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Research Insights
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TRENDS IN SCIENCE EDUCATION FROM THE DIGITAL PERSPECTIVE: A STUDY SUPPORTED BY A BIBLIOMETRIC ANALYSIS

Dr. Ivelina Kotseva, Assist. Prof.,
Dr. Maya Gaydarova, Assoc. Prof.
St. Kliment Ohridski University of Sofia (Bulgaria)

Abstract. This study investigates the intersection of science education and digital technology integration through bibliometric analysis and trend identification. Utilizing multiple search approaches, including combining educational methodologies, the study analyses datasets spanning from 1993 to 2024. Key findings reveal a consistent growth in scientific production over the years, coupled with fluctuations in citation impact. Clustering and co-word network analyses uncover thematic clusters, emphasizing computational thinking, pedagogical content knowledge, and motivation. Factorial analysis further elucidates the underlying structure of the data, revealing dimensions capturing factors related to educational practices, cognitive processes, and attitudinal aspects. Trend topics highlight sustained interest in fundamental educational concepts like education, students, and science, alongside emerging focuses on engagement, attitudes, and skills.

Keywords: science education; educational approaches; digital technologies; Bibliometrix; bibliometric analysis

Introduction

In the transition from an industrial to a digitalized society, there emerge needs for knowledge and skills necessary for living in a world with new challenges and unresolved problems. This places new demands on educational systems regarding the goals of education, the curriculum, the educational approaches and methods of teaching, the organization of the learning process, and the assessment. Educational goals are reoriented towards acquiring knowledge and skills aimed at successfully integrating students into society, which also changes the approaches to achieving these goals. The modern educational environment includes digital technologies, which support it and make it more effective in facilitating teaching, learning, and assessment. Digital technologies assist in visualizing content. They reduce the time for learning by creating conditions for building mental models of the studied processes and phenomena. The question is what is the interaction and mutual assumption of teaching methods and approaches and digital technologies, tools, platforms, apps, etc. which expand the possibilities for successful pedagogical communication between teachers and students in science education and may expand better outcomes.

In the context of this introduction, we formulate our research questions as follows:

RQ#1: What are the contemporary educational goals and most common approaches in science education?

RQ#2: How has the integration of digital technology influenced trends in science education research over the past three decades?

RQ#3: What are the key thematic clusters and associations between science education and digital technology revealed through bibliometric analysis?

RQ#4: What are the underlying dimensions and factors shaping the discourse on science education and digital technology integration as uncovered by factorial analysis?

The competency-based approach in science education

Our research on modern educational approaches and educational goals in science education begins with the competency-based approach, on one hand because it is relevant, and on the other hand because we are seeking connections with the development of digital competences in science education.

The concept of key competences in education has evolved over time and has been influenced by various educational philosophies, theories, and policy initiatives. The idea of key competences can be traced back to the progressive education movement of the late 19th and early 20th centuries. Educators such as John Dewey emphasized the importance of providing students with practical skills, critical thinking abilities, and social competences to prepare them for active participation in democratic society (Dewey 2016). In the mid-20th century, the focus in education shifted towards the development of basic skills such as reading, writing, and arithmetic.

The concept of key competences gained momentum in the late 20th century with the emergence of competency-based education (CBE) models. CBE focused on the development of specific skills, knowledge, and abilities that are relevant and meaningful in various contexts, including academic, professional, and personal domains. In the 1990s, the European Union (EU) began to emphasize the importance of key competences for lifelong learning and employability. The competency-based approach, as described by the European Qualifications Framework (EQF)[1], redirects the goals of education from acquiring and reproducing knowledge to acquiring methods and approaches for solving real problems. The Program for Key Competences of the European Union[2] is accepted as a primary framework for educational goals. The concept of key competences was discussed even before the adoption of the program in 2006 when Rychen and Salganik describe three categories of competences – interaction in heterogeneous social groups, independent actions, and interactive use of technologies, which are necessary for a successful life in society (Rychen & Salganik 2003).

The Framework for 21st Century Learning acknowledges the business recommendations to education for preparing the American educational system for the new demands of the 21st century (Trilling & Fadel 2009). This framework for 21st-century educational trends includes the learning outcomes, the contemporary educational environment, student assessment standards, and teacher professional qualifications. The included skills are divided into three major groups – (i) information, communication, and technology skills, (ii) learning and innovation skills, and (iii) life and work skills. Digital skills are included in the first group. Some authors (Larson & Miller 2011) point out that the learning outcomes necessary for life should include creative and innovative thinking, communication and collaboration, critical thinking and problem-solving, easy access to information, making digital connections in society, etc. From a psychological aspect, the framework is based on the idea of active student learning, which shapes critical thinking, creative thinking, teamwork, and communication (the so-called "4Cs skills" – critical thinking, creativity, communication, collaboration (Griffin et al. 2011; Griffin et al. 2012). Skills are defined in four main directions – ways of thinking, ways of working, tools for working, and life skills (values and ethical norms) (Binkley et al. 2012). Digital skills also fall into the tools for working category. Additionally, in that context the term information literacy is defined in three aspects concerning digital technologies – *knowledge, skills, and attitudes/values/ethics*.

The goals of science education are determined by the educational curricula in individual countries, but general trends towards which these programs are oriented can be outlined. The goals of science education are evolving to incorporate digital literacy and problem-solving skills in line with modern technological advancements. The emphasis is on fostering critical thinking, inquiry-based learning, and the ability to apply scientific knowledge to real-world problems. Key outcomes, which are expected, are:

(1) Proficiency in utilizing digital tools for scientific inquiry and data analysis;

(2) Competence in evaluating and synthesizing scientific information from various sources, including digital resources;

(3) Ability to apply scientific principles and methods to analyze and solve complex problems;

(4) Proficiency in communicating scientific concepts effectively, both orally and in writing, using digital platforms;

(5) Development of ethical and responsible attitudes towards scientific research and technology use.

Overall, the aim is to prepare students to be scientifically literate individuals capable of navigating and contributing to an increasingly technology-driven society.

