A Bibliometric Analysis of eHealth Scholarship (2000-2024): Multidisciplinary Contributions and Research Trends

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Abstract

Background: Fueled by innovations in technology and health interventions to promote, restore, and maintain health, and safeguard well-being, the field of eHealth yielded significant scholarly output over the past quarter century.

Objective: To understand the big picture of research developments and multidisciplinary contributions to eHealth that have shaped this field by 2024, we analyzed evidence from three corpora: 10,022 OpenAlex documents with eHealth in title, 5,000 most relevant eHealth articles according to the Web of Science (WoS) algorithm, and all available (n=1,885) WoS eHealth reviews.

Methods: Using VOSviewer, we built co-occurrence networks for WoS keywords and OpenAlex concepts. We examined clusters, categorized terminology, and added custom overlays about eHealth technologies, stakeholders, and objectives. A co-citation map of sources referenced in WoS reviews helped identify scientific fields supporting eHealth. After synthesizing eHealth terminology, we proceeded to build a conceptual model of eHealth scholarship grounded in bibliometric evidence.

Results: Several research directions emerged from bibliometric networks: eHealth studies on self-management and interventions, especially in mental health; telemedicine, telehealth and technology acceptance; privacy, security, and design concerns; health information consumers' literacy; health promotion and prevention; mHealth and digital health; and HIV prevention. Conducted at the individual, health system, community, and society level, eHealth studies focused on health and wellness across the human lifespan. Keywords internet (2017 mean publication year), telemedicine (2018), telehealth (2018), mHealth (2019), mobile health (2020), and digital health (2021) were strongly linked to literatures indexed with eHealth (2019). Different types of eHealth applications were supported by research on infrastructures: networks, data exchange, computing technologies, information systems, and platforms. Researchers' concerns for eHealth data security and privacy, including advanced access control and encryption methods, featured prominently in the maps, along with terminology related to health analytics. Review authors cited a wide range of medical sources and journals specific to eHealth technologies, as well as journals in psychology, psychiatry, public health, policy, education, health communication, and other fields. The Journal of Medical Internet Research stood out as the most cited source. The concept map showed a prominent role of political science and law, economics, nursing, business, and knowledge management. Our empirically derived conceptual model of eHealth scholarship incorporated commonly researched stakeholder groups, eHealth application types, supporting infrastructures, health analytics concepts, and outcomes.

Conclusions: Drawing upon contributions from many disciplines, the field of eHealth has evolved from early studies of internet-enabled communications, telemedicine, and telehealth to research on mobile health and emerging digital health technologies serving diverse stakeholders. Digital health has become a popular alternative term to eHealth. We offered practical implications and recommendations on future research directions, as well as guidance on study design and publication.

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Keywords:

eHealth; conceptual model; bibliometric analysis; bibliometric analyses; VOSviewer; telemedicine; telehealth; tele-medicine; tele-health; virtual care; virtual health; virtual medicine; remote consultation; mHealth; mobile health; mobile application; mobile applications; app; apps; application; smartphone; smartphones; applications; digital; digital health; digital technology; digital intervention; digital interventions

Introduction

The field of eHealth is about the use of digital technology in healthcare delivery, management, and education. In its definition, the World Health Organization (WHO) emphasizes the aspect of cost-effectiveness and secure use of information and communications technologies in support of health and health-related fields [
1]. Expedited by the recent Covid-19 pandemic [2-3], multiple technologies that are broadly labeled as eHealth facilitate remote patient monitoring, improve access to medical services, and enhance efficiency in healthcare systems. For example, mobile health (mHealth) applications provide significant value for patients [4] and can be used for data sharing with healthcare providers for personalized care, to enable continuum of care and a better understanding of the condition progression and response to therapy during the medical appointments. Artificial Intelligence (AI), a recent advancement in eHealth, poised to reshape medicine improving the experiences of providers and patients [5] through pattern recognition and generate insights that can improve diagnosis, treatment, and patient outcomes. These and other eHealth technologies enable patients to actively participate in their healthcare decisions and promote preventive care through personalized health information [6]. With the potential to streamline workflows and improve healthcare outcomes, eHealth leverages information technology to transform access to and delivery of healthcare services [7].

This comprehensive bibliometric analysis examines the scholarly landscape of eHealth research over the past 25 years. We map research directions in this domain and the contributing scientific disciplines that have shaped the field. Bibliometric methods allow to quantitatively analyze published studies and their metadata to describe research output and to visualize intellectual structures and trends [8] in scientific domains of interest. The field of eHealth was the subject of bibliometric reviews, however, their scope was almost always limited to select technologies, regions, eHealth user experiences, or narrowly defined health and wellness goals.

Most bibliometric reviewers summarized literature subsets defined by eHealth user needs, such as promoting physical activity, healthy eating, and weight loss [9-12], preventing substance use [13], and providing e-mental health during the Covid-19 pandemic [14]. In addition, bibliometric researchers reviewed digital technologies for health behavior change [15] and eHealth tools for anticoagulation management after cardiac valve replacement [16].

A distinct subset of bibliometric studies focused on eHealth and health informatics competencies [17], literacy [18], and information and communication technology use by individuals experiencing homelessness [19]. Region-specific bibliometric reviews demonstrated global interest in eHealth research: Medical informatics and telemedicine in Sub-Saharan Africa and BRICS countries [20], eHealth research in Southeast Asia [21], and European funding of research on ambient assisted living [22].

Technology-centered bibliometric reviews assessed literatures on technology adoption [23], telehealth [24], the internet of things [25], telemedicine in rural areas for cost-effective and sustainable healthcare [26], mobile health as a means of involving citizens and public agencies in cardiovascular disease prevention [27], and artificial intelligence adoption by healthcare organizations [28].

Two broad-scope bibliometric reviews published in 2022 were dedicated to eHealth [29] and digital technologies [30]. The former study was limited to 2,989 bibliometric records (2000-2021) that mentioned eHealth in titles; the latter included only 403 recent (2017-2021) publications. Other eHealth reviews, published prior to 2022, did not include recent studies on evolving eHealth technologies such as blockchain and AI [6, 31].

To address gaps and limitations of past bibliometric reviews of eHealth, this study was designed with a broad chronological scope (2000-2024). It included recent publications from 2022-2024 from two different databases, a comparison of articles and reviews, and documents that mentioned eHealth not only in titles but also in abstracts or keywords. Our overarching aim was to examine a wide range of studies to provide a comprehensive overview of the eHealth research field, tracking its research directions, concept evolution, chronological developments, and multidisciplinary roots. A broad understanding of eHealth scholarship, as it developed over a quarter century, is critical for informing policymakers, funders, researchers, educators, and practitioners about the dynamics of the field and thus supporting informed decision-making and advancing further research.

First, we endeavored to reveal research directions by analyzing the structure and contents of bibliometric networks. The network structures may help to identify distinct groupings of interrelated research topics. The network contents may provide clues about the stakeholder groups and their needs, which eHealth technologies were designed to support. We asked: What research directions define the domain of eHealth (RQ1)?

Second, we aimed to understand the chronological development of eHealth scholarship by examining publication trends across two document types, research articles and review articles. Their comparison might indicate areas that had accumulated a sufficient body of primary literature to warrant its synthesis. Additionally, to gain insights into the maturation of research concepts and topics within the broader eHealth domain, we attempted to identify temporal lags between the emergence of active research areas and the publication of corresponding review articles summarizing those literatures. We posed this question: How did eHealth scholarship – articles and reviews – develop over time (RQ2)?

Third, to offer a comprehensive account of eHealth as a multidisciplinary field, we attempted to document the disciplinary origins by mapping intellectual structures that have shaped the eHealth field. Our inquiry was guided by this question: On what scientific fields does eHealth research build, as evidenced by cited sources and OpenAlex concepts that tag eHealth articles (RQ3)?

Methods

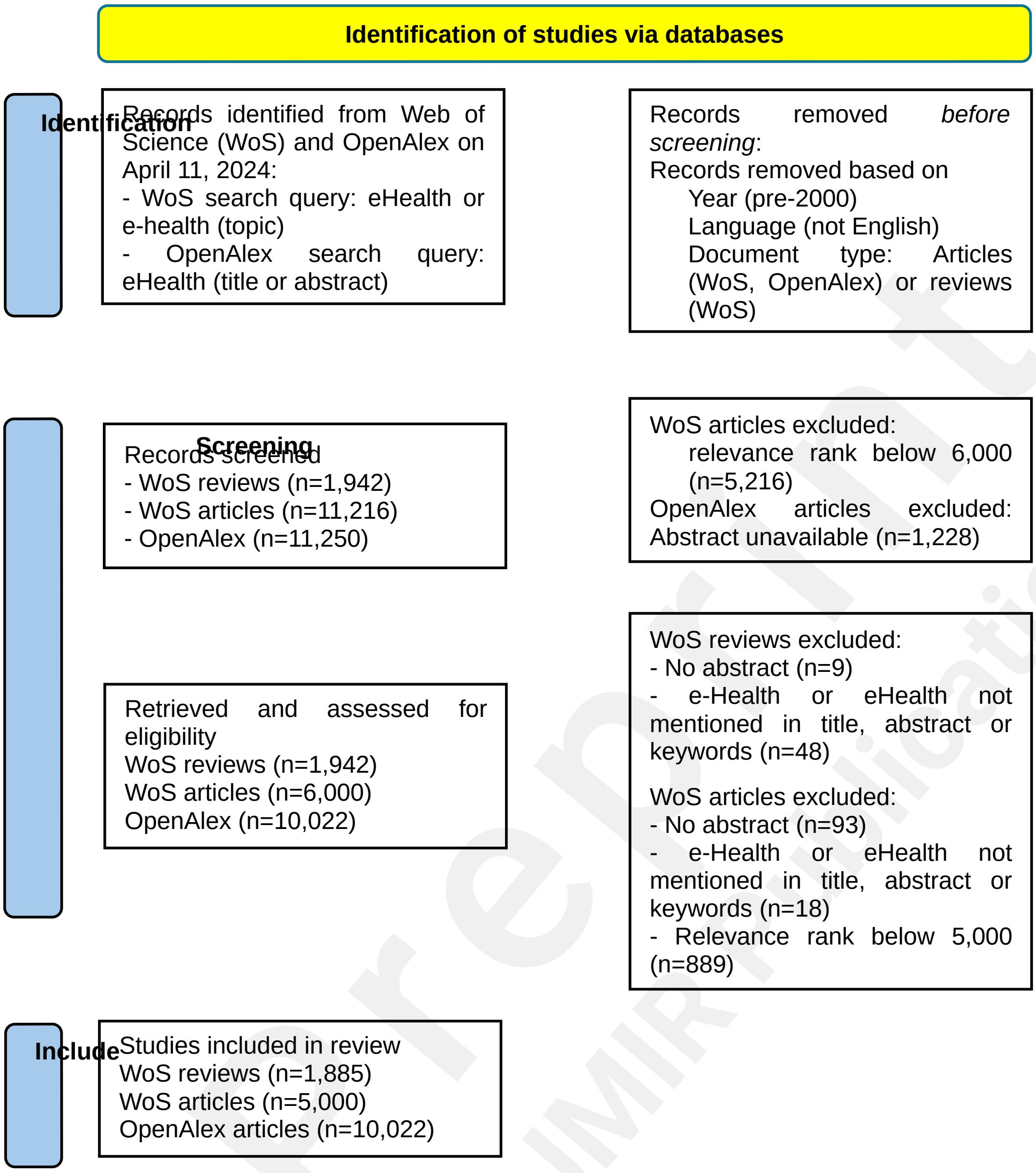
Overview of Data Sources

We retrieved and screened two sets of Web of Science (WoS) records with eHealth or e-Health in titles, abstracts, or keywords: 1) 5,000 most relevant articles, according to the WoS raking algorithm and 2) a non-overlapping collection of 1,885 WoS eHealth reviews written in English since 2000.

Figure 1 shows the study identification process as a PRISMA diagram, including search queries performed in WoS and Open Alex databases; initial removal of records based on year, language, and document type; and subsequent record screening choices guided by research questions and database limitations.

The hyphenated search term, e-Health, produced both relevant and irrelevant records. Any word ending with "e" before the word "health" was counted as e-Health, prompting manual screening of WoS records. Not knowing exactly how many records would be screened out, we oversampled WoS articles. Only 5,000 WoS articles with the highest relevance ranks were retained post-screening. To extend our WoS findings, we also obtained 10,022 OpenAlex articles with eHealth in their titles or abstracts. OpenAlex search query was limited to eHealth to avoid potential issues with the hyphenated search term.

Figure 1. A PRISMA diagram for eHealth publications included in this review.



Bibliometric Approach

We built and analyzed the following types of bibliometric networks or maps in VOSviewer [32]: keyword co-occurrence networks for WoS datasets and a concept co-occurrence network for an OpenAlex dataset. The contents of networks were examined to identify eHealth research directions, conceptualized as eHealth technologies, stakeholders, and their needs. Keywords are controlled vocabulary used by the authors and WoS database managers to index studies. They differ from concepts, which OpenAlex assigns to the majority (85%) of published works in its database. OpenAlex uses a hierarchical system of around 65,000 concepts, each linked to a Wikidata ID, to tag scientific publications with one or more concepts that are assigned based on the contents of the title, abstract, and the title of host venue [33]. Concepts could add value above and beyond keywords because OpenAlex designers hierarchically organized concepts like a family tree, starting with 19 major categories that branch out into discipline-relevant concepts [33].

Bibliometric networks are comprised of nodes, e.g., keywords, concepts or cited journals, and the lines that link them [32]. The links represent relationships between nodes. For example, the more publications in our collection are indexed with the same keywords (or tagged with the same concepts), the stronger they would be linked and the closer they would be located to each other in our maps. Node size indicates the frequency of a specific keyword or concept – the number of documents that are indexed or tagged with it. Moreover, related nodes are grouped into clusters. Network overlays are information layers that highlight select keywords in red, such as those related to eHealth objectives, while the remaining keywords are shown in blue. Overlays help to contextualize the meaning of individual keywords through spatially close and linked nodes, which show keyword co-occurrences and interconnected research domains.

An abstract review was performed on multiple occasions to decipher ambiguous keywords or concepts or to identify examples of studies relevant to our main findings.

