widely used in vocational and technical training programs where practical skills and job-specific competencies are paramount. This includes healthcare, information technology, manufacturing, and skilled trades.

### B. CBET Programme and Healthcare

It is reported that the CBE educational model deemphasizes the time spent learning and emphasizes the achievement of competencies and demonstrable outcomes, especially given the increasing need for medical education to satisfy accreditation bodies and exhibit social accountability.

CBE in pharmacy often follows developments in CBE for medicine.

A literature review revealed several articles that provide an overview of the application of CBE in medicine, dentistry, and nursing. The literature on CBE concerning pharmacy education is emerging, but most available evidence describes isolated experiences in specific countries or institutions.

It is reported by McMullen *et al.* [2] that when a total of 173 records were analyzed, a working definition of CBE specific to physicians was developed—Competency-Based Education (CBE) is an approach to preparing physicians for practice that is fundamentally orientated to graduate outcome abilities and organized around competencies derived from an analysis of societal and patient needs. It de-emphasizes time-based training and promises greater accountability, flexibility, and learner-centeredness. This is one main reason why CBET is commonly adopted in the healthcare sector, and this gain in traction for CBET can be attributed to a combination of educational, economic, and technological factors.

However, the development of a framework is challenging. There have been many reports and studies of adopting CBET in various programs in different areas of study, especially in the medical field. This is due to the global reforms in the education of healthcare workers that have culminated in the implementation of CBET [2, 7]. Competency frameworks are commonplace in the health professions and align with the CBET model. In pharmacy, these frameworks regulate career entry, benchmark standards of practice, and facilitate expertise development [8]. Different assessment methods were employed in CBET, including performance assessments, simulations, portfolios, and authentic tasks. Technologies like online platforms and simulation software were noted as a growing trend in competency assessments.

While numerous studies and reports explore the development of these frameworks, it is noteworthy that the commonly documented cases predominantly originate from medical education. Despite this, there is no universally standardized approach, with the majority relying on national frameworks, literature reviews, stakeholder consultations, and qualitative methods like semi-structured interviews. It is essential to highlight that many reviewed studies either lack or offer only vague summaries of the framework development and validation processes [9]. In addition, the primary obstacle in CBET programs regarding competency and assessment is the standardizing of competency definitions, evaluating soft skills, ensuring the assessment process's fairness and reliability, and training faculty to develop and assess CBET programs [10], which researchers might be looking into as CBET matures.

### *C. Learning Pathways*

The CBET framework is widely reported to be especially useful where higher education institutions increasingly serve a more diverse student body [11]. One way of addressing the needs of this non-traditional student population is to integrate remote, mobile, or online learning. Integrating these approaches into the CBET structure is feasible and recommended as it facilitates student-centered, individualized learning paths [12]. Many CBET programs have transitioned to completely web-based or hybrid structures, integrating a combination of face-to-face and

online components [13–15]. Some of these online programs utilize modules as the primary form of content delivery and assessment. Many non-traditional students must balance major life responsibilities in addition to academic work. Having a program that offers distance education options and allows them to progress at their own pace, ensuring that they do not fall behind, is ideal for these students. The flexibility of CBET can potentially increase non-traditional student enrollment in programs. Based on the literature reviewed, CBET is an appropriate strategy for today's diverse student body especially with the emerging technology in learning and training [16].

### *D. Technologies in Training*

As CBET is an educational approach aiming to serve a more diverse student body, distance learning is another area of discussion closely tagged to CBET. Early distance learning dates to the 1980s, when individuals could complete work and courses independently. People who signed up for such a method are for various financial, personal, or social reasons [17].

