From Education 4.0 (E.D. 4.0) to Education 5.0 (E.D. 5.0): Bibliometric insights to reach the Society 5.0 global vision.

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From Education 4.0 (E.D. 4.0) to Education 5.0 (E.D. 5.0): Bibliometric insights to reach the Society 5.0 global vision.

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Abstract

Education serves as a foundational pillar for a country's economic prosperity and infrastructural development. The rapid emergence and surge of Artificial Intelligence (AI), Machine Learning (ML), and automation have catalyzed the Education 4.0 (E.D. 4.0) global landscape, creating the demand for Industry 5.0 (I.D. 5.0) competencies in university graduates. Key I.D. 5.0 identifiers are analytical and creative thinking, transparent communication, and empathy. To meet these skillsets, university curricula at Higher Education Institutes (HEIs) are undergoing a rapid transformation from E.D. 4.0 to E.D. 5.0. However, systematic literature reviews reveal (i) inconsistency among researchers on E.D. 5.0 terminology/attributes, and (ii) rather sparse universal markers of E.D. 5.0 that the pedagogical community agrees on. Following a recent mapping work of I.D. 4.0 to E.D. 4.0 [12], we perform a bibliometric analysis with qualitative and quantitative insights on VOS viewer on the Scopus scientific database to identify (i) elements of E.D. 5.0 currently observed in HEIs, (ii) key attributes to transform from the E.D. 4.0 to the E.D. 5.0 vision (for all fields, and specifically, for engineering and chemical engineering) and (iii) pedagogical strategies/impacts to enable the transform towards the Society 5.0 global vision. Coupled with the use of conscious, ethical Artificial Intelligence tools (ChatGPT, Jasper AI, Copilot, Gemini, etc.) and learning modalities (active/experiential/inquiry-driven, flipped-classroom, etc.) will empower students to individualize learning experiences/outcomes. However, e-learning must be supplemented by open discussions [13], and project-based/textbook-based learning, especially for foundational subjects. Within chemical engineering, core subjects and topics like calculus, transport phenomena, chemical thermodynamics, separation processes, and plant/process design (undergraduate capstone) must be taught through a mix of pedagogical strategies. Our results reveal an increase (especially since 2017, coinciding with the COVID-19 pandemic [36]) in publications; the shift from E.D. 4.0 to E.D. 5.0 is most observed in computer science, engineering, social sciences, economics, econometrics and finance, and business, management, and accounting. Global South countries (India, China, Malaysia, Indonesia) lead this change than their Global North counterparts (the United States, the United Kingdom, and Europe); publication trends show a cubic increase with a strong correlation coefficient ($\boldsymbol{R^2 > 0.97}$), anticipating strong future research interest in E.D. 4.0 to E.D. 5.0 research. A synergistic integration of these learning modalities, competencies, and pedagogical strategies into HEI curricula will lead to the realization of E.D. 5.0/Society 5.0. In parallel, Industry 4.0 (I.D. 4.0) is correspondingly transforming to I.D. 5.0, and HEIs need to be mindful and accordingly produce university graduates who are perceived as valuable and can secure lucrative career prospects, in an ever-evolving global landscape. This pivotal work lays out a comprehensive, elaborate procedural foundation to map E.D. 4.0 to E.D. 5.0 (thereby also catalyzing the E.D. 5.0 to I.D. 5.0 transformation) devoid of any a priori assumptions, demonstrating the universal, reproducible nature of our work.

Keywords
Education 4.0 (E.D. 4.0), Education 5.0 (E.D. 5.0), Industry 4.0 (I.D. 4.0), Industry 5.0 (I.D. 5.0), Society 5.0, Pedagogy, Bibliometric Analysis, Curriculum Design, Higher Education Institutes (HEIs).

Introduction

The world today exists at a very interesting transition, with a new generation of industrial revolution (Industry 5.0, hereafter termed I.D. 5.0; a table of abbreviations/acronyms used in this work is presented in **Appendix B**) being ushered in with the unprecedented rise of Artificial Intelligence (AI). A direct impact of this is a pedagogical revolution in Higher Education Institutes (HEIs), leading to the swift transformation of Education 4.0 [12, 50] to Education 5.0 (hereafter referred to as E.D. 5.0). Some hallmark identifiers of E.D. 5.0 are the seamless convergence of intelligent tutoring, robotics, and the Internet of things (IoT) [1], Machine Learning (ML) [1,12], Augmented and Virtual Reality (AR/VR) [1] and the overarching influence of AI, which has been a key characteristic since the E.D. 4.0-I.D. 4.0 revolution [12]. These attributes are also commonly identified as key enabling technologies characterizing the E.D./I.D. 4.0 to E.D./I.D. 5.0 revolution [51] and learning [50]. In a post-pandemic, more digitally shifted world, Education 5.0 holds the potential to facilitate a more individual, learner-centric environment that leverages the latest technological and pedagogical resources to empower the student [2,3]. A transition from a higher education environment to a workplace requires graduates to possess academic and practical readiness [49]. A direct consequence of this integration is the emergence of pedagogy, engineering education, and a conscious global initiative towards curriculum design/revamp/innovation [13,14]. A direct emergence of this is I.D. 5.0, where human society collaborates with cutting-edge resources in the workplace to advance the frontiers of knowledge [51]. A clear distinguishing attribute of E.D. 5.0 is its strong emphasis on student well-being, focusing on physical, emotional, and mental health [3]. E.D. 5.0 is an improvement on E.D. 4.0 limitations and is consciously designed to be adaptive towards meeting the changing needs of I.D. 5.0 and Society 5.0 [3,5].

In 2021, the European Commission established initiatives to set up I.D. 5.0 standards, which subsequently became a global initiative [35]. E.D. 5.0 significantly differs from E.D. 4.0 in several key attributes [54], notably with a strong emphasis on AI-driven personalized learning, individualized learning paths, based on learner behavior analysis, advanced adaptive systems that can adjust the difficulty level, pacing, content delivery, etc. The move from E.D. 4.0 to E.D. 5.0 necessitates a humanization of the education and pedagogical needs of students at Higher Education Institutes (HEIs) [15]. There are several disciplines where the transformation from E.D. 4.0 to E.D.5.0 is presently observable, such as chemical engineering, electrical and electronics engineering, industrial engineering, mechanical engineering, information technology, computer science, etc. The integration of E.D. 5.0 with I.D. 5.0 is crucial for realizing Society 5.0 targets, a vision born out of a strategic plan of Japan's then Prime Minister Shinzo Abe, to integrate science, technology, political initiative, and society, to increase individual and collective welfare [22, 27, 30, 45, 47]. Society 5.0 is uniquely characterized by the Internet of Things (IoT), AI, Big Data, and sophisticated machine/robot interaction with humans [45], and is also viewed as a panacea that reduces the global socio-economic gap [22]. But attempts to realize the E.D. 5.0 vision also pose several challenges, such as a need for reform and alignment of the education system with national digital transformation goals for Costa Rica [9], the reluctance of educational systems in countries like Afghanistan to adapt towards E.D. 5.0 goals [46], the difficulty of HEI curricula to coincide with the ever-evolving needs of I.D. 5.0 [33], minimal education freedom in Mexico [7], etc. However, some promising survey trends demonstrate the value students place on the Society 5.0 and Community 5.0 vision [53], such as AI integration into a project management masters' program in Kyiv, Ukraine [48], training E.D. 5.0 aware mathematics teachers in Zimbabwe [34], student perception of sustainability into a traditional oil and gas elective [13], assessing instructor/curriculum readiness in Bachelors of Education in Biology program in Indonesia [8], the conscious incorporation of Agile methods into a data-driven design and modeling course in chemical engineering [14], & the incorporation of industry standards, codes and recommendation into the chemical engineering undergraduate capstone at the University of Toronto, Canada [21].

Evidence from the literature suggests that the shift to E.D. 5.0 is rather recent, arising from 2019 (around the time of the COVID-19 pandemic [11, 36]), and therefore, we expect these bibliometric networks to be less robust/connected. This trend of integrating pedagogy with learning modalities (active/experiential/inquiry-based) is perhaps also a testament to the current undergraduate classroom demographics: GenZ and GenAlpha, who are less reliant on textbook-based learning and are used to consuming information on shorter timescales via social media (e.g., Instagram and TikTok reels, YouTube shorts, etc.). Educators with a GenZ student body should be competent in initiating/implementing student-centric learning approaches to develop technological platform-based skills while applying novel technology-supported strategies and methods [26 and references within]. This phenomenon might arise as early as primary school [43] and creates unique, unprecedented teaching hurdles at HEIs for present-day lecturers/professors/instructors. Initial experimental attempts to shift towards I.D. 5.0 reveals four themes: the need for essential interpersonal skills for I.D. 5.0, effective instructional strategies, learning challenges, and a need for detailed support systems [24]. Recent work in Malaysia shows promise for overcoming this, by unifying a Substitute, Augmentation, Modification, and Redefinition (SAMR) model with Technological Pedagogical Content Knowledge frameworks [44]. However, research in Zimbabwe shows educator concerns about the adoption of E.D. 5.0, primarily from personal, collaborative, refocusing, and managerial aspects [39]. They appear most concerned (on a Likert scale) about how E.D. 5.0 would impact them personally and least concerned about how the E.D. 5.0 vision is to be implemented. Recent works have also found value in employing Maturity Models to quantify the E.D. 4.0 to Society 5.0 vision [29] or by using Quadruple/Quintuple Helix Models to create a "smart-sustainable" learning environment

[11]. Others have found potential and promise in the use of Virtual Reality (VR) in a 5.0-era classroom environment [31]. The long-term vision of Society 5.0 is to prepare students to become competent, caring, global citizens [17].

In light of the complex, multi-faceted works in recent years that have comprehensively attempted to capture this interplay between E.D. 4.0/I.D. 4.0, and E.D. 5.0/I.D. 5.0 and Society 5.0, it is critical to analyze the key factor contributing to this change: the shift from E.D. 4.0 to E.D. 5.0, will lead to a consequential shift from I.D. 4.0 to I.D. 5.0, which will lead to the Society 5.0 vision [30]. Indonesia currently has some nascent pedagogical initiatives aimed at experimentally realizing this transition [16], while Bulgaria has attempted this with new library models, to innovate the student learning experience [56]. Therefore, this work focuses on capturing key elements of the E.D. 4.0-E.D. 5.0 shift, using bibliometrics (an initial, restrictive attempt to map E.D. 4.0 & Society 5.0 exists [18]), to obtain tangible, qualitative insights.

Methods

To address the key issues identified in the literature search, a set of Research Questions (hereafter referred to as RQs) were formulated, as summarized in **Table 1**. These RQs form the basis for a detailed bibliometric search on the Scopus database. For each RQ, a search criterion is implemented, and any duplicate results are eliminated using appropriate Inclusion & Exclusion criteria. Search results reveal this work to be a recent topic, but this result is expected since the literature shows that a shift from E.D. 4.0 to E.D. 5.0 has only occurred in recent years. However, despite this being a recent topic, we were able to obtain robust qualitative and quantitative insights on this shift. Note that we have categorized our RQs into three sub-sections: the first four RQs (in orange) capture general trends on the shift from E.D. 4.0 to E.D. 5.0, the next four RQs (in green) narrow down the scope of the previous RQs specifically to engineering and STEM-based fields. The last three RQs (in blue) focus even further, specifically from a lens of chemical engineering within STEM/engineering-based fields. We felt this was the best approach to show global trends and attributes of this phenomenon, and then, capture even more granular details within engineering, and then, within chemical engineering. In the next section, we present the results arising from our comprehensive analysis.

Table 1: Research Questions (RQs) proposed for bibliometric analysis to study E.D. 4.0 to E.D. 5.0 trends.

RQs	Broader Description of the hypothesized Research Questions (RQs)
RQ_1	What key elements and attributes of E.D. 5.0 are found in HEIs?
RQ_2	What insights are obtained from the literature to shift from E.D. 4.0 to E.D. 5.0?
RQ_3	What pedagogy-centric insights are obtained from the literature to shift from E.D. 4.0 to E.D. 5.0?
RQ_4	What pedagogy-centric insights are obtained from the literature to shift from E.D. 4.0 to E.D. 5.0, within Higher Education Institutes (HEIs)?
RQ_5	What key elements and attributes of E.D. 5.0 are found in HEIs, specifically within engineering?
RQ_6	What insights are obtained from the literature to shift from E.D. 4.0 to E.D. 5.0, specifically within engineering?
RQ_7	What pedagogy-centric insights are obtained from the literature to shift from E.D. 4.0 to E.D. 5.0, specifically within engineering?
RQ_8	What pedagogy-centric insights are obtained from the literature to shift from E.D. 4.0 to E.D. 5.0, within Higher Education Institutes (HEIs), specifically within engineering?
RQ_9	What key elements and attributes of E.D. 5.0 are found in HEIs, specifically in chemical engineering?
RQ_{10}	What insights are obtained from the literature to shift from E.D. 4.0 to E.D. 5.0, specifically in chemical engineering?

RQ_{11}	What pedagogy-centric insights are obtained from the literature to shift from E.D. 4.0 to E.D. 5.0, within Higher Education Institutes (HEIs), specifically in chemical engineering?

Results

We now present the results of our bibliometric analysis and identify causal factors resulting in the E.D. 4.0 to E.D. 5.0 transition. Our observed trends appear consistent across all RQs. For each RQ, the co-citation maps and analysis results are presented in the corresponding figures, available in **Appendix A**.

RQ_1 (Key elements of E.D. 5.0 in HEIs): The first RQ focused on understanding and capturing the extent to which E.D. 5.0 has been adopted across Higher Education Institutes (HEIs). A search performed on Scopus limited to the last decade (2014-2024) returned a match of 12396 articles, and the resulting co-citation network/map is presented in **Figure 1**. The most prominent and relevant keywords matching our search are human/humans, article, male/female, controlled study, adult, major clinical study, middle-aged, procedures, genetics, Artificial Intelligence (AI), and child. This suggests that the field of medicine has taken the lead in implementing E.D. 5.0 measures. Across disciplines, the order of implementation is medicine (13%, 3337 articles), computer science (11%, 2828 articles), engineering (10%, 2557 articles), social sciences (7%, 1795 articles) and environmental science (6%, 1495 articles). Chemical engineering stands at 3% (705 articles), suggesting that there is potential for this field to evolve ahead to meet E.D. 5.0 competencies. The top five countries leading these implementation efforts are China (15%, 3480 articles), the United States (10%, 2339 articles), India (7%, 1569 articles), the United Kingdom (4%, 1031 articles), and Germany (3%, 790 articles). Interestingly, we observe two Global South superpowers (India and China) taking the lead on these implementation efforts, as against their Global North counterparts. Publication trends for RQ_1 for the last decade show a cubic increase in the number of publications $N_{articles}$ with time t ($N_{articles} \sim t^3$); these results are summarized in **Figure 2**. A strong correlation coefficient ($R^2 = 0.9972$) provides additional quantitative evidence to our observation trends.

RQ_2 (Capturing the shift from E.D. 4.0 to E.D. 5.0): Next, we wanted to capture the most global attributes of the shift from E.D. 4.0 to E.D. 5.0 and narrowed the search criteria on Scopus. The search led to a match of 6794 articles, and the resulting co-citation map is presented in **Figure 3**. The largest clusters are centered around the following keywords: human/humans, Industry 4.0 (I.D. 4.0), article, AI, female/male, Industry 5.0 (I.D. 5.0), adult, controlled study, sustainable development/sustainability, Internet of Things (IoT), engineering education, digital transformation, Machine Learning (ML), education, students, Virtual Reality (VR), decision making, blockchain and industrial revolution. This reveals that the move from E.D. 4.0 to 5.0 is characterized by similar aspects of the E.D. 4.0 revolution [12] but now has a more human-focused aspect. Additionally, these keywords are all indicative of a digital twin – which is a virtual replica of a system or process and is often used to tailor the learning process to a person. This is a key differentiator between the 5th and 4th generations of industrial revolutions. The fields leading this change are computer science (17%, 2507 articles), engineering (14%, 2133 articles), the social sciences (11%, 1668 articles), business, management and accounting (10%, 1456 articles) and medicine (6% 933 articles). The top five countries where this shift is most observed in the last decade are India (11%, 1127 articles), China (8%, 872 articles), the United States (7%, 741 articles), Indonesia (5%, 536 articles) and the United Kingdom (4%, 450 articles). Again, a strong correlation coefficient ($R^2 = 0.9877$) proves that the move from E.D. 4.0 to 5.0 has occurred rapidly in the last decade, particularly over the last five years. All these results are summarized in **Figure 4** and prove the validity of our RQ. While the move towards the 5th Industrial Revolution has become prominent over the last few years globally, it has occurred slowly and steadily over the last decade and is only now ramping forward.

RQ_3 (Capturing the shift from E.D. 4.0 to E.D. 5.0 from a pedagogy lens): We naturally wanted to investigate how pedagogy has impacted the shift towards E.D. 5.0 globally and accordingly narrowed our search. 528 articles matched the search criteria and led to the creation of the co-citation map presented in **Figure 5**. The top clusters are centered around engineering education, I.D. 4.0, students, e-learning, teaching, digital transformation, higher education, AI, education, curricula, sustainability/sustainable development, E.D. 4.0, I.D. 5.0, learning, Industrial Revolutions, Society 5.0, technology, VR, decision making, Augmented Reality (AR), humans, and learning systems. This set of keywords presents clear evidence of the direct impact that pedagogy makes to impact this shift and proves that we must see pedagogy as a tool to catalyze this change. Subject areas where this change is most apparent and perceivable are social sciences (24%, 266 articles), computer science (20%, 222 articles), engineering (12%, 130 articles), business, management, and accounting (9%, 101 articles) and economics, econometrics and finance (6%, 64 articles).

The top five nations best matching our RQ_3 search criteria are Indonesia (14%, 105 articles), India (10%, 80 articles), the United States (6%, 42 articles), Malaysia (5%, 38 articles), and the United Kingdom (4%, 31 articles). As shown in **Figure 6**, publication trends remain similar, but the trends are only observable from 2017 – in other words, this means that it has only been since 2017 that pedagogy has been harnessed as a suitable tool to empower the global shift from E.D. 4.0 to E.D. 5.0. This is a very interesting observation and is reinforced by a strong correlation coefficient ($R^2 = 0.9894$), further validating our conclusion.

RQ_4 (Capturing the impact of HEIs and pedagogy to enable the E.D. 4.0 to E.D. 5.0 shift): In the context of universities and HEIs, this is the most significant RQ that can capture the most observable traits and attributes of the shift from E.D. 4.0 to E.D. 5.0. The search was narrowed even further and returned a match of 249 articles. However, we were still able to generate a co-citation network as shown in **Figure 7**, with the largest clusters being centered around these keywords: engineering education, I.D. 4.0, AI, teaching, students, curricula, e-learning, sustainability, higher education/education, digital transformation, sustainable development, Industrial Revolutions, covid-19, I.D. 5.0, digitization, E.D. 4.0, Society 5.0, sustainable development goals, systematic literature review, VR, teachers, education computing, learning/learning systems and metaverse/metaverses. When analyzed together, these keywords present a narrative that the world has observed in recent years: the occurrence of the COVID-19 global pandemic triggered a global shift from in-person to online learning. Consequently, HEIs have assimilated pedagogical measures in recent years to make the learning experience more personalized and more holistic, which led to the incorporation of specific learning modalities (active/experiential/inquiry-driven/flipped classroom) into the classroom experience. Disciplines that were most able to make the shift successfully were: (expectedly) computer science (21%, 119 articles), social sciences (20%, 109 articles), engineering (11%, 63 articles), business, management and accounting (10%, 57 articles) and economics, econometrics and finance (7%, 38 articles). Chemical engineering stands at 3%, suggesting that this field has some significant changes to be made, to realize the E.D. 5.0 vision. Countries leading this change are India (15%, 58 articles), Indonesia (10%, 41 articles), the United States (6%, 23 articles), Portugal, and the United Kingdom (each at 4%, 16 articles respectively). As seen in **Figure 8**, we again observe a strong correlation coefficient ($R^2 = 0.9865$) suggesting that even with a limited dataset, our results are still robust.