Data Analyses

To answer RQ1, we analyzed network clusters – groups of co-occurring keywords or concepts that commonly reflect thematically distinct research directions [34-35]. A comparative analysis of two keyword co-occurrence networks was done. The network built for articles most relevant to eHealth, as determined by the WoS ranking algorithm, was compared to the network for all available eHealth reviews from WoS. Specifically, we compared clusters that imply research directions, and node sizes, indicative of similarities and differences in research directions pursued by article authors versus review authors. In both maps, we assessed nodes with strongest links to eHealth to reveal terminology at the heart of this research domain.

We used binary 0, 1 coding to highlight keywords about groups involved with eHealth (who); health conditions, needs or care settings addressed by eHealth interventions (what); and eHealth technologies or technology-related keywords (how). To estimate reliability, a second trained coder independently identified technology-related keywords from a list of 677 keywords selected for mapping, achieving a high level of agreement, κ=.96 (95% CI, .93 to .98), P<.001. Additional keyword coding was done as we developed a conceptual model of eHealth research. Binary codes were assigned to technology keywords based on their relevance to eHealth umbrella terminology or eHealth applications, objectives, infrastructure, data security/privacy, and health analytics. We added the abovementioned codes to a scores file in VOSviewer to display them as custom overlays to the keyword map for WoS articles.

RQ2 was answered by contrasting network overlays to draw conclusions about publication recency for articles and reviews. We also computed mean publication years for groups of keywords that characterized eHealth application types.

Evidence for RQ3 came from the scientific literatures behind eHealth reviews, which were assessed using a co-citation map. In this network type, the nodes correspond to journals and other cited sources. The relationships between journals are defined based on the frequency with which they are jointly referenced or “co-cited” within the bibliographies of eHealth literature reviews. The larger the node size, the more frequently the journal was cited by the authors of eHealth reviews. We chose reviews for this analysis because their bibliographies tended to be most comprehensive and focused on well-researched eHealth aspects.

A concept co-occurrence network for OpenAlex eHealth studies was used to gather additional evidence about the multidisciplinary nature of eHealth to answer RQ3. In an OpenAlex concept map, many nodes are represented by discipline-relevant concepts nested within major categories, both of which are relevant to answering question 3. Tagging the greatest number of eHealth studies, major categories would be the largest nodes in this map, whereas the smallest nodes would be specific topics relevant to our understanding of technologies researched by eHealth scholars. Similar to the network of WoS article keywords, we enhanced OpenAlex concept network with custom overlays highlighting technologies, health topics (physical health, illness, wellness, and mental health), and other concept characteristics such as risk (e.g., security) and money (e.g., economics). Concept attributes were first coded using LIWC-22, a computational linguistics program, then converted to binary scores (code 0 or “not present” assigned to LIWC score of 0; code 1 was assigned to all other LIWC scores). The binary scores were manually verified and refined prior to being added as new overlay scores to the VOSviewer map file, in addition to mean publication year and normalized citations overlays.

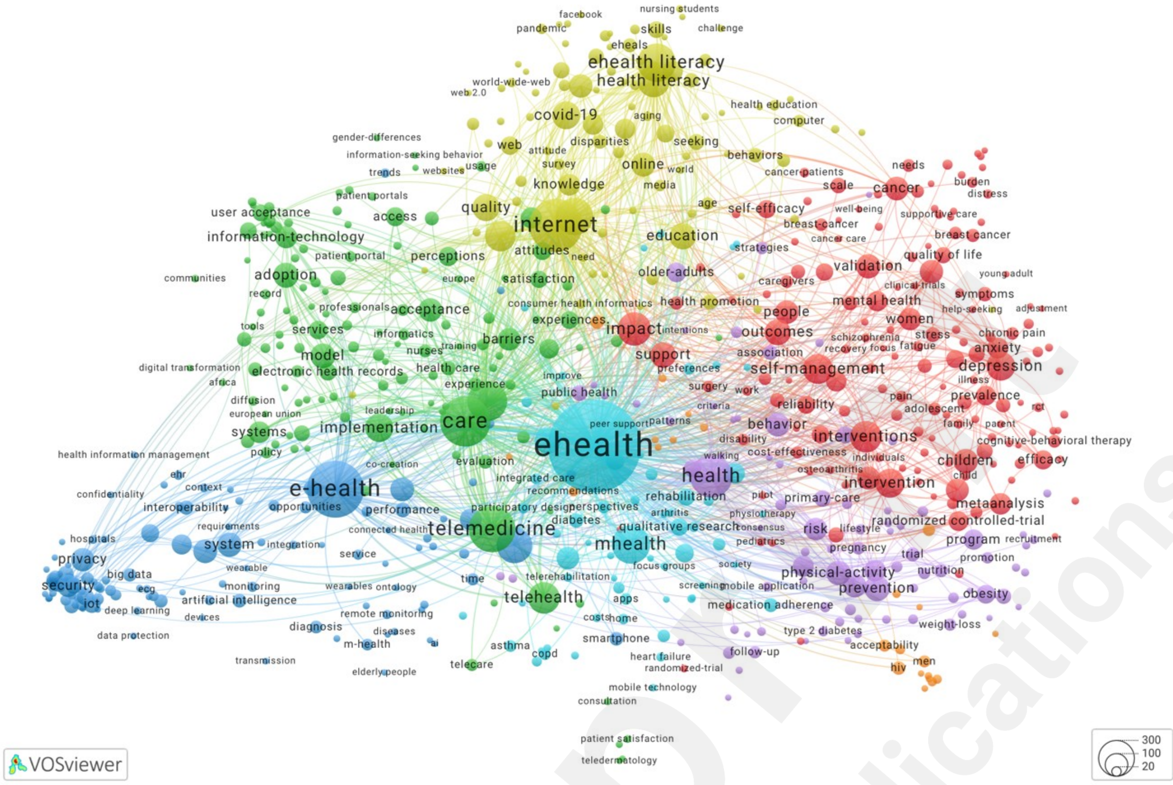
To help readers follow our map interpretations, we employed italics to denote references to specific network nodes, be they are WoS keywords, cited journals, or OpenAlex concepts. Unless noted otherwise, we consistently listed nodes based on the number of articles they represent, from high to low.

Results

eHealth Research Directions: Articles

In Figure 2, we presented a keyword co-occurrence cluster map. Color-designated clusters are thematically linked groups of keywords derived from WoS articles. We provided a URL for an interactive map where the number of articles indexing each keyword can be explored, as well as keyword interconnections. The more any two keywords co-occur across many articles, the more likely they are to be located near each other, within the same cluster, and linked. The map shows 677 keywords and 1,000 strongest links. Alternately spelled nodes *eHealth* and *e-Health* had the strongest co-occurrence link. Additionally, the keyword *eHealth* was strongly linked to nine other keywords: *telemedicine*, *mHealth*, *internet*, *digital health*, *self-management*, *mobile health*, *intervention*, *telehealth*, and *depression*.

Figure 2. A keyword co-occurrence network for 5,000 eHealth articles: A cluster map. Keywords that occur 10 times or more were mapped. An interactive map is available from Leiden University's VOSviewer Online application: https://tinyurl.com/2yr4vj6g.



Next, we summarized clusters by categorizing their most frequently occurring keywords in Table 1 to identify stakeholders, care needs or settings, and eHealth technologies. Cluster 1 (red) encompassed thematically diverse nodes related to eHealth with a centrally positioned *self-management* keyword indexing 217 articles, the third highest occurring keyword after *impact* and *interventions*. Abstracts that mentioned "self-management" suggested the authors defined it as an oversight of one's own health conditions, e.g., to cope with a chronic disease by reducing anxiety, fatigue, or depression or to prevent negative health outcomes. Mental health (*depression*, *anxiety*, *psychological distress*, *schizophrenia*, *cognitive-behavioral therapy*), cancer, and pain related keywords were particularly prominent in this cluster. The cluster had keywords that described study populations: young people, cancer survivors, and caregivers. Article authors reported eHealth intervention technologies – web-based and mobile applications – used for assessment, reporting of symptoms and adverse events, cognitive interviewing, and supporting self-management goals, for example, by generating and communicating self-management actions. Together, keywords *intervention* and *interventions* indexed 863 studies.

Table 1. Keywords Indexing eHealth Research Articles, by Cluster: Who, What, and How of eHealth.

Cluster number (color) and name	Who: Keywords that Designate Groups Involved with eHealth	What: Health Conditions, Needs, or Care Settings	How: eHealth Technologies and Technology-Related Keywords
1 (red): Self-management and interventions for mental health, dementia, cancer, and pain	*children, people, adolescents, women, parents, adolescent, caregivers, survivors, youth, cancer survivors, cancer-patients, child, family, pediatrics, childhood, individuals, young-people, carers, families, family caregivers, parent, young-adults, caregiver, informal caregivers, mothers, young adult, young-children*	*self-management, depression, cancer, quality-of-life, anxiety, mental health, social support, mental-health, quality of life, stress, dementia, breast cancer, cognitive-behavioral therapy, oncology, chronic pain, breast-cancer, pain, chronic illness, disability, cognitive-behavior therapy, psychotherapy, fatigue, palliative care, mindfulness, distress, psychological distress, supportive care, schizophrenia, disorder, patient activation, alzheimers-disease, cognitive behavioral therapy, illness, osteoarthritis, hospital anxiety, sleep, substance use, functional assessment, glycemic control, health-related quality of life, help-seeking, anxiety disorders, cancer survivorship, depressive symptoms, low-back-pain, psychological treatments, symptom management, cancer care, insomnia, urinary incontinence, well-being, behavioral health, comorbidity, loneliness, person-centred care, postpartum depression, self-management program*	*ehealth intervention, web-based intervention, e-learning, mobile apps, version, mobile app, e-mental health, web-based, online intervention*
2 (green): Telemedicine, telehealth, telecare, and technology	*patient, physicians, nurses, professionals, developing countries, older people, saudi arabia,*	*access, primary health care, empowerment, patient empowerment, patient-centered care, patient participation, disease management,*	*telemedicine, technology, telehealth, information-technology, usability, electronic health records, user acceptance, information-systems,*

acceptance	*patients, facilitators, communities, europe, physician, africa, australia, developing-countries, doctors, leadership, european union, healthcare professionals, middle-income countries, stakeholders*	*patient engagement, consultation, human factors, telepsychiatry, behavioral intention, information-seeking behavior, patient safety, peer support*	*electronic health record, records, health informatics, technology acceptance model, telecare, ict, information technology, technology acceptance, medical informatics, informatics, health information technology, patient portal, personal health records, record, electronic health, personal health record, patient portals, e-mail, health information systems, health information-technology, mobile phones, information management, health information exchange, medical-records, e-health services, electronic medical-records, digitalization, data mining, electronic medical records, information systems, digital transformation, gamification, health records, teledermatology, remote consultation, technology adoption, medical records, nursing informatics, tam*
3 (dark blue): e-Health technology, including privacy, security, design	*management, hospitals, elderly people*	*diagnosis, medicine, monitoring, multiple sclerosis, medical services, chronic diseases, ecg, diseases, decision-support, tuberculosis, patient monitoring, personalized medicine, home monitoring*	*e-health, iot, internet of things, cloud computing, blockchain, interoperability, artificial intelligence, smartphone, machine learning, big data, authentication, cloud, networks, protocol, m-health, architecture, encryption, internet of things (iot), sensors, mobile, sensor, access control, ehr, remote monitoring, fog computing, algorithm, 5g, algorithms, edge computing, electronic healthcare, deep learning, cryptography, network, privacy protection, smartphones, access-control, platform, ehealth services, body area*

			networks, wireless, health information management, attribute-based encryption, data protection, ontology, sensor networks, servers, wearable technology, activity recognition, ai, devices, e-health systems, transmission, wearables, patient monitoring, mobile-health, accelerometer, artificial intelligence (ai), data privacy, e-health system, electronic health record (ehr), mobile computing, ontologies, protection, wearable, wireless sensor networks, connected health
4 (yellow): eHealth literacy	*older adults, students, china, users, consumers, nursing students, african americans, college students, young adults, adolescence, consumer, chinese, university students*	*health literacy, communication, covid-19, education, knowledge, health promotion, information-seeking, disparities, patient education, health education, health information-seeking, health disparities, readability, information seeking, awareness, online health information seeking, decision making, misinformation, covid-19 pandemic, personalization, cyberchondria, health information seeking, coronavirus*	*internet, ehealth literacy, online, internet use, social media, web, digital divide, e-health literacy, eheals, computer, digital health literacy, digital literacy, consumer health informatics, health technology, world-wide-web, website, electronic health literacy, social networks, instrument, assessment, online health information, computer literacy, websites, facebook, web 2.0*
5 (purple): Health promotion and prevention of disease through active lifestyle choices	*adults, older-adults, population*	*prevention, physical-activity, physical activity, exercise, obesity, disease, engagement, primary-care, overweight, pregnancy, weight-loss, hypertension, diet, health behavior, behavior-change, behavior change, smoking, type 2 diabetes, smoking-cessation, cardiac rehabilitation,*	*ehealth interventions, mobile application, user experience*

		cardiovascular-disease, smoking cessation, cardiovascular disease, diabetes mellitus, self-regulation, weight loss, childhood obesity, blended care, health-promotion, sedentary behavior, blood-pressure, healthy lifestyle, self-monitoring, preventive medicine, behaviour change, impairment, walking, cardiovascular diseases, health behaviors, lifestyle intervention, mellitus, secondary prevention	
6 (light blue): mHealth and digital health	*elderly, aged, society*	*primary care, chronic disease, rehabilitation, diabetes, medication adherence, self-care, asthma, copd, home, integrated care, stroke, heart failure, multimorbidity, inflammatory bowel disease, shared decision-making, arthritis, health equity, heart-failure, chronic obstructive pulmonary disease, equity, medication, screening, inequalities, obstructive pulmonary-disease, physiotherapy, rheumatology, ulcerative-colitis*	*ehealth, mhealth, digital health, mobile health, mobile phone, user-centered design, apps, app, participatory design, telemonitoring, mobile applications, telerehabilitation, information and communication technology, mobile technology, health apps, virtual-reality, application*
7 (orange): HIV prevention	*united-states, men, gay, young men, african-american*	*decision-making, hiv, hiv prevention, sex, antiretroviral therapy, sexual health, behavioral intervention, hiv/aids*	*Acceptability, intervention development, digital, digital technology*

Note. Keywords are listed in the order of their occurrence counts, from high to low, excluding the keywords used to index less than 10 articles. To explore keywords interactively, use these Figure 2 overlays: https://tinyurl.com/2d7h2z87 for keywords that designate groups involved with eHealth (who); https://tinyurl.com/2bko7z7h for health conditions, needs, or care settings (what); and https://tinyurl.com/2xhg93ha for eHealth technologies and ideas (how). All overlays to Figure 2 map are listed in the Appendix.