The increased accessibility of the internet and advancements in online technology have opened new avenues to cater to the diverse needs of non-traditional students. Many CBET programs have transitioned to fully web-based or hybrid structures, incorporating face-to-face and online components. The surge in demand for online courses is met by CBET, offering a framework where online education becomes the primary instructional method. Though distance learning has always been around, it was not until the COVID-19 pandemic that saw a 180-degree shift in the mindset in education – The transition to non-traditional learning. In the CBET structure, students can learn at their own pace and on their schedule, making it particularly effective in an online format where synchronization with others is not essential. This approach allows students to swiftly complete proficient tasks while taking more time to review challenging material. Reports have also shown that the dropout rates are lower as students are more motivated.

Modern learning management systems facilitate interactive instruction, provide instant feedback, guide students to additional relevant content based on their responses, and enable progression to more advanced material only upon demonstrating competence. These technological advancements contribute to a more efficient implementation of CBET, creating an environment that aligns with the diverse learning preferences and schedules of students engaged in online education. Yet, the challenge of implementing CBET sometimes still lies in adopting technology, especially in developing countries, and faculties' mindset and training in adopting technologies to deliver classes [12, 17].

### *E. Addressing the Gaps*

The summary above shows many domains, topics, and research areas related to CBET. The range is so wide that it touches on history, pedagogy, the technology used in CBET, and possible learning pathways. Though it is reported that CBET is commonly used in domains such as healthcare, information technology, manufacturing, and skilled trades, there is no quantitative data to show the research trend within these domains as the years go by.

In preparing for a data-driven exploration of CBET literature, it is essential to recognize the breadth of areas impacted by its principles, from curriculum development and assessment strategies to policy implementation and beyond. As the field has grown, so has its complexity and the variety of associated research topics.

Given the expanse of literature surrounding CBET, traditional review methods might be inadequate for capturing the nuanced development of research themes over extensive periods. Hence, this study will employ advanced topic modeling techniques that harness machine learning algorithms to identify patterns and themes within textual data on a large scale to address this. This analytical tool enables researchers to systematically sift through the academic corpus, revealing major research trajectories and shifts in focus over time.

### III. METHODOLOGY

This study comprehensively explores predominant themes and subjects within prior research on competency-based education and training. Employing topic modeling techniques, we analyze academic literature sourced from the Web of Science, a leading database containing abstracts and citations of peer-reviewed literature across diverse domains. The examined corpus comprises journal articles, books, book chapters, and conference papers spanning 1998 to 2024. The search strategy was designed to identify relevant works on competency-based education and training by combining two distinct sets of keywords. The initial set comprises the key descriptive term “competency-based”. In contrast, the second set incorporates the various terms used in the literature to describe education and training, such as ‘teaching’, ‘learning’, ‘assessment’, ‘training’, ‘education’, ‘Instruction’, ‘curriculum’, ‘pedagogy’, ‘student’, and ‘learner’ and their various word forms of the root word, such as associated nouns, adjectives, and different tenses. Subsequently, a thorough examination of the abstracts within the collection was conducted, resulting in 4634 records after excluding unqualified records.

Topic modeling is a widely utilized technique in Natural Language Processing (NLP), aiming to extract latent topics from text corpora for enhanced comprehension of underlying themes and structure. Traditional algorithms like Latent Dirichlet Allocation (LDA) [18] face challenges like noisy data, overlapping topics, and poor interpretability. Addressing these limitations, BERTopic [19] emerges as a promising alternative, leveraging the Bidirectional Encoder Representations from Transformers (BERT) architecture. In this study, we qualitatively analyzed the abstracts of selected papers using BERTopic, which is known for its ability to generate coherent topics and competitive performance. It surpasses classical models like LDA and Non-negative Matrix Factorization (NMF) [20] and recent clustering-based approaches such as CTM [21] and Top2Vec [22].