Let us specify the skills in science education as expected outcomes in education. Some scholars (Wilson & Bertenthal, 2005) define the following goals as the most important and fundamental when studying natural sciences:

(1) Presentation and interpretation of data;

(2) Identification and classification of information;

(3) Measurement as a simple form of mathematical modeling;

(4) Planning and conducting research, which involves identifying and separating measured variables into categories – dependent, independent, controlled – and formulating hypotheses to explain relationships between variables;

(5) Explanation of facts based on evidence, including the use of models, scientific theories, and principles, and demonstrating the inconsistency of alternative hypotheses;

(6) Analysis and interpretation of data; data transformation;

(7) Evaluation of data to create an argument how these data support or reject a given claim, as well as assessing the reliability of the data.

All the expected outcomes listed above for natural sciences can be achieved and supported with various digital technologies.

Research on other educational approaches applicable to science education

Alongside the competency-based approach, our research on the scientific literature related to specific educational approaches applicable to science education highlights the following:

Inquiry-Based Learning

This approach involves students actively in the scientific process through questioning, investigation, and discovery. Teachers facilitate learning by posing questions, guiding investigations, and encouraging critical thinking. Inquiry-based learning promotes deeper understanding and long-term retention of scientific concepts (Dewey 1938; National Research Council 2000). The use of scientific research approaches in education brings learning closer to the nature of science – describing, explaining, and predicting natural phenomena and processes in various settings (Pedaste et al. 2015). Research skills (RS) are defined as "skills and abilities to understand how scientific knowledge is obtained in various scientific disciplines, to evaluate the validity of scientific claims and need for new scientific ideas and concepts, and to understand how these ideas and methods function." (Fischer et al. 2014). Research skills (RS) and digital skills (DLS) are at the core of research approaches in a digital environment (Blankendaal et al. 2023), forming new skills called digital research skills (DRS).

Problem-Based Learning (PBL) - involves presenting students with real-world problems or scenarios that require scientific inquiry and problem-solving skills to resolve. Students work collaboratively to investigate the issue, gather data, analyze information, and propose solutions, fostering both content knowledge and critical thinking skills (Barrows 1986; Savery 2006). Problems can be clearly defined by the teacher or unstructured (Ruiz-Primo 2009). Problems are also divided into routine (with a clear decision-making procedure) and non-routine (without a clear decision-making procedure). This approach also fosters research skills, teamwork skills, and lifelong learning skills, as well as developing critical thinking (Kurt 2020).

Project-Based Learning (PBL) - involves students working on extended, interdisciplinary projects that address real-world problems or challenges. In science education, PBL encourages students to apply scientific knowledge and skills to authentic situations, fostering creativity, critical thinking, and motivation (Blumenfeld et al. 1991; Thomas 2000).

Model-Based Inquiry (MBI) - involves using conceptual models to guide students' exploration and understanding of scientific phenomena. Students engage in model construction, refinement, and evaluation to develop explanatory models that represent scientific concepts and principles (Schwarz & White 2005; Windschitl et al. 2008).

Collaborative Learning - involves students working together in groups to achieve common learning goals. In science education, collaborative learning fosters peer interaction, discussion, and cooperation, leading to enhanced understanding of scientific concepts and development of teamwork skills (Slavin 1996; Johnson et al. 1998).

Design-Based Learning (DBL) - involves students designing and creating solutions to authentic, complex problems or challenges using scientific principles and engineering practices. This approach integrates science, technology, engineering, and mathematics (STEM) concepts while emphasizing creativity, critical thinking, and problem-solving skills (Edelson 1999; Kolodner 2002).

Context-Based Learning - situates scientific concepts within relevant real-world contexts, such as societal issues, environmental challenges, or everyday experiences. By connecting science to students' lives and interests, context-based learning enhances motivation, engagement, and understanding of scientific principles (Bennett & Holman 2002). In design-based learning, students engage in the iterative process of problem identification, solution generation, testing, and refinement, mirroring the practices of scientists and engineers. Context-based learning, on the other hand, emphasizes the application of scientific knowledge in relevant contexts, promoting deeper understanding and meaningful learning experiences for students.

Differentiated Instruction - involves tailoring instruction to accommodate the diverse learning needs, interests, and abilities of students. In science education, differentiated instruction may include offering multiple pathways to learning, varying instructional strategies, and providing additional support or enrichment opportunities (Tomlinson & Allan 2000; Tomlinson 2014).

Experiential Learning - involves hands-on experiences where students directly engage with materials, experiments, or real-world phenomena. This approach emphasizes learning by doing, allowing students to actively explore scientific concepts and develop practical skills (Dewey 1938; Kolb 2014).

These educational approaches in science education are supported by research and have been implemented in various educational settings to promote effective teaching and learning of scientific concepts and skills.

Methods and tools of the bibliometric analysis

The main method of research in our study alongside the previous overview we made is bibliometric analysis of the results from searches using keywords in the Web of Science database. Analysis and visualisation are made with Bibliometrix package in R. The searches cover all years (1985 - 2024). Full records and cited references are exported for all types of document in all available languages. The searches were conducted on May 7, 2024 in the sequence given in Table 1. Searches 2 to 11 have to bring clarity upon the scientific production connected to science education, the digital perspective that we identify broadly with the keyword "digital", and the educational approaches we are interested in. As with the term "digital", we just use simple keywords like "competence", "inquiry", "collaborative", etc. in order to make our searches as broader as possible. Absolute numbers indicates that "inquiry", followed by "collaborative" and "competence" may have influence on the landscape of science education with connections to the digital perspective. The reason to combine all educational approaches in one last search (№12) is the small size of datasets in searches 2 to 11 (excluding 2, 3 and 7).