Cluster 2 (green) keywords were dedicated to *telemedicine* and *telehealth*, as well as health organizations' electronic record systems (e.g., *electronic health records*) used for storing information that is accessed, used, and documented during a telehealth session. This cluster's keywords mentioned eHealth stakeholders who were patients, different provider groups, health leaders, and also communities. Specifically, telemedicine was researched as a means of building community capacity and communities of practice. In rural communities, telemedicine connected remote populations to providers, strengthening local health systems. Geographically dispersed providers could improve their medical practice through telemedicine-enabled knowledge sharing within communities of practice. Also prominent in this cluster were nodes related to *acceptance* and *adoption* of eHealth technologies. Abstracts that mentioned TAM, *Technology Acceptance Model,* or *UTAUT,* Unified Theory of Acceptance and Use of Technology, referred to stakeholder reactions to telehealth technologies and their impact on patient-provider relationship with an emphasis on improved *access* to care and *patient empowerment, patient engagement,* and *patient participation*.

Keywords in cluster 3 (dark blue) were especially focused on three technological aspects of eHealth, namely, eHealth technology infrastructure, data security and privacy, and health analytics. Keywords relevant to the eHealth technology infrastructure were, for example, *internet, online, internet of things, cloud computing, blockchain, information-systems, interoperability, smartphone, cloud,* etc. The second group included *security, blockchain, authentication, encryption, access control, cryptography, privacy protection, access-control*, and other data security and privacy considerations. The third group was about health analytics: *artificial intelligence, machine learning, big data, algorithm, algorithms, deep learning, data mining,* etc. The most frequent stakeholder keywords in cluster 3 were *management* and *hospitals*, in contrast with keywords related to patients in cluster 1 and providers in cluster 2.

Cluster 4 (yellow) was about eHealth literacy, health information seeking, and concerns about misinformation and decision making during the Covid-19 pandemic. This subset of studies focused on younger and older age groups, with a strong focus on students. With the help of eHealth tools and skill assessments for health education, researchers studied demographic and behavioral aspects of health information seekers who engage with online health information. They described their research using keywords such as *internet, eHealth literacy, social media, computer, digital health literacy, consumer health informatics, world-wide-web,* and *website*. This cluster also included keywords *disparities* and *digital divide*.

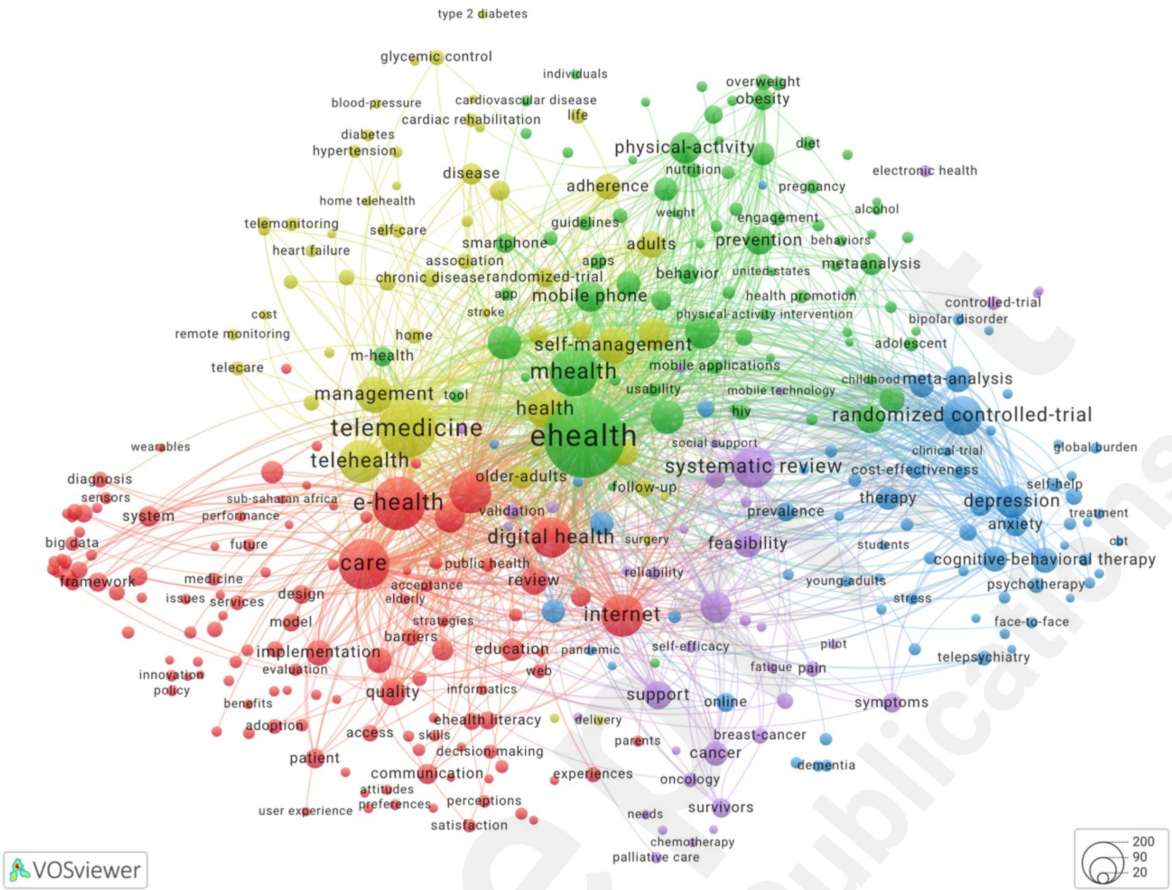
The remaining three clusters contained the smallest number of keywords. Nodes in cluster 5 (purple) reflected the needs of adults and older adults in physical activity and lifestyle changes to prevent obesity, hypertension, cardiovascular disease and diabetes. Researchers studied how these needs were addressed through eHealth interventions and mobile applications. Cluster 6 (light blue) keywords suggested a focus on eHealth, mHealth, and digital health applications, as well as telemonitoring, telerehabilitation, and communication technologies, for managing chronic diseases and medication adherence in older adults. The care types spanned primary care, rehabilitation care, home care, and integrated care. Finally, keywords in cluster 7 (orange) indexed research on eHealth interventions for HIV prevention among men who have sex with men.

While analyzing clusters, we found keywords that could be described as general or umbrella terms (*ehealth, e-health, technology, digital health, internet use*, etc.) and more specific eHealth applications (*telemedicine, mhealth, telehealth, mobile health, electronic health record, telecare*, etc.). In addition, we encountered many instances of keywords that shed light on eHealth objectives (*ehealth literacy, health literacy, communication, education, prevention, quality-of-life*, etc.). Scattered across all clusters, eHealth objectives pertained to stakeholders' health conditions, needs, or care settings. We coded these keyword groups, as well as subgroups about technology infrastructures, data security/privacy, and health analytics, to make them available as overlays (see Appendix).

eHealth Research Directions: Reviews, Compared to Articles

Figure 3 shows a cluster map for reviews obtained from the WoS database. Cluster colors in Figures 2-3 were set automatically by VOSviewer based on the number of nodes in a cluster. Despite differences in cluster colors, many keywords, for instance those related to mental health or obesity prevention, were grouped in similar ways in both maps. Out of 358 keywords that appeared in Figure 3, 89% of keywords were present in Figure 2. Similarly to Figure 2, the node *eHealth* in Figure 3 was strongly linked to nodes *mHealth, telemedicine, digital health, telehealth,* and *internet*.

Figure 3. A keyword co-occurrence network for 1,885 eHealth reviews: A cluster map. Keywords that occur 10 times or more were mapped. An interactive map is available from Leiden University’s VOSviewer application: https://tinyurl.com/28o3h7hs



A close examination of a subset of 318 keywords that appeared in Figure 2 and Figure 3 revealed differences in eHealth topics covered by articles versus reviews (see Table 2). A delta of z-scored keyword occurrence counts for keywords used to index reviews vs. articles was used as an indicator of research focus for the two document types. We asked, which eHealth topics were more or less likely to be covered by eHealth reviews, as compared to eHealth articles? Several patterns emerged when we analyzed differences (Δ > .5 SD).

Table 2. Top Keywords Indexing eHealth Articles, by Cluster, Compared to Keywords Indexing eHealth Reviews.

eHealth articles (Figure 2)		eHealth Reviews (Figure 3)
Cluster number (color) and name	10 most frequent keywords	Keywords more (+) and less (-) likely used to index reviews, as compared to articles, in SD units
1 (red): Self-management and interventions	*impact, interventions, self-management, intervention, depression, outcomes, support, children, validation, cancer*	More likely: *randomized controlled-trial* (+1.9), *feasibility* (+.7); less likely: *impact* (-1.0), *cognitive-behavioral therapy* (-.7), *social support* (-.7), *self-efficacy* (-.6)
2 (green): Telemedicine, telehealth, telecare, and technology acceptance	*care, telemedicine, technology, telehealth, implementation, adoption, model, acceptance, barriers, information-technology*	More likely: *telemedicine* (+1.2), *telehealth* (+1.1); less likely: *adoption* (-1.2), *acceptance* (-1.2), *barriers* (-.8), *implementation* (-.7), *trust* (-.7), *usability* (-.7), *user acceptance* (-.7)
3 (dark blue): e-Health technology, incl. privacy, security, design	*e-health, management, system, health-care, framework, privacy, security, design, challenges, healthcare*	less likely: *e-Health* (-2.2), *privacy* (-.9), *security* (-.8), *design* (-.6), *internet of things* (-.5), *cloud computing* (-.5)
4 (yellow): eHealth literacy	*internet, ehealth literacy, information, health literacy, communication, covid-19, quality, education, online, health information*	Less likely: *internet* (-7.5), *ehealth literacy* (-3.0), *information* (-2.2), *health literacy* (-1.9), *communication* (-1.5), *health information* (-1.2), *literacy* (-1.0), *covid-19* (-.9), *education* (-.8), *internet use* (-.8), *older adults* (-.6), *quality* (-.5), *skills* (-.6)
5 (purple): Health promotion and disease prevention	*health, prevention, physical-activity, behavior, adults, risk, physical activity, exercise, program, older-adults*	No differences were observed greater than +/-.5 SD
6 (light blue): mHealth and digital health	*ehealth, mhealth, digital health, mobile health, mobile phone, primary care, chronic disease, qualitative research, rehabilitation, diabetes*	More likely: *digital health* (+1.4), *mhealth* (+1.0), *mobile health* (+.8), *mobile phone* (+.7); less likely: *ehealth* (-7.5), *primary care* (-.8)
7 (orange): HIV prevention	*decision-making, hiv, united-states, acceptability, men, implementation science, recommendations, gay, hiv prevention, intervention development*	No differences were observed greater than +/-.5 SD

Similar to reviews conducted in other health disciplines [36], eHealth review authors attempted to summarize experimental research. A *randomized controlled trial* keyword indexed a disproportionately greater share of reviews than articles. Second, review authors favored studies on telemedicine, telehealth, digital health, and mobile health (mHealth). Feasibility studies were also a likely subject of literature reviews.

Other keywords salient in the eHealth article map did not receive much attention from review authors. Two findings that stood out the most were 1) few reviews of *eHealth* (or *e-Health*) literature, a research domain this study was designed to address, and a disproportionately small number of reviews on eHealth literacy relative to the number of articles in this area. Also, reviews somewhat underrepresented studies on e-Health technologies indexed with keywords *privacy* or *security*, and issues of eHealth technology adoption, such as *barriers*, *usability*, and *user acceptance*. Some mental health keywords, for instance eHealth applications of *cognitive-behavioral therapy* or those related to *social support* and *self-efficacy* were more frequently used to index articles than reviews. These under-reviewed topical areas may be considered by systematic review authors interested in eHealth.

