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Diabetes Self-Management in the Digital Health Era: A Concept Analysis Using Natural Language Processing

Donghwan Lee

Donghwan.lee@duke.edu

Duke University School of Nursing

Aderonke Kareem

Duke University School of Nursing

Solhee Shin

Gyeongnam Center for Infectious Disease Control and Prevention

Leila Ledbetter

University Libraries, Virginia Polytechnic Institute and State University

Aaliyah Alvin

Duke University Medical Center Library & Archives

Ryan J. Shaw

Duke University School of Nursing

Kais Gadhoumi

Duke University School of Nursing

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Abstract

Diabetes self-management is increasingly shaped by digital health technologies, yet existing conceptual definitions do not fully reflect this evolving landscape. This study aimed to refine the concept of diabetes self-management in the digital health era by applying Rodgers' evolutionary method integrated with Natural Language Processing (NLP). Ninety-seven studies were analyzed through a dual-phase design combining manual review and computational clustering of sentence-level embeddings. The analysis identified core attributes, including daily behavioral routines, cognitive and psychological processes, multilevel social support, personalization, digital health integration, and dynamic patient–provider relationships. Antecedents encompassed physical and psychological demands, emotional readiness, access to education and support, resource and technology availability, and health and digital literacy. Consequences included improved clinical outcomes, enhanced quality of life, empowerment, and reduced healthcare burden. Integrating manual and NLP-based approaches strengthened conceptual clarity and provided a contemporary framework for understanding diabetes self-management within digitally enabled patient-centered care.

INTRODUCTION

Chronic illness extends beyond physiological symptoms, shaping the lived experiences of individuals and families while imposing significant burdens at personal, societal, and systemic levels, including nearly three-quarters of global deaths, increased disability, and rising healthcare costs[1–4]. In response, self-management has become central to chronic illness care, as individuals must take active roles in navigating daily life, sustaining quality of life, and making health-related decisions outside clinical settings[5,6]. Among chronic illnesses, type 2 diabetes mellitus is especially significant. Type 2 diabetes is one of the most prevalent and burdensome conditions globally, and its successful management depends almost entirely on effective self-management[7]. Individuals must engage in a continuous "juggling act" of balancing medical tasks with emotional and social well-being[8]. More than 90% of diabetes care occurs outside of clinical settings and is carried out by individuals themselves[9,10]. Yet despite its central role, sustaining effective diabetes self-management remains a persistent challenge[11].

In response to the need for more accessible and personalized self-management support, digital health has emerged as a promising approach for individuals with type 2 diabetes. Digital health technologies, including mobile health applications, telehealth platforms, wearable devices, and remote monitoring tools, offer new opportunities to overcome barriers to care, such as transportation limitations and geographic isolation[12,13]. These tools enable individuals to track health metrics like blood glucose, blood pressure, weight, physical activity, and medications, access educational resources, and communicate with providers in real-time, fostering informed decision-making and proactive diabetes self-management[14,15].

Building on these advances, the mid-2010s marked the beginning of a distinct digital health era. This period was characterized by the adoption of foundational interoperability standards, such as Fast Healthcare Interoperability Resources (FHIR), and the widespread implementation of certified electronic health records (EHRs), which have accelerated digital innovation and data exchange in healthcare[16]. This turning point was internationally recognized in the 2015 United Nations General Assembly, which emphasized the transformative potential of information and communications technology in expanding equitable access to care[17,18]. The COVID-19 pandemic further catalyzed these developments, accelerating telemedicine and remote patient monitoring as essential components of chronic illness management[19]. Digital health tools have since become increasingly integrated into formal care models, supporting real-time adjustments to care plans and enhancing provider–patient communication through integration with platforms like EHRs[20,21]. Together, these advances underscore digital health as a key enabler of patient-centered, data-driven self-management strategies for individuals living with type 2 diabetes.

As digital health becomes increasingly embedded in healthcare delivery, technology is reshaping traditional care practices and becoming a routine component of diabetes management[22]. This evolving role of digital health underscores the need to revisit and refine the concept of diabetes self-management. Defining and refining concepts is essential for scientific progress, as they serve as the building blocks of theory, provide the language for studying phenomena, and ensure that research remains systematically linked to real-world problems[23]. According to Rodgers[24], concepts are not static; they evolve through use and in response to emerging challenges. In this context, diabetes self-management must be refined to reflect the transformative influence of digital health on how individuals engage with and manage type 2 diabetes. Therefore, this study aims to refine the concept of diabetes self-management in the digital health era, addressing the complexities and shifting needs of individuals within this rapidly changing healthcare landscape.

To capture this evolving concept, this study extends Rodgers' evolutionary method by integrating Natural Language Processing (NLP) techniques. Traditional concept analysis relies on inductive reasoning and manual review of selected literature, which, while rigorous, is constrained by sample size and researcher subjectivity. In contrast, NLP enables the systematic examination of large textual corpora, uncovering patterns in language use, contextual meanings, and emergent themes that may remain hidden in conventional approaches[25,26]. This computational extension not only increases scalability and reproducibility but also introduces novel analytic dimensions by bridging qualitative theory-building with data-driven methods. In doing so, this study extends concept analysis beyond its traditional boundaries by introducing methodological innovation and providing a contemporary, data-informed understanding of diabetes self-management in the digital health era.