The next set of RQs was intended to further refine our search criteria, and focus more on engineering and Science, Technology, Engineering, and Mathematics (STEM) based or centric fields.

RQ_5 (Key elements of E.D. 5.0 in HEIs in engineering): A search performed on Scopus for this RQ led to 6971 articles matching our criteria. The resulting co-citation network captures the most synergistic aspects of these papers, as is presented in **Figure 9**. Search clusters are most clustered around these keywords: article, human/humans, AI, controlled study, I.D. 4.0, ML, IoT, chemistry, engineering education, sustainability/sustainable development, I.D. 5.0, male/female, decision making and deep learning. Disciplines most matching this search are computer science (15%, 2456 articles), engineering (15%, 2344 articles), social sciences (7%, 1153 articles), environmental science (7%, 1081 articles), and physics and astronomy (5%, 818 articles). Chemical engineering contributes to 4% of this distribution, with 592 articles being published over the last decade about this RQ. While this is a sign of progress, more needs to be done when compared to other disciplines. Countries that lead this initiative are China (18%, 2316 articles), India (9%, 1176 articles), the United States (7%, 890 articles), the United Kingdom (3%, 457 articles) and Germany (3%, 397 articles). What is interesting to note is that for all trends analyzed till now, China and India emerge as the major Global South players and contribute significantly towards the shift towards E.D. 5.0. The correlation coefficient for this RQ is again strong ($R^2 = 0.9929$), which proves that our analysis is robust. The correlation coefficient is also stronger as there is a larger dataset that VOS viewer can scan through, to produce the co-citation network. All these results are summarized in **Figure 10**.

RQ_6 (Capturing the shift from E.D. 4.0 to E.D. 5.0 in engineering): Next, we specifically wanted to analyze and capture how the shift from E.D. 4.0 to 5.0 has manifested in engineering fields. To do this, we narrowed down the search from the previous RQ, leading to a match of 5095 articles. Therefore, this means that most of the articles that matched the RQ_5 search have also captured this shift! Looking at the results presented in the co-citation map in **Figure 11**, the largest clusters are centered around the following keywords: I.D. 4.0, AI, I.D. 5.0, sustainability/sustainable development, IoT, engineering education, digital transformation, ML, human, article, decision making, blockchain, students, Industrial Revolutions, VR, e-learning, innovation, digitization, learning systems, smart manufacturing, AR, systematic literature review, manufacturing, humans, Society 5.0, education, digital twin, big data, deep learning, technology, bibliometric analysis, digital technologies and higher education. These keywords are again evidence of the coherence of our analysis, as these keywords capture key elements and attributes of the E.D. 4.0 to E.D. 5.0 shift that is currently occurring in engineering. Fields best matching our search criteria were found to be computer science (19%, 2260 articles), engineering (17%, 2000 articles), social sciences (11%, 1311 articles), business, management and accounting (10%, 1213 articles) and economics, econometrics and finance (5%, 642 articles). The top five countries that best matched our search criteria are India (12%, 980 articles), China (8%, 648 articles), the United States (5%, 434 articles), Indonesia (5%, 392 articles), and the United Kingdom (4%, 332 articles). Again, our research and postulated trends are supplemented by a strong value of the correlation coefficient ($R^2 = 0.9842$) as summarized in **Figure 12**. Our results demonstrate that the 5th Industrial Revolution is currently underway globally, and specifically visible across these nations.

RQ$_7$ (Capturing the shift from E.D. 4.0 to E.D. 5.0 from a pedagogy lens, specifically in engineering): Next, we further refined the search to approach the move from E.D. 4.0 to E.D. 5.0 in engineering, from the lens of pedagogy. A search implemented on VOS viewer led to a match of 441 articles, and the consequently arising co-citation network is presented in **Figure 13**. The largest clusters are centered around the keywords of engineering education, I.D. 4.0, students, e-learning, AI, digital transformation, higher education, education, E.D. 4.0, sustainability/sustainable development, teaching, curricula, I.D. 5.0, learning, VR, decision making, Industrial Revolutions, AR, technology and Society 5.0. These keywords clearly show that there is a pivotal role HEIs, and pedagogy play towards facilitating the shift to E.D. 5.0, and it has been observed more prominently from 2017 (which is the earliest year for which we have data matching our search criteria). Classified by fields, the top sectors where this initiative and transformation has been observed are the social sciences (23%, 216 articles), computer science (21%, 196 articles), engineering (13%, 121 articles), business, management and accounting (9%, 89 articles) and economics, econometrics and finance (6%, 56 articles). Chemical engineering only contributes 7 articles in this area, suggesting that much more needs to be done in the field to realize the E.D. 5.0 vision in engineering, from a pedagogical perspective. Countries leading these efforts are Indonesia (12%, 79 articles), India (12%, 77 articles), the United States (6%, 38 articles), Malaysia (5%, 34 articles) and the United Kingdom (4%, 27 articles). Publication trends also show a strong coherence ($R^2 = 0.9903$) over the past decade, as shown in **Figure 14**.

RQ$_8$ (The shift from E.D. 4.0 to E.D. 5.0 from a pedagogy lens, specifically in HEIs in engineering): Finally, we performed one final refinement of the search criteria to analyze how Higher Education Institutes (HEIs) specifically have adopted over the last decade to enable the shift from E.D. 4.0 to E.D. 5.0. To that effect, our search on Scopus returned a match of 210 articles fitting this criterion. The resulting co-citation network (refer to **Figure 15**) reveals the largest cluster to center around the following keywords: engineering education, I.D. 4.0, AI, e-learning, students, curricula, higher education, sustainability/sustainable development, digital transformation, teaching, education, Industrial Revolutions, I.D. 4.0, E.D. 4.0, VR, covid-19, learning/learning systems, metaverse/ metaverses, education computing, systematic literature review, AR, decision making, digitization, distance learning, and IoT. The fields most matching our search are computer science (22%, 106 articles), social sciences (19%, 90 articles), engineering (13%, 60 articles), business, management, and accounting (10%, 50 articles) and economics, econometrics and finance (7%, 33 articles). Chemical engineering has a meager contribution of 3 articles, which leads us to conclude that this field must take appropriate measures to realize the E.D. 5.0 vision by tactically employing pedagogy and engineering education as tools in engineering at HEIs. Countries best matching this search are India (16%, 55 articles), Indonesia (10%, 34 articles), the United States (6%, 21 articles), Malaysia (4%, 14 articles) and the United Kingdom (also at 4%, 14 articles). Again, we are only able to record data for this initiative since 2017, yet we observe a strong coherence ($R^2 = 0.9832$) and an increase in publication trends, as evident in **Figure 16**. In summary, the RQs analyzed till now have presented definitive, conclusive evidence of (i) an observable shift from E.D. 4.0 to E.D. 5.0 that has occurred over the last decade, (ii) this shift has been observed across some specific fields (engineering, social sciences, computer science, etc.), (iii) the major impetus for this change has arisen from countries from the Global South (India, China, Malaysia, Indonesia, etc.) and (iv) this change has been observed globally across HEIs.

Finally, we decided to specifically limit the search to chemical engineering (and fields indirectly associated with it), to analyze and get even finer details specific to this discipline. The next three RQs present results from this aspect.

RQ$_9$ (Key elements of E.D. 5.0 in HEIs, specifically in chemical engineering): A search conducted on Scopus for this RQ led to us obtaining a match of 705 articles over the last decade. The low number of articles is expected since we have tremendously narrowed the search. However, we were still able to capture good details, as presented in the co-citation network in **Figure 17**. The largest clusters are centered around the following keywords: article, controlled study, human/nonhuman, pH, metabolism, unclassified drug, chemistry, carbon, genetics, I.D. 4.0, priority journal, Scanning Electron Microscopy (SEM), adsorption, nanoparticles, density functional theory, procedures, synthesis, AI, and animals. While these keywords are mostly on certain specific areas of research in chemical engineering, we still end up with two important keywords (I.D. 4.0 and AI) that hint at the shift occurring within this field towards E.D. 5.0. The reason why chemical engineering scored lower as a discipline in our previous RQs now becomes evident – it appears that the shift towards E.D. 5.0 is still in its nascent stages, and further work needs to be done to achieve the Society 5.0/ E.D. 5.0/ I.D. 5.0 vision in chemical engineering. For this search, the fields most matching were chemical engineering (31%, 705 articles), chemistry (16%, 357 articles), engineering (11%, 257 articles), materials science (10%, 217 articles) and computer science (7%, 169 articles). Countries leading our search results are China (35%, 361 articles), the United States (6%, 65 articles), India (6%, 63 articles), Germany (3%, 30 articles) and Brazil (3%, 26 articles). Publication trends have shown a steady increase ($R^2 = 0.9785$) over the last decade, as shown in **Figure 18**. It is testimony to the fact that although this field has yet to achieve the E.D. 5.0 target, efforts have increased over the last decade to realize this.

RQ_{10} (Capturing the shift from E.D. 4.0 to E.D. 5.0, specifically within chemical engineering): Next, we narrowed the search further by aiming to capture within chemical engineering those works that have explicitly addressed or proposed any initiatives to move from E.D. 4.0 to E.D. 5.0, and 287 articles matched our search criterion. The most relevant keywords arising from the co-citation network in **Figure 19** are I.D. 4.0, article, AI, engineering education, I.D. 5.0, ML, controlled study, nonhuman, pH, students, big data, chemistry, education, unclassified drug, IoT, sustainability/sustainable development, kinetics, ML, metabolism, adsorption, digital twin, learning systems, robotics, learning systems, and smart manufacturing. Note that narrowing the search leads to the emergence of similar keywords as we have encountered before, this corroborates our previous conclusion that the move from E.D. 4.0 to E.D. 5.0 has also begun in chemical engineering in the last decade. The fields best matching our search are chemical engineering (30%, 287 articles), engineering (17%, 162 articles), materials science (11%, 111 articles), computer science (11%, 110 articles), and physics and astronomy (9%, 88 articles). Countries who have most implemented the E.D. 4.0 to 5.0 transition are China (20%, 79 articles), India (7%, 26 articles), Poland (5%, 19 articles), Germany (5%, 18 articles) and Malaysia (3%, 11 articles). Surprisingly, even with the (rather) limited number of datasets for this RQ, we were pleased to see similar publication trends as those of our previous RQs, supplemented by a strong ($R^2 = 0.9839$) coefficient of correlation, as presented in **Figure 20**.

RQ_{11} (Capturing the shift from E.D. 4.0 to E.D. 5.0 from a pedagogy lens, specifically in chemical engineering): We further narrowed the search even further, to investigate if there were any pedagogical approaches found in chemical engineering that have facilitated the E.D. 4.0 to 5.0 shift over the last decade. As the search was very narrow, results were (expectedly) limited, with only 7 articles meeting our search criteria. While we do present our results here, we caution the reader to generalize the conclusions for RQ_{11}, as it is only with time that we can gauge the accuracy of the predictions presented for this RQ. Surprisingly, we obtained a co-citation network for this RQ, as shown in **Figure 21**. The clusters are centered around the keywords of the digital twin, engineering education, students, education, I.D. 4.0, 6G, active learning, advanced technologies/technology, AI, autonomous robotics, big data, and big data analytics. Note that one of the keyword clusters is active learning, which is a key pedagogical methodology currently implemented in HEIs. To us, this assures that even with our limited dataset, the bibliometric analysis can capture some tangible details and aspects of this transformation. Fields where this transformation is most visible are chemical engineering (29%, 7 articles), engineering (25%, 6 articles), computer science (13%, 3 articles), materials science (13%, 3 articles) and chemistry (8%, 2 articles). The top countries matching our search were Austria, China, Finland, India, Indonesia, Malaysia, South Africa, and Spain (each with 1 article at 12.5% contribution). While we recognize this as (extremely) preliminary data, we still wanted to present this RQ, as it directly identifies the scope for future research work in this field. These results are summarized in **Figure 22**.

Conclusions

Our analysis results are multifaceted, and comprehensive, and call for a conscious investigation and revamp of the role of HEIs to prepare future I.D. 5.0 attractive professionals [48]; educators also need to transform to higher thinking levels, in the era of Society 5.0 [55]. The distinguishing feature of Society 5.0 is the vivid interconnect between humans, systems, and things in cyberspace, and AI-assisted optimized results are used as feedback, to improve this interaction [38]. Our bibliometric analysis co-citation networks also echo the conscious evolution of 4Cs (Communication, Collaboration, Creativity, and Critical Thinking) abilities in the classroom [33]. Assimilation of these skills and teaching approaches by educators in HEIs can pave the path towards ushering in the E.D. 5.0-I.D. 5.0 revolution. Recent works show that realizing I.D. 4.0/I.D. 5.0 is the first step towards the Society 5.0 vision and requires the strategic and innovative use of the 4Cs [25]. This same trend is qualitatively observed in all our co-citation networks, independently proving this I.D. 5.0/Society 5.0 interdependence. Luna et al. [32] suggest pedagogical transformation and the creation of an omni digital education, assisted by Information and Communication Technology (ICT); our results also confirm this. We also agree with the observations of Broo et al [10] that the hallmark identifiers of I.D. 5.0 are (i) transdisciplinary education and an approach fostering lifelong learning, (ii) sustainability, resilience, human-centric design-oriented modules, (ii) courses on hands-on data fluency and management, (iii) human/agent/machine/robot/computer interactions and interplay. The realization of I.D. 5.0 in any institute will inevitably and chronologically usher in the Society 5.0 vision [11], and HEIs can benefit from this knowledge by jumping on the bandwagon sooner rather than later. Educators must continue to play a crucial role by demonstrating teaching/research competence, acting as role models to their students, being at the forefront of pedagogical research/innovation and keeping themselves updated, and demonstrating and inspiring qualities such as leadership, teamwork, creativity, competence, problem-solving, and critical thinking [19, 20 and references within]. Most importantly, our RQs reveal some very interesting (and consistent) trends: the countries currently leading the E.D. 4.0 to E.D. 5.0 transformation are India, Malaysia, Italy, and Portugal, while countries like the United States, the United Kingdom, China, and Canada are yet to perform and enact these initiatives. Our results show that the United States, the United Kingdom, and China are now taking initiatives to move from E.D. 4.0 to E.D. 5.0, especially in engineering and STEM-based fields. Disciplines where this transformation is most evident and observable currently are Computer Science, Engineering (STEM fields), Economics, Econometrics and Finance, Business, Management and Accounting and Social Sciences. Within chemical engineering, our bibliometric analysis echoes these trends and calls for more implementation and transformative measures to make the E.D. 4.0 to E.D. 5.0 shift for this field. Publication trends show a clear increasing trend; it appears that this shift may also have been likely catalyzed by the occurrence of the COVID-19 global pandemic (since publication trends show a sharp, rapid increase from 2021). We expect this trend to continue, and thus, this work presents the first comprehensive bibliometric mapping of this phenomenon and identifies clear attributes and indicators that HEIs can work towards, to transform towards E.D. 5.0, to realize the I.D. 5.0 and Society 5.0 vision. The regression coefficient $R^2 > 0.97$ for all our RQs suggests extremely strong coherence of our data, strengthening evidence for our claims; and we may say with strong certainty that research articles studying E.D. 4.0 to E.D. 5.0 trends are expected to grow rapidly in chemical engineering, engineering, and is likely a trend that will impact almost all fields in future. In summary, this work presents a comprehensive overview, supported by robust evidence, of the transition from E.D. 4.0 to E.D. 5.0, and reveals a solid, bibliometric analysis-based methodology to capture and analyze these changes. Future work we intend to undertake, building on this work is to investigate socio-cultural challenges and economic barriers that can empower economies towards adopting an E.D. 5.0 framework, and how these discrepancies are observed specifically in the Global North and Global South blocs. Recently, we were also able to conclusively demonstrate the existence of an AI implementation gap between the two country blocs, which is further widened if two major Global South players (India and China) are excluded from the analysis. It is likely this AI gap also impacts the realization and actualization of the E.D. 5.0 – I.D. 5.0 – Society 5.0 vision globally.

Conflicts of Interest

The authors declare no conflicts of interest.

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Appendix A: Bibliometric analysis results for our posed Research Questions (RQs).

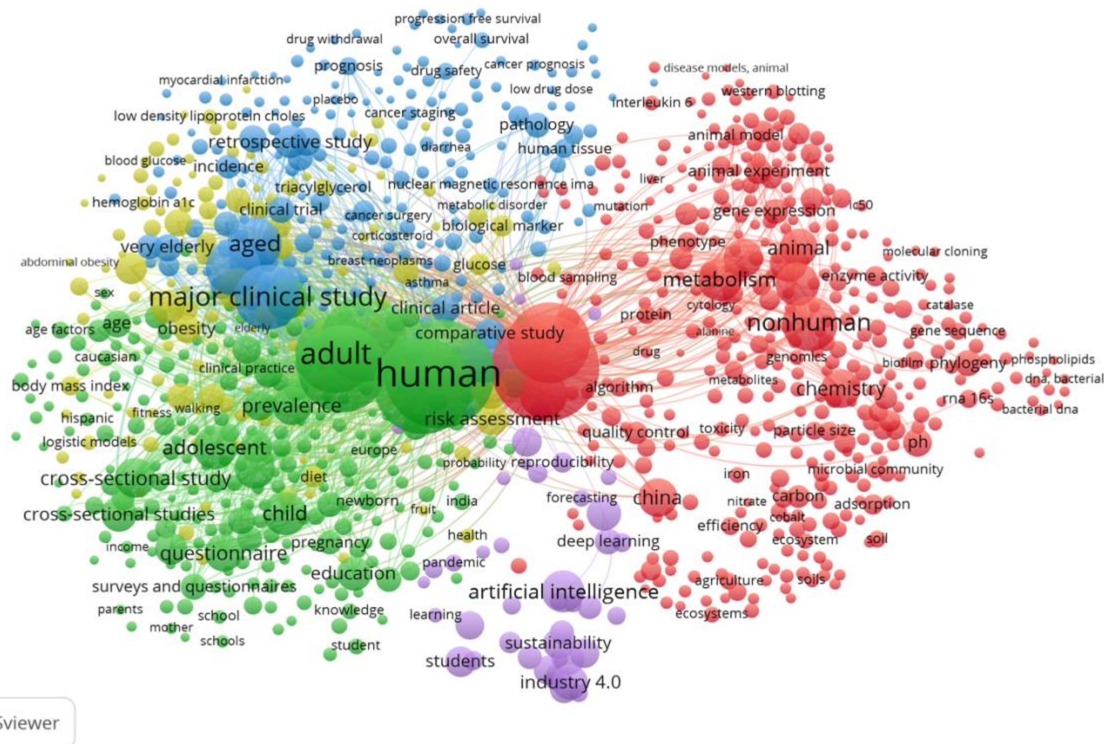
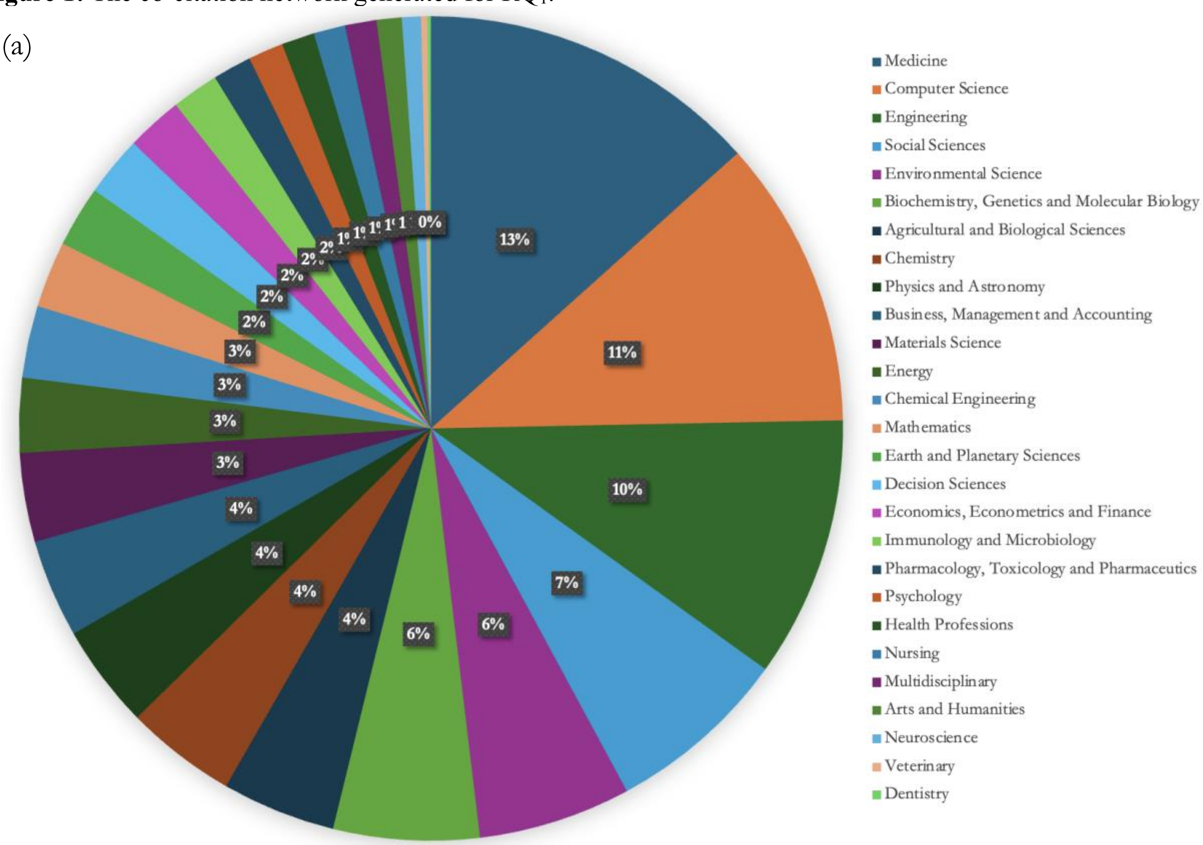


Figure 1: The co-citation network generated for RQ_1.