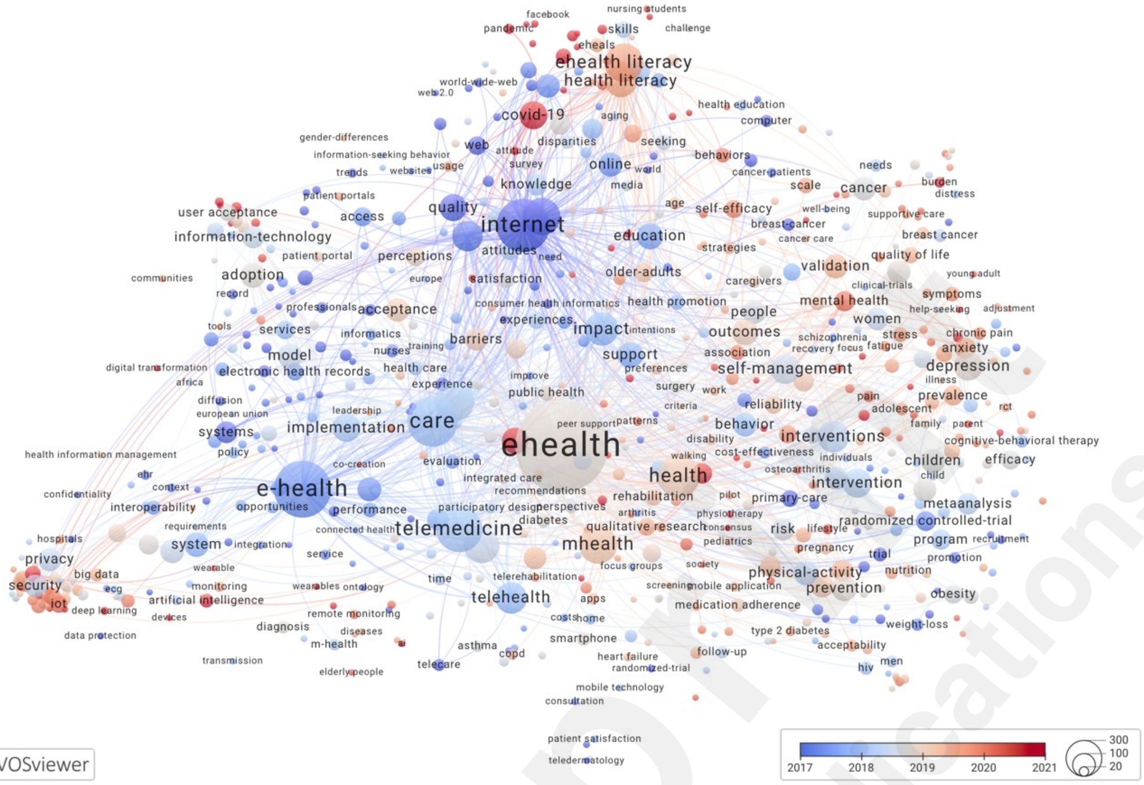
Publication Recency

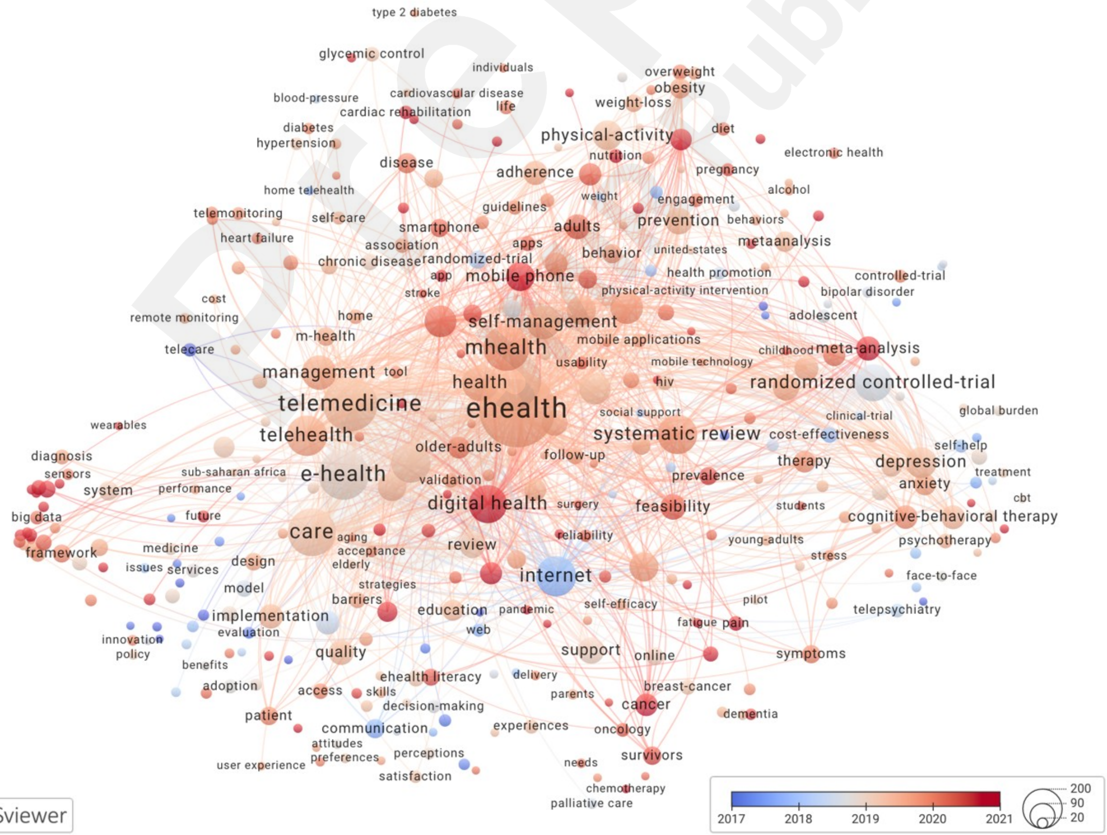
To answer RQ2, a comparison of mean publication years overlays for eHealth articles and reviews was used to identify trends in empirical research production and its subsequent synthesis. Figure 4 shows publication recency overlays for eHealth articles and reviews.

Both map legends range from 2017 (blue) to 2021 (red) and are centered around 2019 (grey color). In the top overlay of Figure 4 with keywords for articles *eHealth* was most strongly linked to *telemedicine* (M=2018) and *mHealth* (2019), followed by *internet* (2017), *telehealth* (2018), *mobile health* (2020), and *digital health* (2021). Mean publication years were most recent (2021-2022) for eHealth articles indexed with *Covid-19* or *pandemic, mindfulness, wearables, digital health, deep learning* and *blockchain, burden*, and *artificial intelligence*. Some of the same keywords (*deep learning, Covid-19*, and *artificial intelligence*) also represented the most recent (2021-2022) collections of reviews, in addition to the following keywords: *men, sedentary behavior, internet of things (iot), fatigue,* and *patient-reported outcomes*.

Excluding methods-related keywords, keywords with the oldest mean publication years (2012-2016) represented eHealth articles on *telepsychiatry, computer, web, information technology, ethics, weight loss, medical informatics, breast-cancer,* and *primary-care*. In addition to *health information technology and medical informatics*, the oldest reviews (2016-2017) were indexed with keywords *computer, health communication, smoking-cessation, telecare, records, user acceptance, electronic medical records,* and *internet use*. Importantly, e-Health consistently indexed older publications in both maps, as compared to eHealth, which is a welcome terminology standardization trend given the difficulties we encountered while retrieving e-Health publications.

Figure 4. Publication recency overlays to maps in Figures 1-2: Keywords indexing articles (top) and reviews (bottom). Interactive overlays: https://tinyurl.com/2dgeo5u2 (articles) and https://tinyurl.com/24tkgc5z (reviews).





Calculated across 318 keywords that appeared in Figures 2-3, the mean publication year was 2018.77 for eHealth articles and 2019.80 for eHealth reviews, a difference of about 12 months. The time gap between the mean publication date for all articles and all reviews indexed with mHealth was 8 months, M(356)= 2019.47 for articles and M(303)=2020.10 for reviews. The time gaps were 11 months for studies indexed with eHealth, M(2,089)=2019.08 and M(837)=2019.96, for articles and reviews, respectively; 15 months for telemedicine, M(522)=2018.32 and M(422)=2019.62; and 16 months for telehealth, M(242)=2018.07 and M(236)=2019.93.

Multidisciplinary Contributions to eHealth Scholarship: Journal Names in Reference Sections of eHealth Reviews

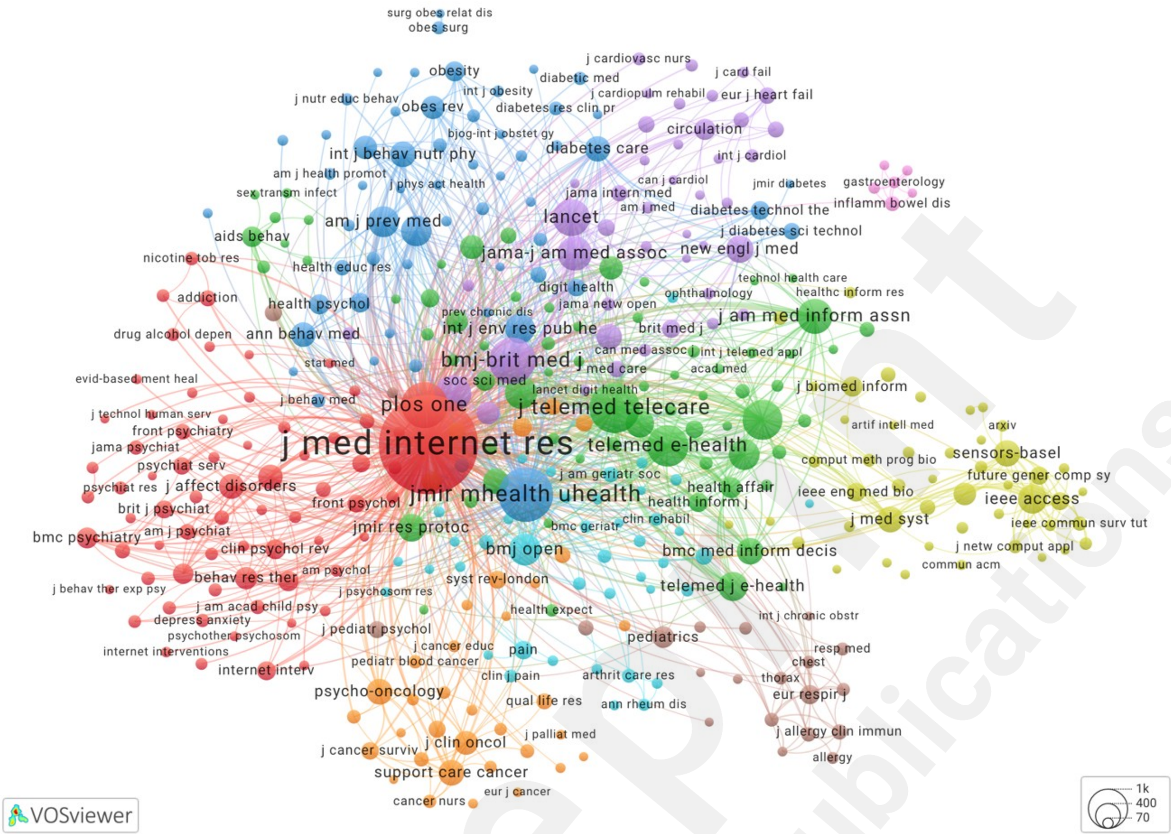
To answer research question 3, we analyzed multidisciplinary contributions using journal names that appear in reference sections of eHealth reviews (see Figure 5).

A nine-cluster model of journals contributing to eHealth reviews highlighted the leading role of the *Journal of Medical Internet Research* (*JMIR*). It was cited the most, specifically, 6,329 times in 1,884 reviews for which citation lists were available. It belonged to the largest cluster (cluster 1, red) with a large group of journals mostly dedicated to psychology and psychiatry.

Cluster 2 (green) largest nodes were telemedicine, eHealth and telecare journals, followed by journals in other disciplines – health informatics, public health, health services, medical education and health communication, clinical practice, HIV/AIDS research, and healthcare policy. Interestingly, we did not observe journals specializing in social media in this or any other cluster, given social media keywords observed in Figures 2 and 3.

Cluster 3 (dark blue) encompassed mHealth and ubiquitous health content (*JMIR mHealth and uHealth*), followed by cited sources in the fields of preventive medicine and public health; nutrition, obesity, and exercise; behavioral medicine and health psychology; and diabetes and endocrinology, among other disciplines.

Figure 5. A co-citation network of sources for 1,885 eHealth reviews: A cluster map. Sources that occur 50 times or more in eHealth reviews' reference lists were mapped. Link to an interactive map: https://tinyurl.com/274ugxye.



Cluster 4 (yellow) was somewhat unique in that its sources were less likely to be co-cited with sources from other clusters. Related to sensors, artificial intelligence, and health informatics, journals in cluster 4 had an information technology, computing, healthcare, and biomedical focus. An interdisciplinary journal *Nature* was also in this cluster, a distant node with stronger co-citation ties to medical sources than most computing journals in this cluster.

Cluster 5 (purple) included journals in general and internal medicine, cardiology and cardiovascular medicine, epidemiology, and other specialized medical fields. Several leading medical journals (*BMJ: British Medical Journal, The Lancet, JAMA: Journal of the American Medical Association, and The New England Journal of Medicine*) were among the largest nodes in this cluster.

In addition to general medical research sources, cluster 6 (light blue) had journals on pain, digital medicine, geriatrics and aging, rehabilitation and disability, rheumatology, and neurology. Cluster 7 (orange) was dedicated to cancer and oncology journals, and journals in related healthcare fields, including psycho-oncology, palliative care and symptom management, nursing in oncology, quality of life and patient outcomes, cancer education, nursing, and palliative care.

Most journals in cluster 8 (brown) belonged to either respiratory medicine and allergology or pediatrics and adolescent medicine, confirming our earlier findings about eHealth interventions for this age group. Finally, cluster 9 (pink) consisted of gastroenterology journals, particularly those focusing on inflammatory bowel diseases and related conditions. It is important to note that some fields, such as nursing, were represented by journals in many clusters.

Multidisciplinary Contributions: A Concept Map of eHealth Studies from OpenAlex

In addition to a cited journals analysis, we gathered evidence of multidisciplinary contributions directly from a large corpus of eHealth articles in OpenAlex, which were tagged with one or more of concepts. Concepts reflect disciplines, theories, methods, and other abstract ideas. We developed a custom thesaurus to select discipline-revealing concepts for Figure 6 map. Specifically, after removing most methods and statistics related concepts (e.g., sample or odds ratio), geography, general ideas (e.g., work), and merging synonymous concepts, we mapped the remaining 392 concepts representing disciplines and ideas relevant to eHealth. Each mapped concept occurred at least 20 times.

