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Citizen science as a relevant approach to the challenges of complex thinking development in higher education: mapping and bibliometric analysis

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Educational strategies have undergone significant transformations in an era marked by rapid globalization, advancements in communication technologies, and challenges like the COVID-19 pandemic. Amid these changes, Citizen Science (CS) has gained prominence as an innovative educational approach, particularly in fostering complex thinking skills necessary to navigate contemporary global trends. This study aims to fill the knowledge gap regarding the effectiveness of CS projects in developing complex thinking competencies within higher education. Through a bibliometric analysis of 28 Scopus-indexed articles from 2000 to 2022, this research maps the landscape of CS as an educational strategy and evaluates its alignment with complex thinking development. The analysis indicates a strong link between CS projects and the enhancement of complex thinking and its sub-competencies. It demonstrates that CS initiatives have successfully achieved their educational objectives, substantially enriching the learning experience. Furthermore, the research highlights a growing trend in applying CS for educational purposes. These findings suggest that CS can be a valuable component of higher education curricula, offering a practical method for developing critical competencies in students. The study underscores the potential of CS to contribute meaningfully to the evolution of pedagogical practices and provides a foundation for future research to build upon, particularly in the context of higher education's response to global educational demands.

Introduction

Global phenomena such as human rights crises, armed conflicts, migrations, environmental challenges, and pandemics are reshaping the landscape of higher education. These issues underscore the pressing need for educational reforms that address the content of learning and the development of critical competencies. The decline in democratic engagement is alarming and indicative of a broader crisis in citizenship, independent thinking,

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and the capacity to address complex social issues related to gender, race, and identity. Such a backdrop of uncertainty and tension necessitates innovative educational strategies that empower individuals to navigate and contribute to an increasingly complex world.

Citizen Science (CS), rooted in the democratization of scientific inquiry, has emerged as a promising approach within higher education. It leverages mass collaboration to advance scientific knowledge and cultivate various competencies among participants. It aligns with UNESCO's vision for transforming the scientific process, advocating for a model of science that is inclusive, participatory, and capable of bridging gaps in science, technology, and education. This study explores the potential of CS to act as a catalyst in higher education, specifically examining its role in enhancing complex thinking sub-competencies that are vital for grappling with contemporary global challenges.

The central research question guiding this inquiry is: How does integrating CS as a pedagogical strategy impact the development of complex thinking sub-competencies in higher education? The study employs a bibliometric analysis to map the influence of CS on these competencies, aiming to uncover trends and assess the educational value of CS initiatives. By doing so, it seeks to provide insights into the transformative potential of CS in equipping students with the skills necessary to engage with and address the multifaceted challenges of our time.

The importance of incorporating complex thinking into Education 4.0. In response to current educational challenges, we propose several pathways for higher education, notably the shift towards knowledge democratization facilitated by the technological revolution inherent in Education 4.0. Morin (1996) presciently argued that digital transformation would catalyze a shift from a traditional, restrictive educational paradigm to one characterized by openness and adaptability, more suited to the 21st century. Thus, Education 4.0 is not just about bridging the digital divide across generations and socioeconomic backgrounds (Oliveira et al., 2022) but also about harnessing the potential of CS, communication technologies, and innovative methodologies to enrich educational experiences.

The twentieth century has witnessed substantial changes in various domains, including education; however, despite these advances, educational practices have scarcely evolved since the century's commencement, clinging to a traditional framework and encountering difficulties in altering educational paradigms. In this context, teachers are often products of a generation educated within this conventional schooling paradigm (Hubbard and Datnow, 2020; Marshall, 2010), confined to classroom settings where teacher-student interactions suggest an imbalanced power dynamic and where disciplinary knowledge is segmented, detached from the burgeoning issues of social reality. This paradigm fails to capture the complexity of reality and its global repercussions in localized settings (Morin, 1996). Consequently, cultivating interdisciplinary spaces and developing sub-competencies in complex thinking is imperative for a comprehensive understanding of the interconnected phenomena that characterize the present day.