(a)



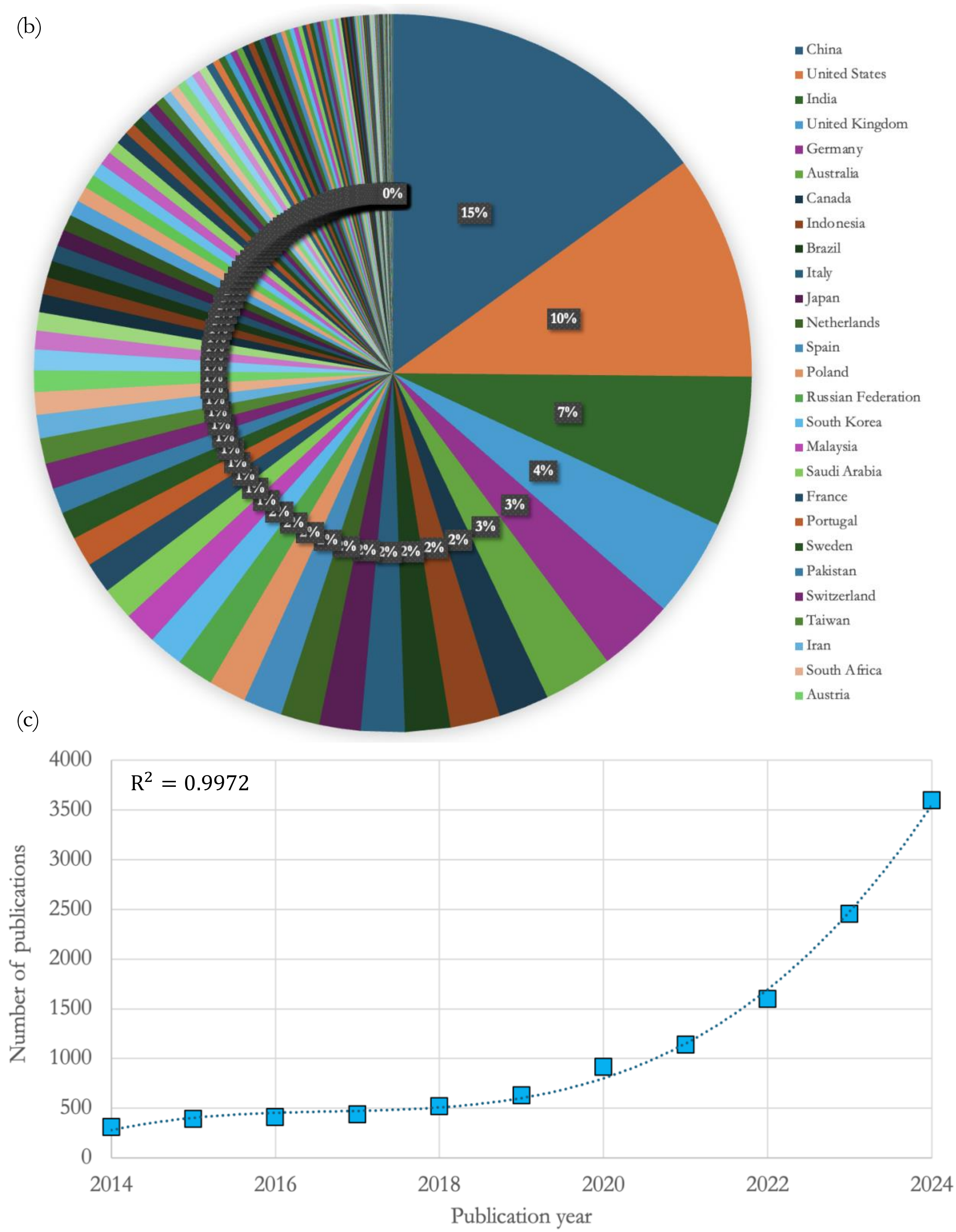


Figure 2: (a) RQ_1 trends by discipline areas/sectors, (b) by countries, and (c) publication trends in the last decade.

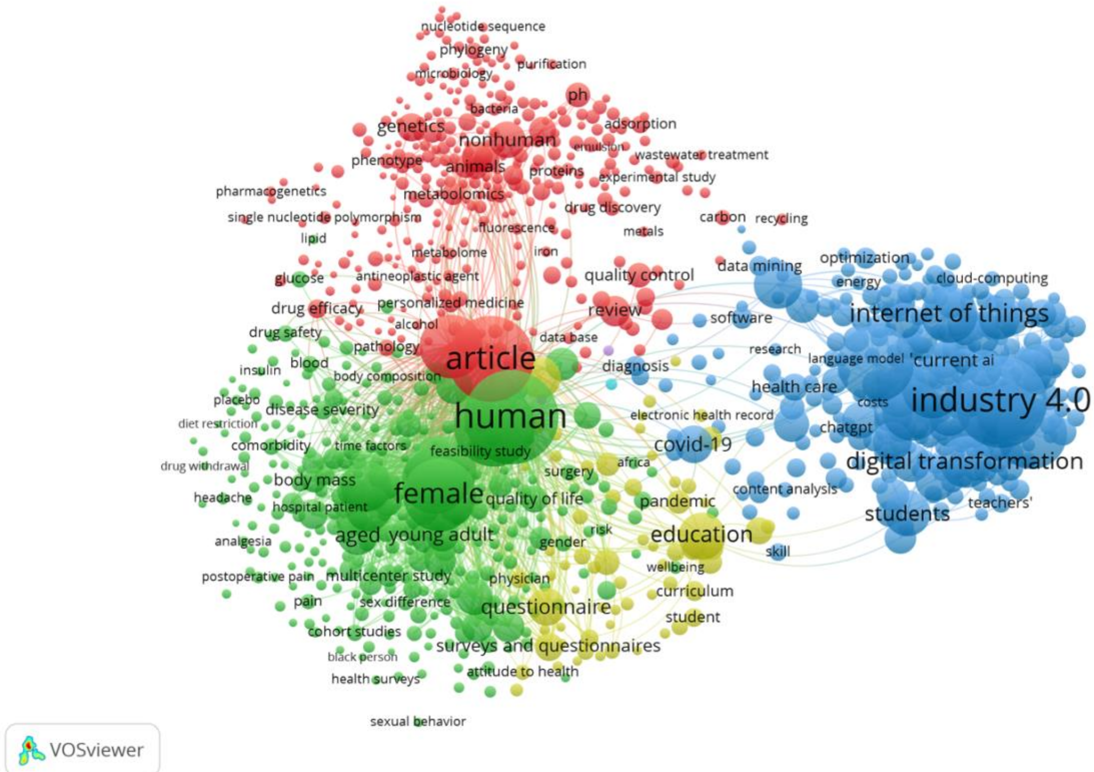
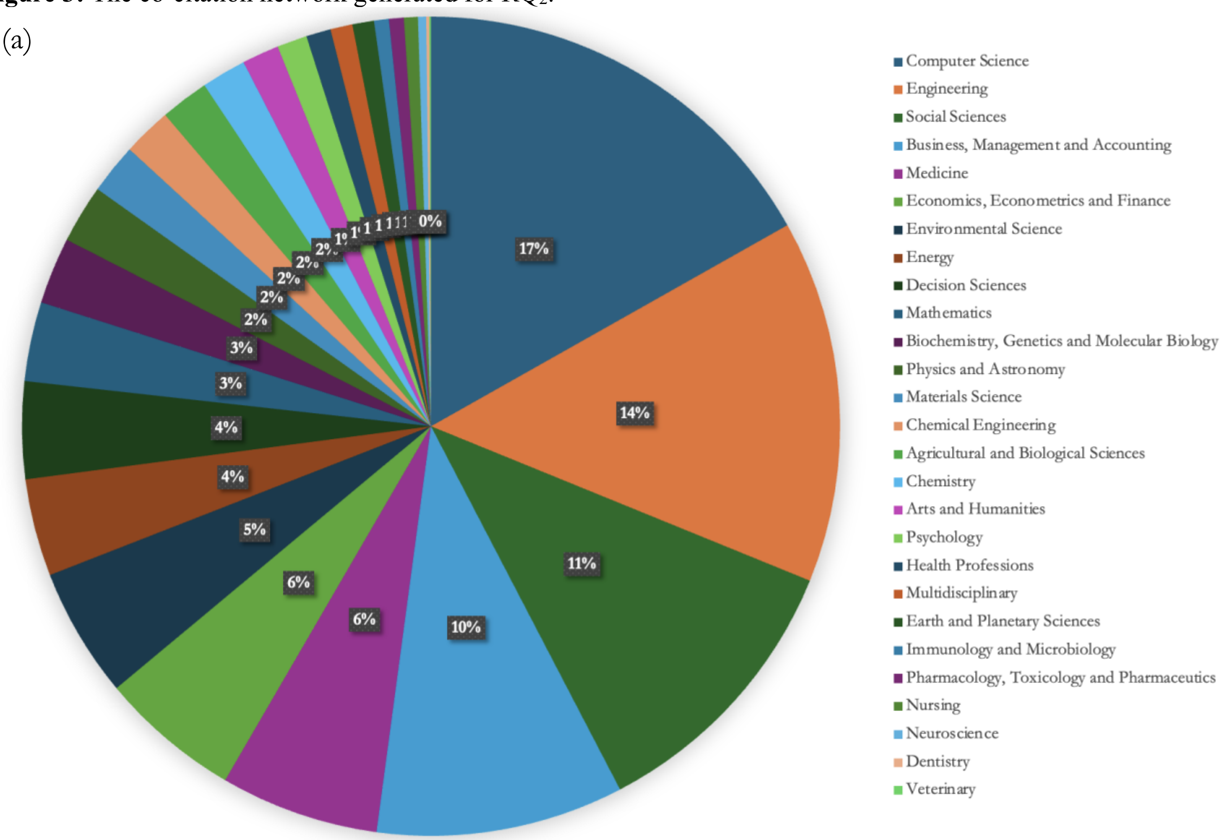
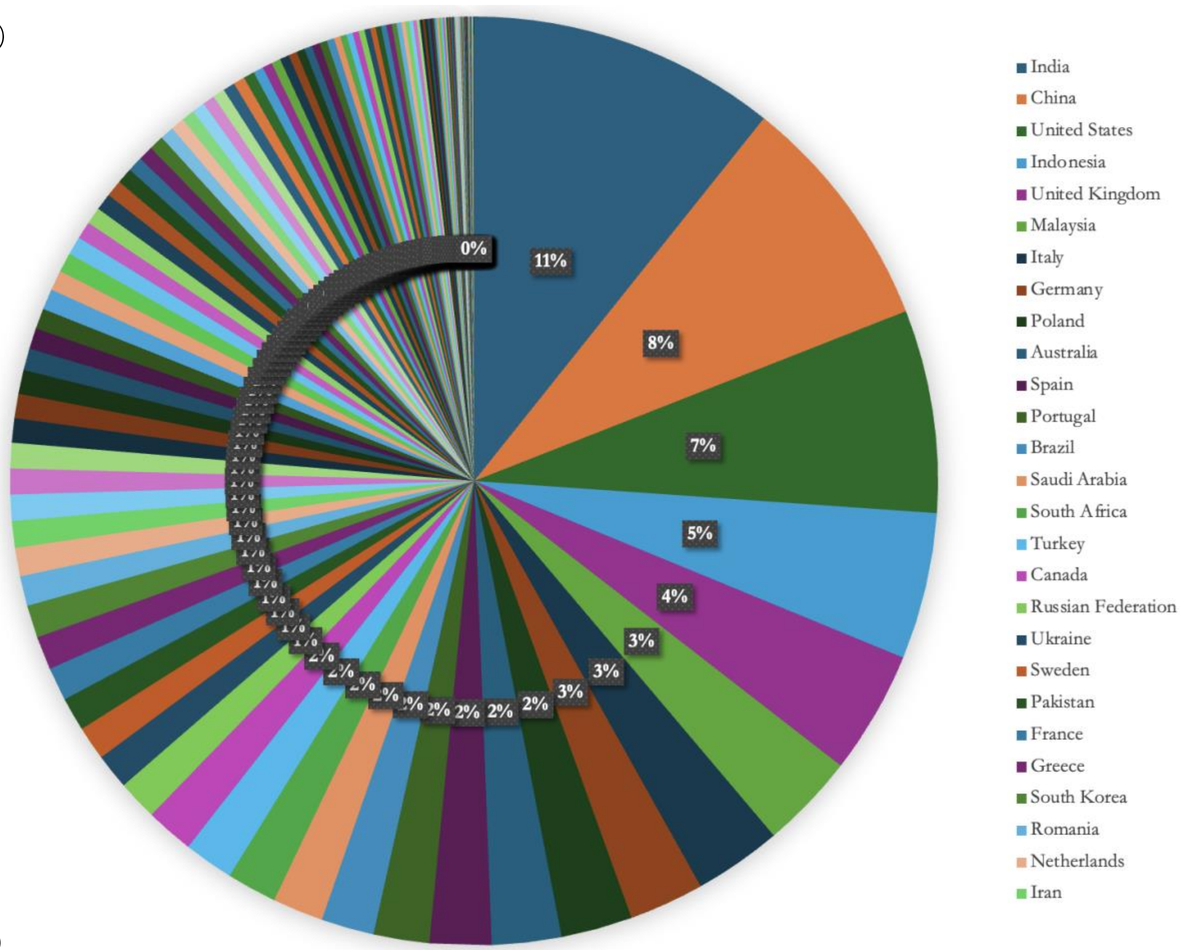


Figure 3: The co-citation network generated for RQ_2.

(a)



(b)



(c)

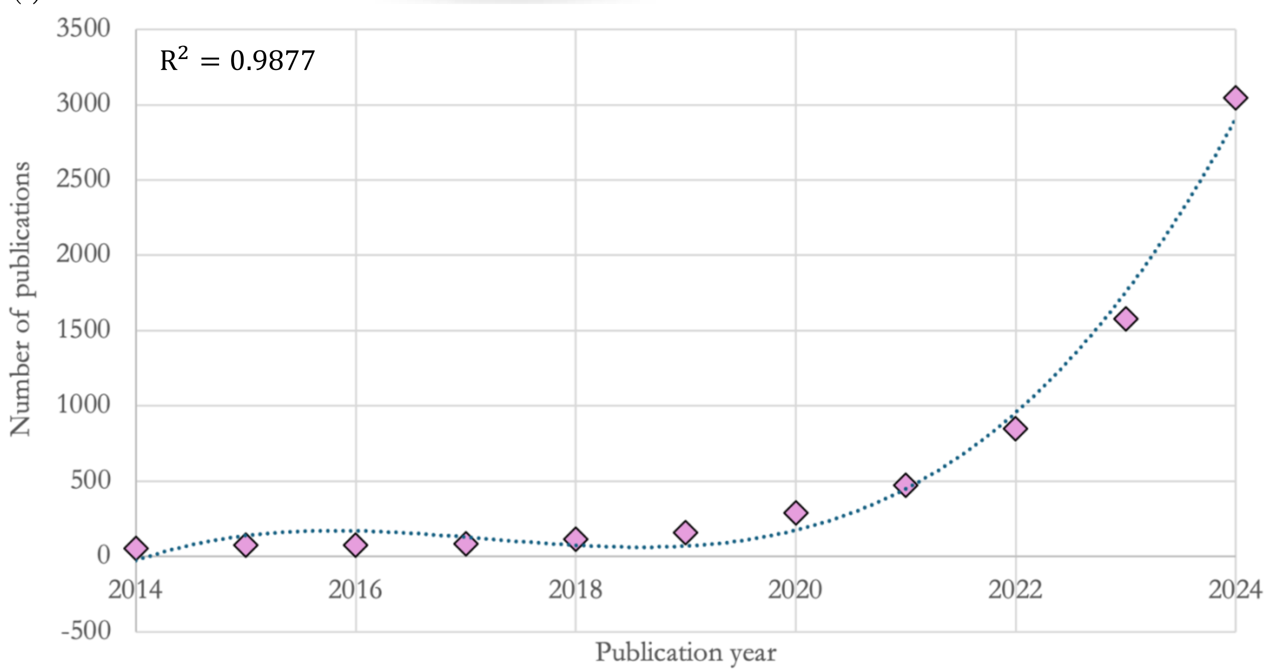


Figure 4: (a) RQ_2 trends by discipline areas/sectors, (b) by countries, and (c) publication trends in the last decade.