Table 1. Searches by keywords (WoS)

Search, №	Keywords and number of documents, WoS
1	"science education" AND "digital", (2986)
2	"science education" AND "digital" AND "competence", (101)
3	"science education" AND "digital" AND "inquiry", (204)
4	"science education" AND "digital" AND "problem-based", (26)
5	"science education" AND "digital" AND "project-based", (37)
6	"science education" AND "digital" AND "model-based", (25)
7	"science education" AND "digital" AND "collaborative", (153)
8	"science education" AND "digital" AND "differentiated", (23)
9	"science education" AND "digital" AND "context-based", (0)
10	"science education" AND "digital" AND "design-based", (47)
11	"science education" AND "digital" AND "experiential", (25)

12	"science education" AND "digital" AND ("competence" OR "inquiry" OR "problem-based" OR "project-based" OR "model-based" OR "collaborative" OR "differentiated" OR "context-based" OR "design-based" OR "experiential"), (536)

In this way, two large sets of data appropriate for bibliometric analysis are available:

– The set that connects the field of science education most broadly with digital skills, competence, technologies, tools, platforms, etc. (Search №1), and

– The set that most broadly connects science education with digital technologies, tools, platforms, etc., within the reference of a particular educational approach (Search №12).

Despite the great number of documents (536) in Search 12 that allows a separate bibliometric analysis, we consider that a further analysis only for Search 1, which is based on science mapping, network and factorial analysis, will give sufficient information for our research questions. Moreover, Search 12 is a subset of Search 1.

Results and interpretation

Performance analysis for Search №1 (main information about data)

The data spans from 1993 to 2024. There are 1136 sources including journals, books, and other materials and a total of 2986 documents in the dataset. The average annual growth rate of the documents is 10.94%, indicating a consistent increase in the number of documents over time. The average age of documents in the dataset is 6.92 years. On average, each document has received 5.604 citations. The total number of references cited across all documents is 69990. There are 2087 instances of Keywords Plus and 7959 instances of author-provided keywords. There are a total of 7470 unique authors and 575 documents were authored by a single author. On average, each document has 3.19 co-authors, and 11.42% of these co-authorships are international collaborations. The data includes various types of documents such as articles, book chapters, data papers, proceedings papers, books, book reviews, corrections, editorial materials, meeting abstracts, and reviews.

Performance analysis for Search №1 (annual scientific production)

The number of articles appears to have varied over the years. Firstly, the number of articles remained relatively low during the early years (1993-2000), with a gradual increase. From 2001 to 2007, there was a steady increase in the number of articles produced each year, with a notable increase in 2006 and 2007. The period from 2008 to 2018 saw rapid growth in scientific production, with a significant increase in the number of articles published each year.

The growth rate appears to peak around 2018. There's a fluctuation in the number of articles in recent years. While there was a decrease in 2019 compared to 2018, there's a noticeable drop in 2020, followed by a slight increase in 2021 and a significant decrease in 2022. The number of articles sharply declines in 2023 and 2024. The fluctuations in recent years might be influenced by various factors such as changes in research funding, shifts in research focus, global events (like the COVID-19 pandemic), or changes in publication trends. Overall, the data shows a general trend of increasing scientific production over the years, with some fluctuations in recent years. Further analysis could be done to understand the underlying reasons behind these fluctuations and to predict future trends (Figure 1).

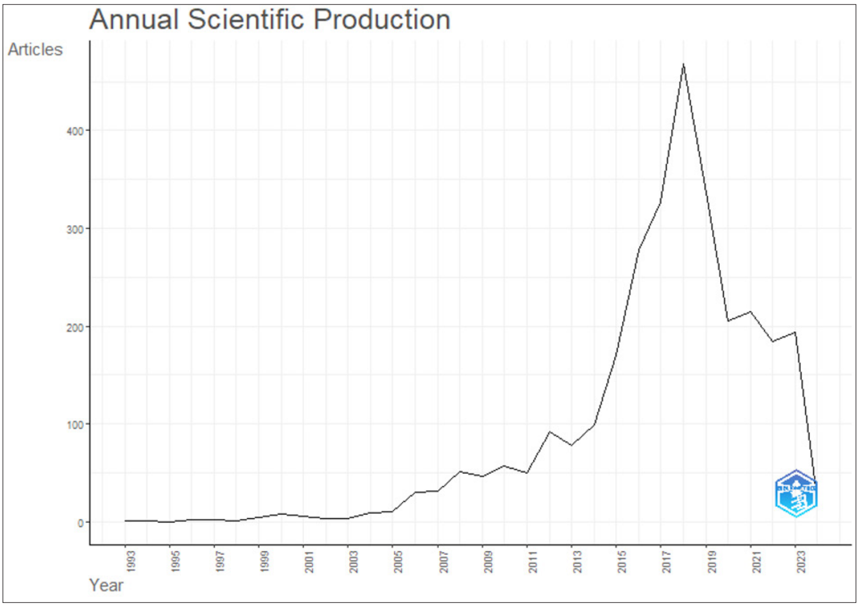

Figure 1. Annual Scientific Production (1993 – 2024) (for Search 1)

Performance analysis for Search №1 (average citations per year)

From 1993 to 1997 the average number of citations per article (MeanTCperArt) is consistently zero, indicating that no citations were received on average for articles published in these years. In the next period from 1998 to 2003 the average number of citations per article starts to increase gradually, with notable spikes in 2003 where it reaches 27 citations per article. This increase suggests a growing impact of research published during these years. There are fluctuations in the average number of citations per article during the period 2004-2009, with some years experiencing higher averages than others.

However, overall, there is a trend of increasing citation impact during this period, peaking at 24.21 citations per article in 2009. In 2010 – 2014 the average number of citations per article remains relatively high during these years, although there are some fluctuations. The average ranges from 4.36 to 14.72 citations per article. The average number of citations per article starts to decrease gradually from 2015 to 2024 with some fluctuations. However, there's a noticeable decrease towards the later years, dropping to 0.2 citations per article in 2024. The number of years over which citations were accumulated for articles published in each respective year decreases as we move towards the later years. This suggests that recent articles tend to accumulate citations more quickly.