During the pandemic, we shifted towards hybrid models, representing a significant advancement, yet considerable room remains for improvement. Insights from Dhawan (2020), Malatyinszki (2020), and Willermark and Gellerstedt (2022) highlighted that virtual classes should not merely replicate traditional classroom settings in a digital format. Furthermore, it has become apparent that the teacher is not the sole custodian of knowledge; students can seek information through various platforms, engaging with expert lectures, specialized content, and virtual essays, among other resources (Hajar Halili, 2019). This access allows students to complement, enhance, challenge, and even surpass the knowledge provided by their teachers, facilitating a shift from a one-sided to a dialogic relationship between students and teachers.

The traditional classroom is undergoing a crisis; students turn to the web for video conferences, video essays with experts, databases, and cutting-edge knowledge. This wealth of content, accessible through media technologies, fosters an autonomous approach to learning, redefining the teacher's role as a mediator and facilitator within an open classroom (Huck, 2020). Such a shift necessitates reimagining the educational space as a forum for dialog that transcends geographical, linguistic, and cultural barriers. It also calls for adopting innovative educational strategies (Ramírez-Montoya et al., 2022) and creating democratic spaces for knowledge access, thereby underscoring the need to integrate approaches that nurture complex thinking for the students' sustainable development. Consequently, the challenges confronting education, especially higher education, are substantial and require a comprehensive and inclusive approach to align with global objectives.

Integrating complex thinking into the learning process can be a strategic move. Morin (1996) posits that complex thinking weaves together interdisciplinary perspectives for problem-solving, highlighting the necessity for a situated and critical analysis that coalesces disparate strands of knowledge. Echoing this, RÉ (2020) suggests that curricula grounded in complexity can be designed with a multidisciplinary approach to meet global needs and challenges. Silva Pacheco (2020) describes complex thinking as a meta-competency, which Vázquez-Parra et al. (2022) define as encompassing critical, systemic, and scientific thinking, with innovative thinking also recognized as essential. Therefore, complex thinking is indispensable for 21st-century education for a multifaceted examination of problems from various angles and perspectives.

Citizen Science projects as an educational strategy. Exploring and experimentation within the real-world are at the heart of scientific inquiry. Advancing science involves observing phenomena, documenting them, and testing hypotheses to confirm or revise them; these are crucial steps in the scientific process. However, an individual's capacity to gather sufficient data to support a theory is often limited by logistical constraints, such as the inability to be in multiple places simultaneously. This limitation is not new; even Darwin depended on the contributions of others to illustrate his findings (Organ, 1994). The collaborative approach to data gathering has evolved into what we now recognize as CS, which broadens the scope of volunteer involvement to include not just data collection but also interpretation, analysis, and even the development of projects from problem identification to the dissemination of results, often in partnership with professional researchers (Eitzel et al., 2017). While initially, the focus of observation in CS was predominantly on natural phenomena such as plants, animals, and atmospheric conditions, it has since expanded to encompass virtually every scientific discipline.

Exposure to nature is advantageous for those seeking to learn through observation, but urban sprawl has increasingly truncated this possibility. In the case of students in educational institutions, the bridges to counteract the lack of proximity to these phenomena have been constructed beyond books and laboratories, expanding from audiovisual interactive media to integrating new technologies for their simulation (Chernikova et al., 2020). This somewhat artificial way of experiencing science has been enhanced by the widespread adoption of mobile devices, becoming the norm for teaching and learning even when there may be access to the local environment (Bonfield et al., 2020). Against this detachment, contemporary CS has contributed to the convergence of face-to-face experimental science by leveraging modern technologies, bringing students—and teachers—back to the field.