RESULTS

The final literature search, conducted on April 14, 2025, yielded 2,375 records. Complete search strategies, including database-specific date ranges and filters, are provided in Supplementary Table 1. After duplicate removal (n=362), 2,013 records were screened for eligibility. During the full-text review, 280 articles were examined by an independent reviewer. Studies were excluded for reasons such as outcomes not aligned with the review focus (n=10), ineligible study design (n=16), ineligible population (n=10), or not conceptually relevant to diabetes self-management (n=147).

After applying the inclusion and exclusion criteria, 97 studies were retained for analysis. Non-English papers were not deliberately excluded, although none met the inclusion criteria at the full-text level. The final dataset included studies conducted across 23 countries. The most common study designs were qualitative studies (n=25), randomized controlled trials (n=21), and development-focused evaluations such as pilot, feasibility, or usability studies. Less common designs included cross-sectional surveys, mixed methods approaches, and secondary data analyses. Detailed study characteristics, including country, study design, population, and the designated review phase for each article (Phase 1 or Phase 2), are presented in Supplementary Table 2, and the overall screening and selection process is illustrated in the PRISMA flow diagram (Figure 1).

Phase 1: Manual Concept Analysis

Approximately 25% of the included studies (n=24) were randomly selected and manually reviewed by the three independent reviewers. Inter-rater reliability analysis demonstrated substantial agreement (Fleiss' κ=0.80, 95% CI [0.79, 0.81]), confirming consistency in the identification of attributes, antecedents, and consequences of diabetes self-management in the digital health era. Table 1 summarizes how each reviewer independently identified and categorized relevant text segments across the attributes, antecedents, and consequences. Table 2 presents the integrated findings, combining the reviewers' finalized manual classifications with the results of the NLP-based analysis. The complete independent reviewer classifications, along with the comparative alignment used to evaluate agreement and generate the reliability statistics, are provided in Supplementary Table 3.

Table 1. Summary of Manual Concept Analysis Findings Across Three Independent Reviewers

Dimension	Reviewer A	Reviewer B	Reviewer C
Attributes	• Health Engagement (Diabetes) • Digital Literacy • Executive Competence • Patient and Clinician Communication	• Complexity & Continuity • Self-Regulation & Motivation • Educational / Supportive System & Social Interaction • Digital Health–Driven Autonomy & Engagement	• Daily Behavioral and Lifestyle Components • Cognitive and Psychological Determinants of Self-Management • Social and Environmental Context • Personalization and Person-Centered Care • Digital Health for Diabetes Self-Management • Dynamic Patient–Provider Relationship
Antecedents	• Motivation and Self-efficacy • Access to Technology • Individual Factors • Patient Clinician Factors	• Complexity and Disease Burden • Self-Regulation and Motivation • Educational / Supportive System & Social Interaction • Autonomy and Active Engagement in Digital Self-Management	• Demands of Diabetes Self-Management • Emotional Readiness for Change • Access to Education and Ongoing Support • Access to Resources and Technology
Consequences	• Health Outcomes • Psychological Outcomes • Social Outcomes	• Complexity & Continuity • Self-Regulation & Motivation • Educational / Supportive System & Social Interaction • Digital Health–Driven Autonomy & Engagement	• Clinical and Health Outcomes • Quality of Life and Psychosocial Well-being • Empowerment, Autonomy, and Motivation • Long-Term Maintenance and Sustainability • System-Level and Economic Implications

Table 2. Summary of Findings from Manual and NLP-based Concept Analyses

Dimension	Phase 1. Manual Concept Analysis	Phase 2. NLP-Based Concept Analysis
Attributes	1. **Daily Behavioral and Lifestyle Components** • Daily Self-Management Activities • Lifestyle Change as an Ongoing Process 2. **Cognitive and Psychological Factors of Self-Management** • Knowledge and Skills • Self-Efficacy, Competence, and Motivation • Psychological and Identity Dimensions 3. **Social and Environmental Context** • Addressing Social Determinants of Health • Multilevel Social Support: Family, Community, and Digital Platforms 4. **Personalization and Person-Centered Care** 5. **Digital Health for Diabetes Self-Management** • Digitalizing Health for Monitoring and Decision Support • Digital Literacy • User Experience • Interoperability, Access, and Infrastructure 6. **Dynamic Patient–Provider Relationship** • Professional Support in the Digital Era • Digital Health-Driven Patient-Provider Communication	1. **Self-Management as the Core of Diabetes Care** • Centrality of Self-Management in Diabetes Care • Behavioral and Lifestyle Components of Self-Management • Necessity of Lifestyle Modification and Ongoing Self-Management 2. **Patient-Centered Support and Empowerment** • Individualized Feedback and Patient-Centered Care • Engagement, Adherence, and Empowerment • Education and Support as Essential Enablers • Peer-Enabled Support and Learning through Online Communities 3. **Digital Health and Technology Integration in Diabetes Self-Management** • Comprehensive Monitoring and Datafication of Self-Management • Accessibility and Empowerment through Digital Health Technologies • Evaluation and Appropriateness of Mobile Apps • Strengths and Limitations of Mobile Health Apps • User-Centered Design and Personalization 4. **Contextual and System-Level Considerations** • Chronic and Global Burden of Diabetes • Patient Characteristics and Disease Context as Influential Factors
Antecedents	1. **Demands of Diabetes Self-Management**	1. **Patient and Disease Characteristics**