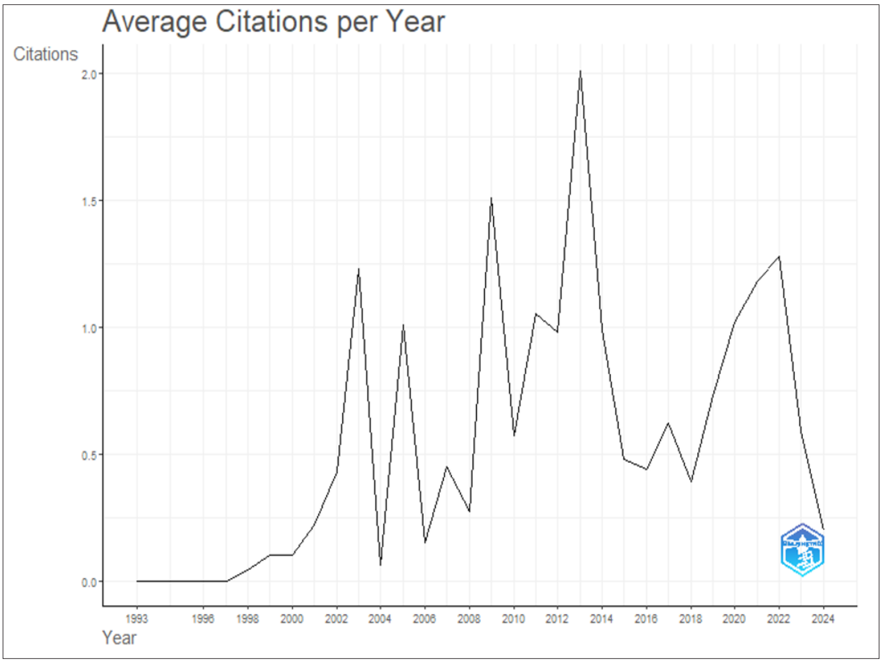

Figure 2. Average citations per Year (for Search 1)

The data indicates trends in citation impact over time, with periods of increasing impact followed by periods of fluctuation and decline. The decrease in average citations per article in the later years may suggest changes in research practices, publication patterns, or citation behavior. Further analysis would be needed to understand the underlying factors contributing to these trends.

Performance analysis for Search №1 (most relevant sources and corresponding author's countries)

China has the highest number of articles (793) and is the most frequent corresponding author country (26.6% of the total articles). However, the ratio of multiple corresponding papers to total papers is relatively low (4.9%). The USA follows China with 454 articles, accounting for 15.2% of the total articles. Interestingly, the ratio of multiple corresponding papers (the number of articles where there were multiple corresponding authors from the respective country) to total papers is higher for the USA (6.6%) compared to China.

Other countries like Indonesia, Bulgaria, Russia, Germany, and the United Kingdom also have significant contributions, each with more than 80 articles. Some countries have a higher proportion of multiple corresponding papers, indicating collaborative efforts or projects involving researchers from those countries. For example, the Netherlands, Estonia, and Singapore have relatively high MCP (Multiple Corresponding Papers) ratios. The data shows representation from a wide range of countries, indicating the global nature of scientific collaboration and research contributions (Figure 3).

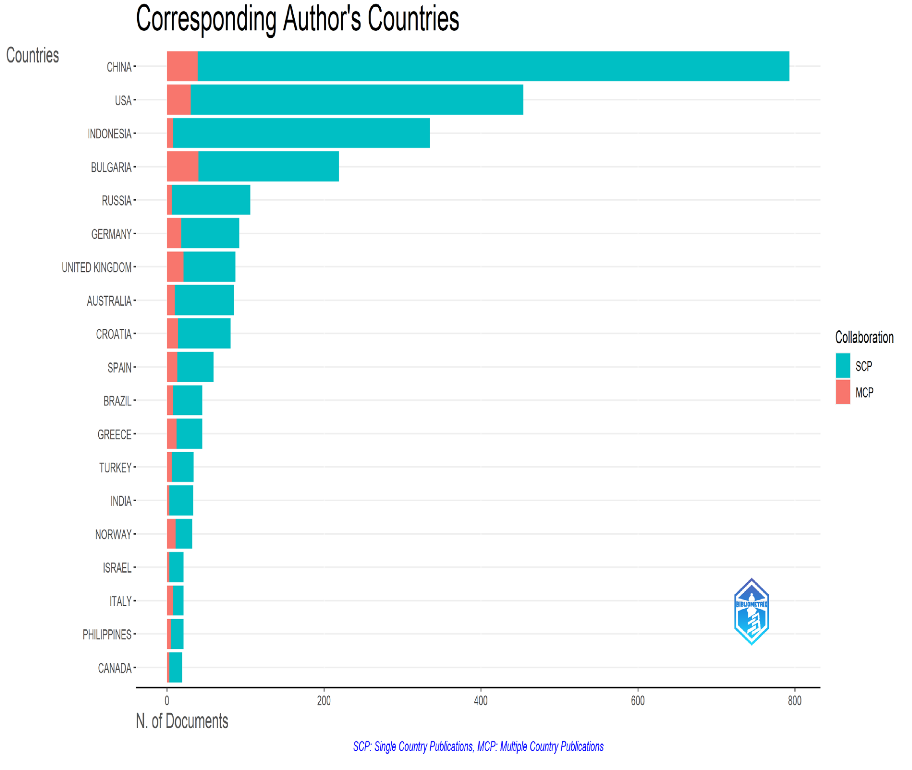

Figure 3. Corresponding Author's Countries

Science mapping and network analysis for Search 1 (clustering by coupling)

The following data (Figure 4) represent the results of clustering by coupling in the bibliometric analysis, where each line consists of a thematic cluster along with associated terms and their respective confidence levels, frequency, centrality and impact.

Cluster 1 (Computational thinking, K-12, Robotics) seems to focus on the integration of computational thinking, K-12 education, and robotics with high confidence levels. Computational thinking and K-12 have a confidence level of 87.5%, while Robotics has a confidence level of 80%. These terms are strongly associated with each other, indicating a high likelihood that they appear together frequently in the analysed literature.