Figure 6. A concept co-occurrence network for 10,022 eHealth articles from OpenAlex: A cluster map. Concepts that occur 20 times or more were mapped. An interactive map is available from Leiden University's VOSviewer application: https://tinyurl.com/248zvmlx

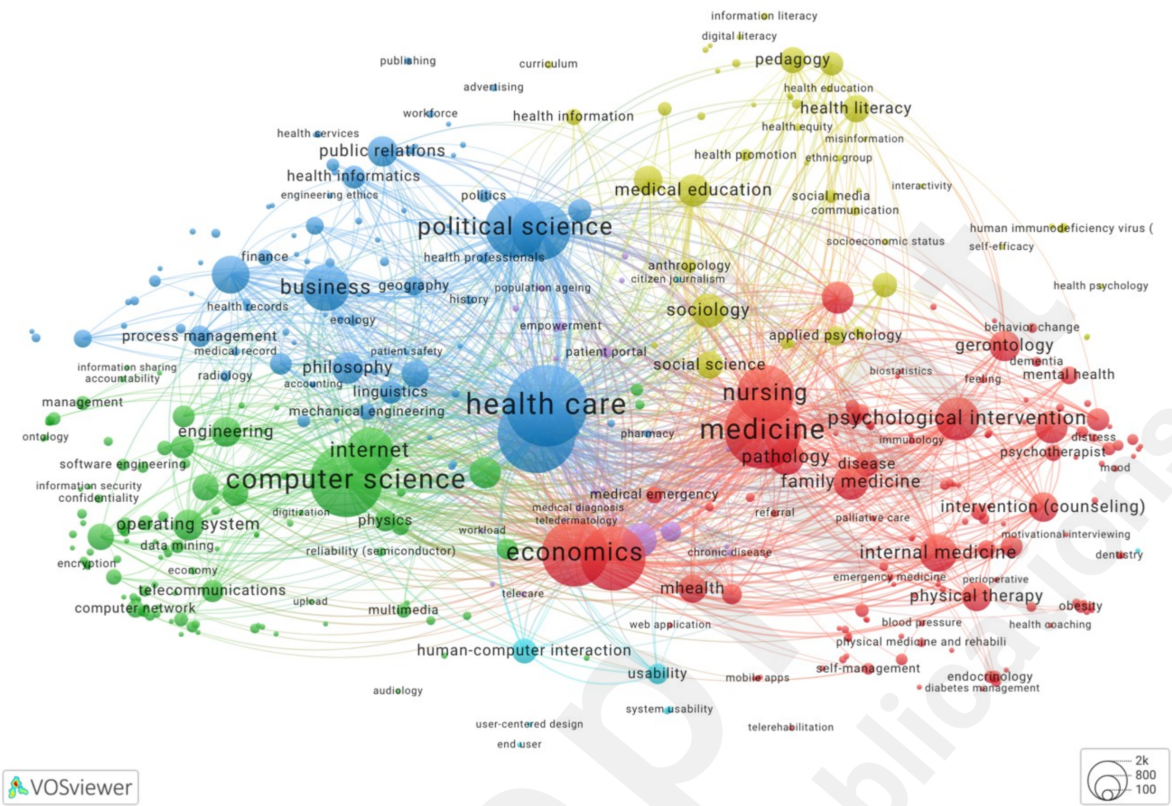


Figure 6 validated our earlier journal-level findings from Figure 5, confirming eHealth research connections to healthcare services, medicine, psychology, public health, education, and computer science. It also added to our understanding of the multidisciplinary nature of eHealth research by highlighting the prominent role, according to node size, of political science and law, economics, business, and knowledge management. The strongest connections with eHealth were observed for *medicine* and *nursing*, *computer science*, followed by *economics* and *economic growth*, *political science*, and *law*. Whereas these concepts were most central to eHealth, numerous other fields, ranging from human-computer interaction and engineering to philosophy and linguistics, contributed to eHealth scholarship. In Figure 6 network, eHealth had the strongest links to *internet* and *intervention*, followed by the four concepts strongly connected to eHealth in Figures 2-3: *telemedicine, mHealth, digital health*, and *telehealth*.

In Table 3, we contextualized our cluster-based findings with map overlays, examining how study attributes and concept characteristics were distributed across the map depicted in Figure 6.

Table 3. Overlays to Figure 6 Map: Overlay Name, Interactive Map Link, Definition, and Summary

Overlay Name/ Interactive Map Link / Definition	Summary of findings
Publication year: https://tinyurl.com/27wsed82 Mean year for all articles represented by a concept	Overall, older publications on map's left (business, engineering, law, political science, and many computer science concepts) than on the right (medical and health disciplines, human-computer interaction). Notable exceptions in cluster 2: *edge computing*, *deep learning*, *enhanced data rates for GSM evolution*, *audiology*, and *blockchain* with 2020-21 mean pub. years.
eHealth technology or related concept: https://tinyurl.com/23gsmjc4	Most technology concepts fell under computer science and engineering. Health literacy ideas (e.g., *digital divide*) and *social media* tended not to co-occur with other technology concepts.
eHealth objective: https://tinyurl.com/2a834blf Concepts related to desired outcomes or goals	Objectives were widely spread across clusters. They fell into the categories of healthcare services (access, safety, and quality); supporting providers; fostering sustainable and efficient health systems; encouraging collaboration and communication; promoting public health; enhancing user experience, empowerment, and engagement; safeguarding data and information security.
Health issues or field: https://tinyurl.com/2cqsn3yb Broadly defined concepts related to health and health disciplines including illness, wellness, and mental health	A plethora of disciplines concerned with disease, health, and wellness (from high to low node size): *Medicine*, *psychology*, *internal medicine*, *pathology*, *family medicine*, *psychiatry*, *environmental health*, *gerontology*, *physical therapy*, *public health*, *clinical psychology*, *surgery*, *alternative medicine*, etc.
Illness: https://tinyurl.com/2ybh33ne Concepts specific to diseases and health conditions	Pathology, surgery, infectious diseases, and cancer concepts had the highest count of studies.
Wellness: https://tinyurl.com/2avqly69 Concepts specific to health promotion and maintenance	Health literacy, alternative medicine, and quality of life, self-management, physical activity interventions had the highest count of studies.
Mental health: https://tinyurl.com/23hcfw2n Concepts related to cognitive, behavioral, and emotional well-being	Psychology and psychiatry concepts, especially those related to interventions, had the highest count of studies. Conditions included anxiety, dementia, distress, suicide ideation, insomnia, depression, and addiction.
Risk: https://tinyurl.com/27e7agsm Concepts related to risk in technology or health domains	Risk reduction concepts were related to computer security (access control, information security, cloud computing security) and engineering risk analysis. Other risk concepts included pandemic risks, poison control, patient safety, suicide prevention, adverse effects, vaccination, and injury prevention.
Economics and business:	Economics, economic development, business, and

https://tinyurl.com/2ajltxvq Relevant concepts and fields	marketing concepts had the highest count of studies.

According to the mean publication year overlay, the nodes with the most recent mean publication year were misinformation (2022) and new technologies such as edge computing (2021), deep learning (2022); pandemic concepts (2021); and concepts about mental health and psychological well-being including depressive symptoms, mental health literacy, insomnia, loneliness, all of which had a mean publication year of 2021. Older eHealth articles were represented by studies classified by OpenAlex as computer science, engineering, business, health informatics, and public relations. Setting aside concepts not specific to eHealth technologies, telematics (2008), semantic web (2013), web service (2013), information technology (2013), ubiquitous computing (2013), health information technology (2014), information sharing (2014), cross-domain interoperability (2014), and informatics (2014) were the oldest technology-related concepts with the pre-2015 mean publication year. These findings assist in answering research question 2 about eHealth research development over time. Other overlays explained in Table 3 addressed concepts specific to eHealth technologies and objectives, as well as different aspects of health. Below we highlighted several points most pertinent to multidisciplinary contributions.

The technology overlay demonstrated that 137 out of 392 OpenAlex concepts (35%) mapping eHealth were directly linked to technology, a clear indication that eHealth multidisciplinarity is only partially grounded in data sciences, engineering, and computer sciences. Interestingly, the *social media* concept (also represented as a keyword in Figures 1-2) stood out as an eHealth literacy technology with relatively weak co-occurrence relationships to most other eHealth technologies. We found some evidence of research on social media information campaigns and pandemic interventions, for example, a moderated Facebook group that brought together 200 providers and more than 58,000 laypeople from Denmark to support an informed approach to following pandemic guidelines [36]. Nevertheless, our maps consistently depicted social media as a small domain, suggesting this research played a modest role in the eHealth literature we examined.

When OpenAlex map and WoS maps were created, VOSviewer calculated node scores indicative of mean citations and normalized citations. These analyses were outside of the study scope, therefore, we shared them in our Appendix.

Discussion

Below we synthesize eHealth research directions by creating typologies of eHealth applications, other technologies, and their objectives. Furthermore, we explore groups of stakeholders involved in eHealth and systematize levels of research. Our synthesis lays the groundwork for an evidence-based conceptual model of eHealth, grounded in a continuous 25-year research effort.

To illustrate provided typologies with examples, we attempted to give priority to publications labeled by WoS as “highly cited papers” because their selection procedure controls for the field of study and the distribution of citations over time [37]. When no WoS highly cited papers were available, we manually picked pertinent articles and reviews using topic relevance, citation counts, and recency as our selection criteria.

Also in this section, we discuss our findings related to publication recency and multidisciplinarity. We conclude by stating limitations and implications for research and practice.

Objectives of eHealth

Keywords and concepts from our maps offered insights into intended uses for eHealth technologies. Research into clinical applications of eHealth technology was in support of patient monitoring, diagnosis, treatment, and rehabilitation, as well as patient-provider communication. Public health objectives were directed at improving health literacy, education, prevention, quality of life, and well-being. There were also organizational and societal objectives, which we discuss in a section that introduces eHealth research levels.

Consistent with prior research that emphasized consumer-oriented eHealth solutions, patient-centeredness, and ownership of one’s health as defining features of eHealth [7], we found strong evidence of eHealth research on fostering engagement, self-care, participation, and person-centeredness. These keywords from Figure 2 indexed the highest number of studies: *self-management, self-efficacy, social support, engagement, satisfaction, participation, self-care, empowerment, motivation, patient empowerment,* and *involvement*. Self-management apps, for instance, were successfully used to facilitate medication adherence and adherence to treatment of noncommunicable diseases: cancer, respiratory diseases, cardiovascular diseases, and diabetes. In one study, an EHR-linked online system for reporting cancer symptoms dispensed automated advice for either self-management or medical attention [38]. Improvements in physical and psychological well-being were reported for cancer patients who used the system. A 2022 systematic review of factors influencing mHealth app adherence, defined as following the intended program as designed, found 17 studies of mHealth apps for self-management of noncommunicable diseases with over 15,000 participants [39]. The review showed 53.4% overall app adherence and 89.5% medication app adherence.

This study highlighted eHealth objectives from past studies as an overlay to the concept map to guide objective setting by future eHealth designers. Our objectives overlay and the keyword map can be used for brainstorming possible measures to set intervention user prerequisites (e.g., health literacy, self-efficacy, motivation), outcomes, and manipulation checks to evaluate internal validity. The concepts and keywords in these maps reflect established terminology, facilitating literature searches for measurement instruments and the replication of past studies.

Technologies supporting eHealth

The keyword eHealth served as a catch-all term, labeling research on a variety of technologies. Using information from our maps, we systematized terminology relevant to eHealth applications and their supporting technological infrastructures. Infrastructures of interest to eHealth researchers included networks, data exchange, computing technologies, information systems, and platforms.

The highest number of studies was observed for the internet, followed by the internet of things, cloud computing, blockchain technology for secure data exchange, smartphones, sensors, fog computing, and 5G. Other well-studied eHealth infrastructures were wireless sensor networks and body area networks that expanded the reach of eHealth applications, facilitating remote monitoring and health interventions over vast geographic areas. Hardware, from smart phones to specialized sensors in wearables, enabled data collection and health monitoring. In addition, eHealth scholars explored platforms – websites, social media, and mobile apps relevant to eHealth.

Researchers' concern for eHealth data security and privacy, e.g., through advanced access control mechanisms and encryption techniques, was a prominent feature in our maps, as well as terminology related to health analytics and artificial intelligence that supports it.

Applications of eHealth can be categorized as education and informatics, telehealth, mobile health (mHealth), health record management, and wearables. Table 4 summarizes eHealth application types with references to well-cited papers that illustrate relevant research. Calculated for studies indexed with different keyword groups, mean publication years approximate an eHealth application development timeline, from education and informatics (2016) to wearables (2021).

Table 4. Characteristics of eHealth WoS Articles by eHealth Application Type

Application type	Keywords from Figure 2	M pub. year	Research examples: Relevant articles and reviews, in chronological order
Education and Informatics	*e-learning, consumer health informatics*	2016.24	A framework for analyzing health-related webpages [40]; consumer health informatics review [41]
Telehealth	*telemedicine, telehealth, telecare, telemonitoring, telerehabilitation, teledermatology*	2018.02	A systematic review of telemedicine reviews calling for controlled interventions with emphasis on the patient perspectives, economic analyses, and evidence of effectiveness [42]; telehealth and telemedicine during Covid-19 [43]; applications of telemedicine [44]
Health Record Management	*electronic health record, ehr, patient portal(s), personal health record(s)*	2018.45	Clinical predictions using big datasets [45]; a model for distributed personal health records [46]; use of blockchain to improve electronic health record sharing [47]; health equity in patient portal research [48]; outcomes of patient portals and personal health records [49]
Mobile Health (mHealth)	*mhealth, mobile health, m-health, app(s), mobile application(s) mobile app(s), health apps*	2019.74	Theory and policy implications of “average” mHealth app users – young, highly educated, and e-health literate [50]; mHealth application selection based on user satisfaction, functionality, usability, and information quality [51]; adoption of mHealth services in Bangladesh [52]; mHealth apps for prevention or management of noncommunicable diseases [39]
Wearables	*Wearable(s), wearable technology*	2021.01	internet of things as a platform to connect people and devices, e.g., smart wearables and wearable biosensors [53]; wearable textiles [54]; wearables for sleep monitoring [55]; use of wearables: during Covid-19 [56], for treating cancer [57], and for managing alcohol use disorder [58]

Note. To explore eHealth applications and other technology keywords interactively, use overlay links provided in the Appendix.

eHealth stakeholders and research analysis levels

We systematically categorized eHealth stakeholder groups and identified highly cited publications, including articles and reviews, that exemplify research involving these stakeholders. As demonstrated in Table 5, the studies we reviewed encompassed participants from all age groups, covering the entire lifespan.