	• Physical Demands • Psychological Demands 2. **Emotional Readiness for Change** 3. **Access to Education and Support** 4. **Access to Resources and Technology**	2. **Access to Guidance, Education, and Structured Support** 3. **Access to Digital Health Technology** 4. **Health Literacy and Digital Literacy** 5. **Linkages Between Self-Management and Healthcare Providers**
Consequences	1. **Clinical and Health Outcomes** 2. **Quality of Life and Psychosocial Well-being** 3. **Empowerment, Autonomy, and Motivation** 4. **System-Level and Economic Implications**	1. **Healthier Behaviors and Clinical Outcomes** 2. **Enhanced Knowledge and Self-Awareness** 3. **Empowerment, Self-Efficacy, and Motivation** 4. **Reduced Healthcare Burden**

Attributes

The manual analysis identified six attributes of diabetes self-management in the digital health era. First, daily behavioral and lifestyle components encompassed routine activities such as blood glucose monitoring, dietary adjustments, medication adherence, and sustained lifestyle changes, reflecting the ongoing and complex nature of diabetes care. Second, cognitive and psychological factors included knowledge, skills, motivation, and self-efficacy, highlighting the importance of patient confidence and emotional well-being in sustaining long-term engagement. Third, the social and environmental context underscored the role of social determinants of health and multilevel social support across family, community, and digital platforms in shaping self-management behaviors. Fourth, personalization and person-centered care emphasized tailored education, adaptive strategies, and alignment with individual values and preferences. Fifth, digital health emerged as a defining attribute, encompassing remote monitoring, decision support, digital literacy, user-friendly experiences, and infrastructural considerations for interoperability and access. Finally, a dynamic patient–provider relationship was central, where digital tools facilitated digital health–driven communication that enhances, rather than replaces, professional support.

Antecedents

Four major antecedents were identified. Demands of diabetes self-management captured both the physical (e.g., diet, exercise, insulin use, continuous monitoring) and psychological burdens (e.g., depression, distress, stigma) associated with daily disease management. Emotional readiness for change reflected motivational processes, autonomy, self-efficacy, and relatedness, which were essential for adopting and sustaining self-care behaviors. Access to education and ongoing support were consistently emphasized, with diabetes self-management education and structured follow-up highlighted as critical to skill development and sustained engagement. Lastly, access to resources and technology

represented the enabling role of mobile apps, devices, and digital platforms, while also acknowledging challenges such as connectivity issues and digital inequities.

Consequences

Four categories of consequences were identified. Clinical and health outcomes included improved glycemic control, reduced complications, and prevention of comorbidities. Quality of life and psychosocial well-being reflected reduced distress, improved mental health, and greater life satisfaction, although glycemic improvement did not always translate into psychological benefits. Empowerment, autonomy, and motivation highlighted how self-management enhanced confidence, decision-making, and long-term adherence. Finally, system-level and economic implications underscored reduced healthcare utilization and costs, while also recognizing the broader social and productivity benefits of effective self-management.

Phase 2: Natural Language Processing-Based Concept Analysis

A total of 73 articles comprising 16,218 sentences were processed through the NLP pipeline. Cluster analysis showed that the corpus was optimally described by six clusters. One of the six clusters was thematically centered on diabetes self-management and contained 3,308 sentences. Sub-clustering analysis within this cluster identified five distinct sub-clusters, averaging approximately 600 sentences each. From each of the five sub-clusters, 30 representative sentences (~5%) were selected to identify the attributes, antecedents, and consequences of the concept. Figure 2 visualizes the two-stage clustering process by projecting the sentence-level SBERT embeddings into a two-dimensional space using UMAP. Panel (a) shows the six primary clusters derived from the full corpus, and Panel (b) displays the five sub-clusters within the diabetes self-management–focused cluster.

Attributes

A broad set of attributes was identified. Self-management as the core of diabetes care was reinforced, emphasizing that daily behavioral and lifestyle activities such as diet regulation, physical activity, medication adherence, and ongoing monitoring are indispensable for effective disease management. Patient-centered support and empowerment were highlighted through individualized feedback, real-time prompts, and tools that fostered engagement, adherence, and motivation. Education and support remained central, with digital platforms extending structured guidance beyond traditional care. Peer-enabled support and online communities emerged as valuable spaces for social learning, knowledge exchange, and emotional encouragement. Digital health and technology integration encompassed comprehensive monitoring and datafication, as well as the accessibility and empowerment made possible by digital platforms. This attribute also captured the importance of systematic evaluation of mobile apps, recognition of their strengths and limitations, and the need for user-centered design and personalization for diabetes self-management engagement. Finally, contextual and system-level considerations were evident, including recognition of the chronic and global burden of diabetes, the

necessity of sustained lifestyle modification, and the influence of patient and disease characteristics on the feasibility and effectiveness of self-management.

Antecedents

Five categories of antecedents were identified. First, patient and disease characteristics such as demographics, psychosocial factors, comorbidities, and disease trajectory shaped individual capacity for engagement in self-management. Access to guidance, education, and structured support was foundational for building the skills and knowledge necessary for effective self-management. Access to digital health technology included the use of mobile apps, glucose-monitoring devices, and online resources that facilitate daily care. Health literacy and digital literacy were critical in enabling patients to interpret data, set goals, and act on feedback. Finally, linkages with healthcare providers underscored the role of professional oversight and integration of patient-generated data into clinical care.