Cluster 2 (Education, Knowledge, Students) is centred on general education themes such as knowledge and students, with a high frequency and impact. Education and Knowledge have confidence levels of 54.2% and 76.5%, respectively, while Students have a confidence level of 54.3%. While Education and Students have moderate confidence levels, Knowledge has a high confidence level.

Cluster 3 (Beliefs, Mathematics, Education) explores themes related to beliefs and mathematics in education, albeit with lower confidence levels and impact. Beliefs and Mathematics have confidence levels of 28.6% and 30.8%, respectively, while Education has a confidence level of 6.2%. The confidence levels for all terms in this cluster are relatively low, indicating a weaker association between beliefs, mathematics, and education compared to other clusters.

Cluster 4 (Science, Students, Education) lacks centrality and impact information, making it difficult to assess its significance accurately. Science, Students, and Education have confidence levels of 19.4%, 13%, and 10.4%, respectively. Similar to Cluster 3, the confidence levels for terms in this cluster are relatively low, suggesting a weaker association between science, students, and education compared to other clusters.

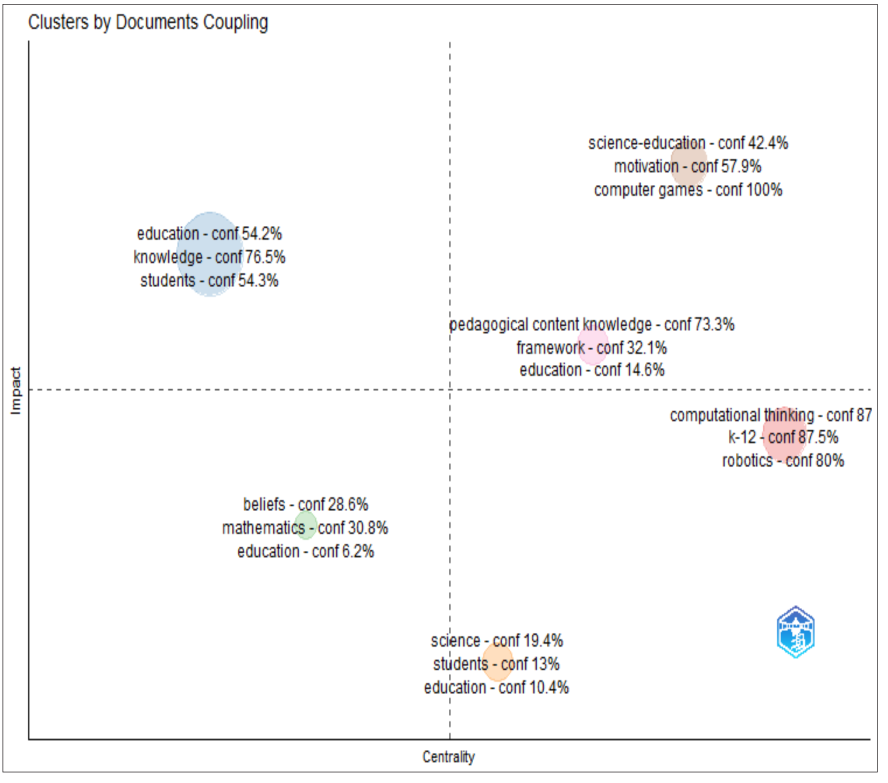

Figure 4. Clustering by coupling

Cluster 5 (Science-Education, Motivation, Computer games) highlights the importance of science education, motivation, and computer games with high confidence and impact levels. Science-Education and Motivation have confidence levels of 42.4% and 57.9%, respectively, while Computer games have a confidence level of 100%. This cluster shows a strong association between science education, motivation, and computer games, with computer games having the highest confidence level, indicating a significant presence of this term in the analysed literature.

Cluster 6 (Pedagogical content knowledge, Framework, Education) emphasizes pedagogical content knowledge and frameworks within education, showing moderate to high confidence and impact. Pedagogical content knowledge and Framework have confidence levels of 73.3% and 32.1%, respectively, while Education has a confidence level of 14.6%. Pedagogical content knowledge stands out as the term with the highest confidence level in this cluster, suggesting its strong association with the other terms, albeit to varying degrees.

Science mapping and network analysis for Search 1 (co-word network)

The co-word network analysis with nodes in a bibliometric analysis represents different concepts or terms, and various metrics associated with these nodes such as cluster, betweenness centrality, closeness centrality, and PageRank. Overall, the analysis suggests that the network consists of three distinct clusters, each representing different aspects of education and related concepts. Cluster 1 focuses on motivation, performance, and teaching strategies, Cluster 2 revolves around science education and modelling, while Cluster 3 encompasses a broad range of educational concepts including curriculum, pedagogy, and subject-specific knowledge.

Cluster 1 is formed by key concepts like *motivation, performance, achievement, engagement, classroom, strategies, chemistry, self-efficacy, online, information, computational thinking, challenges, experiences*. They appear to be closely related in a cluster with moderate to high betweenness centrality and closeness centrality. They have moderate importance in the network based on PageRank. Terms like "motivation," "performance," "achievement," and "engagement" may indicate that this cluster is related to student outcomes and classroom dynamics. "Motivation" has the highest betweenness centrality, suggesting its critical role in influencing other terms related to student outcomes and engagement. Closeness centrality measures how quickly a node can interact with other nodes in the network. For example, terms like "motivation," "performance," and "engagement" have relatively high closeness centrality values, indicating their efficiency in information flow within the cluster. PageRank reflects the importance of a node based on the number and quality of links pointing to it. "Motivation" and "performance" have notable PageRank values, suggesting their importance in the context of student outcomes and classroom dynamics.

Cluster 2 is formed by key concepts like *science-education, skills, thinking, literacy, models, representations, simulation, children, curriculum, and tool*. This cluster seems to revolve around concepts related to science education and pedagogy, with moderate to high betweenness centrality and closeness centrality. These concepts have moderate importance in the network based on PageRank. Terms like "science-education" and "skills" in Cluster 2 exhibit high closeness centrality, suggesting their influence and connectivity within the cluster.