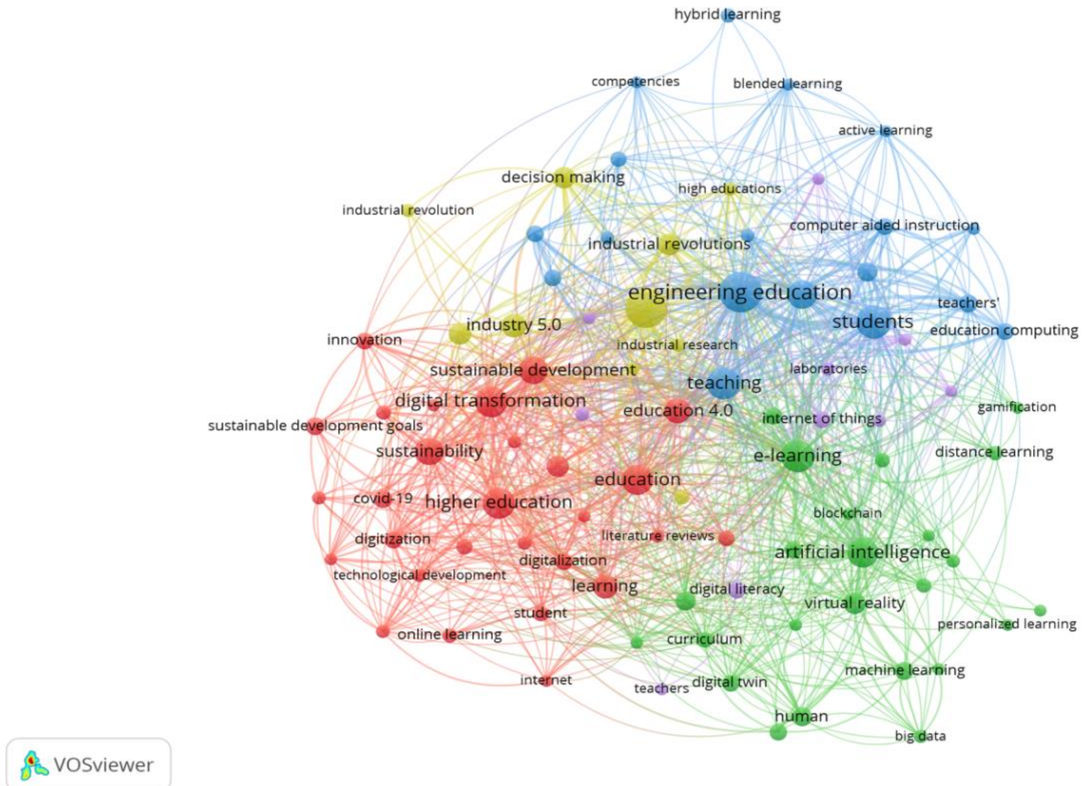
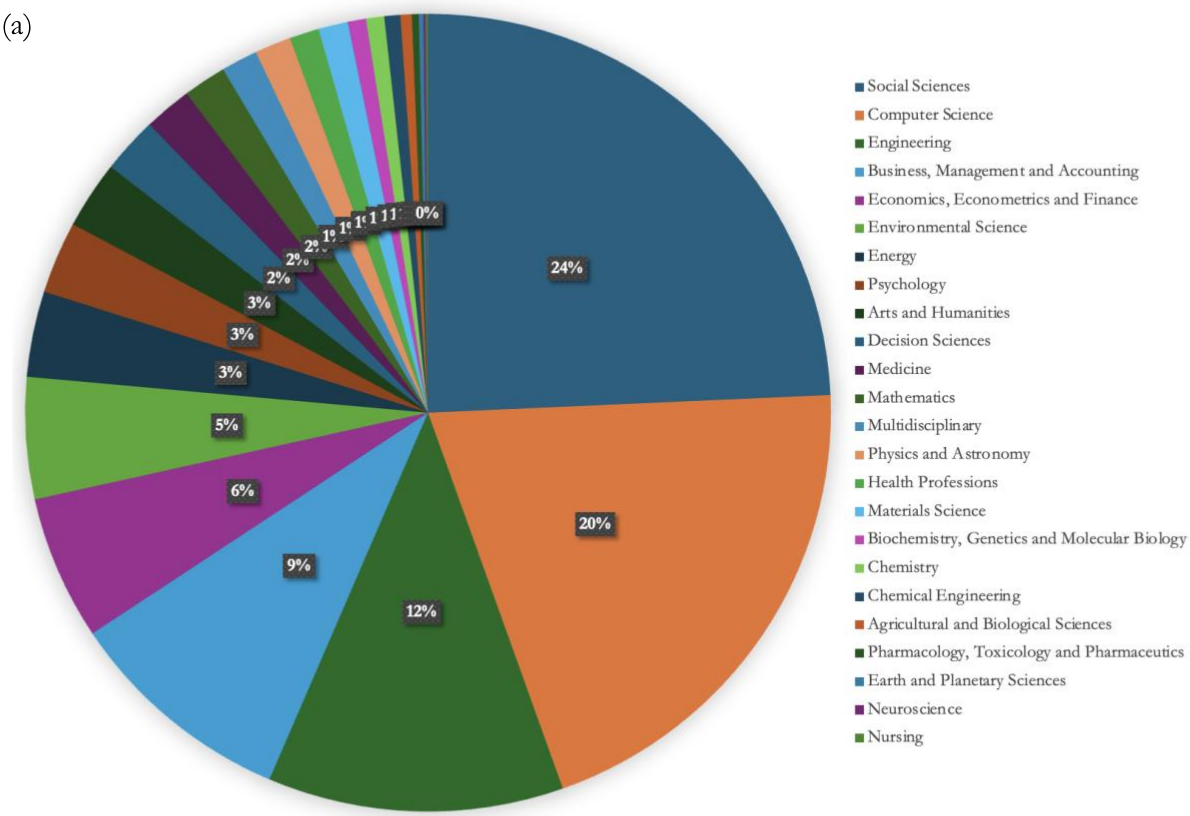


Figure 5: The co-citation network generated for RQ$_3$.

(a)



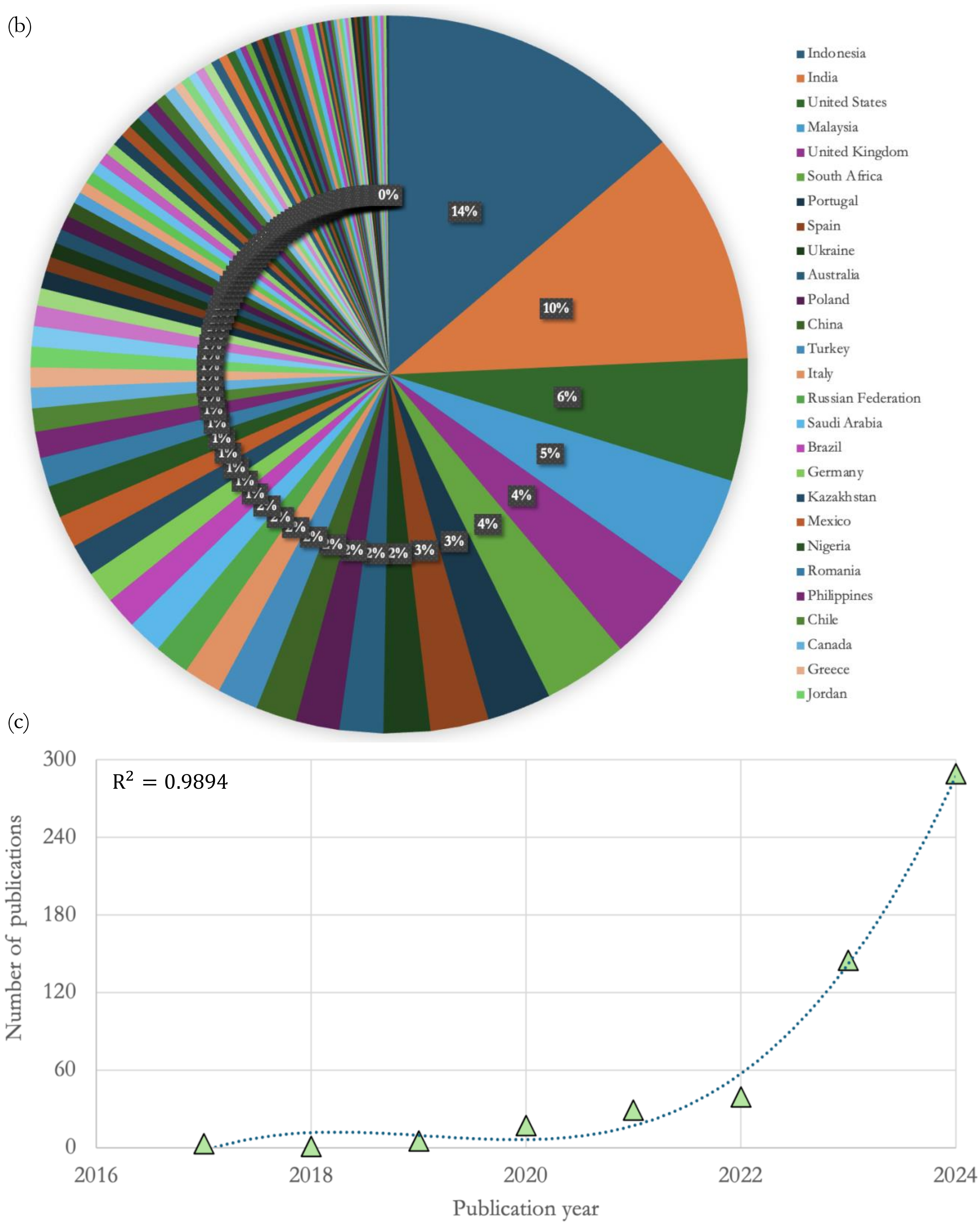


Figure 6: (a) RQ_3 trends by discipline areas/sectors, (b) by countries, and (c) publication trends in the last decade.

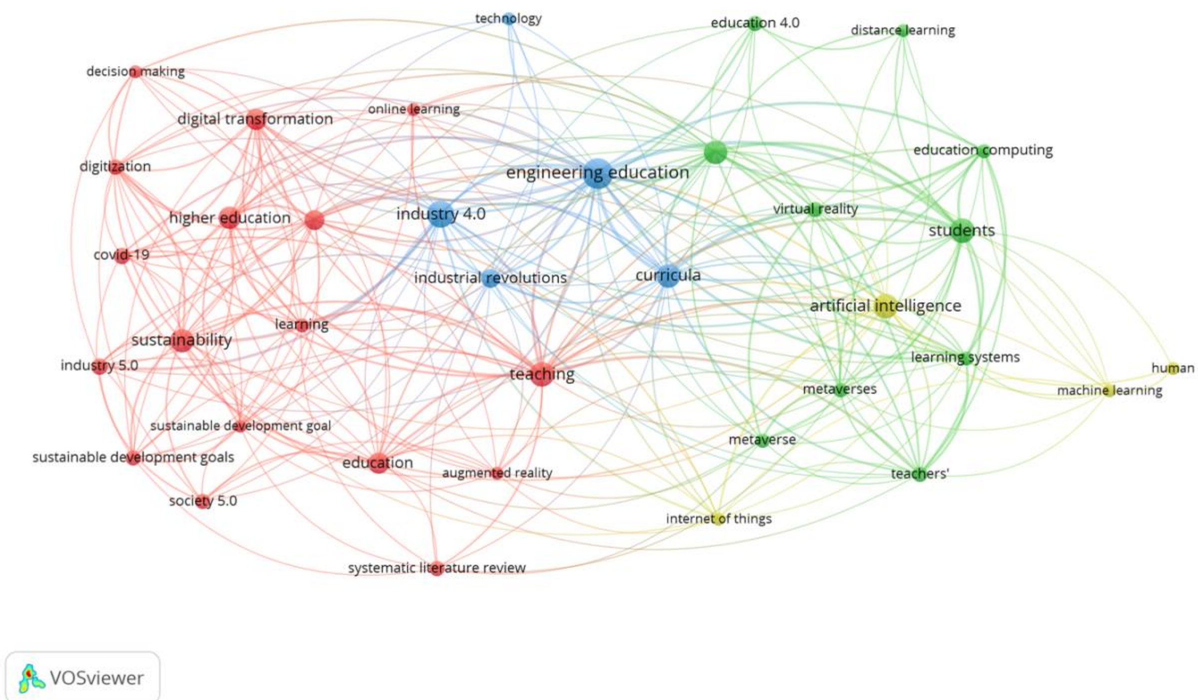
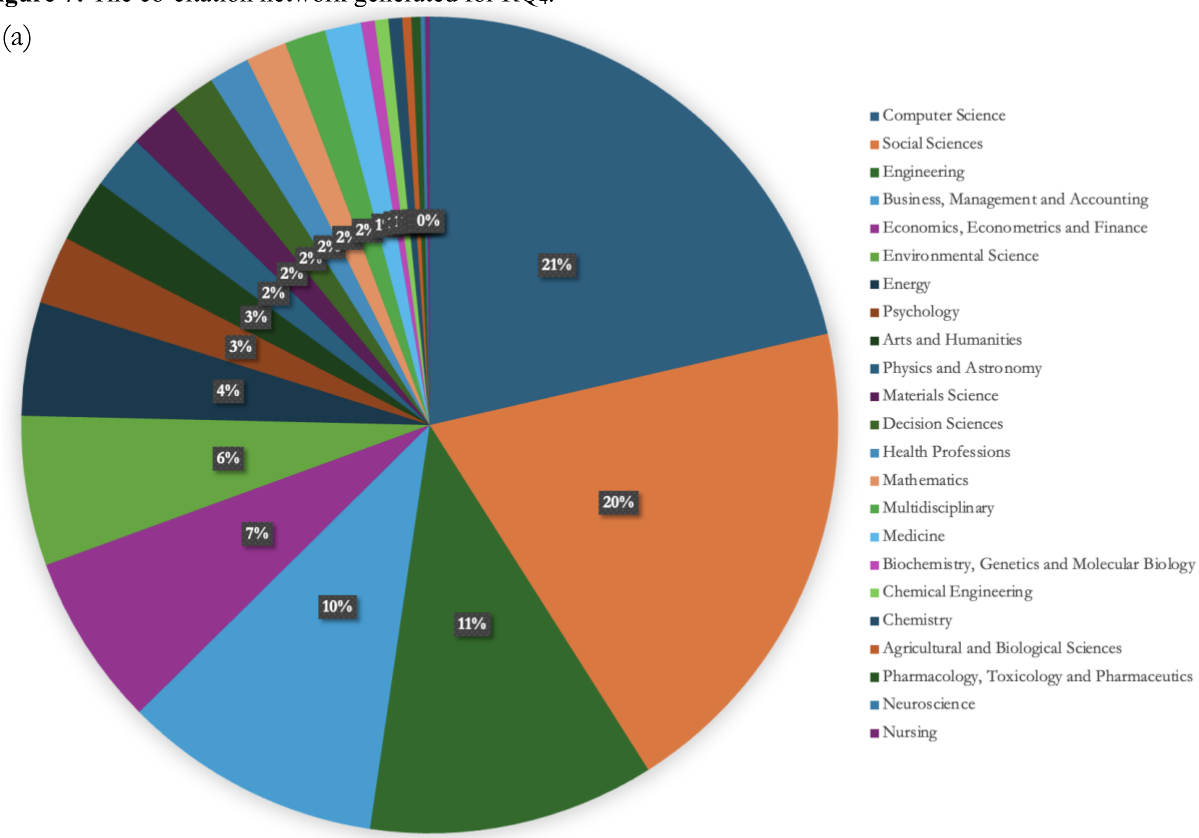
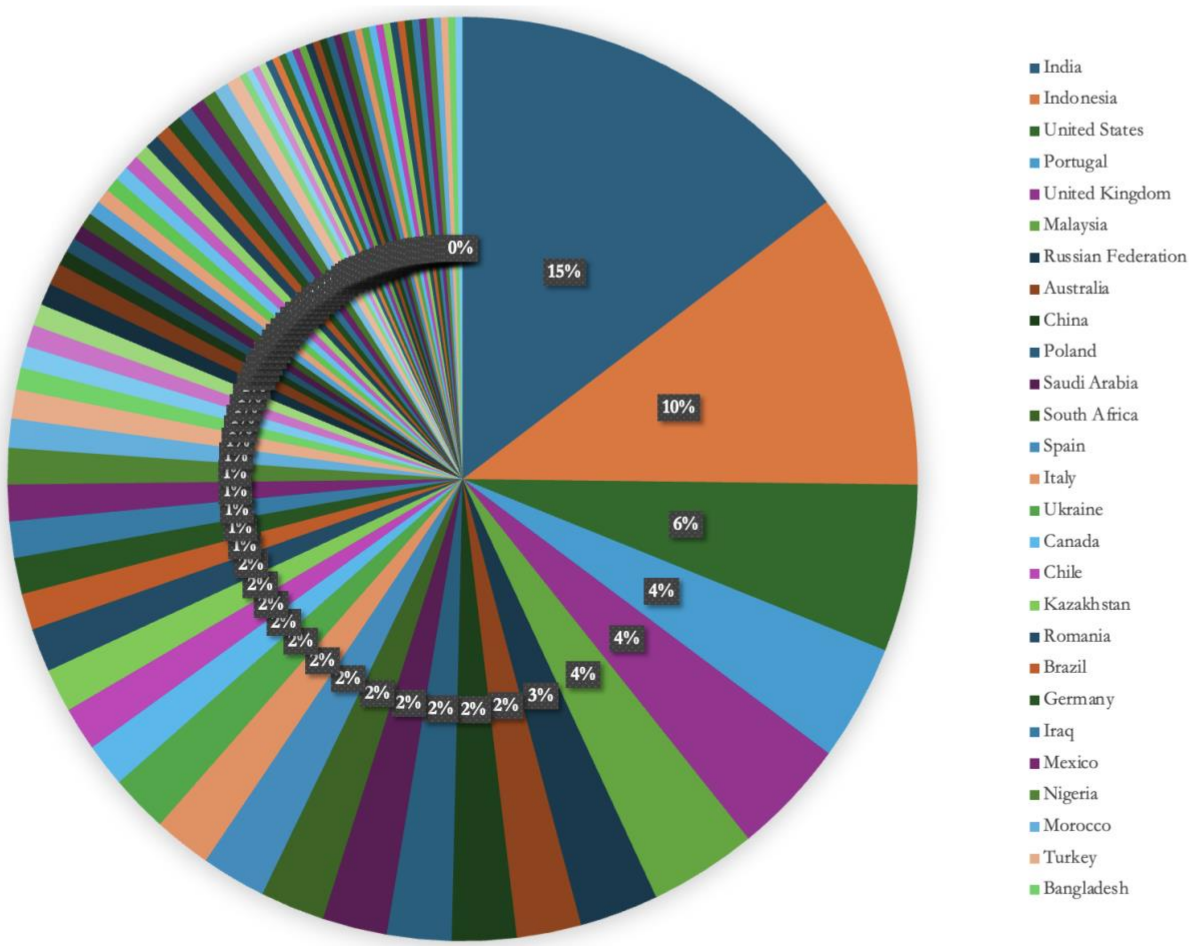


Figure 7: The co-citation network generated for RQ_4.

(a)



(b)



(c)

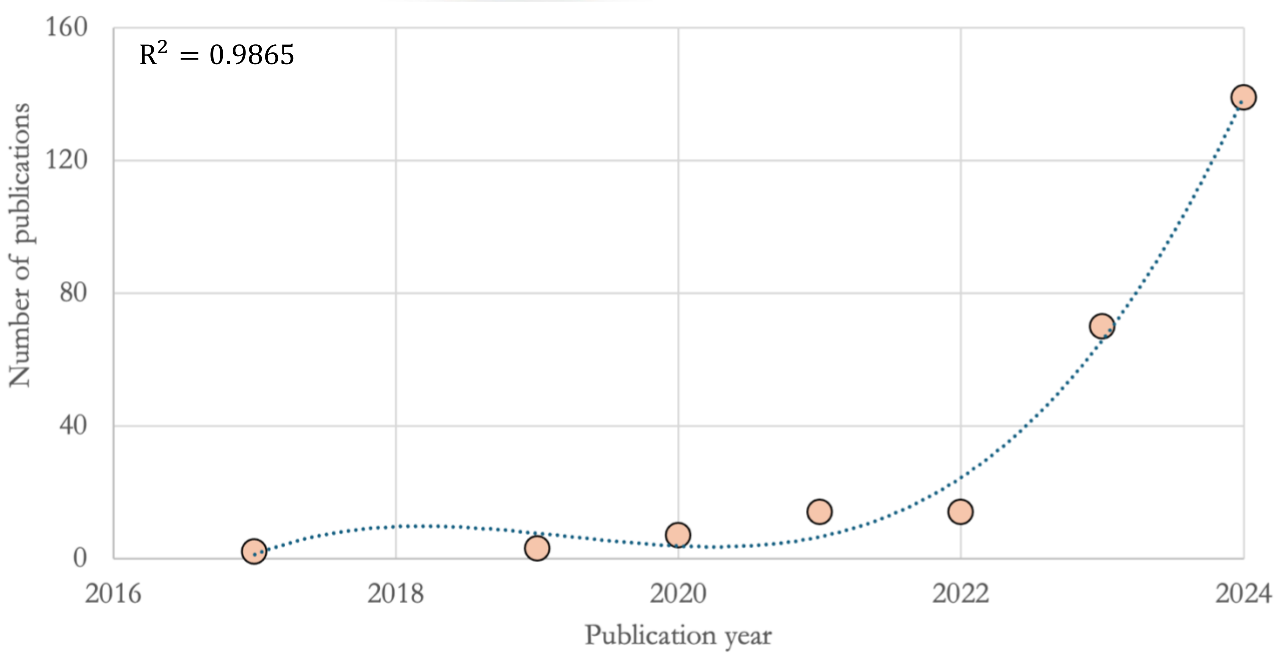


Figure 8: (a) RQ_4 trends by discipline areas/sectors, (b) by countries, and (c) publication trends in the last decade.