While CS aimed initially to engage the public as volunteers in formal research endeavors, it has impressively entered into academic settings, facilitated by the ease of recruiting participants from educational institutions, thus ensuring project continuity. In contemporary educational settings, it is common to see students engaged in outdoor activities, using their smartphones to collect data and geotagging images and sounds to create extensive databases that support grander research initiatives (Herodotou et al., 2018). The synergy between research and educational environments—scientists and educators alike—has become apparent, with both recognizing the reciprocal advantages of incorporating CS projects into regular curricular activities (Ryan et al., 2018). For students, participating in hands-on, real-world scientific inquiries enhances their engagement and instills a sense of contributing to meaningful research, thereby adding value to their educational experience (Condon and Wichowsky, 2018). From a curricular perspective, CS projects are instrumental in cultivating a range of competencies and skills in students, integrating multiple disciplines in the process.

Employing CS projects as an educational strategy immerses students in an experience that embodies the principles of transparency, collaboration, and knowledge dissemination, which are at the forefront of modern educational frameworks. UNESCO's endorsement of open science underscores approaches that align with the ethos of CS, particularly in fostering interactions among ecosystem participants to enhance science literacy (UNESCO, 2021). Integrating CS into the curriculum promotes collaboration between different sectors, inviting open engagement from societal actors beyond traditional research communities (Sanabria-Z et al., 2022). This inclusive approach also opens avenues for dialog among diverse knowledge systems, giving voice to vulnerable communities or minority groups often underrepresented in scientific endeavors (Hicks et al., 2019). On a practical level, physical and digital research infrastructures, such as advanced scientific instruments, open data repositories, computing systems for data analysis, and tools for open dissemination, are all critical components of open science that align with its core values and principles and enrich learning.

Incorporating CS projects into education can significantly enhance an individual's comprehensive understanding of the phenomena under study. Developing frameworks to assess student outcomes in CS projects and establishing guidelines are crucial for tailoring these initiatives to educational settings (Kelemen-Finan et al., 2018). Indeed, educational impact measurements can be integrated into a broader set of indicators, such as those outlined in the typology by Sanabria-Z et al. (2022), "Threshold for CS projects." This typology includes variables like context awareness, technological innovation, citizen engagement, and complex thinking. Operationalizing CS as a pedagogical method through curricular integration empowers students as change agents who inspire others to adapt to change rather than resist it (European Research Council, 2022). Therefore, to effectively track the progress of CS in education, it is vital to continually document and analyze the themes, methodologies, and outcomes of CS projects over time.

Exploration of emerging trends through mapping review and bibliometric analysis. The pace of scientific and academic progress across various disciplines is accelerating. Conducting a literature review provides a comprehensive overview of the major research trajectories within a subject area and identifies less-explored fields (Ridley, 2019). Literature reviews, especially systematic ones, are crucial for uncovering trends and gaps from such studies, thereby aiding in knowledge creation on these topics (Onwuegbuzie and Frels, 2016). The Search, Appraisal, Synthesis, and Analysis (SALSA) framework is widely recognized and adaptable to multiple disciplines (Jesson et al., 2011; Machi and McEvoy, 2012). The SALSA method involves four steps: 1. Search, which entails defining search strings and selecting appropriate databases; 2. Appraisal, where inclusion and exclusion criteria are established for analysis; 3. Synthesis, where information is categorized according to the mapping's objectives; and 4. Analysis, which includes a quantitative bibliometric analysis of the reviewed publications, is complemented by a qualitative examination of the prominent themes and concepts that emerge from the mapping questions.

Therefore, the literature review is a powerful tool that identifies and explores specific topics of interest. The advancement of scientific and academic research is often marked by the publication of study results, which contributes to the proliferation of knowledge through articles in scientific journals. This has led to increased publication of studies subject to rigorous evaluation processes, assessing their potential contributions to their respective fields (de Bakker et al., 2016; Goyal and Kumar, 2021). In this context, bibliometric analysis has emerged as a fundamental method for discerning research direction (Ellegaard and Wallin, 2015). Bibliometric analysis primarily involves a bibliographical review of selected studies, encompassing data related to authors, publications, geographical distribution (Zhuang et al., 2013), disciplines involved (Hou et al., 2022), and the time frame of the studies (Huffman et al., 2013), among other metrics. Thus, identifying these publications, authors, countries, and other relevant data has become essential to understanding research processes and trends.