Table 5. Highly Cited eHealth Papers by Stakeholder Group

Keywords	Topical areas of highly cited papers, in chronological order
	Age-based eHealth technology user groups
Young children or *children*	eHealth literacy of parents whose children have special care needs [59]; eHealth solutions for pediatric asthma control [60]; a review of digital mental health (computer-assisted therapy, smartphone apps, and wearable technologies) [61]
Adolescents	Use of technology to find health information [62]; a review of health literacy and health behaviors [63]
College/ university students or *nursing students*	Internet use to retrieve health information [64]; a review of digital mental health interventions for depression, anxiety, psychological distress, and stress [65]
Young adults, adults	Quality of mHealth apps [66]; a review proposing a conceptual framework for engagement with digital behavior change interventions [67]; perceptions of video visits with established primary care clinicians [68]
Older adults, elderly people or *aged*	A review of aging in place [69]; health information seeking behaviors [70]; reviews of smart homes (home health monitoring) [71] and physical activity interventions [72]; a call for inclusive online and offline solutions to mitigate risks of Covid-19 [73]; reviews of telerehabilitation in physical therapy [74], barriers and facilitators to using eHealth technologies [75], and eHealth literacy as a mediator -- how health-related information changes health-related behaviors [76]
	Other eHealth technology user groups
Patients, cancer patients or *cancer survivors*	Reviews of mobile health [77] and technology for Parkinson's disease patients [78]; recruitment into digital health interventions [79]; reviews of health literacy [80] and factors influencing eHealth intervention outcomes [81]; fog-driven internet of things (mobile health, assisted living, e-medicine, implants, early warning systems) [53]; reviews of internet of things and cloud computing [82], home consultation systems [83], digital solutions at the beginning of the Covid-19 pandemic [84], and telehealth use during Covid-19 [43]; an online eHealth system for self-reporting symptoms during cancer treatment [38]; a review of mHealth apps for prevention or management of noncommunicable diseases [39]
Family/informal caregivers, carers parents or mothers	Internet-based technology for supporting self-care in primary care [85]; a review of eHealth for cancer [86]
Healthcare professionals, physicians, nurses or *doctors; health organizations*	A review of providers' role in eHealth implementation [87]; trust in health information from specialist doctors and dentists [88]; smart hospitals [89]; EHR usability and nurses' informatics competence [90]; a review of online health misinformation [91]; medical data exchange through edge computing and blockchain [92]

Communities, countries or societies	Patients' online communities [93]; societal impacts of internet of things [94], digital inequalities [95], Covid-19 infodemic [96], and digital literacy [97]; fog-driven internet of things architecture (population monitoring in smart cities) [53]; adoption of mHealth services in Bangladesh and low-income countries [52]; poor engagement with digital health by some communities [98]; health technologies for internet of things in a 5G-enabled, fully connected society [99]; a review of Covid-19 pandemic accelerating digital transition in society as a whole [84]; desire for telemedicine in developing countries [100]; health equity in digital health systems – a review of country-specific policies [101]

Our corpora offered evidence of eHealth research at the individual, community, country, and society-wide level. At the individual level, researchers studied health consumers' and providers' participation in telemedicine, mobile health, and web-based interventions. There was a strong focus on interventions to meet health needs in the areas of mental health, wellness, chronic and infectious diseases, with an emphasis on such outcomes as self-management and self-care, prevention, behavior change, adherence, self-efficacy and motivation, health risk reduction and mortality. Individual-level eHealth studies were not limited to interventions; they also included a large body of health literacy research, as well as descriptive studies of internet and social media use by individual health information seekers. At the organizational or health system level (see cluster 2 in Figure 2), researchers studied electronic health/medical records, patient portals, and health information and clinical decision support systems.

Several small nodes in our maps referred to communities, notably, *community* in Figure 3, and *community, communities, and community-based participatory research* in Figure 2, and *community health* in Figure 6. In their abstracts, scholars discussed interventions for communities, aiming to produce community-level outcomes, for example, to promote knowledge exchange among geographically dispersed providers or between laypeople and providers [e.g., 103]. In addition, eHealth scholars studied disease-specific online communities and conducted community-based participatory research to build a variety of eHealth tools for caregivers in support of their emotional, belongingness, and help-seeking needs.

The country/societal or global level was represented by two sets of studies. The first set included scholarship on new and emerging technologies with potential impact on all levels of eHealth, including the societal level: internet of things, cloud computing, blockchain, artificial intelligence, etc. At the highest level, these technologies can be applied, for example, for disease surveillance, secure data sharing, or population health predictions. It also included research about technology standardization, policy, ethics, and governance. Given regional and global efforts to strategically allocate resources for health technologies, such as WHO's Global Initiative on Digital Health [104], we expect an increase of relevant publications at the societal or global level, which may be indexed as "digital health" rather than "eHealth." The second set of studies encompassed pre-pandemic and pandemic publications of health information available through global social media and the internet, with a focus on the quality and usage of health information from electronic sources.

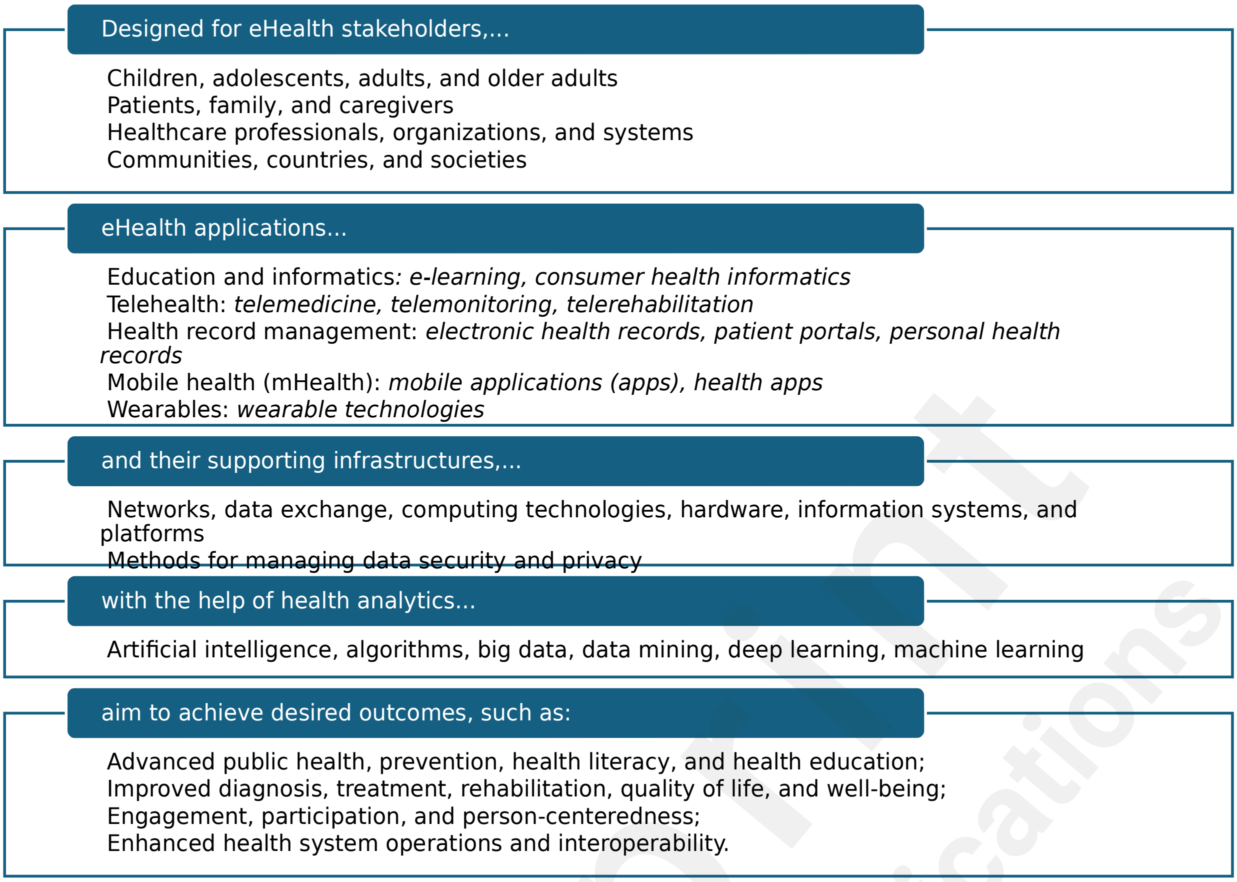
Within a proposed eHealth domain titled "health in our hands," social media has been conceptualized as an "interacting for health" technology [7]. Although social media keywords appeared in our maps, node sizes were unexpectedly small, considering worldwide use of social media platforms [105] and health researchers' interest in harnessing their power for health communication campaigns [106-107]. We likely failed to capture many relevant social media studies that did not mention eHealth in their titles, keywords, or abstracts. At the same time, an eHealth keyword is unlikely to be assigned to studies on problematic use of social media, e.g., when social media contributes to adolescents' poor mental health [108]. Under-representation of social media publications within eHealth is consistent with a claim that there may be a "dominant pathogenesis paradigm" in social media research [109], which manifests itself in the plethora of addiction scales and other measures of mental illness, physical inactivity, or poor sleep employed by scholars in this domain [109]. Bringing social media under the eHealth (or digital health) umbrella will extend our knowledge of interventions that make use of support groups, virtual coaching, health education campaigns, etc. An alternative paradigm of "interacting for health" could stimulate experimental, longitudinal, and multi-level research conducted on social media platforms and websites with social media functionality. At the health system or societal level unit of analysis, social media can be conceptualized as an eHealth technology in support of health policy, e.g., for gathering digital publics' input on health services and systems [110] or gauging public reactions to health policy issues, health systems, and organizations.

A Conceptual Model of eHealth

To our best knowledge, this review represents one of the most comprehensive attempts to date to systematize research into eHealth by creating typologies of stakeholders, applications, and supporting technologies. Our findings align with earlier bibliometric studies of eHealth and digital health. We confirmed previously identified research directions, such as eHealth literacy [29-30], self-management [30], physical activity [29], mental health [29], Covid-19 [30], and technological infrastructures that support eHealth applications [25]. Consistent with our findings, a 2023 bibliometric review of internet of things research incorporating the search term "eHealth" demonstrated scholarship on blockchain applications, 5G networks, data analytics, and artificial intelligence technologies [25]. We also replicated the finding that the term "digital health" was more recent than "eHealth" [30] and corroborated an earlier report regarding the pivotal role of *The Journal of Medical Internet Research* within the field of eHealth [29]. In 2021 bibliometricians highlighted the role of social sciences, especially psychology, in eHealth scholarship [31]. We extended the findings of their study, which focused exclusively on eHealth articles in WoS' social sciences research area, by demonstrating interconnections between psychology and other disciplines and depicting specific branches of psychology. According to our concept map, the highest number of studies were tagged as social psychology, followed by clinical, applied, developmental, cognitive, and health psychology. Despite eHealth applications' emphasis on patient-provider communication, the field of communication was represented by small nodes in our concept map. Other social sciences – psychology, education, business, and economics – were more salient, which is another similarity between our study and an earlier bibliometric analysis of multidisciplinary contributions [31].

Building on the main points of the preceding discussion sections, Figure 7 presents a conceptual model of eHealth scholarship. It consists of five building blocks that delineate the domain of eHealth as it has been explored over the past quarter century. The five blocks are stakeholders, applications, supporting infrastructures, analytics, and outcomes. Empirically derived categories depict the composition of each constituent building block.

Figure 7. A bibliometrically derived conceptual model of eHealth stakeholders, technologies, and outcomes explored by eHealth scholars, 2000-2024.



How eHealth research developed over time

The earliest eHealth scholarship was rooted in computer and web technologies used for patient-provider communication and treatment of specific health conditions, as well as in telecare and medical informatics. In contrast, the most recent eHealth scholarship was represented by articles and reviews dedicated to the Covid-19 pandemic and a variety of newer technologies, such as artificial intelligence, wearables, digital health, blockchain, and internet of things. In our keyword maps, Covid-19 had strong links to telemedicine, expedited by the recent Covid-19 pandemic [46], and digital health. We also observed small nodes with recent research dedicated to cyberchondria and eHealth applications to promote mindfulness and treat urinary incontinence.

The keyword e-Health, as compared to eHealth, consistently indexed older articles and reviews, suggesting a shift toward terminology standardization. We recommend that library database managers and future authors consistently index their studies with keyword eHealth to avoid problems in retrieving e-Health publications.

Another likely terminology shift is towards *digital health*, adopted in many WHO documents and defined as “the systematic application of information and communications technologies, computer science, and data to support informed decision-making by individuals, the health workforce, and health systems, to strengthen resilience to disease and improve health and wellness” [111]. Digital health has gained popularity as an umbrella term alternative to eHealth, according to our analyses. This finding confirmed nearly decade-long concerns documented by Shaw and colleagues in their interviews with eHealth researchers, educators, practitioners, and policy makers [7]. One of their informants stated:

> You know eHealth is really old fashioned? Nobody talks about eHealth anymore. Electronic health—everything’s electronic! The devices, everything! We’ re talking about digital health,

digitizing health, not eHealth [7, p. 3].

As more studies are indexed with digital health, the use of an eHealth keyword may decline. We recommend that future bibliometricians query both search terms to achieve historic depth of their corpora for tracking this research field’s evolution.

The multidisciplinary nature of eHealth

We observed multidisciplinarity in both inputs and outputs of eHealth science, that is, in foundational literatures presented as the names of cited journals and disciplinary tags assigned to eHealth publications by OpenAlex. Some of the journals were technology-oriented (JMIR, telemedicine journals, or journals about sensors), however, most cited journals were not specific to health technology, suggesting a broad support for eHealth applications studies from a variety of medical fields. Psychology, psychiatry, public health, preventive medicine journals were prominent in our source co-occurrence map. Other journals were specific to age groups, ranging from pediatric to gerontological sources, which suggests that eHealth draws upon literatures concerned with health and wellness across the human lifespan. According to our OpenAlex concept map and its mean publication year overlay, the eHealth scholarship originated as computer science and engineering research in support of medicine, nursing, and public health with ongoing contributions by eHealth literacy scholars. The core interest of eHealth – technological innovations and interventions – was supported by disciplines concerned with policy, law, and economy. The research domain of eHealth, therefore, is defined much broader than medical or health technologies and includes many other fields.

These findings have implications for policymakers, practitioners, those who shape research priorities, and educators. First, it may be challenging to identify individuals with expertise in both health and technology [112], therefore, policy development panels and teams involved in eHealth research or implementation may need to include both health specialists and technology experts. Our visualization of disciplines relevant to the eHealth domain supports resource allocation beyond the intersection of technology and health, to involve more diverse fields, for example, health literacy and social sciences. Effective policy and regulatory framework development for eHealth must account for the technological, clinical, legal, ethical, economic, and societal implications of eHealth solutions.

Second, funding of studies conducted by multidisciplinary research teams should be prioritized by research funders to bring together researchers and relevant stakeholder groups, such as clinicians, public health officials, healthcare leaders, patients and health advocacy groups, technologists or industry representatives, policymakers, and community members. Within each eHealth research subdomain, defined by our map clusters, engagement of relevant stakeholder groups and user panels (e.g., those listed in Table 1) may help to ensure that future research addresses real-world needs and concerns, while also enhancing the relevance of research findings and their translation into practice.

Third, educators can utilize our visual representations as teaching aids. Big picture perspectives communicated in our maps offer a holistic view of the eHealth research domain. For example, individuals involved in healthcare management, public health, and digital health education may the maps to introduce their students to the multidisciplinary field of eHealth. They can position their respective disciplines within the network of other contributing fields to emphasize the benefits of multidisciplinarity, collaboration, and broad knowledge acquisition. Educators may also encourage students to research concepts that appear within the keyword and concept maps to find inspiration outside of the core literatures they are typically exposed to within their academic programs. Finally, the maps may also serve as an exploratory starting point for novice researchers who are interested in eHealth or digital health and need to narrow down their research focus.