Consequences

Four consequence categories were observed. Healthier behaviors and clinical outcomes were the most frequently reported, with digital interventions improving adherence to treatment regimens, lifestyle changes, and glycemic control. Enhanced knowledge and self-awareness reflected the ability of patients to understand the relationship between behaviors and outcomes, strengthening self-management capacity. Empowerment, self-efficacy, and motivation captured the psychological benefits of digital health engagement, including greater confidence, autonomy, and social connectedness. Finally, reduced healthcare burden highlighted the broader system-level effects of effective self-management, including fewer complications, decreased hospitalizations, and lower healthcare costs, particularly when digital tools extend access to underserved populations.

A summary of the identified attributes, antecedents, and consequences identified in the NLP-based concept analysis is listed in Table 2.

DISCUSSION

The purpose of this study was to refine the concept of diabetes self-management in the context of the digital health era. Drawing on 97 studies analyzed through both manual review and NLP-based approaches, we systematically identified the attributes, antecedents, and consequences of the concept. Integrating findings from both approaches further provides an opportunity to update and clarify the definition of diabetes self-management within today's digital health landscape.

In the digital health era, diabetes self-management can be understood through a set of defining attributes that describe how individuals navigate and sustain daily care. The findings show that behavioral elements are central to diabetes self-management. Daily routines such as medication adherence, dietary regulation, physical activity, and glucose self-monitoring continue to form the foundation of effective management[27–29]. Importantly, these behaviors are not static but involve

continuous, lifelong adaptation to individual health conditions, personal demands, and environmental circumstances[30–32]. Beyond behaviors, cognitive and psychological factors shape the capacity to initiate and sustain self-management. Knowledge and skills, competence, motivation, and self-efficacy enable individuals to begin and maintain lifelong self-management practices[31,33]. These factors also foster constructive psychological adaptation, helping individuals live with chronic conditions while cultivating positive attitudes[34]. Promoting these psychological dimensions can strengthen a healthy social identity[35,36], support the pursuit of personal goals and values[9], and enhance proactive, sustained engagement in self-management[37].

Social and environmental contexts shape diabetes self-management for everyone, yet systemic inequities create disproportionate barriers for racial and ethnic minorities and socioeconomically marginalized groups[36–38]. These contexts influence individuals' capacity to engage in daily management by shaping access to resources, supportive environments, and opportunities for care. However, the lived realities of individuals affected by structural inequities reveal persistent gaps in how digital health is approached and implemented[36]. These gaps include limited tailoring of digital tools to diverse users' needs, uneven engagement among racially and socioeconomically marginalized groups, and design features that may unintentionally reinforce stigma or require resources not equally available [36,37,39]. Addressing these gaps requires demonstrating how digital health tools can actively mitigate, rather than reinforce, existing disparities. Within this broader landscape, multilevel social support encompassing family, community, and digital platforms plays a crucial role in enabling sustained self-management. In the digital health era, online communities and virtual platforms have expanded forms of social connection, extending support networks beyond geographic and temporal boundaries[10,40].

Digital health technologies have become central attributes of self-management. These technologies enable continuous monitoring, tracking, and visualization of physiological data and integrate with daily routines to deliver real-time feedback, personalized recommendations, and improved communication with providers[40–42]. By fostering adaptive, patient-centered care, these technologies strengthen self-management capacity and confidence[27,31]. Another important dimension of digital health is the user experience. Sustained self-management engagement using digital health depends on both cognitive understanding and emotional factors, such as trust, satisfaction, and perceived usefulness of technology, alongside considerations such as privacy, digital literacy, and fit with daily life [43,44]. Accordingly, intuitive design, personalization are essential for sustaining adoption and maximizing the benefits of digital health tools[45]. Mobile applications are particularly prominent in diabetes care, offering features such as tracking, monitoring, education, and communication[46–48]. However, their potential is often limited by challenges of integration, comprehensiveness, and evidence-based design, underscoring the need for systematic evaluation of app content and features to ensure reliability, safety, and clinical relevance[46,49,50].

Finally, digital health technologies are reshaping individuals' roles in diabetes care, enabling them to act as active partners in decision-making rather than passive recipients. Through real-time monitoring, data

interpretation, and enhanced communication with providers, individuals gain greater capacity to engage continuously in managing their health[27,51]. This shift supports timely feedback, shared decision-making, and a more collaborative and dynamic relationship among individuals, providers, and technologies in diabetes self-management[31,43,52].

Beyond these core attributes, diabetes self-management also depends on a set of antecedents that provide the necessary conditions for individuals' readiness and capacity to engage effectively in daily care. A central foundation is the balance between the physical and psychological demands of managing a chronic illness[30,53]. Physical demands include frequent glucose monitoring, medication administration, and ongoing lifestyle decisions[9,30,42,54]. Psychological demands require adapting to chronic illness, maintaining a constructive identity, and managing distress, depression, anxiety, or stigma[34–36]. Emotional readiness—including motivation, autonomy, competence, and relatedness—further supports sustained engagement[37,51]. Education and ongoing support are also essential antecedents. Self-management education improves clinical outcomes when paired with continued reinforcement through regular contact with healthcare providers or peer networks, which helps embed coping strategies and behavior change into daily routines[30,31,52].