Cebral-Loureda et al., (2022) posit that Bibliometrics, a subset of scientometrics, employs quantitative-statistical analysis of bibliographic data to assess research trends and outputs. Urbizagastegui-Alvarado (2021) highlights two critical types of analysis in bibliometric studies: a) analysis according to activity, which includes data on publication distribution, author connections, collaboration patterns, and more, and b) analysis according to impact, which reveals the publication's impact factor, citation count, and frequency of concepts within articles, thereby assessing the influence of journals within their respective fields. The article underscores the importance of combining a qualitative literature review to gain a deeper understanding of the topics related to the theme and its various aspects with a quantitative bibliometric analysis that evaluates the bibliographic footprint and impact of the research.

Materials and methods

The methodology of this paper was a literature review enriched by a bibliometric analysis. This approach facilitated gathering qualitative and quantitative data pertinent to using CS as an educational strategy, particularly its utility in fostering complex thinking competencies in higher education. The review process identified trends related to this subject by examining various studies.

Mapping questions. The research questions formulated for this mapping seek to provide a comprehensive overview of the characteristics of various studies conducted over time on CS as an educational strategy. Furthermore, this research examines the integration of complex thinking competency and its sub-competencies of critical, innovative (creative), scientific, and systemic thinking. Table 1 presents the mapping questions, which fall into three dimensions: (1) Scope: this dimension aims to clarify the type of CS research, whether it involves actual projects

Table 1 Mapping questions (MQ).

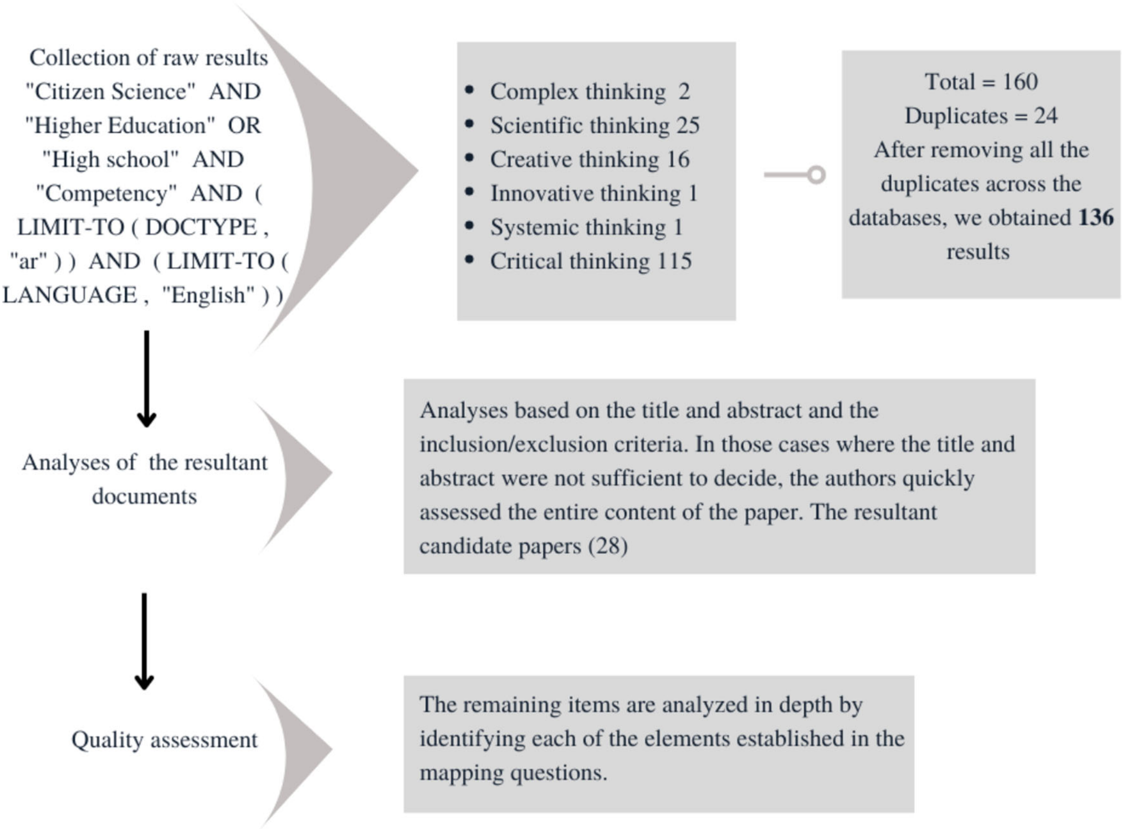
Dimension	Mapping questions	Possible answers based on literature
Scope	MQ1. What type of CS research is addressed, as classified by Wiggins and Crowston (2011)?	1. Action 2. Conservation 3. Investigation 4. Virtual 5. Education
	MQ2. Does the research explore the relationship between CS, education, and complex thinking?	1. Yes 2. No
Approaches and trends	MQ3. If the relationship with complex thinking is addressed, on which sub-competency does the project focus?	1. Complex thinking 2. Critical thinking 3. Innovative—creative— thinking 4. Systemic thinking 5. Scientific thinking
	MQ4. Does the CS approach serve as an educational strategy?	1. Yes 2. No
	MQ5. To which educational level does the CS project contribute?	1. High school 2. Higher education
Metrics	MQ6. What is the annual production per search chain?	Number of publications per year
	MQ7. Who are the most prominent authors, which countries are most active, and what are the key areas of knowledge in the field?	Author, country, and area of knowledge
	MQ8. Who are the authors with the greatest intellectual structure on the subject?	Intellectual structure network of authors
	MQ9. What are the key terms most frequently used in these studies, and how are they interconnected?	Keywords, keyword network, and trends