Limitations

One of the study limitations is exclusion of e-Health articles from OpenAlex search query to avoid potential issues with the hyphenated search term. The literature of interest is undoubtedly broader than the 10,022 articles we mapped. Moreover, our study addressed high-level patterns in meta-data, limiting visualizations to keywords and concepts that met pre-set occurrence thresholds, specifically, keywords used in no less than 10 studies and concepts tagging 20 or more OpenAlex articles. Less frequently used keywords and concepts were excluded, some of which were likely very useful in understanding eHealth.

Our study revealed a recent trend to index eHealth studies with a digital health keyword. Mapping of literatures obtained with search queries inclusive of both terms (eHealth and digital health) would provide the most comprehensive and up-to-date depiction of the research domain. Therefore, future bibliometric research should incorporate both terms.

While this bibliometric study did not offer a summary of evidence that can be expected from traditional systematic reviews, e.g., on integrating eHealth solutions into practice, it provided a high-level overview of past research, pertinent terminology, and interlinked research directions, which were categorized and synthesized to develop a conceptual model of eHealth scholarship.

Practical implications and suggestions for future research

The implications of our findings are presented in Table 6, along with recommendations for future studies. The implications are organized into three groups: Practical implications of our conceptual model and maps; availability of numerous and recent reviews in many eHealth research areas; and multidisciplinary contributions to eHealth. For future researchers, we offer recommendations on research directions, as well as guidance on study design and publication.

Table 6. Study Implications and Suggestions for Future Research

STUDY IMPLICATIONS
The value of our conceptual model and interactive bibliometric networks • Practitioners, educators, and novice researchers can use this study's maps, terminology, typologies, and conceptual model to gain a comprehensive understanding of eHealth, expanding the boundaries of their academic or practice fields. • Mapped concepts and keywords align with the established terminology, aiding researchers and practitioners in the selection of eHealth outcomes and the identification of measurement instruments. • Mean publication recency overlays can inform funders' decisions to stimulate research on emerging topics that are currently represented by a small number of studies (e.g., mindfulness, urinary incontinence, cyberchondria).
Availability of synthesized evidence from eHealth reviews • To keep pace with new research developments, researchers and practitioners may turn to recent eHealth systematic reviews, especially those synthesizing evidence on interventions, common eHealth applications, and feasibility studies. • The keyword map for reviews (Figure 3) can be used to develop queries for identifying reviews of interest.
Significance of multidisciplinary contributions of eHealth • Informed policy and regulatory framework development should consider the technological, clinical, legal, ethical, economic, and other societal implications of eHealth solutions. • Funders should extend support to scholars and practitioners from diverse disciplines identified in our study. They should also consider funding research from underrepresented disciplines, such as communication. • Funders should also support research engagement of relevant stakeholder groups and user panels, including the groups we identified.
SUGGESTIONS FOR FUTURE RESEARCH
Research directions • Our maps can serve as an exploratory starting point for novice researchers who are interested in eHealth and need to narrow down their research focus. • Social media research under the eHealth umbrella (e.g., media support groups, virtual coaching, health education campaigns, and other social media "interacting for health" interventions) will promote the social media for health" paradigm, which is distinctly different from the dominant pathogenesis paradigm.
Design considerations • These eHealth topical areas with abundant literatures and relatively few reviews may be considered by systematic review authors: eHealth literacy; data privacy/security; eHealth technology adoption (barriers, usability, and user acceptance); and mental health topics of social support, self-efficacy, and eHealth applications of cognitive-behavioral therapy. • Researchers should consider multiple units of analysis when designing studies and identifying outcome variables. • Bibliometricians seeking to achieve historic depth in their corpora should query e-Health, eHealth, and perhaps also digital health for the broadest search.

Guidance on publishing new studies

- Researchers should index their studies with a keyword eHealth rather than e-Health for consistent retrieval.
- Researchers can identify potential journals for submitting their studies by utilizing the interactive co-citation network of sources we developed.

Conclusion

The multidisciplinary field of study at the crossroads of health and technology is widely recognized as eHealth. Over the past 25 years, researchers studied a broad range of established and emerging technologies – educational and informatics tools, telehealth services, health record management, mobile health, and wearables – in support of consumer-oriented solutions for patient monitoring, diagnosis, treatment, rehabilitation, and patient-provider communication. Beyond healthcare services, the field of eHealth offers a large body of literature on health literacy, disease prevention, and wellness. Conducted at the individual, health system, community, and society level, eHealth research continues to develop by incorporating new technologies, responding to health emergencies, and addressing the needs of diverse stakeholders.

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Conflict of Interest

Authors declare that they have no conflict of interest.

Data and materials availability

All data are available in the main text or the supplementary materials. Map files can be downloaded from map URLs provided in figures. Original YouTube comments (initial posts and first-level replies) can be accessed through YouTube using the video descriptions provided in Supplementary Materials.

Multimedia Appendix 1

Additional overlays and publication impact.

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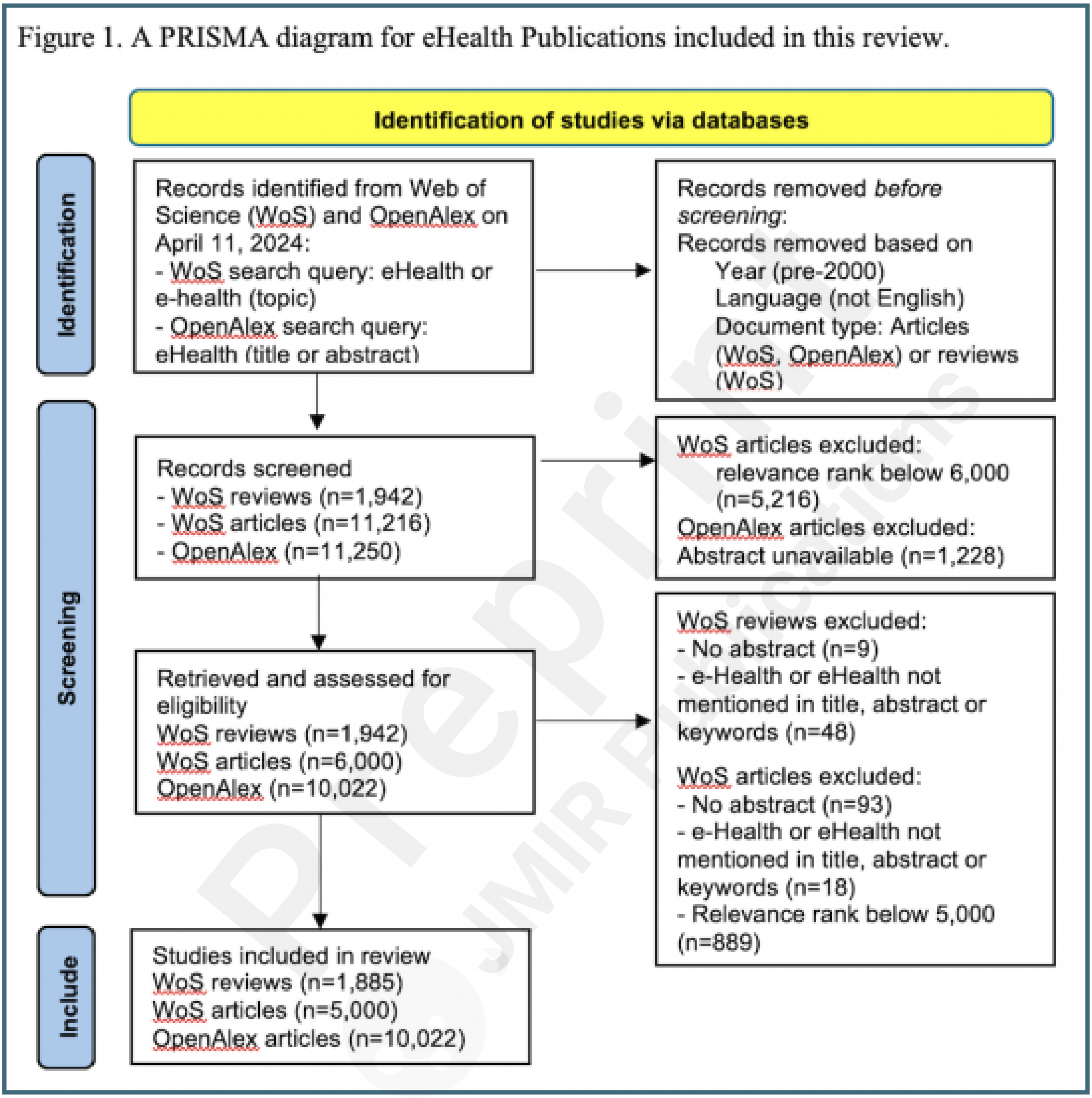
Supplementary Files

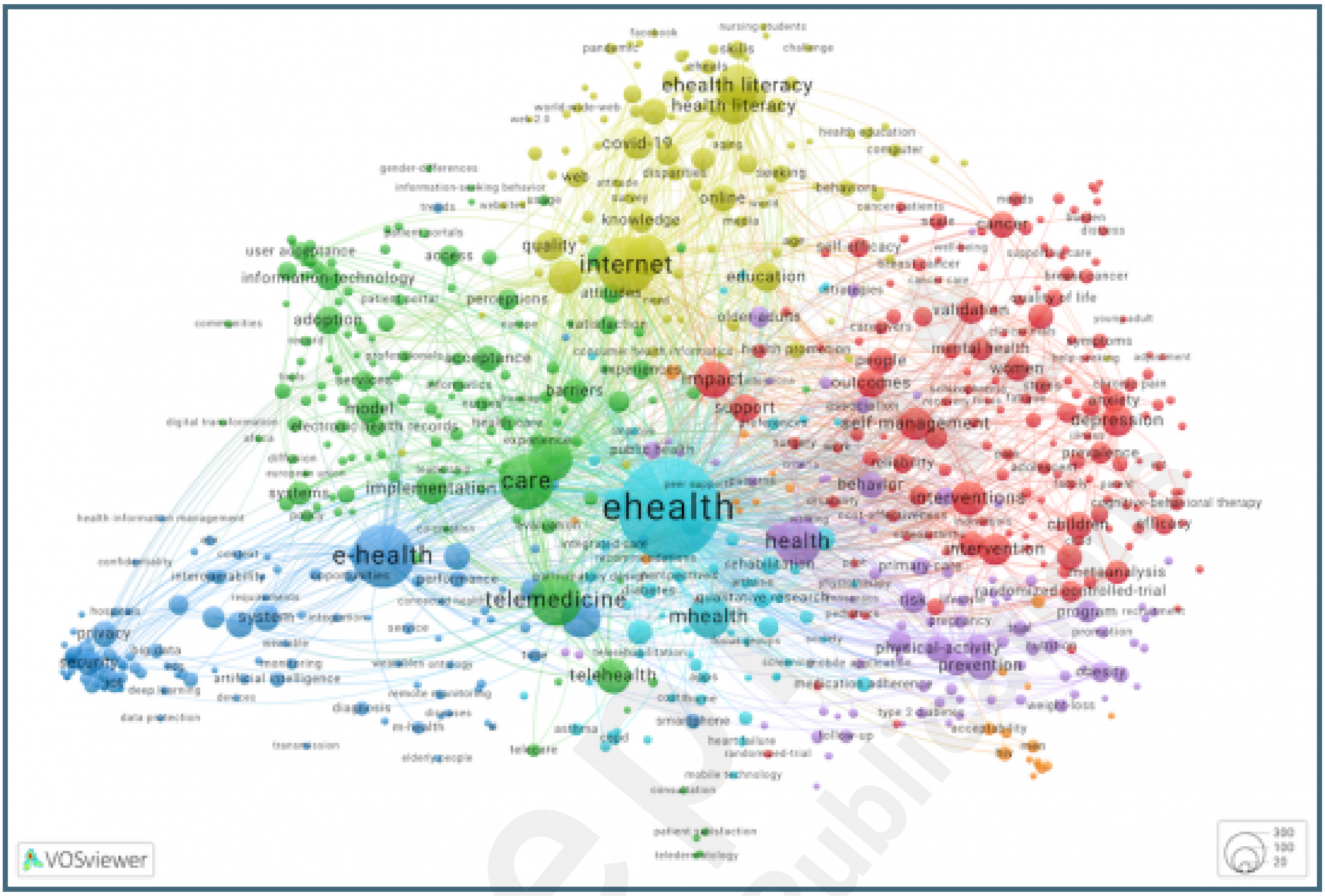
Untitled.
URL: http://asset.jmir.pub/assets/6f172524c860b54dde6e97f7eb0f9f2f.docx