Finally, ***Cluster 3*** is formed by key concepts like *education, students, science, knowledge, technology, framework, model, design, teachers, inquiry, instruction, impact, attitudes, mathematics, school, beliefs, pedagogical content knowledge, system, conceptions, physics, support, perceptions, environments, outcomes, and implementation*. This cluster includes a wide range of concepts related to education, ranging from pedagogy to specific subject areas such as science and mathematics. These concepts have high betweenness centrality and closeness centrality, indicating their importance in connecting different parts of the network. They also have high importance in the network based on PageRank. “Education” and “students” have high betweenness values in Cluster 3, indicating their importance as central concepts connecting various terms in the network. They also have high PageRank values, indicating their significance as central concepts with many connections to other terms.

Interpreting from the perspective of science education and digital technology terms like “motivation,” “performance,” “achievement,” and “engagement” in Cluster 1 having connectivity with terms like “online”, “information”, “computational thinking” may be crucial for understanding students’ behaviour and academic success, particularly in digital learning environments. Cluster 2, which includes terms like “science-education,” “skills,” and “thinking,” highlights the importance of integrating digital technologies into science education to foster critical thinking and skill development (“models”, “representations”, “simulation”, “children”, “curriculum”, “tool” are also in the same cluster). Cluster 3 emphasizes broader educational concepts like “education,” “students,” “science,” and “technology,” underscoring the role of digital tools and platforms in enhancing teaching and learning experiences across various disciplines, including science education.

Science mapping and network analysis for Search 1 (factorial analysis)

The method of factorial analysis used in Bibliometrix R is MCA (Multiple Correspondence Analysis). The factorial analysis has grouped the terms into clusters based on their similarities and relationships, providing insights into the underlying structure and dimensions of the data. Dim.1 and Dim.2 represent orthogonal dimensions derived from the factorial analysis. These dimensions capture the variance in the data and are used to represent the words or concepts in a lower-dimensional space. Dim.1 represent a spectrum from negative to positive values, indicating opposing characteristics or factors. Terms with positive values might represent concepts related to positive outcomes or attitudes, while those with negative values might represent challenges or negative perceptions. Dim.2 appears to represent another dimension capturing variation in the data. Concepts with positive values might indicate one set of characteristics or factors, while those with negative values might represent another set of characteristics.

According to the information given by Bibliometrix R there are 56 entities (terms) allocated into seven main groups of terms:

Education-related terms*:* Words like “education,” “students,” “teachers,” “school,” “curriculum,” “professional development,” etc., all have positive loadings on both dimensions. These terms are closely related and represent a cluster of education-related concepts.

Science and technology terms*:* Words like “science,” “knowledge,” “technology,” “science education,” “physics,” “chemistry,” “mathematics,” “computational thinking,” “computer simulations,” etc., all have positive loadings on both dimensions.

This indicates a cluster of terms related to science, technology, engineering, and mathematics (STEM) education or subjects.

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***Pedagogical terms**:* Terms like “framework,” “model,” “instruction,” “strategies,” “support,” “implementation,” “challenges,” “experiences,” etc., have positive loadings on both dimensions as well. These terms seem to relate to pedagogical approaches, teaching methods, and instructional strategies.

***Cognitive terms**:* Words like “inquiry,” “thinking,” “perceptions,” “visualization,” “conceptual change,” etc., have high loadings on the second dimension and relatively lower loadings on the first dimension. These terms might represent cognitive processes, mental representations, or conceptual understanding.

***Attitudinal and motivational terms**:* Terms like “motivation,” “engagement,” “attitudes,” “self-efficacy,” “acceptance,” etc., have high loadings on the first dimension and relatively lower loadings on the second dimension. These terms are related to students’ attitudes, motivation, and self-beliefs towards learning and education.

***Technology-related terms**:* Words like “online,” “simulation,” “computer simulations,” “internet,” etc., have high loadings on either one or both dimensions. These terms seem to represent the use of technology in education, particularly in terms of online learning, simulations, and internet-based resources.

***Other terms**:* Some terms like “models,” “conceptions,” “representations,” “literacy,” “information,” “systems,” etc., have various loadings on both dimensions. These terms may represent additional aspects of education, such as conceptual frameworks, cognitive models, information literacy, and systemic approaches.

Dim.1 appears to capture factors related to effective educational practices and outcomes, while Dim.2 seems to represent factors related to cognitive processes and systemic aspects of education. Positive values indicate a strong association with these factors, while negative values suggest a weaker or inverse association.

Trend Topics for Search 1

Another insight on our study can be elicited by the trend topics (Figure 5). The criteria for including a certain topic in trend analysis of Bibliometrix R is “Word minimum frequency” = 5 and “Number of words per year” = 3. We can see that data meet these two criteria from 2012 to 2023.

We analyse the results in Figure 5.

Education, Students, Science – these terms show a similar trend, with mentions starting around 2016 and continuing to increase until 2022. This suggests a sustained interest and focus on education, students, and science in the academic discourse over recent years.

Framework, Model, Design, Teachers, Motivation – these terms also show a consistent presence in the dataset, with mentions starting around 2016 and peaking between 2018 and 2020. This indicates a period of heightened attention to topics related to frameworks, models, instructional design, teacher-related issues, and motivation in education.

Engagement, Attitudes, Skills – these terms demonstrate a slightly delayed emergence, with mentions starting around 2019 and continuing to rise until 2023, which suggests a growing interest in aspects such as student engagement, attitudes, and skills, reflecting evolving priorities in educational research and practice.

Beliefs, Conceptions, Physics, Tool, Internet, Conceptual Change – these terms have varying patterns but generally show mentions spanning from the mid-2010s to the early 2020s. While some topics like beliefs and conceptions show a relatively stable presence over time, others like physics, tools, internet, and conceptual change demonstrate fluctuations in mentions across different years.