or theoretical proposals, and whether there is a connection to complex thinking; (2) Approaches and Trends in Education: this dimension assesses whether the project serves as an educational strategy and specifies the educational level it targets; and (3) Metrics: this dimension quantitatively evaluates the most meaningful bibliometric data from the studies in question.

Data collection and analysis: SALSA framework. We employed the SALSA framework to accurately identify prior studies pertinent to the topic of this research, per the recommendations for mapping and systematic literature reviews by Petersen et al. (2015):

a. Selection of the Database: Scopus was chosen as the database for this research due to its substantial academic and scientific relevance and considered the following criteria: it is recognized as one of the foremost databases for research and dissemination; it ensures the quality of the references it indexes; and a broad range of institutions have access to Scopus, which can facilitate the review process of the articles.
b. Inclusion and Exclusion Criteria: This step is crucial as it is essential to accurately select and define the criteria for the scope of the articles' review. Without proper selection, the analysis and conclusions may not be imprecise. The criteria applied in this mapping were: Inclusion criteria: publications indexed in Scopus; a historical publication that contains the following words in the title, keywords, and abstract: Citizen Science, Education, Higher Education, High school, Complex thinking, Critical thinking, Systemic thinking, Innovative thinking, Creative thinking, and Scientific thinking; and articles in the English language. Exclusion criteria: publications not indexed in Scopus; publications without the following words in the title, keywords, and abstract: Citizen Science, Education, Higher Education, High school, Complex thinking, Critical thinking, Systemic thinking, Innovative thinking, Creative thinking, and Scientific thinking; and other types of publications and languages other than English.
c. For the creation of the search string, it was crucial to incorporate the most pertinent and compelling concepts for analysis. In this instance, the necessary terms to analyze and interrelate with CS included "higher education," "high school," and "competencies." Regarding competencies, separate searches looked for scientific, critical, creative, innovative, systemic, and complex thinking. Notably, this search string was utilized exclusively within the Scopus database. The choice to utilize Scopus as the primary database for our research was a strategic and vital decision. Scopus has a renowned, comprehensive, and authoritative collection of peer-reviewed literature, particularly in education and science. This database was selected to guarantee the dependability and caliber of the data gathered for our study. Although alternative databases exist, the extensive scope and indexing capabilities of Scopus position it as the optimal resource for acquiring a thorough overview of the literature on CS and complex thinking within the educational context. This decision aligns with our objective to conduct a thorough and trustworthy examination of the subject matter.
The resulting query string for Scopus was: "Citizen Science" AND "Higher Education" OR "High school" AND "Competency" AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English")). The competency query considered the terms Scientific thinking, Critical thinking, Creative thinking, Innovative thinking, Systemic thinking, and Complex thinking.
d. Review Process: Following the selection of the database, the establishment of inclusion and exclusion criteria, and the definition of the query string, the subsequent steps for the mapping review were carried out, as depicted in Fig. 1.