BERTopic produces interpretable topics through a three-step process. Initially, documents were transformed into embeddings using a default pre-trained language model, all-MiniLM-L6-v2 [23], mapping sentences to a 384-dimensional dense vector space. Subsequently, the dimensionality of the resulting embeddings is reduced using

Uniform Manifold Approximation and Projection (UMAP) [24] before clustering them using a modified version of Hierarchical Density-Based Spatial Clustering of Applications with Noise (HDBSCAN) [25]. Finally, topic representations are extracted from the document clusters using c-TF-IDF (Class-based Term Frequency-Inverse Document Frequency) [26]. For a term  $x$  within class  $c$ :

$$W_{x,c} = \|tf_{x,c}\| \times \log\left(1 + \frac{A}{f_x}\right)$$

where

$tf_{x,c}$  = frequency of word  $x$  in class  $c$

$f_x$  = frequency of word  $x$  across all classes

$A$  = average number of words per class

## IV. RESULTS

### A. Topic Identification

23 topics were successfully identified, as presented in Table 1. The model extracted representative lexemes, called ‘topic words’, for each identified topic. These topic words are crucial in encapsulating the principal themes or concepts associated with a specific topic within the corpus. BERTopic assigns scores to these topic words, reflecting their relative significance within a given topic (keywords in Table 1 are sorted by the importance scores). Words appearing near and contributing substantially to the semantic essence of a topic receive higher scores.

Table 1. Summary of topics and keywords

Topic	Count	Name	Representation
0	1417	Medical	['surgical', 'resident', 'surgery', 'medical', 'assessment', 'score', 'wa', 'surgeon', 'trainee', 'health']
1	1229	Teaching & learning technology	['teacher', 'learning', 'paper', 'technology', 'approach', 'research', 'student', 'engineering', 'university', 'higher']
2	268	Nursing practice	['nursing', 'nurse', 'np', 'practice', 'clinical', 'care', 'preceptor', 'student', 'simulation', 'competency']
3	79	Pharmaceutical	['pharmacy', 'pharmacist', 'pharmaceutical', 'pharmacology', 'medication', 'cbpe', 'reablement', 'mapps', 'sps', 'student']
4	77	Midwifery	['midwife', 'midwifery', 'maternal', 'newborn', 'facility', 'provider', 'birth', 'service', 'neonatal', 'death']
5	72	Psychology	['psychology', 'psychologist', 'psychiatry', 'psychological', 'eppp', 'apa', 'professional', 'masterslevel', 'training', 'selfcare']
6	71	Dentistry	['dental', 'dentistry', 'oral', 'dph', 'dentist', 'hygiene', 'percent', 'orthodontic', 'global', 'preclinical']
7	64	Social work & gerontology	['social', 'work', 'worker', 'gerontology', 'msw', 'critical', 'field', 'aging', 'practice', 'asabiyya']
8	46	Disaster & humanitarian preparedness	['disaster', 'humanitarian', 'emergency', 'preparedness', 'response', 'incident', 'crisis', 'pfa', 'cbrn', 'ept']
9	40	Veterinarian	['veterinary', 'veterinarian', 'cbve', 'animal', 'aavmc', 'lo', 'vhs', 'orthopedic', 'mindset', 'euthanasia']