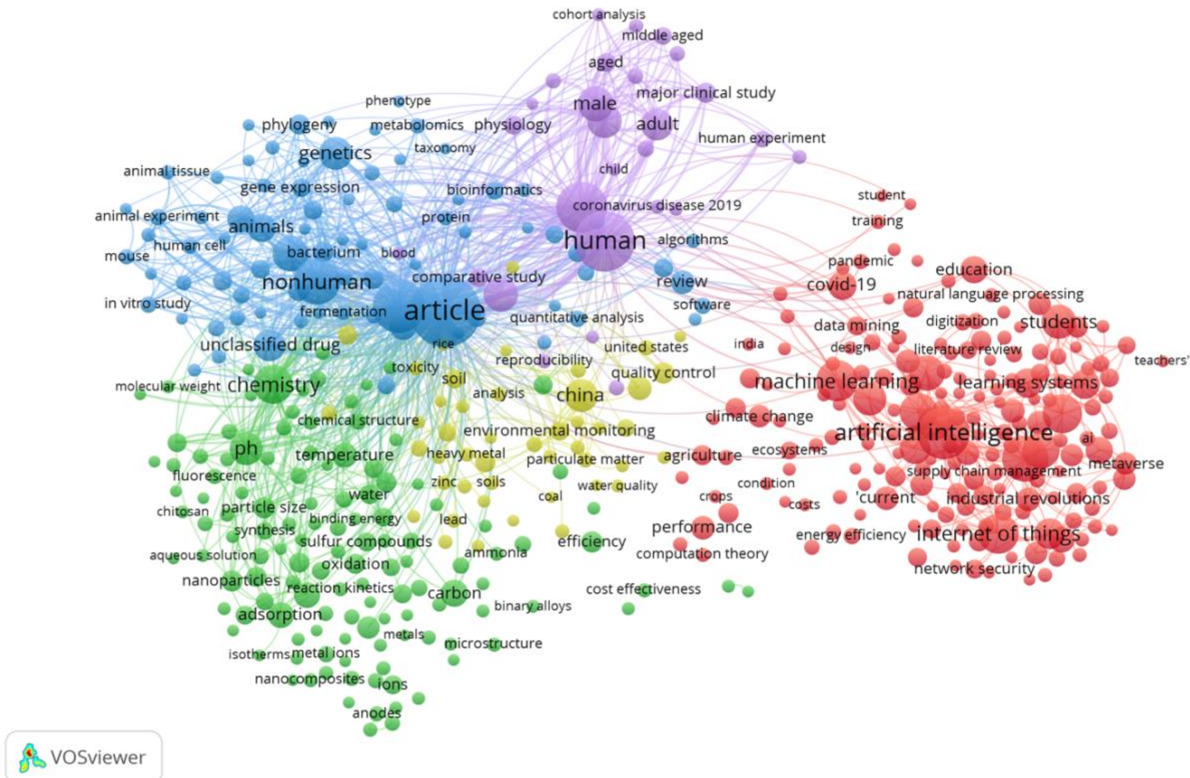
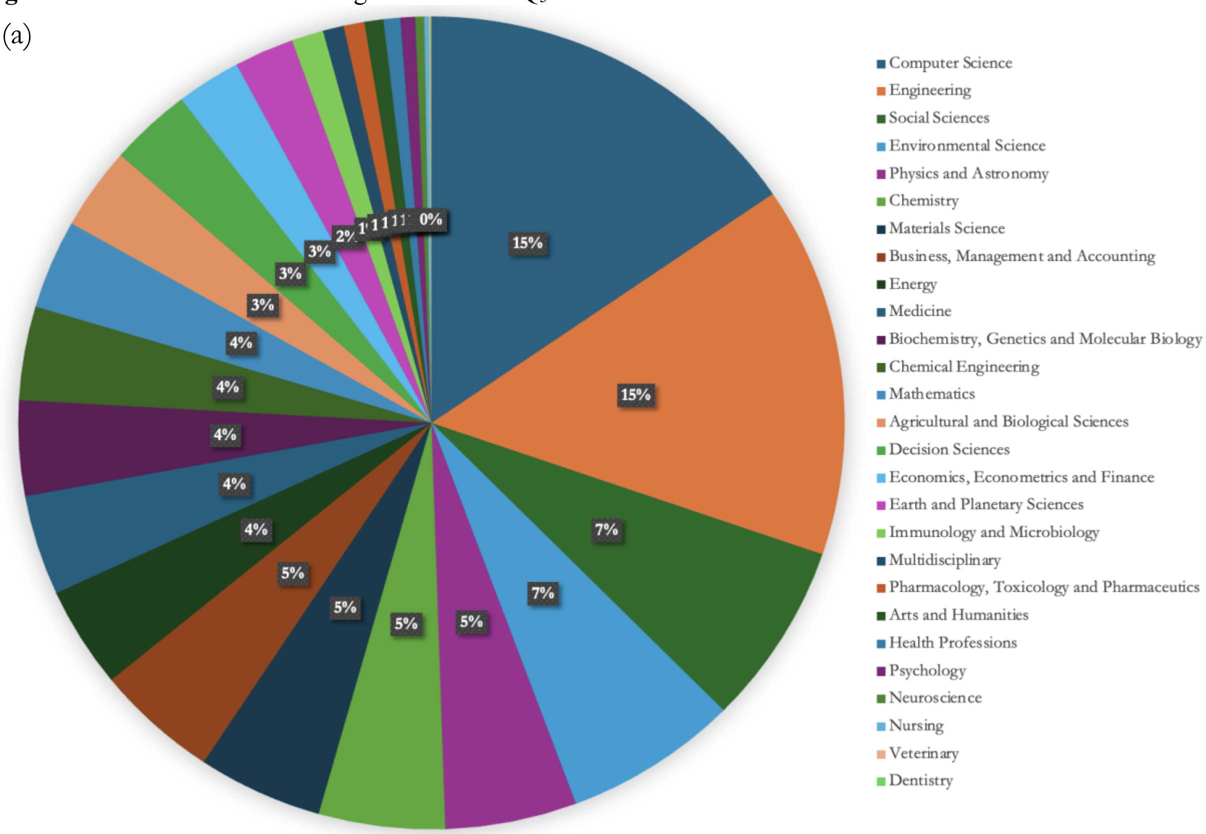
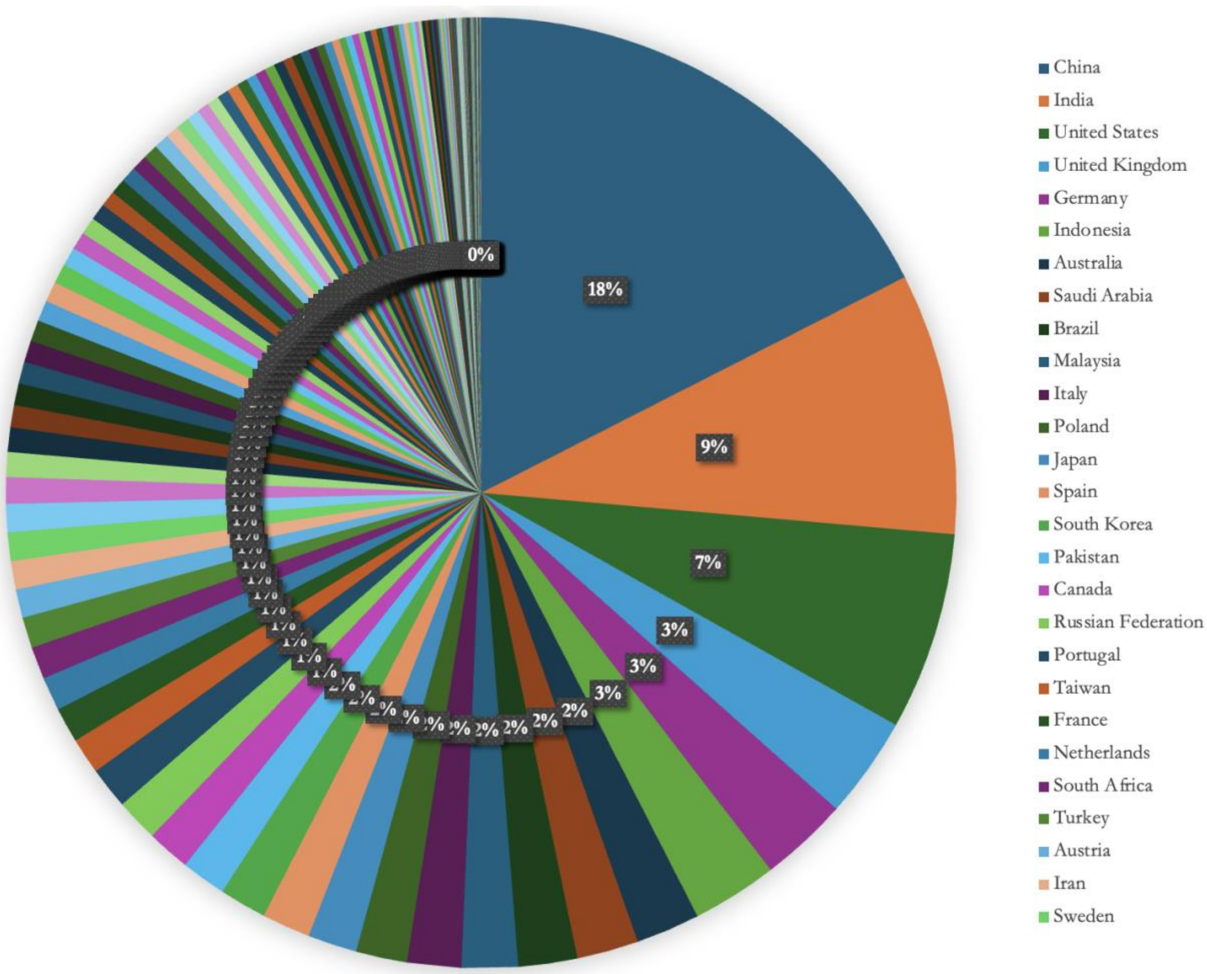


Figure 9: The co-citation network generated for RQ_5.

(a)



(b)



(c)

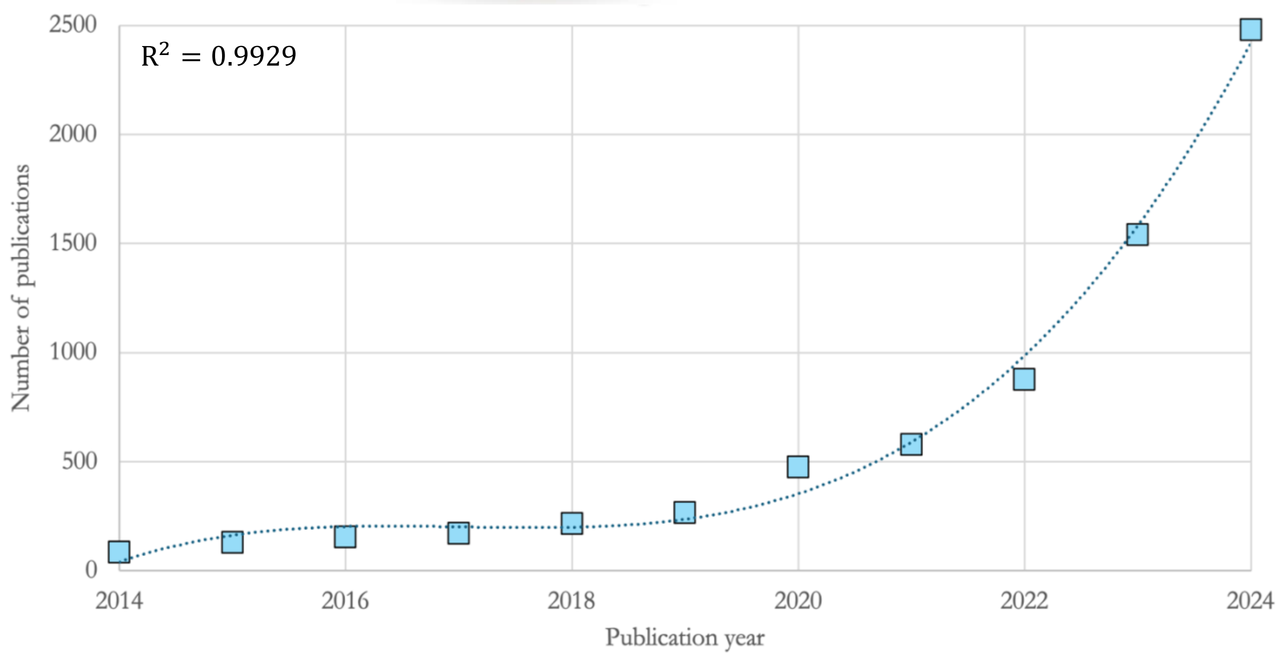


Figure 10: (a) RQ_5 trends by discipline areas/sectors, (b) by countries, and (c) publication trends in the last decade.

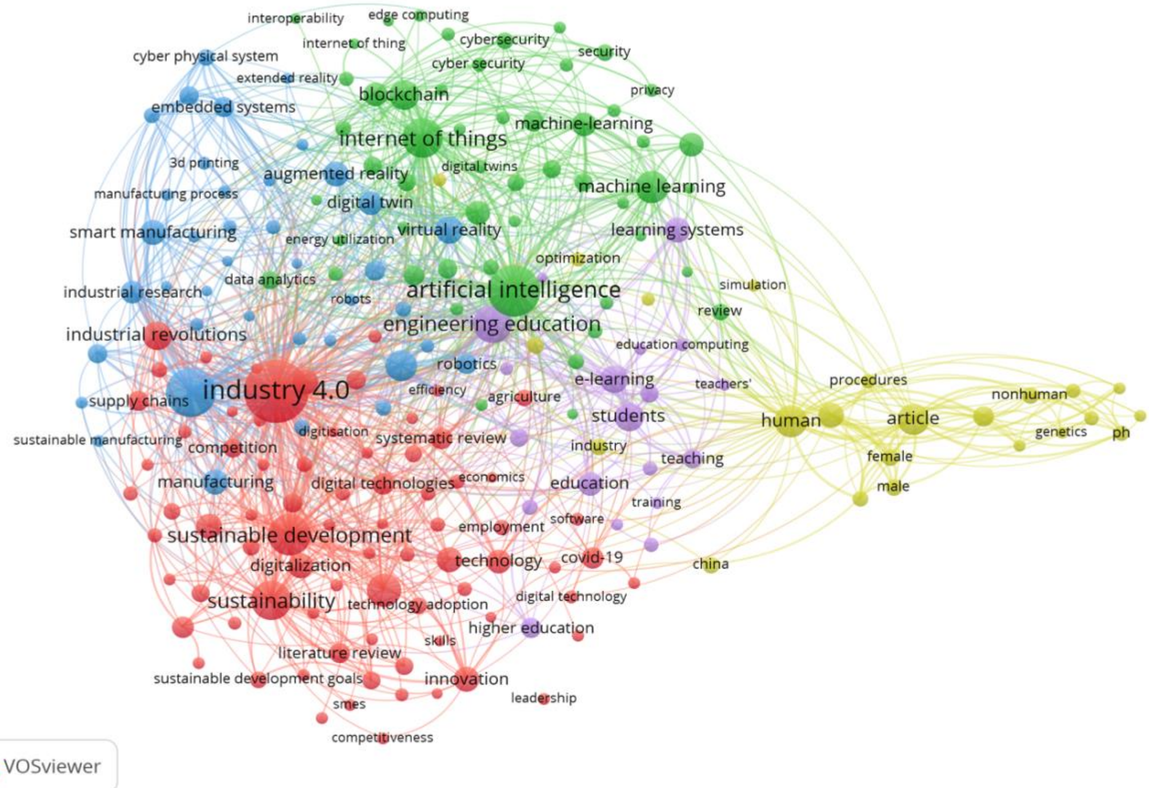
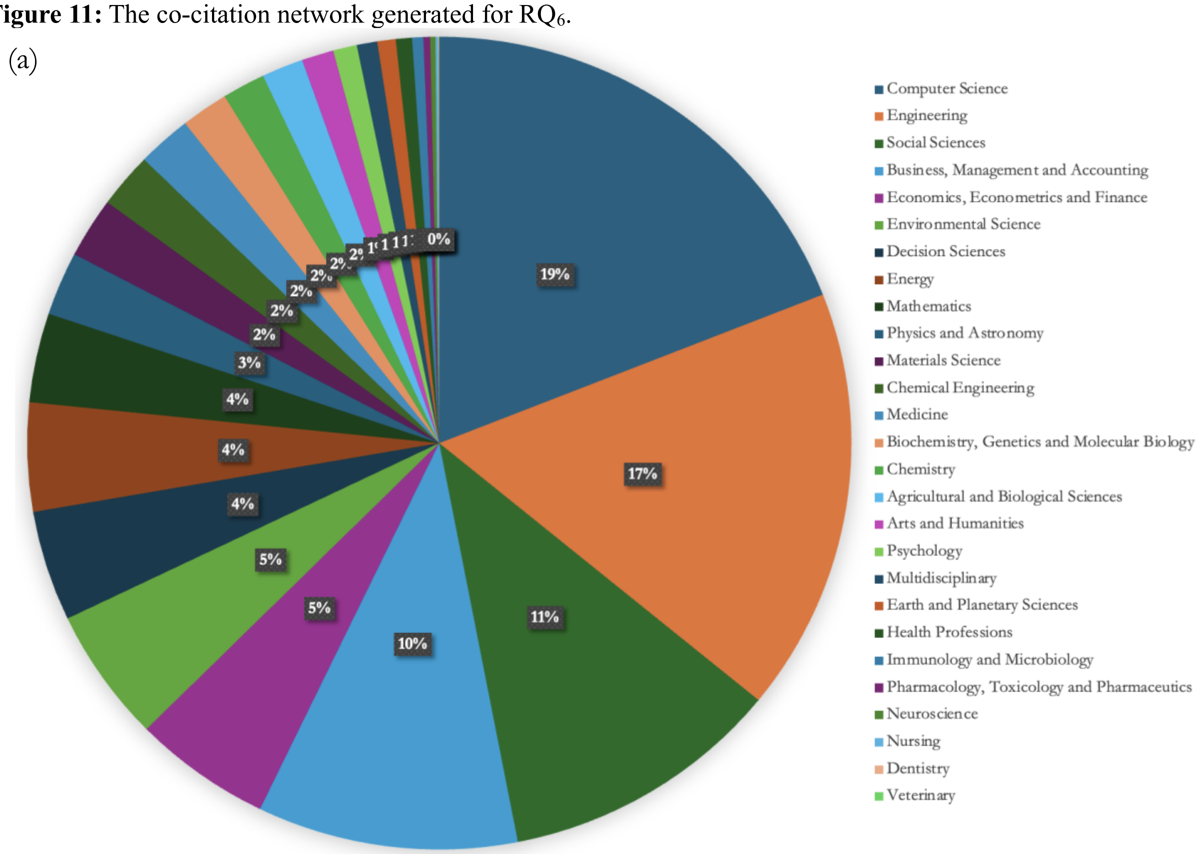


Figure 11: The co-citation network generated for RQ₆.