Figures

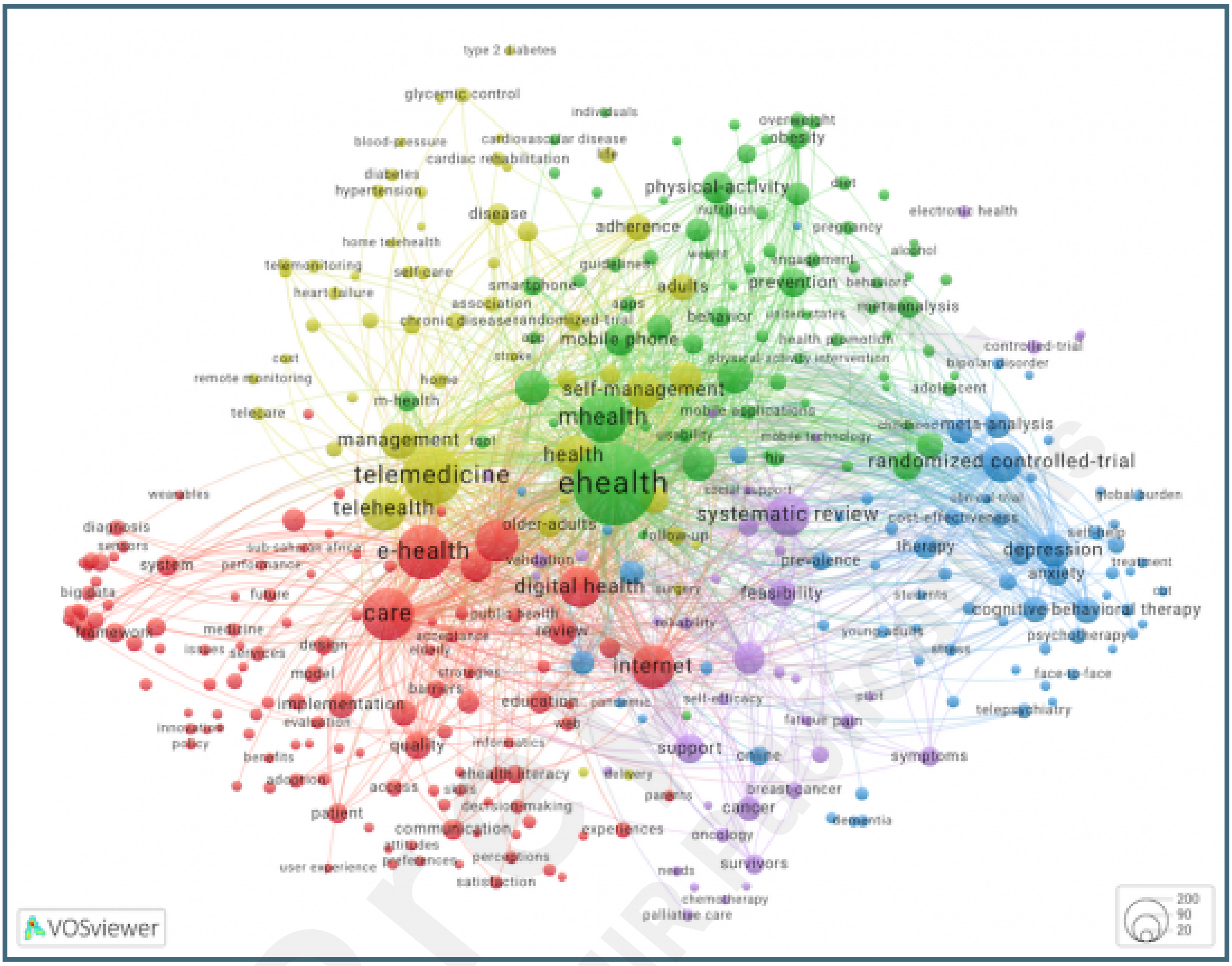
A PRISMA diagram for eHealth publications included in this review.



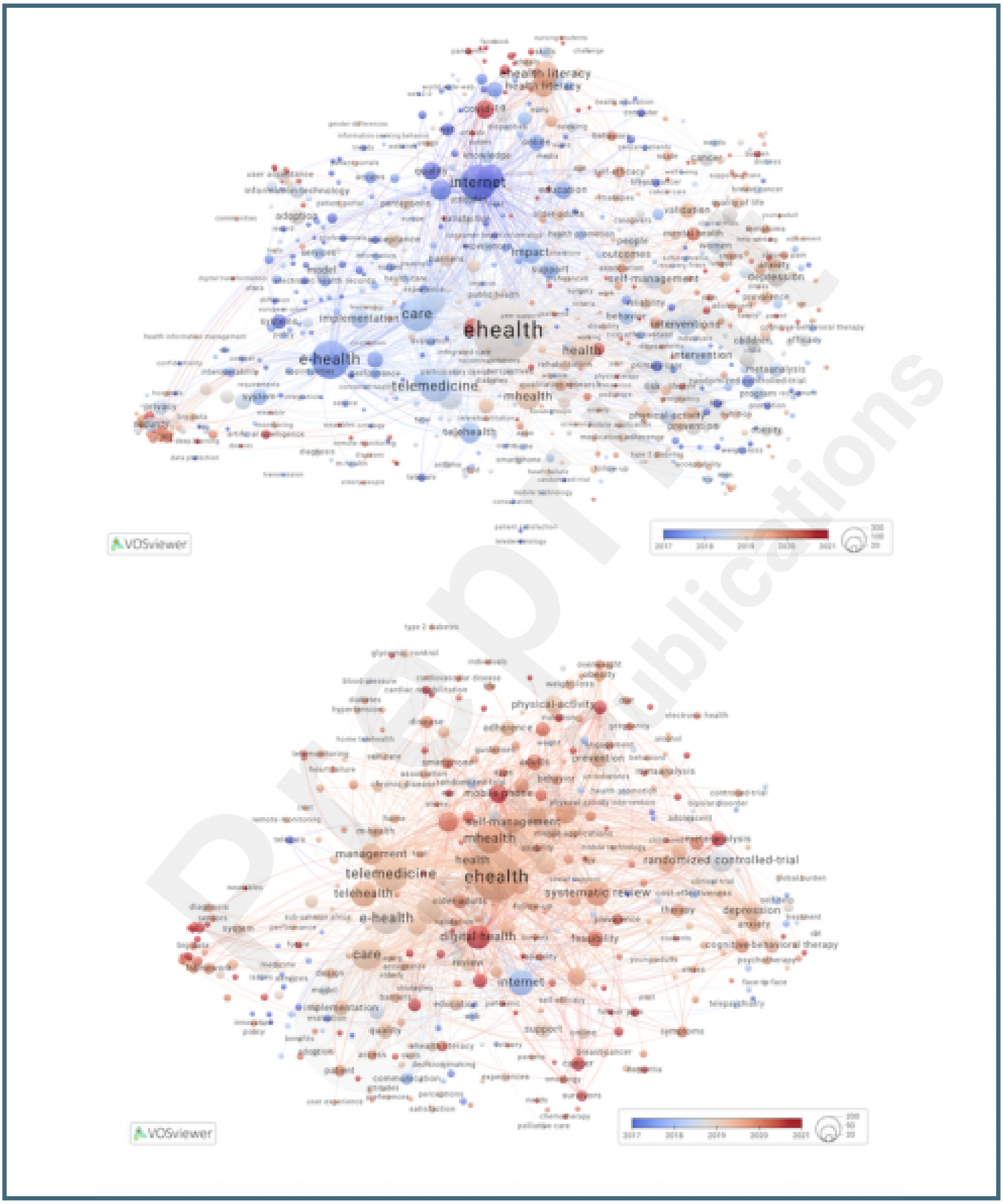
A keyword co-occurrence network for 5,000 eHealth articles: A cluster map.



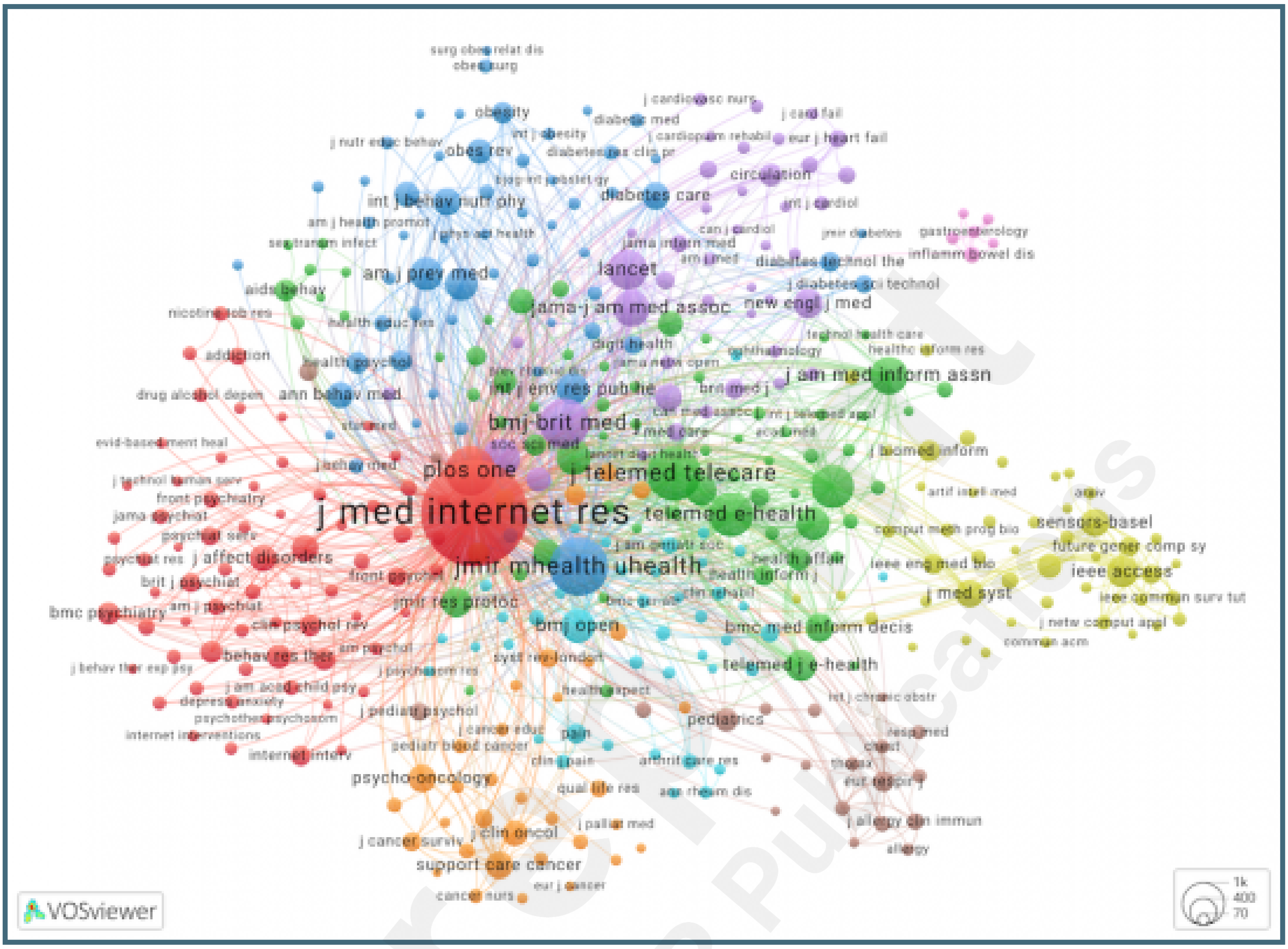
A keyword co-occurrence network for 1,885 eHealth reviews: A cluster map.



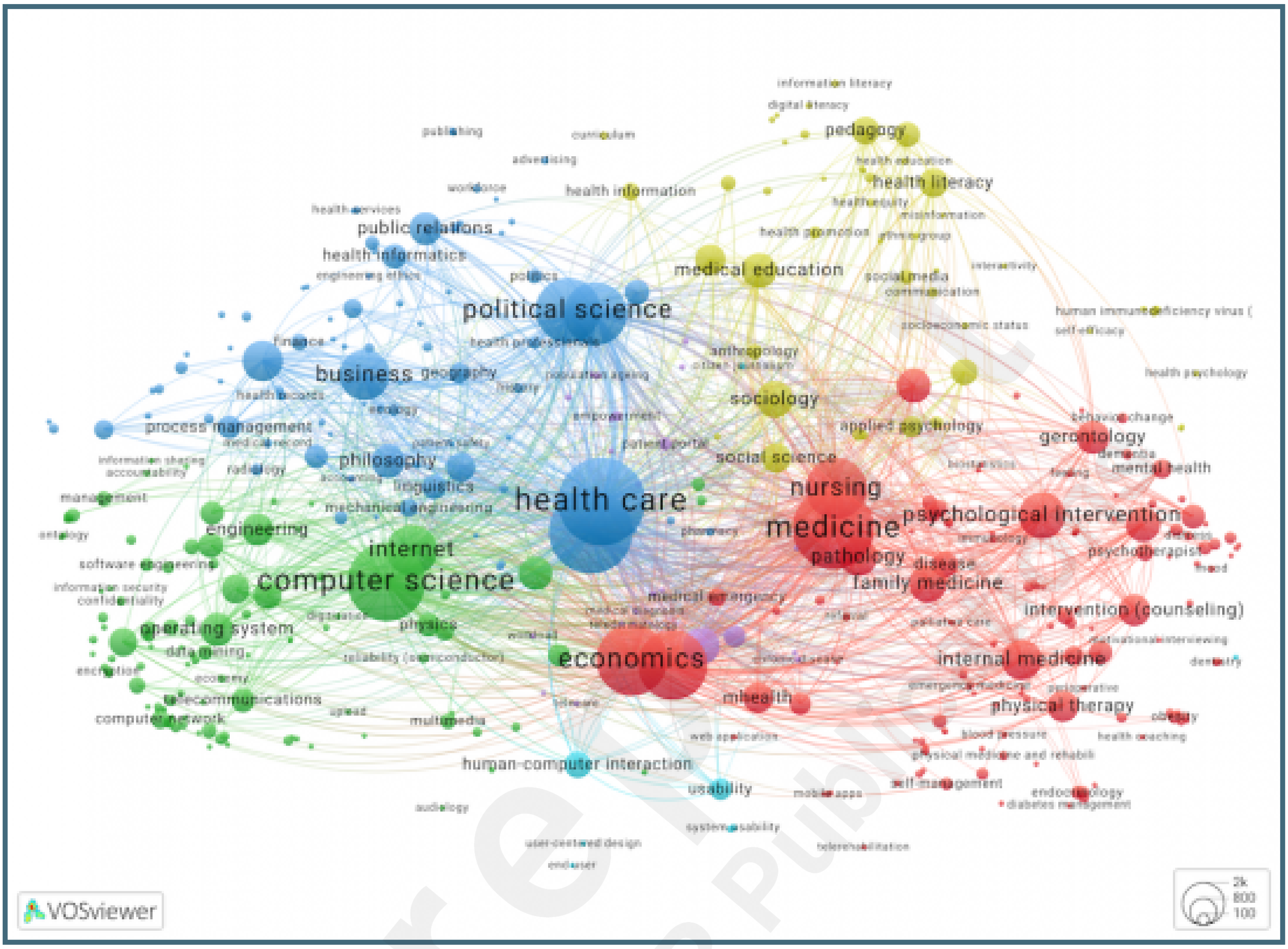
Publication recency overlays to maps in Figures 1-2: Keywords indexing articles (top) and reviews (bottom).



A co-citation network of sources for 1,885 eHealth reviews: A cluster map.



A concept co-occurrence network for 10,022 eHealth articles from OpenAlex: A cluster map.



A bibliometrically derived conceptual model of eHealth stakeholders, technologies, and outcomes explored by eHealth scholars, 2000-2024.

Multimedia Appendixes

Additional overlays and publication impact.
URL: http://asset.jmir.pub/assets/5352a0b2ed6a10804c80451c6e2cda79.docx