10	38	Nutrition & dietetics	['nutrition', 'dietetics', 'dietetic', 'food', 'dietitian', 'inspect', 'rdns', 'hnhnd', 'nfpe', 'workbased']
11	38	Psychoanalytic supervision	['supervision', 'supervisor', 'supervisory', 'psychoanalytic', 'supervisees', 'supervisee', 'psychology', 'psychotherapy', 'multicultural', 'neuropsychology']
12	36	Ophthalmology	['ophthalmology', 'eye', 'vitreoretinal', 'ophthalmic', 'cataract', 'pcr', 'optometry', 'optometrist', 'ophthalmologist', 'vitrectomy']
13	29	Covid19	['covid19', 'pandemic', 'disrupted', 'pathology', 'distancing', 'disruption', '2020', 'outbreak', 'crisis', 'lockdown']
14	25	Endoscopy	['endoscopy', 'endoscopic', 'endoscopists', 'ercp', 'colonoscopy', 'rho', 'gastrointestinal', 'gi', 'trial', 'ngm']
15	23	Psychiatry	['mhfa', 'psychiatry', 'mental', 'rtms', 'srb', 'actd', 'nssi', 'sp', 'therapist', 'trauma']
16	21	Portfolio assessment	['portfolio', 'eportfolio', 'eportfolios', 'pat', 'reflective', 'assessor', 'drawing', 'saturation', 'ieps', 'promotion']
17	17	Pain relief	['pain', 'addiction', 'pcat', 'pns', 'cbtcp', 'opioid', 'prelicensure', 'medicine', 'painrelated', 'nan']
18	14	Dementia care	['dementia', 'caregiver', 'ihss', 'aging', 'lrc', 'aide', 'care', 'home', 'adrd', 'living']
19	14	Bronchoscopy	['bronchoscopy', 'bronchoscopic', 'bronchoscopists', 'inhaler', 'cricoid', 'bradstat', 'mv', 'eb', 'pressure', 'ops']
20	13	Mentoring	['mentoring', 'mentor', 'mentees', 'imnis', 'youth', 'mca', 'mentorship', 'relationship', 'mentormentee', 'iiei']
21	13	Radiation oncology	['ro', 'radiation', 'oncology', 'sbme', 'contouring', 'rtp', 'estro', 'physicist', 'canadian', 'radiotherapy']
22	13	Behaviorial intervention	['bst', 'behavior', 'intervention', 'asd', 'staff', 'aba', 'avb', 'integrity', 'parent', 'soiling']

**B. Topic Popularity and Impact**

Fig. 1 plots the number of articles published on each topic from 1998 to 2023. Data for 2024 is not included in this line chart because there are only two data points in 2024 when the data was collected. It is observable from Fig. 1 that studies on Medical and Teaching & Learning technology are the dominant competency-based education and training research, and the number has increased dramatically since 2010. Apart from these 2 topics, the Nursing practice also attracted considerable attention in the literature, while the remaining topics have a similar number of articles published. The three main topics are described as follows:

**Medical:** Competency-based education and training research focusing on general medical topics, not about specific medical conditions.

**Teaching & learning technology:** Competency-based education and training research focusing on teaching and learning perspective in higher education.

**Nursing practice:** Competency-based education and training research focusing on nursing education and practice. Through an in-depth investigation of the yearly article count for each topic, we found that articles from 1998 to 2009 covered 19 out of the 23 discovered topics. Four new topics emerged since 2010, with 90 publications in total. These four topics are COVID-19, Endoscopy, Psychiatry, and Radiation oncology.

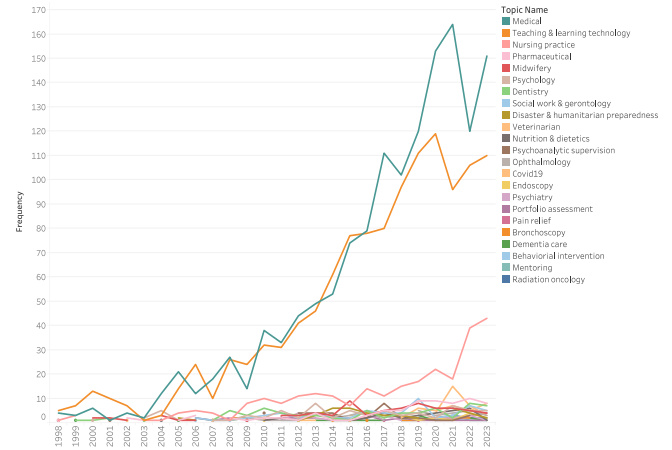


Fig. 1. The popularity of the 23 topics from 1998 to 2023.