In the digital health era, access to resources and technology has become increasingly important. Mobile apps, wearable devices, and telehealth platforms expand opportunities for monitoring, education, and remote support[41,45,55]. However, disparities in connectivity, digital literacy, and socioeconomic resources may limit uptake[38,43], underscoring the need for inclusive, user-centered design[37,45]. Health literacy and digital literacy are crucial antecedents that enable individuals to interpret health information, navigate digital tools, and translate knowledge into action, such as goal setting and making informed decisions[56–58]. Finally, linkages with healthcare providers remain indispensable. Patient-generated data, such as glucose readings, dietary logs, and physical activity records, can be integrated into clinical encounters, allowing providers to tailor counseling and treatment[47,59]. Digital platforms support this integration through continuous communication, strengthening patient–provider partnerships and promoting personalized care[60,61].

Building on these antecedents, effective diabetes self-management gives rise to a range of clinical, psychosocial, and system-level consequences. Consistent engagement improves glycemic control, reduces complications, and lowers the risk of comorbidities[31,40,41]. Self-management also influences quality of life and psychosocial well-being by reducing distress, enhancing coping, and strengthening daily functioning[33,34]. Empowerment and autonomy are central consequences, with self-efficacy supporting sustained behavior change[29]; digital tools further promote confidence and motivation when they facilitate reflection and decision-making[45,51]. Sustaining self-management requires ongoing reinforcement[40]. User-centered digital interventions and continuous support can help maintain engagement and contribute to fewer hospitalizations, lower healthcare expenditures, and reduced

system burden[32,55]. Conversely, inadequate self-management increases clinical risks and costs, underscoring the need for scalable and equitable strategies to promote long-term success[32,41].

At the methodological level, the integration of manual review and NLP-based analysis demonstrates a growing convergence between interpretive and computational approaches in literature synthesis. NLP has been increasingly adopted to address the limitations of manual literature reviews—such as labor intensity, susceptibility to bias, and limited scalability—by organizing large bodies of evidence more efficiently and objectively[62–64]. Recent work also shows that NLP can enhance search precision by identifying conceptual similarities that traditional keyword methods may overlook, thereby improving transparency and reproducibility[65].

Despite these advantages, most NLP applications still focus on describing linguistic patterns rather than advancing theoretical understanding. As Liu et al.[66] argue, generating conceptual insight requires interpreting how identified topics are related to one another. From this perspective, NLP augments rather than replaces human reasoning by enabling researchers to manage large textual datasets and reveal the underlying relational patterns among concepts that support conceptual development[66]. In this study, the dual-phase design combines the contextual depth of manual analysis with the broad analytic coverage of computational methods. The manual review phase captured the contextual and relational aspects of diabetes self-management, while the NLP-based phase expanded insights across a much larger corpus. Together, these approaches demonstrate how integrating manual and computational techniques can strengthen conceptual clarity and analytic depth.

The refined concept of diabetes self-management in the digital health era also carries important implications for practice, policy, and research. In clinical practice, digital health tools should be patient-centered, user-friendly, and adaptable to individual needs, functioning as extensions of professional care rather than substitutes. Such tools can reinforce education, provide personalized feedback, and strengthen therapeutic relationships[51,52]. At the policy level, integrating digital health into chronic illness management requires a strong equity focus. Addressing disparities such as those in broadband access, device availability, and digital literacy is critical to prevent widening gaps in care. Policies that support interoperability, privacy, and responsible data governance are also essential to ensure safe and meaningful use of patient-generated data[37,38,45]. From a research perspective, this study offers a conceptual foundation that warrants empirical testing and further theoretical refinement. Future work should examine the attributes, antecedents, and consequences across diverse populations and chronic conditions, incorporating the lived experiences of patients and caregivers. Longitudinal and intervention-based studies will be particularly valuable in assessing how digital health–integrated self-management translates into sustained behavior change, improved outcomes, and system-level efficiencies.

Despite these contributions, several limitations should be acknowledged. Both manual and NLP-based analysis required researcher interpretation, which, while systematic, cannot fully eliminate subjectivity. Furthermore, the NLP-based concept analysis used in this study represents, to our best knowledge, the first attempt to integrate such computational methods into Rodgers' evolutionary concept analysis. At

present, there are no established methodological standards or unified frameworks for applying NLP to concept analysis. The NLP-based phase relied on sentence embeddings and clustering techniques to identify thematic patterns across a large corpus. While this high-dimensional representation enabled systematic organization and pattern detection, it also raises questions about whether such computational abstraction can fully capture the nuanced, context-dependent meanings central to conceptual inquiry. These methodological uncertainties underscore the need for further refinement, validation, and consensus building as computational techniques become more widely integrated into health science research.

Digital health is reshaping diabetes self-management by strengthening engagement, supporting early detection, and enabling real-time decision-making[67]. Using Rodgers' evolutionary method integrated with NLP, this study reconceptualized diabetes self-management as a multidimensional process shaped by behavioral, psychological, social, and technological factors. Digital health functions as an essential component of this process by facilitating continuous monitoring, personalized feedback, and stronger patient–provider connections. By combining qualitative and computational approaches, this study generated a more comprehensive conceptual understanding of diabetes self-management in the digital era. This refined conceptual foundation provides a contemporary direction for future research and offers guidance for practice and policy efforts that aim to promote equitable, technology-enabled chronic illness care.