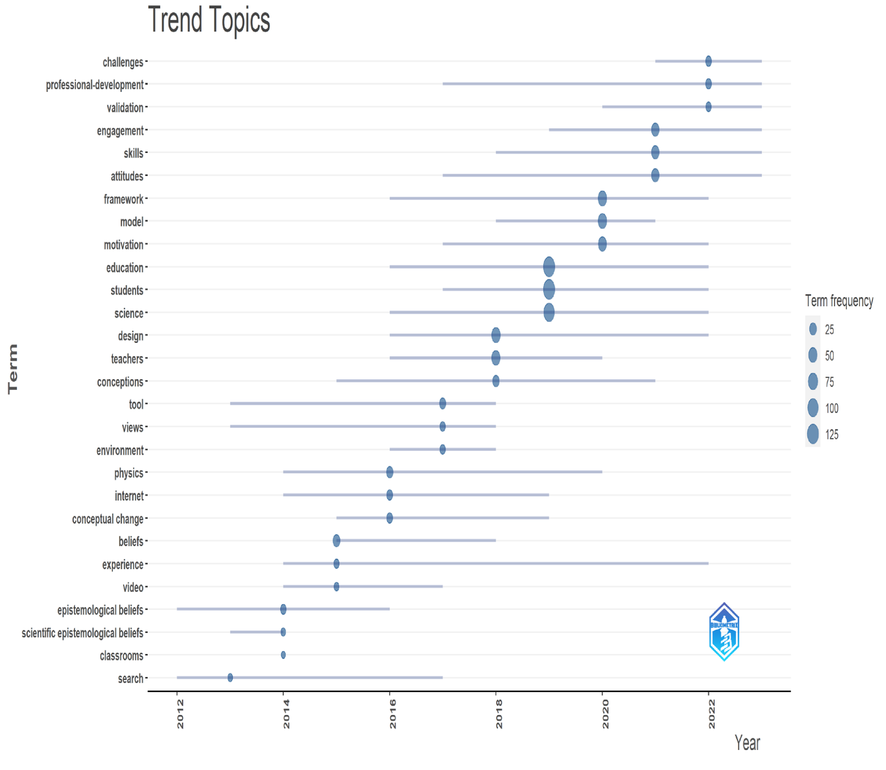

Figure 5. Visualisation of trend topics

Challenges, Professional Development, Environment, Views, Validation – these terms appear to have more scattered mentions across the years, with no clear increasing or decreasing trend. However, there are peaks in mentions for certain years, indicating periods of heightened interest or relevance in the academic discourse.

Epistemological Beliefs, Experience, Video, Search, Scientific Epistemological Beliefs, Classrooms – these terms have fewer mentions compared to the others, with varying patterns of emergence and presence in the dataset. Some, like epistemological beliefs and experience, show a consistent presence, while others like video and search demonstrate fluctuations in mentions over time.

Conclusion

In answer to RQ#1 we discussed modern educational approaches applicable to science education, focusing on competency-based education and other methodologies. Our research emphasized the evolution of key competences in education, tracing their roots to progressive education movements and contemporary frameworks like the European Qualifications Framework (EQF) and the Framework for 21st Century Learning. Alongside competency-based education, various educational approaches are included in our research like Inquiry-Based Learning, Problem-Based Learning (PBL), Project-Based Learning (PBL), Model-Based Inquiry (MBI), Collaborative Learning, Design-Based Learning (DBL), Context-Based Learning, Differentiated Instruction, and Experiential Learning. Research skills (RS) and digital skills (DLS) are highlighted as essential components of these educational approaches, forming new skills termed digital research skills (DRS).

The analysis reveals a progressive increase in scientific production in science education and digital technology integration over time, indicating the growing influence of digital technology in shaping educational research trends (RQ#2). Thematic clusters highlight the interconnectedness of concepts such as computational thinking, pedagogical content knowledge, and motivation within the context of science education and digital technology. These clusters underscore the importance of interdisciplinary approaches in educational research (RQ#3). Factorial analysis uncovers dimensions representing factors like effective educational practices, cognitive processes, and systemic aspects. It identifies associations between terms like "education" and "students" with positive loadings on both dimensions, indicating their importance in educational discourse (RQ#4).

Additionally, fluctuations in citation impact suggest dynamic shifts in research practices, publication trends, and citation behavior over time. Factors such as changes in research focus, funding, and global events may contribute to these fluctuations. Trend topics highlight evolving priorities in science education and digital technology, with increasing attention to concepts like engagement, attitudes, and skills. These trends may reflect a growing interest in student-centered learning and the integration of technology into educational practices.

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NOTES

1. EUROPEAN COMMISSION: DIRECTORATE-GENERAL FOR EMPLOYMENT, SOCIAL AFFAIRS AND INCLUSION, The European qualifications framework – Supporting learning, work and cross-border mobility – 10th anniversary, Publications Office, 2018 [viewed 10 October 2024]. Available from: https://data.europa.eu/doi/10.2767/385613.
2. EUROPEAN COMMISSION: DIRECTORATE-GENERAL FOR EDUCATION, YOUTH, SPORT AND CULTURE, Looney, J., O'Shea, M., Staring, F., Vicentini, L. et al., Key competences for all – Policy design and implementation in European school education – Final report, Publications Office of the European Union, 2022 [viewed 10 October 2024]. Available from: https://data.europa.eu/doi/10.2766/1951.
3. NATIONAL RESEARCH COUNCIL, 2000. Inquiry and the National Science Education Standards: A Guide for Teaching and Learning. Washington: National Academies Press. ISBN 0-309-06476-7.
4. RUIZ-PRIMO, M. A., 2009. Towards a framework for assessing 21st century science skills. Workshop on Exploring the Intersection of Science Education and the Development of 21st Century Skills. Washington, DC.
5. THOMAS, J. W., 2000. A Review of Research on Project-Based Learning. Autodesk Foundation [viewed 10 October 2024]. Available from: https://tecfa.unige.ch/proj/eteach-net/Thomas_researchreview_PBL.pdf

REFERENCES

BARROWS, H. S., 1986. *A Taxonomy of Problem-Based Learning Methods*. Springer [viewed 10 October 2024]. Available from: https://doi.org/10.1111/j.1365-2923.1986.tb01386.x.