(a)



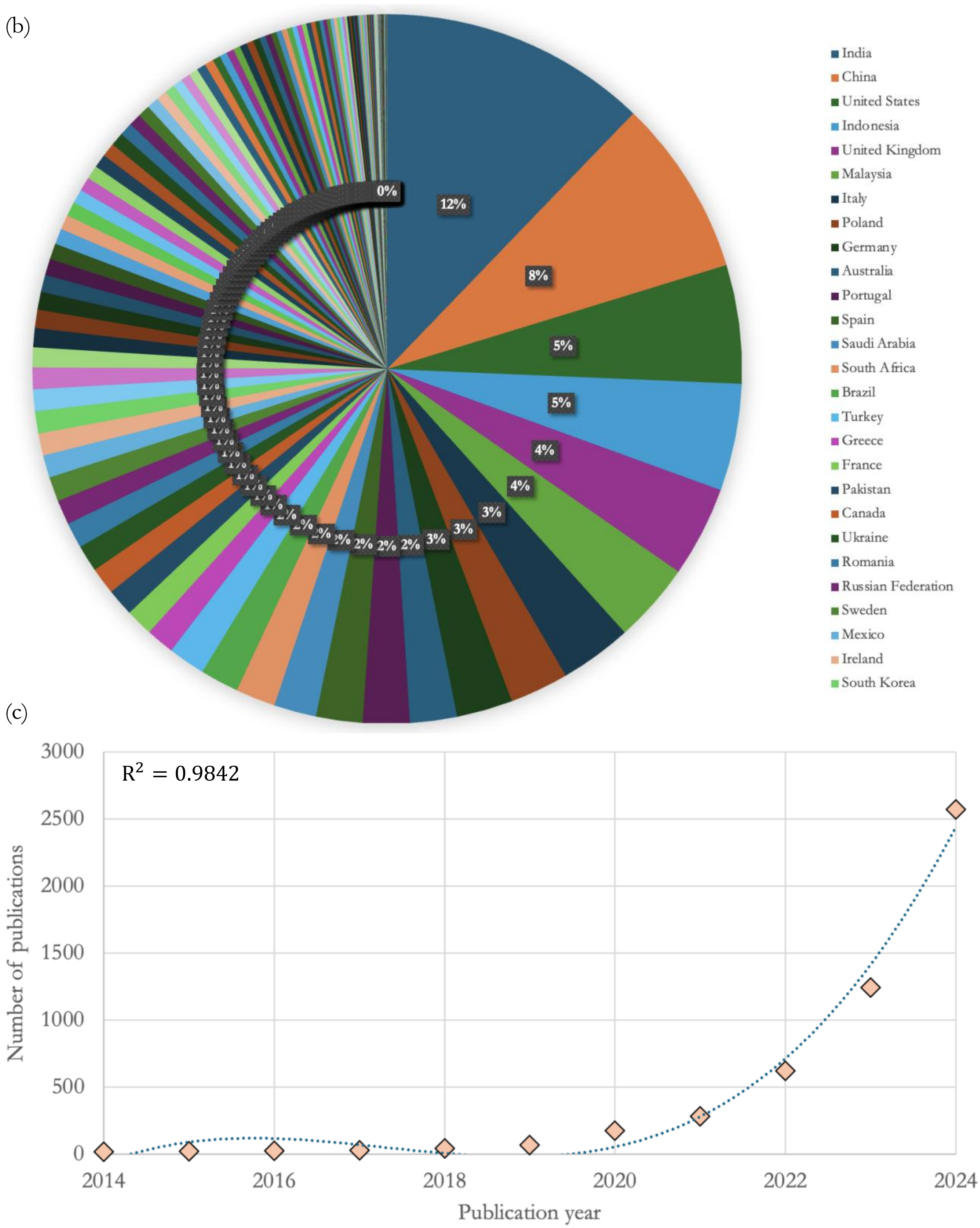


Figure 12: (a) RQ_6 trends by discipline areas/sectors, (b) by countries, and (c) publication trends in the last decade.

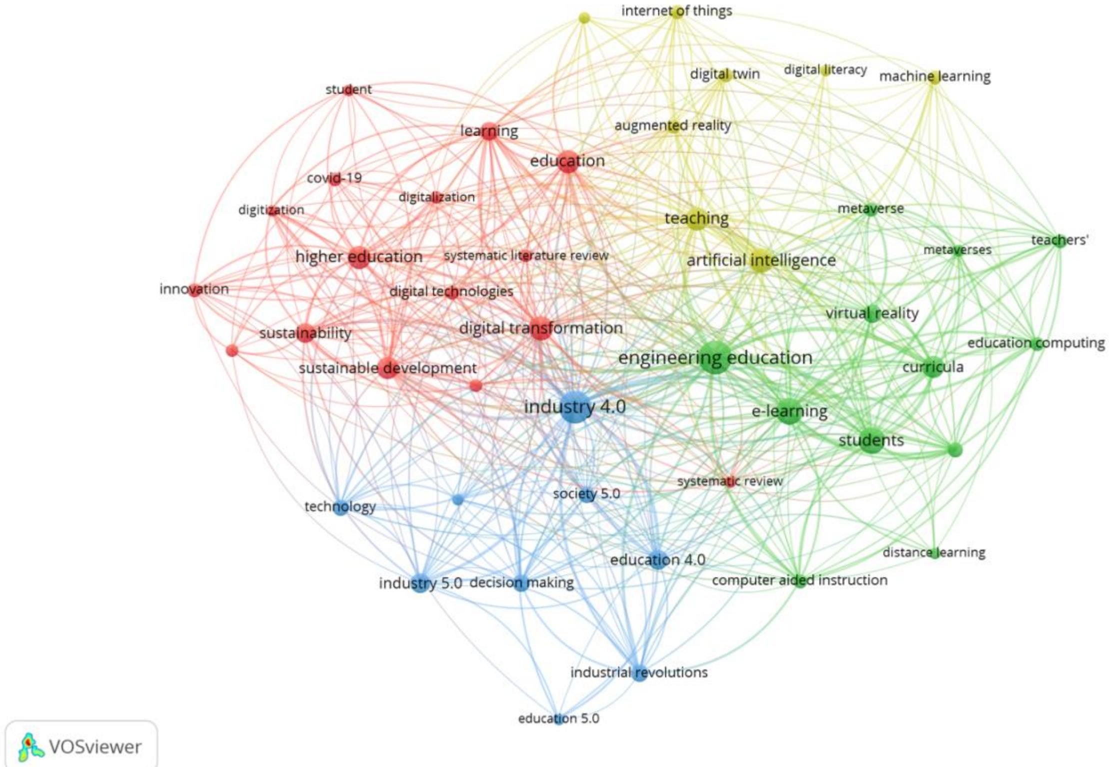
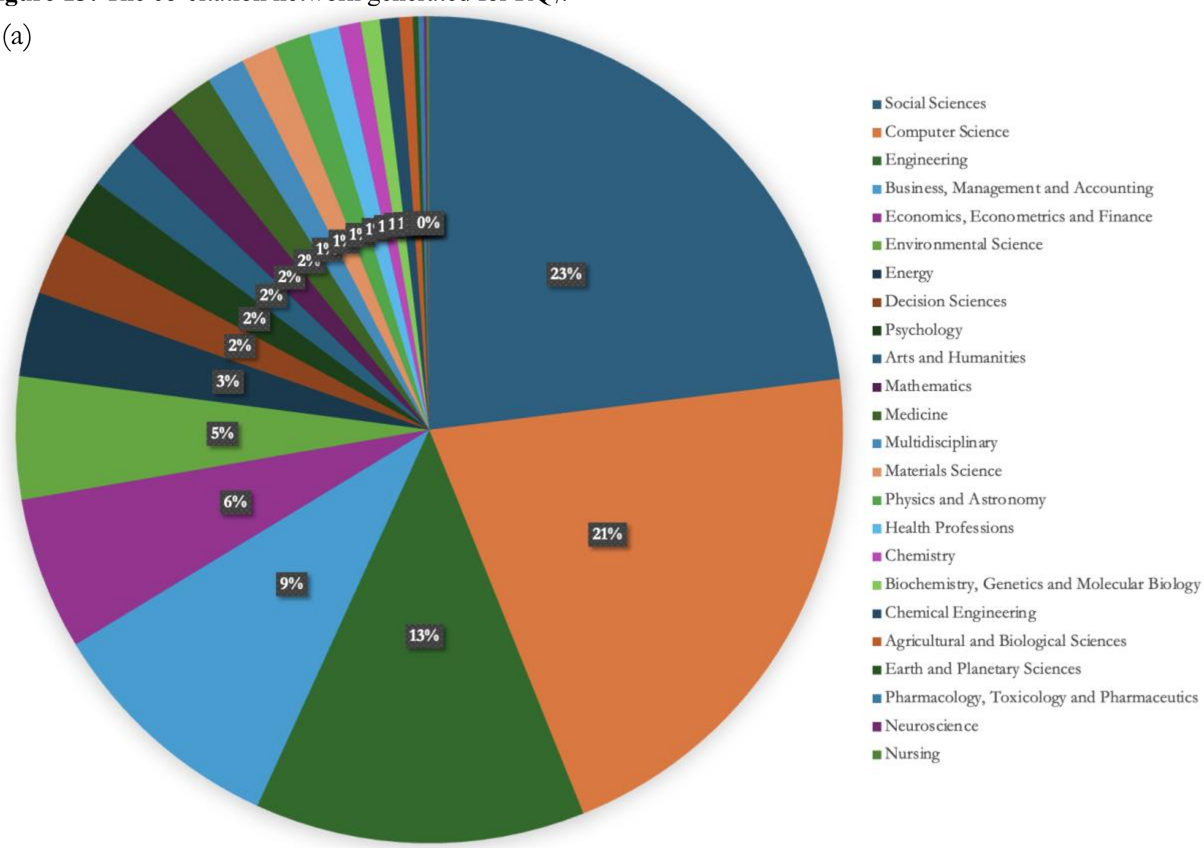
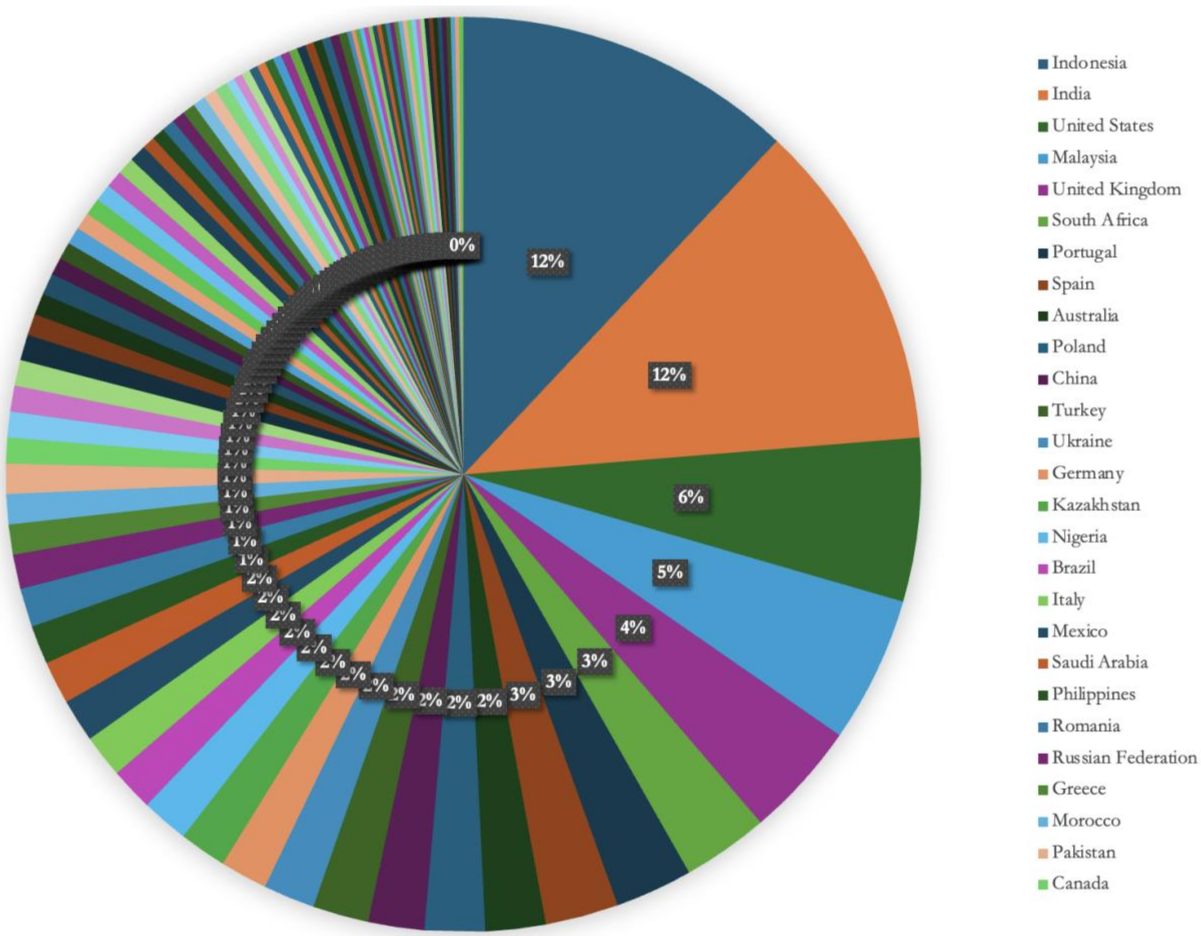


Figure 13: The co-citation network generated for RQ_7.

(a)



(b)



(c)

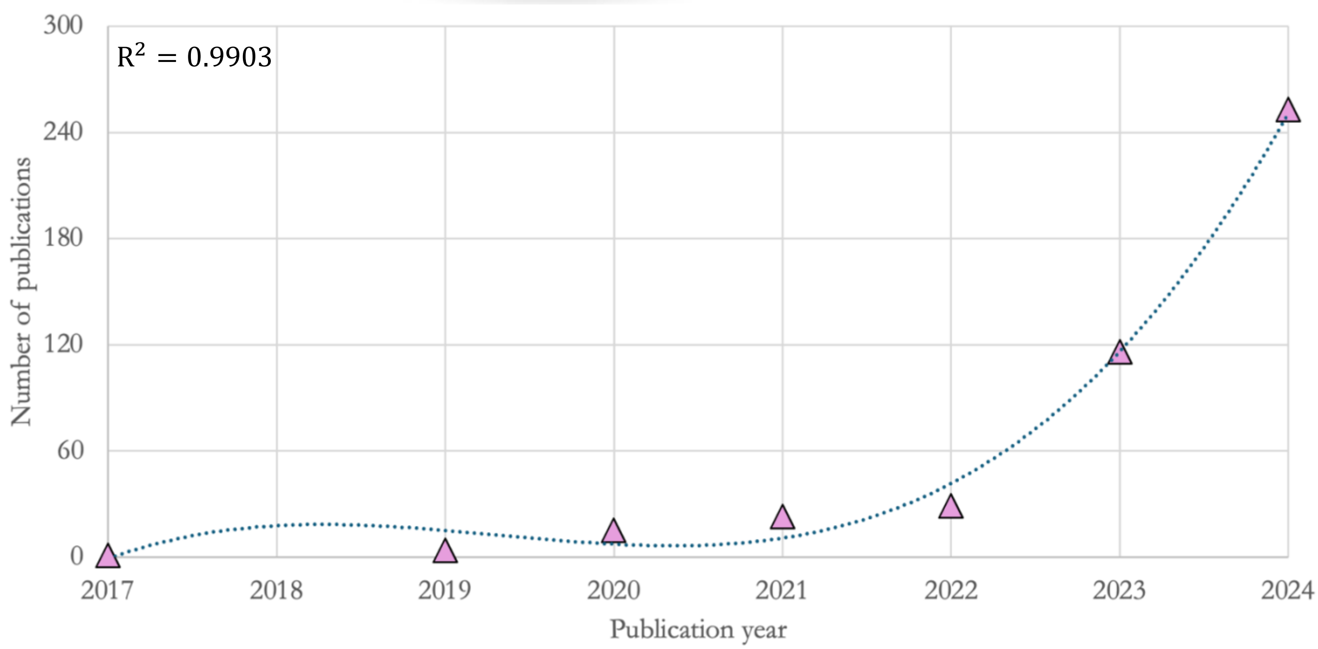


Figure 14: (a) RQ_7 trends by discipline areas/sectors, (b) by countries, and (c) publication trends in the last decade.

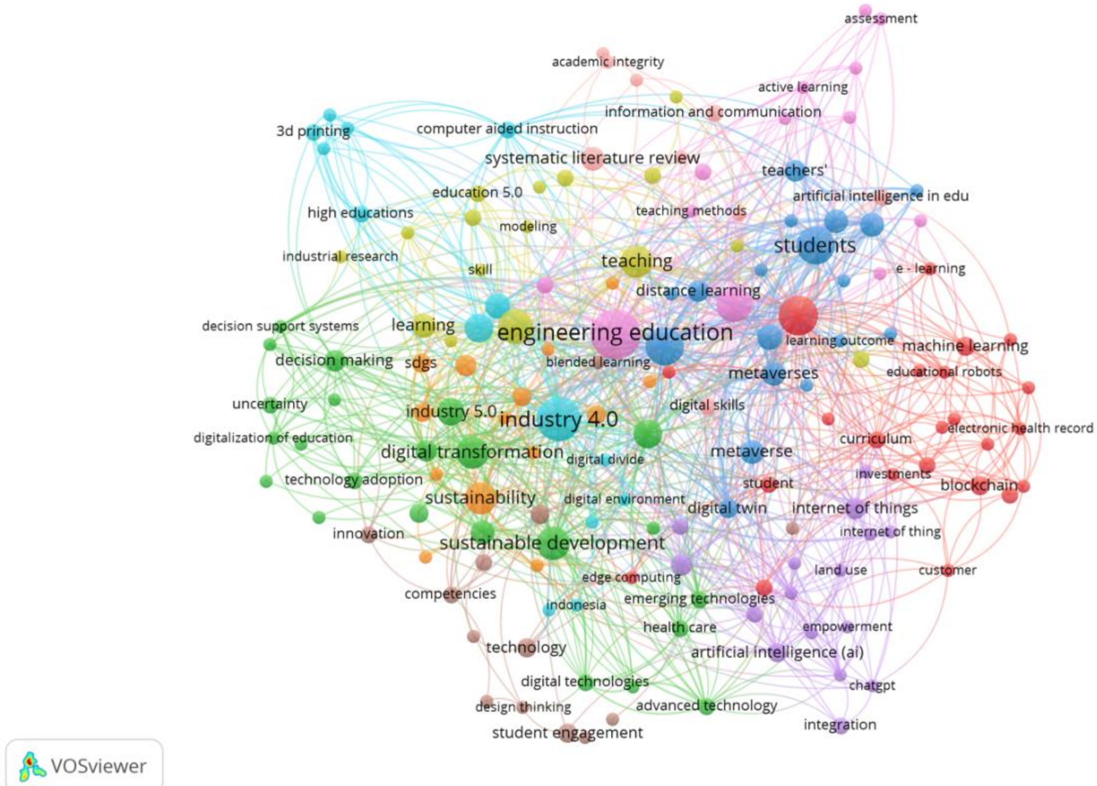
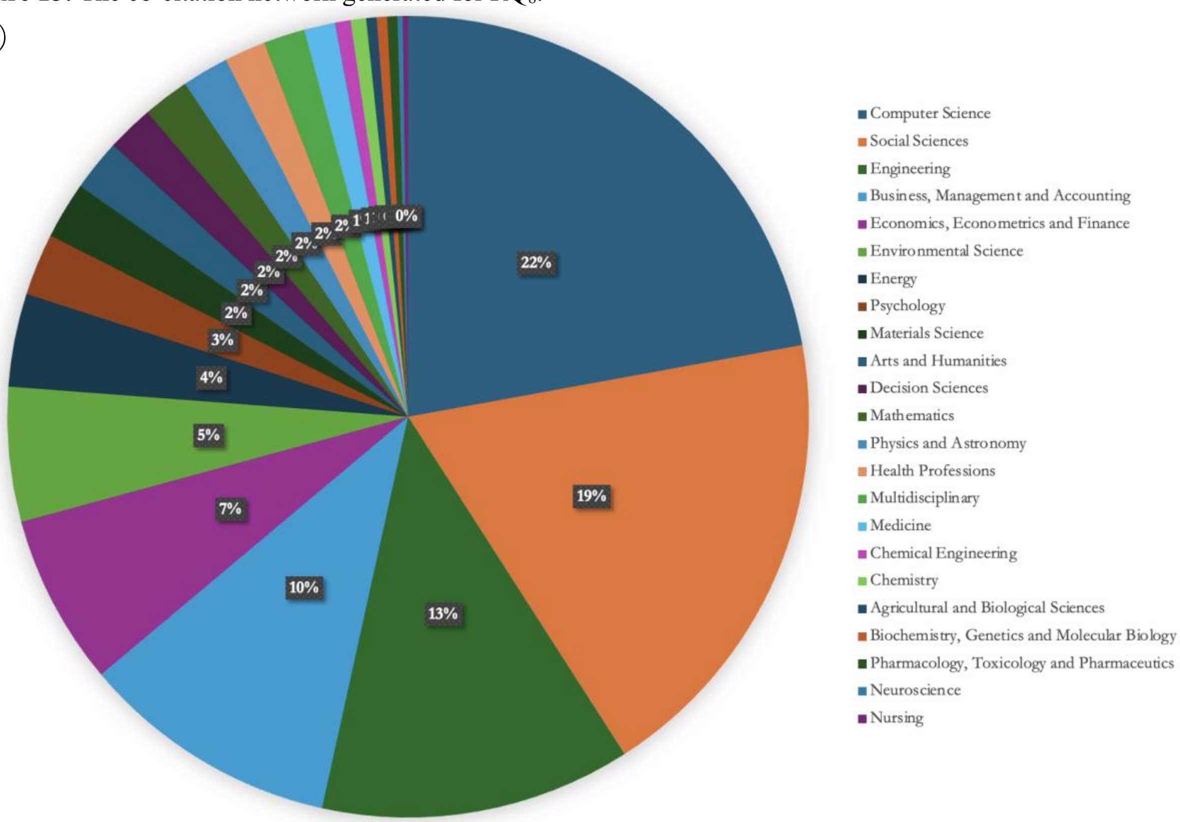
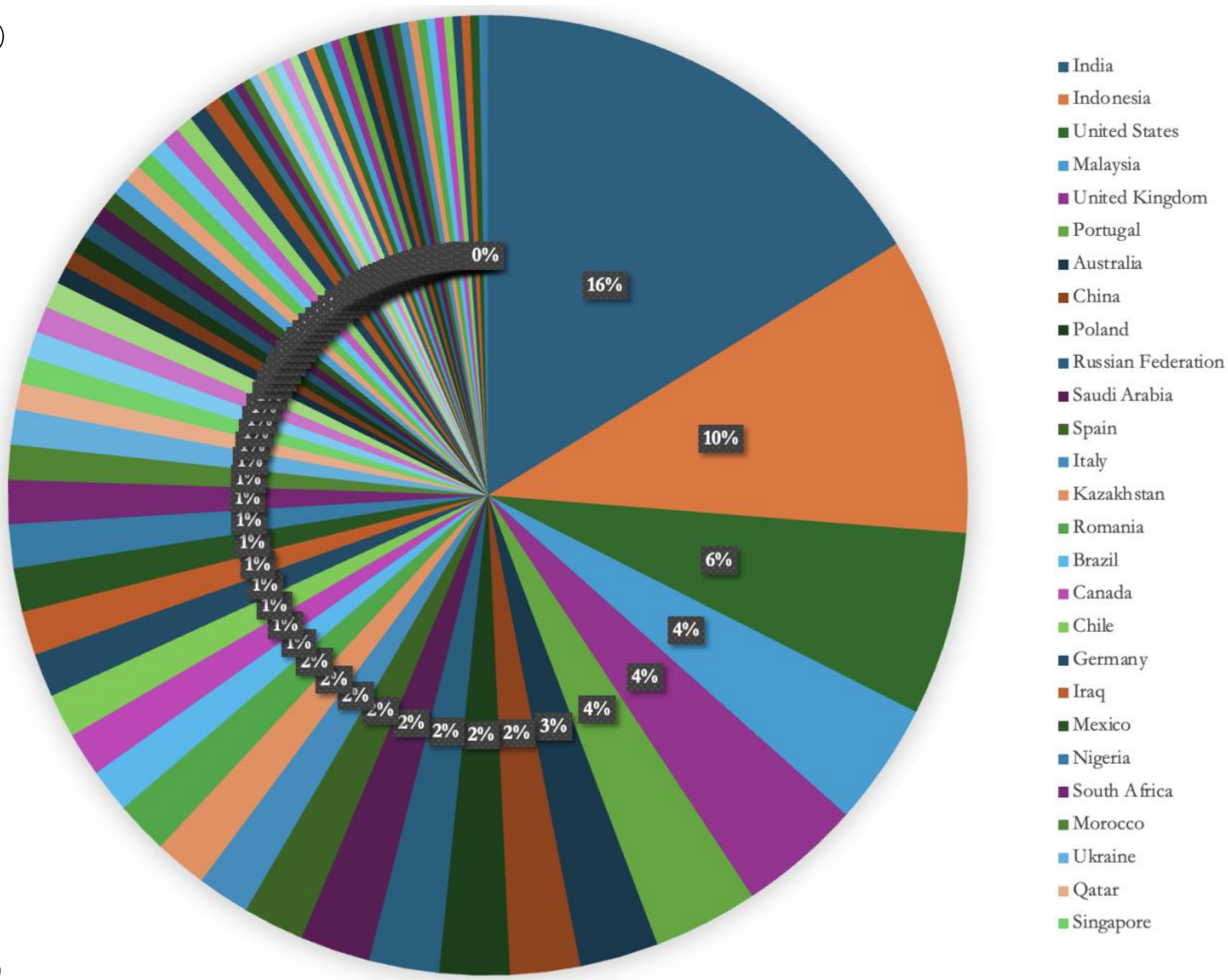