METHODS

Data Collection

A comprehensive literature search was conducted in three electronic databases, including MEDLINE (via PubMed), CINAHL (via EBSCOhost), and IEEE Xplore Digital Library, to identify peer-reviewed studies related to type 2 diabetes, digital health, and self-management. The search strategy was developed by a professional medical librarian in consultation with the author team. Keywords and subject headings representing the three core concepts were iteratively refined, validated against a set of benchmark articles, and peer-reviewed by a second independent librarian to ensure completeness and reproducibility. The search process followed established methodological guidelines for comprehensive literature reviews and concept analyses[24,68]. The search was limited to studies published between 2015 and 2025.

Studies were considered eligible if they (1) focused on adults aged 18 years or older with type 2 diabetes, (2) addressed self-management as a primary or secondary focus, (3) examined the role or application of digital health technologies such as telemedicine, mobile health, wearable devices, or remote monitoring, and (4) reported empirical findings or protocol-level methodological details.

All search results were imported into Covidence (Veritas Health Innovation, Melbourne, Australia) for citation screening and data management. Title, abstract, and full-text screening were conducted

according to the predefined inclusion and exclusion criteria. During the full-text review, studies were excluded if they were review articles, conference abstracts, meeting reports, or retracted papers. Studies were also excluded if they focused on individuals with gestational or type 1 diabetes, included mixed samples of type 1 and type 2 diabetes without stratified results, or did not specify the diabetes type. Outcomes were considered ineligible when studies focused exclusively on a single behavioral or psychological construct (e.g., foot care behavior, self-efficacy, or blood glucose monitoring frequency) or that measured only healthcare utilization metrics (e.g., clinic visits or encounter counts) without addressing broader self-management processes. The screening process was documented using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) flow diagram[68].

Study Design

This study was guided by Rodgers' evolutionary method of concept analysis and implemented using a two-phase design that integrated traditional manual review with computational approaches. Phase 1 consisted of a manual literature-based concept analysis in which approximately 25% of the studies (n = 24) were randomly selected for in-depth review. This proportion was chosen to ensure both feasibility and analytic rigor, consistent with Rodgers' recommendation that at least 20% of the available literature be reviewed to achieve a meaningful analysis[24]. In phase 2, NLP techniques were applied to the remaining 75% of articles (n = 73) to systematically organize and structure the corpus—that is, the full collection of article texts used for the computational analysis. This approach ensured representativeness and scalability while maintaining alignment with Rodgers' framework. The attributes, antecedents, and consequences identified in both Phases were subsequently synthesized to refine the conceptual understanding of diabetes self-management in the digital health era.

Rodgers' Evolutionary Method and Data Extraction

The Rodgers' evolutionary method includes six key steps[24]: (1) identifying the focal concept and related terms; (2) defining the realm of inquiry; (3) extracting attributes, antecedents, and consequences; (4) analyzing conceptual characteristics; (5) incorporating exemplars, if appropriate; and (6) determining implications for conceptual refinement and future research.

Full-text articles were imported into Microsoft Word and reviewed in their entirety for data immersion. Relevant sentences and paragraphs were identified as discrete text segments and deductively categorized according to Rodgers' framework into attributes, antecedents, and consequences. Individual article analyses were then synthesized to identify recurring patterns and reorganized under Rodgers' analytical framework to refine the conceptual boundaries.

Three expert reviewers independently conducted Phase 1 analysis. They identified and categorized attributes, antecedents, and consequences of diabetes self-management within the digital health context. Inter-rater reliability was assessed using Fleiss' kappa. To prepare the data for this analysis, the

reviewers' classifications were brought together, and each identified text segment was treated as a discrete analytic unit. For each unit, the sentences supporting the reviewers' classifications were examined to assess whether the reviewers interpreted and categorized the conceptual element consistently. The patterns of agreement and divergence across reviewers' categorical assignments were then used to calculate Fleiss' kappa and its 95% confidence interval. After completing the reliability assessment, the reviewers met to discuss discrepancies, clarify conceptual boundaries, and refine the analytic framework through consensus to ensure interpretive coherence.

Natural Language Processing-Based Analysis

NLP techniques were applied to the full-text articles assigned to the computational analysis phase, comprising approximately 75% of the total sample. Text was automatically extracted from PDF files and converted into a machine-readable format. All analyses were conducted using Python (version 3.11.2; Python Software Foundation, Wilmington, DE, USA) and open-source libraries for text preprocessing and modeling. Extracted text was preprocessed to correct extraction artifacts (e.g., line breaks, hyphenation), standardize terminology, and remove extraneous symbols. Sentence segmentation was performed with *spaCy* (an open-source Python library for advanced natural language processing), and split tokens were corrected using *pyenchant* (a spellchecking Python library). Sentence embeddings (i.e., numerical representation that captures the semantic meaning of the sentence) were generated with *SentenceTransformers* (SBERT, *all-MiniLM-L6-v2*), an open-source Python framework for sentence, text, and image embedding, and stored with per-file mappings. K-means clustering was applied to identify thematic clusters, with the number of clusters optimized using the elbow method and silhouette scores. To support visual interpretation, Uniform Manifold Approximation and Projection (UMAP) was used to create two-dimensional representations of the high-dimensional embeddings.

For clusters that were thematically relevant to the concept of diabetes self-management, sentences and their corresponding embeddings were exported for detailed qualitative review. Sub-clustering was then performed within these clusters to group similar elements together by major topics and capture specific conceptual themes[69]. From each sub-cluster, a set of representative sentences was selected by ranking the cosine similarity between each sentence embedding and its cluster centroids. Approximately 5% of the total sentence count per sub-cluster was retained for in-depth review. Although there is no established standard for determining the number of representative sentences in concept analysis using NLP, this proportion was determined through iterative testing to achieve data saturation, ensuring that additional sentences beyond this threshold did not yield new thematic insights. These representative sentences provided the textual basis for applying Rodgers' framework to identify attributes, antecedents, and consequences of diabetes self-management.