BENNETT, J. & HOLMAN, J., 2002. Context-based approaches to the teaching of chemistry: What are they and what are their effects? *Chemical education: Towards research-based practice*, vol. 17, pp. 165 – 184 [viewed 10 October 2024]. Available from: https://doi.org/10.1007/0-306-47977-X_8.

BINKLEY, M. et al., 2012. Defining Twenty-First Century Skills. In: GRIFFIN, P., MCGAW, B., CARE, E. (Eds). *Assessment and Teaching of 21st Century Skills,* pp. 17 – 66. Dordrecht: Springer.

BLANKENDAAL, K., et al., 2023. Digital Research Skills in Secondary Science Education: A Guiding Framework and University

Teachers' Perception. *European Journal of STEM Education*, vol. 8, no. 1, pp. 1 – 14.

BLUMENFELD, P. C., et al., 1991. Motivating Project-Based Learning: Sustaining the Doing, Supporting the Learning. *Educational Psychologist*, vol. 26, no. 3&4, pp. 369 – 398 [viewed 10 October 2024]. Available from: https://doi.org/10.1080/00461520.1991.9653139.

DEWEY, J., 1938. *Experience and Education*. *Simon and Schuster*. New York: Macmillan Company.

DEWEY, J., 2016. Excerpts from democracy and education (1916). *Schools*, vol. 13, no. 1, pp. 127 – 139.

EDELSON, D. C.; GORDIN, D. N. & PEA, R. D., 1999. Addressing the Challenges of Inquiry-Based Learning Through Technology and Curriculum Design. *Journal of the Learning Sciences*, vol. 8, no. 3&4, pp. 391 – 450.

FISCHER, F., et al., 2014. Scientific reasoning and argumentation: advancing an interdisciplinary research agenda in education. *Frontline Learning Research*, vol. 2, no. 3, pp. 28 – 45.

GRIFFIN, M., et al., 2011. Engaging stem: Service-learning, technology, science education and community partnerships. *Higher Education, Emerging Technologies, and Community Partnerships: Concepts, Models and Practices*, pp. 51 – 56.

GRIFFIN, P., et al., 2012. *Assessment and teaching 21st century skills.* Dordrecht: Springer. ISBN 978-94-017-9394-0.

JOHNSON, D. W., et al., 1998. *Active Learning: Cooperation in the College Classroom.* Interaction Book Company.

KOLB, D. A., 2014. *Experiential Learning: Experience as the Source of Learning and Development*. FT Press. ISBN 978-0133892406.

KOLODNER, J. L., 2002. Facilitating the Learning of Design Practices: Lessons Learned from an Inquiry into Science Education. *Journal of Industrial Teacher Education*, vol. 39, no. 3, pp. 23 – 38.

KURT, S., 2020. Problem-based learning (PBL). *Educational Technology*.

LARSON, L. C. & MILLER, T. N., 2011. 21st century skills: Prepare students for the future. *Kappa Delta Pi Record*, vol. 47, no. 3, pp. 121 – 123 [viewed 10 October 2024]. Available from: https://doi.org/10.1080/00228958.2011.10516575.

PEDASTE, M., et al., 2015. Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational research review*, vol. 14, pp. 47 – 61 [viewed 10 October 2024]. Available from: https://doi.org/10.1016/j.edurev.2015.02.003.

RYCHEN, D. S. & SALGANIK, L. H., 2003. *Key competencies for a successful life and well-functioning society*. Hogrefe Publishing GmbH. ISBN 0-88937-272-1.

SAVERY, J. R., 2006. Overview of Problem-based Learning: Definitions and Distinctions. *Interdisciplinary Journal of Problem-based Learning*, vol. 1, no. 1.

SLAVIN, R. E., 1996. Research on Cooperative Learning and Achievement: What We Know, What We Need to Know. *Contemporary Educational Psychology*, vol. 21, no. 1, pp. 43 – 69 [viewed 10 October 2024]. Available from: https://doi.org/10.1006/ceps.1996.0004.

SCHWARZ, C. V. & WHITE, B. Y., 2005. Metamodeling Knowledge: Developing Students' Understanding of Scientific Modeling. *Cognition and Instruction*, vol. 23, no. 2, pp. 165 – 205 [viewed 10 October 2024]. Available from: https://doi.org/10.1207/s1532690xci2302_1.

TOMLINSON, C. A. & ALLAN, S. D., 2000. *Leadership for Differentiating Schools & Classrooms.* Heatherton: Hawker Brownlow Education. ISBN 0871205025.

TOMLINSON, C.A., 2014. *The Differentiated Classroom: Responding to the Needs of All Learners.* ASCD, Alexandria. ISBN 10: 0134109503.

TRILLING, B. & FADEL, C., 2009. *21st century skills: Learning for life in our times*. John Wiley & Sons. ISBN 978-0-470-55391-6.

WILSON, M. R. & BERTENTHAL, M. W., 2005. *Systems for state science assessment*. Washington, DC: National Academies Press.

WINDSCHITL, M. et al., 2008. Beyond the Scientific Method: Model-Based Inquiry as a New Paradigm of Preference for School Science Investigations. *Science Education*, vol. 92, no. 5, pp. 941 – 967 [viewed 10 October 2024]. Available from: https://doi.org/10.1002/sce.20259.

Dr. Ivelina Kotseva, Assist. Prof.
ORCID iD: 0000-0003-2932-7069
Dr. Maya Gaydarova, Assoc. Prof.
ORCID iD: 0000-0003-1552-1039
Faculty of Physics
Sofia University
Sofia, Bulgaria
E-mail: iva_georgieva@phys.uni-sofia.bg
E-mail: mayag@phys.uni-sofia.bg