Figure 15: The co-citation network generated for RQ_8.

(a)



(b)



(c)

Figure 16: (a) RQ_8 trends by discipline areas/sectors, (b) by countries, and (c) publication trends in the last decade.

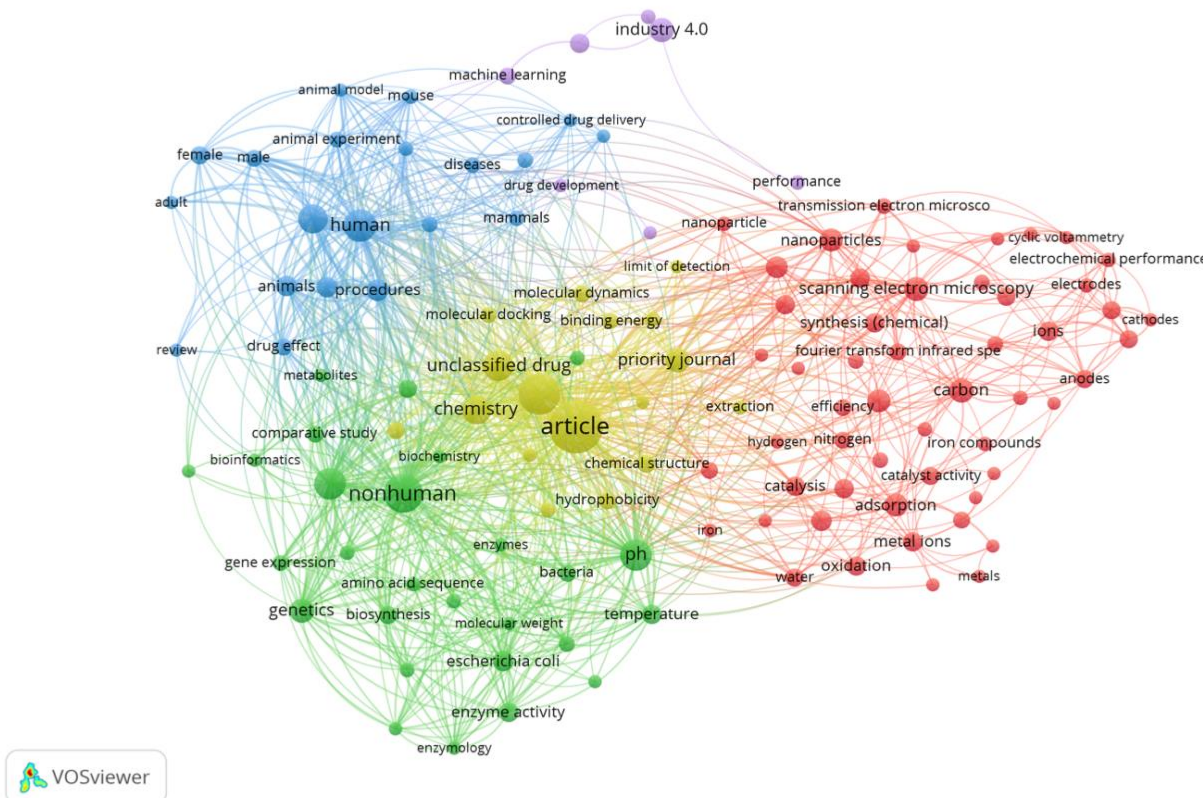
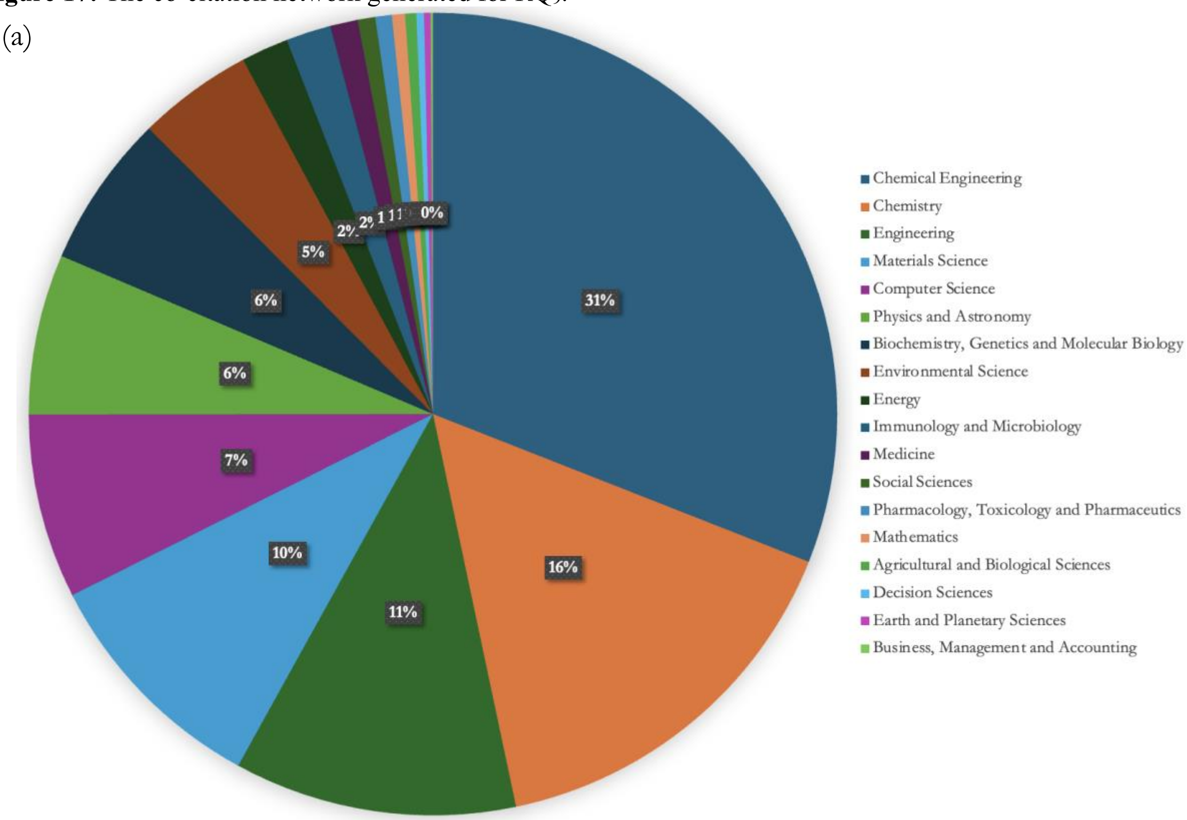
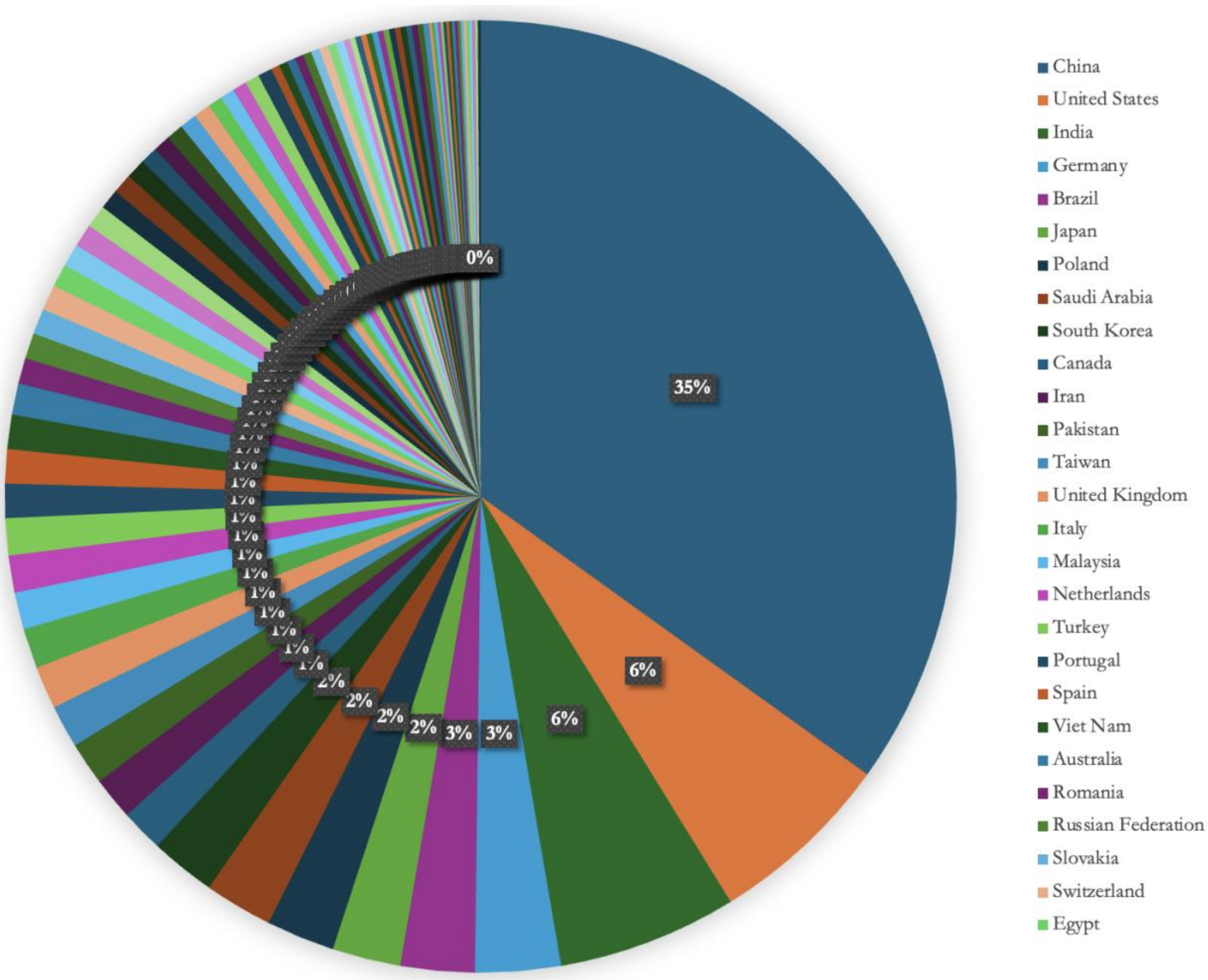


Figure 17: The co-citation network generated for RQ9.

(a)



(b)



(c)

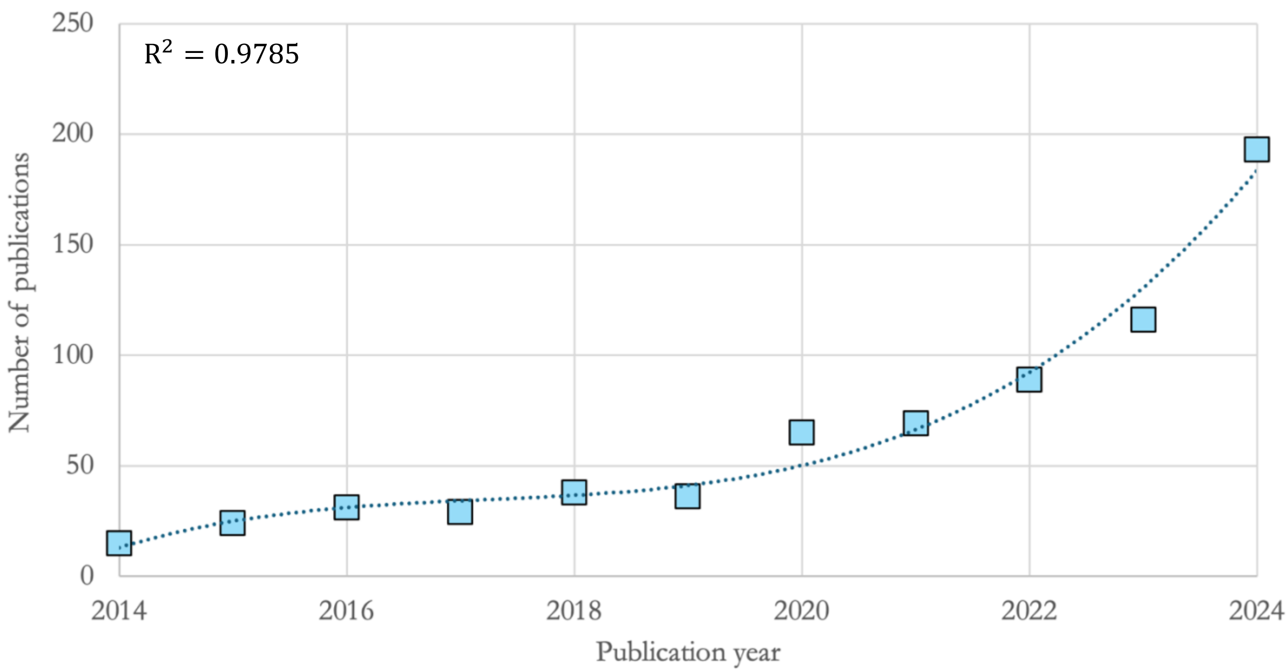


Figure 18: (a) RQ_9 trends by discipline areas/sectors, (b) by countries, and (c) publication trends in the last decade.