Declarations

DATA AVAILABILITY

The data supporting this study are derived from published articles included in the concept analysis and are publicly accessible through the respective journals and databases. A full list of the 97 included studies, along with their descriptive characteristics and phase assignments, is provided in Supplementary Table 2. The extracted text corpora used for NLP processing can be made available from the corresponding author upon reasonable request.

CODE AVAILABILITY

The full set of custom scripts used in this study is available in the publicly accessible GitHub repository *Diabetes-Self-Management-in-the-Digital-Health-Era* (https://github.com/hanlee6461/Diabetes-Self-Management-in-the-Digital-Health-Era). The repository includes code for all analytic steps, including preprocessing, sentence embedding generation, clustering, sub-clustering, and UMAP visualization

AUTHOR CONTRIBUTIONS

D.L. conceptualized the study, led the NLP-based analyses, and drafted the manuscript. A.K. and S.S. conducted the manual concept analysis and contributed to data interpretation. L.L. and A.A. assisted with search strategy development and screening procedures. R.J.S. and K.G. provided methodological guidance, supervised the study, and critically revised the manuscript. All authors reviewed and approved the final manuscript.

CLINICAL TRIAL NUMBER

Not applicable.

HUMAN ETHICS AND CONSENT TO PARTICIPATE DECLARATIONS

This study did not involve human participants, and therefore, ethics approval and informed consent were not required.

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COMPETING INTERESTS

The authors declare no financial or non-financial competing interests.