The research on competency-based education and training is embedded in 3 broad domains: *healthcare*, including physical and mental health. *Education* and *social work*. The *healthcare* domain is identified as many different topics by the BERTopic model because of the different granularities of the focus. Articles with more specific focuses will be identified as separate topics, e.g., *dentistry* and *COVID-19*, rather than *medical* in general. The number of citations among all the articles published from 1998 to 2024 ranges from 0 to 1098. The 25<sup>th</sup> percentile of the number of citations of each article is 2, while the median and the 75<sup>th</sup> percentile are 5 and 15, respectively. Fig. 2 plots the yearly total number of articles and total citations. Several peaks are observed for the total number of citations, with notable spikes in 2010, 2013, and 2017, contributed by several articles with high citations. Particularly in 2020, 11 articles received more than 100 citations up until the data collection date. The number of citations has dropped dramatically since 2019, possibly due to the relatively short period since publication or the lack of significance in recent articles.

Articles with a citation of more than 15 (75<sup>th</sup> percentile) are considered top-cited articles. We compare the topic distribution of all articles and top-cited articles. Consistent with the findings of dominant topics, Medical, teaching & learning technology, and nursing practice are the three topics that contributed most to the citations for all top-cited articles. The medical topic holds a substantial share of attention, constituting 38.75% of all articles. Notably, the focus increases to 48.65% when considering the top-cited articles, indicating a sustained interest and impactful contributions in the medical field. Meanwhile, the focus of the *teaching & learning technology* topic is 33.61% among all articles but only 17.72% among the top-cited articles. This suggests that although there is significant research output in this area, the impact or influence of these works is comparatively lower.

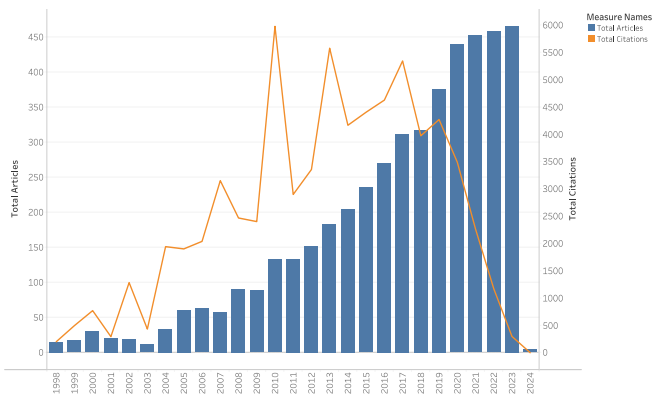


Fig. 2. Number of articles vs. number of citations over the years.

## V. CONCLUSION

The use of CBET is pervasive in the medical field, as evidenced by the existing literature and our research findings. The prevalence of CBET in healthcare education is attributed to global reforms that have reshaped the training of healthcare professionals, resulting in its widespread adoption. Our data underscores the burgeoning popularity of CBET in specific medical subdomains, particularly in nursing and teaching and learning technology.

Through our research methodology, we have identified key focal areas within CBET research, notably encompassing physical health, mental health, social work, and education within the medical field. In the realm of learning and technology, a comprehensive literature review indicates that the CBET framework is notably effective in higher education settings catering to a diverse student body. The integration of remote, mobile, or online learning methods within the CBET structure is not only feasible but also recommended. This integration facilitates student-centered and individualized learning paths, particularly beneficial for non-traditional student populations.

Our data further supports the increasing research focus on integrating remote, mobile, or online learning within the CBET framework, particularly aimed at meeting the needs of diverse learners. While CBET research has traditionally been concentrated in the medical field, our data reveals a growing body of research in learning and technology, suggesting a promising future for CBET in various fields beyond healthcare. This evolving landscape holds potential implications for educators, policymakers, and higher education institutions, encouraging the consideration and adoption of CBET in curricula to create more inclusive learning environments. However, based on the literature and our data, the challenge will lie in developing assessments and adopting CBET beyond medical.

## CONFLICT OF INTEREST

The submitted work was carried out without a conflict of interest.

## AUTHOR CONTRIBUTIONS

Chong Guan conducted and collected the data presented in this research; Mei Zhen Ng conducted the literature review and wrote the conclusion; Yimiao Zhang analyzed the collected data; all authors had approved the final version.

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