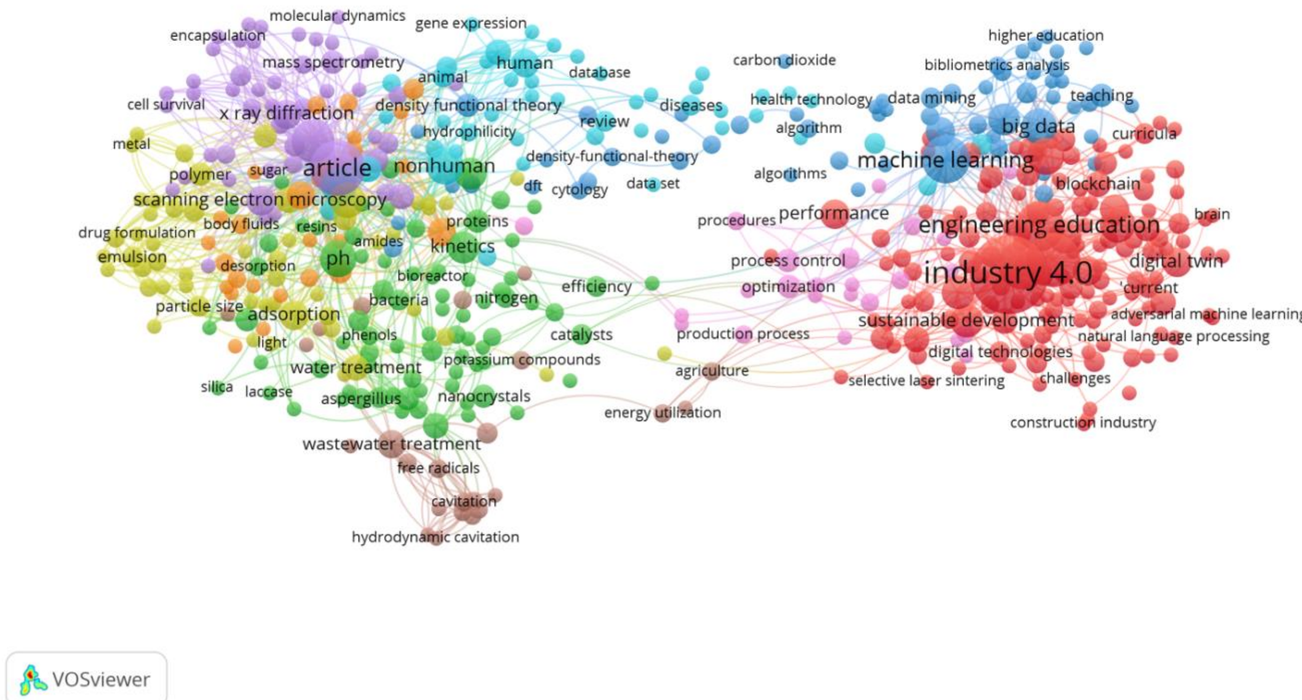
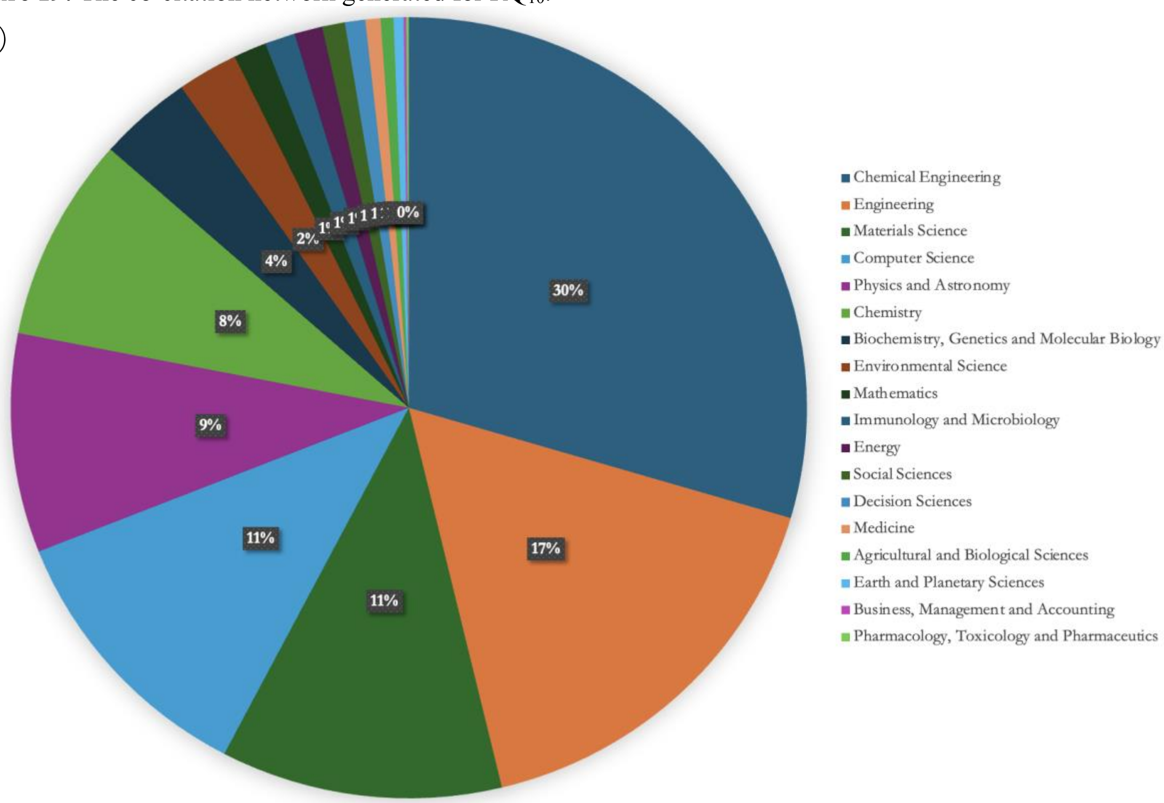
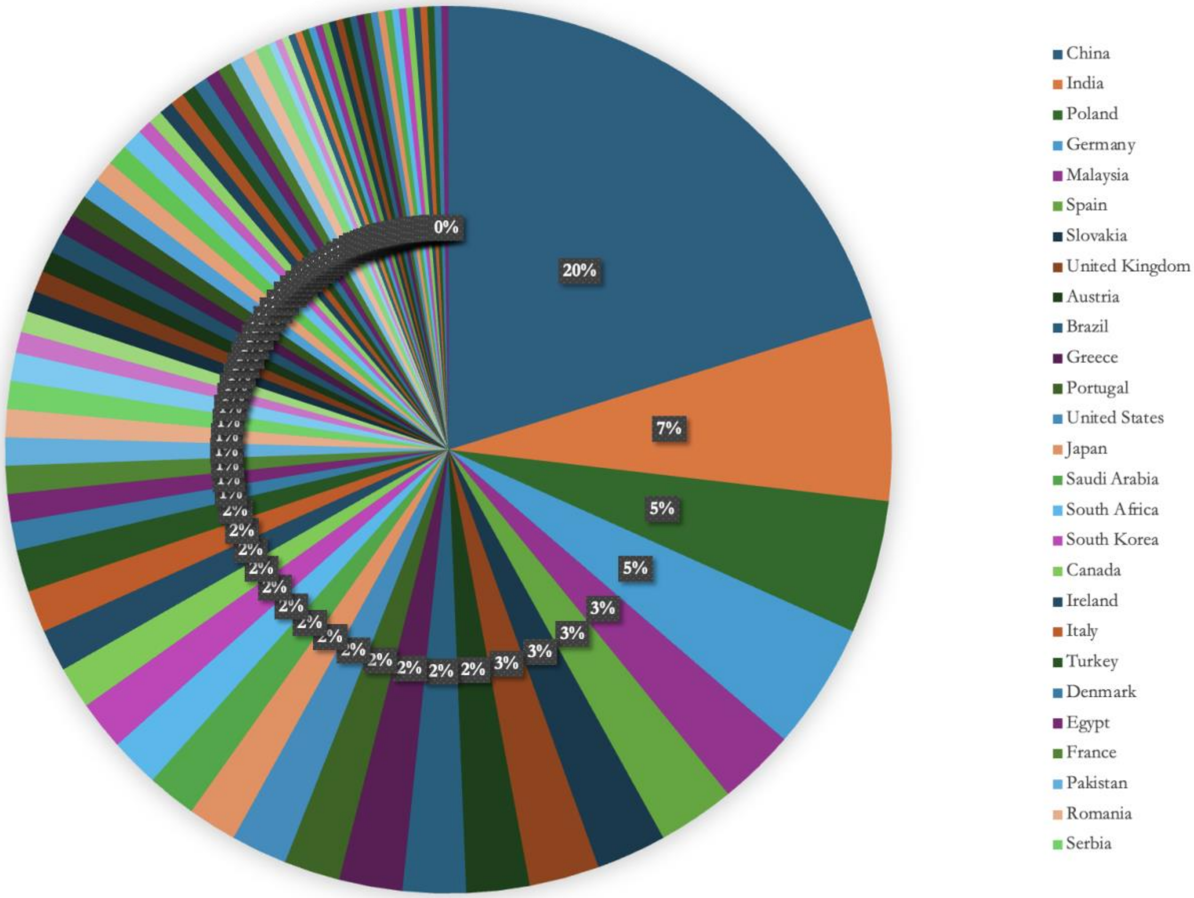


Figure 19: The co-citation network generated for RQ_{10}.

(a)



(b)



(c)

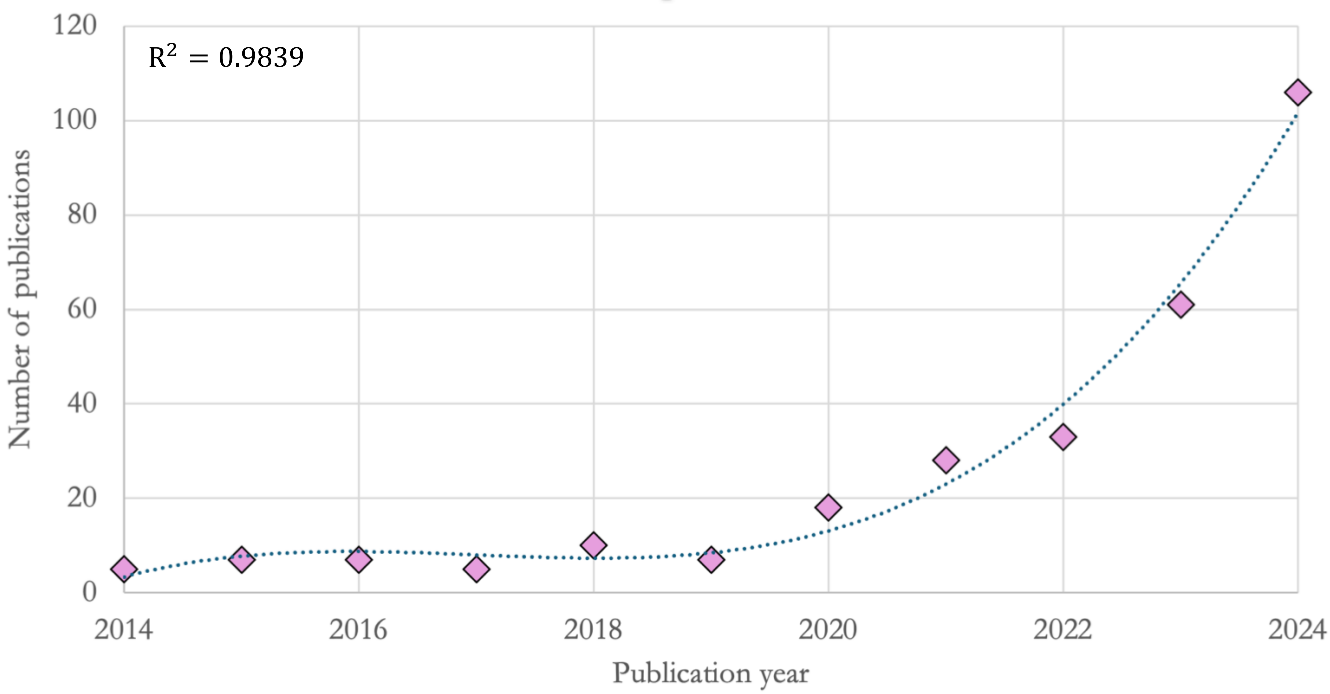


Figure 20: (a) RQ_{10} trends by discipline areas/sectors, (b) by countries, and (c) publication trends in the last decade.

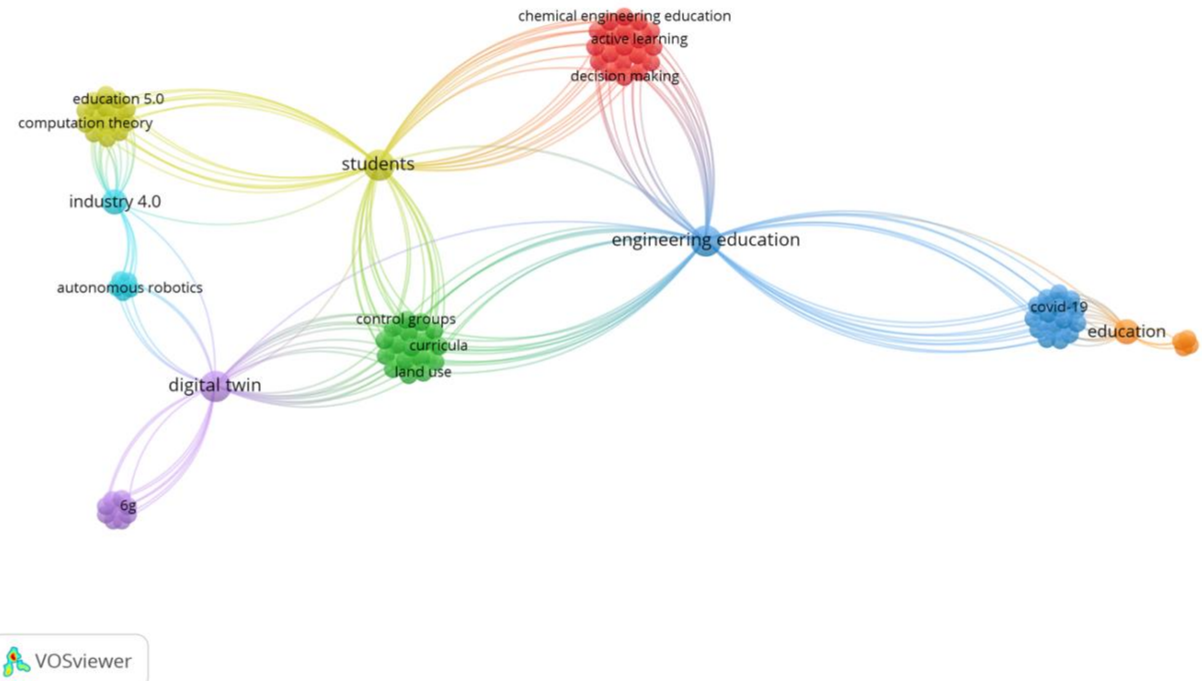
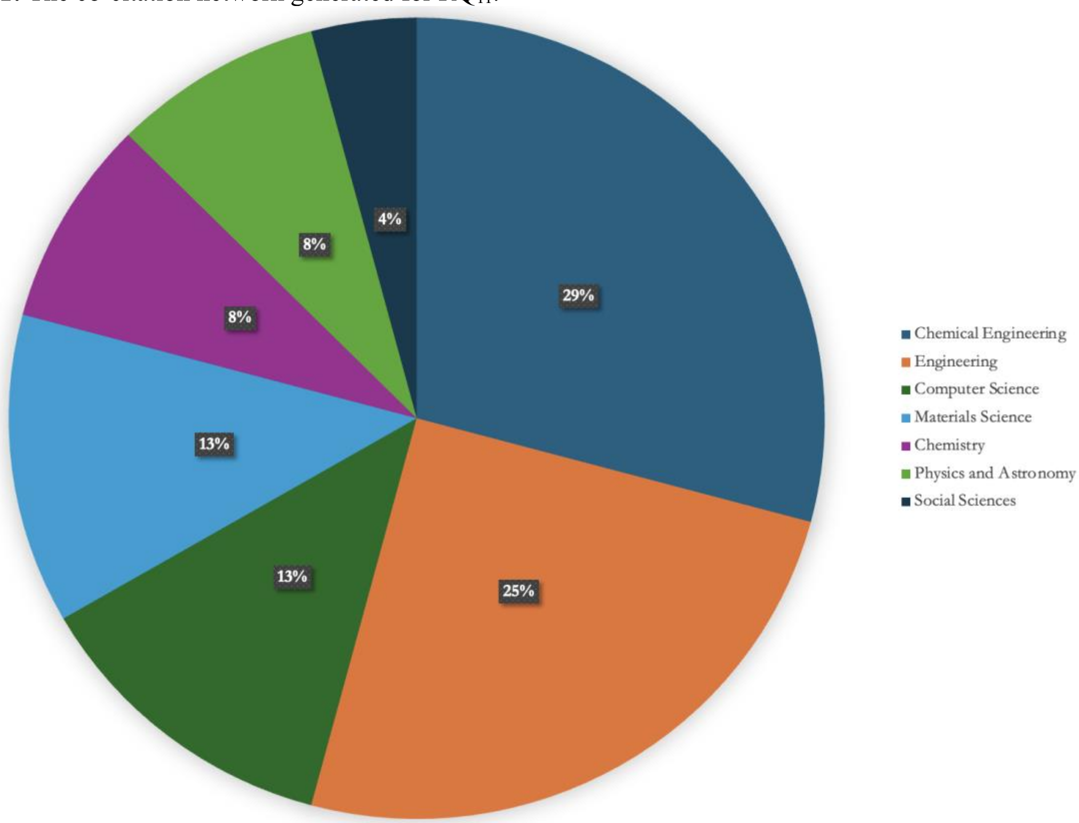


Figure 21: The co-citation network generated for RQ_{11}.

(a)



(b)

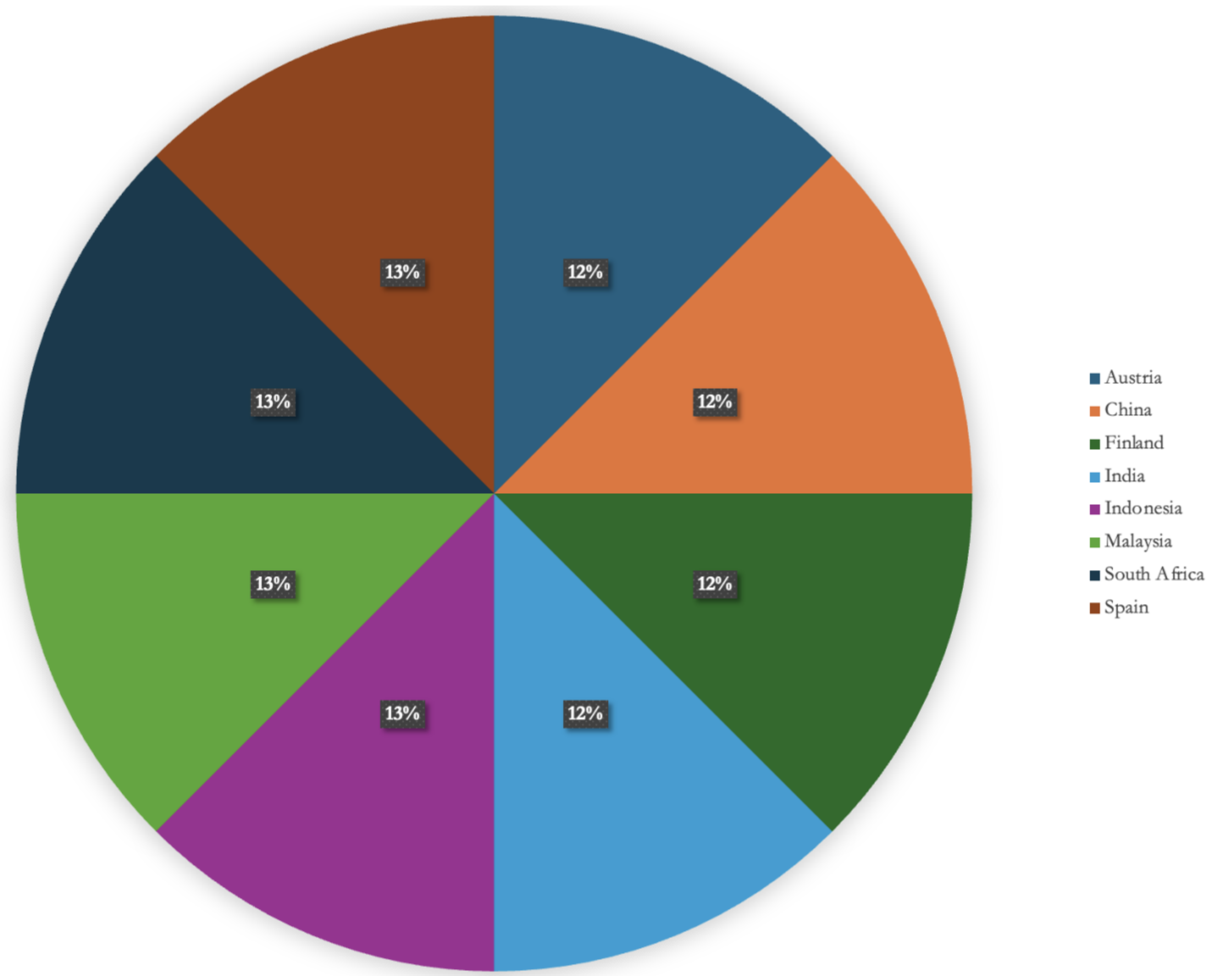


Figure 22: (a) RQ_{11} trends by discipline areas/sectors and (b) by countries in the last decade.

Appendix B: List of abbreviations and acronyms used in this work.

Abbreviation / Acronym	Description
E.D. 4.0	Education 4.0 (4^{th} Education Revolution)
E.D. 5.0	Education 5.0 (5^{th} Education Revolution)
I.D. 4.0	Industry 4.0 (4^{th} Industrial Revolution)
I.D. 5.0	Industry 5.0 (5^{th} Industrial Revolution)
HEI	Higher Education Institutes
AI	Artificial Intelligence
ML	Machine Learning
AR, VR	Augmented Reality, Virtual Reality
RQ	Research Question
IoT	Internet of Things
ICT	Information and Communication Technology
R^2	Correlation coefficient