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Figures

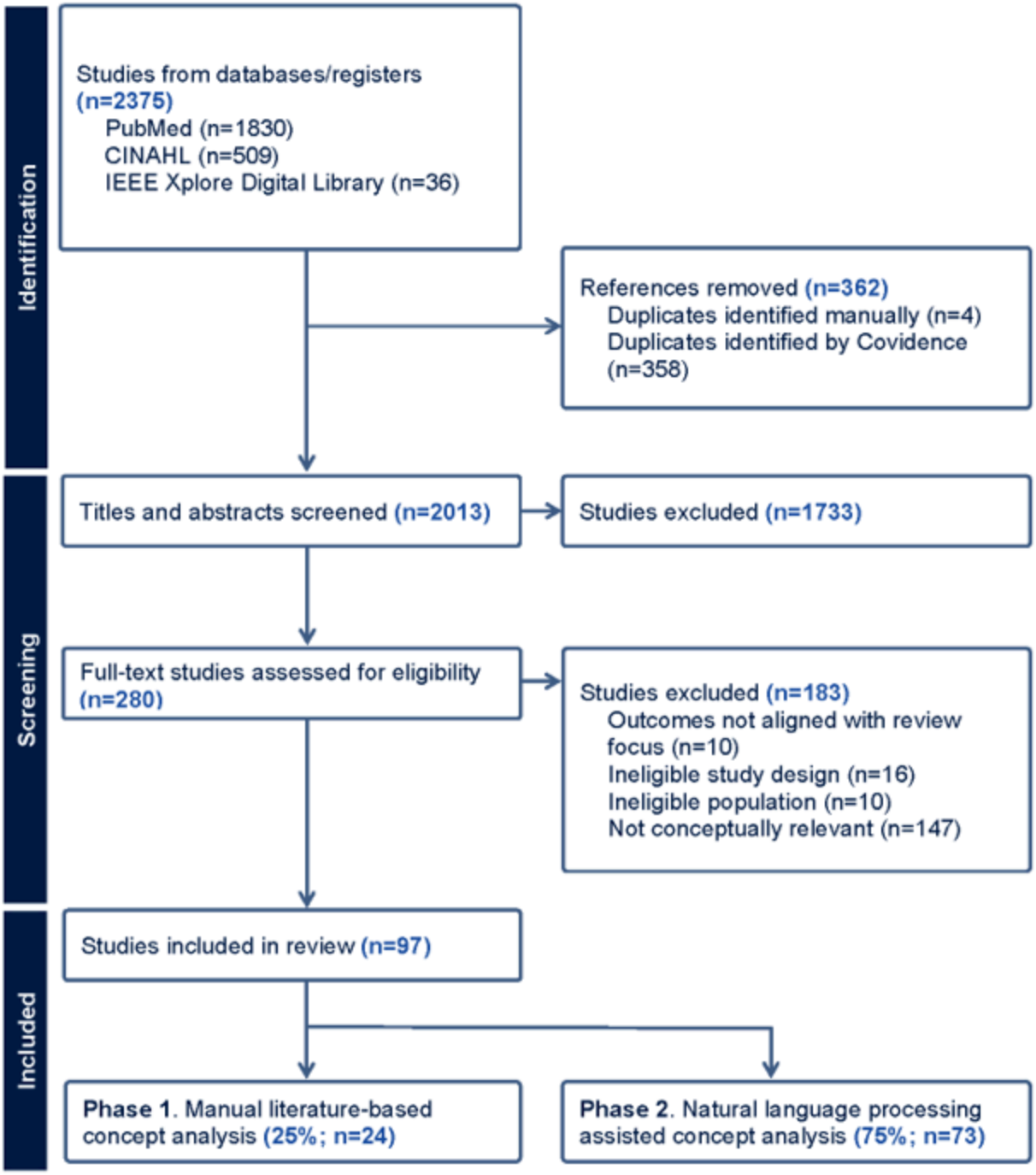


Figure 1

Flow diagram of the Article Selection

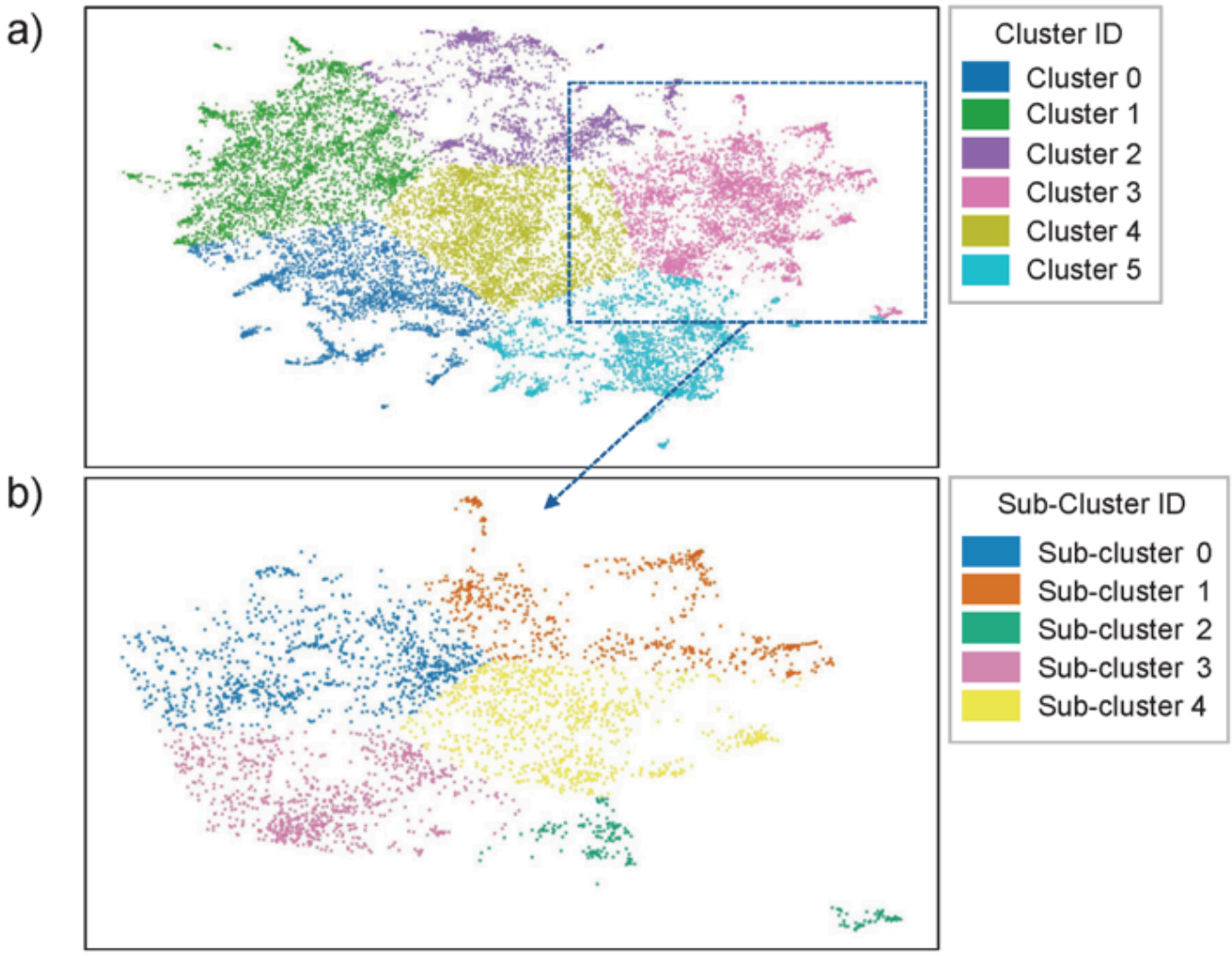


Figure 2

Two-Stage K-Means Clustering with UMAP Visualization of Sentence-Level Embeddings.

Note. High-dimensional sentence embeddings generated with SBERT were projected into a two-dimensional space using UMAP to support visual interpretation.
a) The entire corpus was grouped into six clusters: Cluster 0 (Digital Health Usability & Development), Cluster 1 (Research Design & Procedures), Cluster 2 (Intervention Effectiveness), Cluster 3 (Diabetes Self-Management Processes), Cluster 4 (Patient Support Mechanisms), and Cluster 5 (Patient Perceptions & Technology Acceptance).
b) Cluster 3 was further examined through sub-clustering (k=5) to identify thematic subgroups: Sub-cluster 0 (Self-Monitoring & Personalized Feedback), Sub-cluster 1 (Foundational Self-Management Behaviors & Education), Sub-cluster 2 (Peer Support & Social Learning), Sub-cluster 3 (Diabetes Burden & Clinical Context), and Sub-cluster 4 (Digital App Features & Intervention Design).
Both clustering steps used elbow and silhouette scores to determine optimal cluster counts.

Supplementary Files

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- SupplementaryTables.docx