Data and representation. The study employed computational tools such as R, provided by the R Core Team (2017) with the integrated development environment RStudio Team (2020), to conduct the quantitative bibliometric analysis. These tools are



After removing all the duplicates across the databases, we obtained **136** results

Analyses based on the title and abstract and the inclusion/exclusion criteria. In those cases where the title and abstract were not sufficient to decide, the authors quickly assessed the entire content of the paper. The resultant candidate papers (28)

The remaining items are analyzed in depth by identifying each of the elements established in the mapping questions.

Fig. 1 Process for the mapping review. Collection of raw results, document analysis and evaluation.

widely recognized for their robust statistical computing and graphics capabilities, which are particularly useful for managing, analyzing, and visualizing bibliometric data.

Results

The study results are organized and presented in alignment with each of the mapping questions previously outlined.

MQ1 What type of CS research is being addressed, as classified by Wiggins and Crowston (2011)?

According to the typology established by Wiggins, the following types of CS projects were identified: Conservation projects accounted for 7.1%, investigation projects made up 21.4%, virtual projects constituted 10.7%, and the category with the highest number of projects was education, representing 60.7%. Note that no projects were identified as action-oriented CS projects.

MQ2 Does the research explore the relationship between CS, education, and complex thinking? MQ3. If the relationship with complex thinking is addressed, on which sub-competency does the project focus?

The study determined that irrespective of their specific typology, all projects exhibited some form of correlation to complex thinking, as evidenced through various sub-competencies. The identified sub-competencies of complex thinking, including instances where multiple sub-competencies were combined within a single project, were as follows (see Fig. 2): complex thinking with critical thinking (3.6%); critical thinking alone (25%); critical thinking combined with innovative-creative thinking and scientific thinking (10.7%); critical thinking and scientific thinking (32.1%); innovative-creative thinking and scientific thinking (7.1%); and scientific thinking exclusively (21.4%.)

MQ4 Does the CS approach serve as an educational strategy? MQ5. To which educational level does the CS project contribute?

The analyzed CS projects contributed to educational strategies in various ways, as shown in Table 2. On the one hand, some projects explicitly had educational objectives, such as those by Belluigi and Cundill (2017) and Aristeidou et al. (2021), which served as practical examples of pedagogically driven initiatives. On the other hand, some projects were investigative, like those by Maicas et al., (2020), or virtual, such as Barak and Asakle (2018), which, although not primarily educational, substantially enhanced the students' learning experiences. Figure 3 further delineates the educational levels targeted by these projects, showing a predominance at the high school level, sometimes including educators from that tier, followed by higher education and, to a lesser extent, middle school, primary school, and projects aimed at educators.

MQ6 What is the annual production per search chain?

The annual growth rate of CS projects with an educational focus was 4.43%. Figure 4 shows that this growth has been consistent since 2014, indicating an increased exploration in the field. Prior to that year, the production of such projects was sporadic and less regular.

The evolution of themes within CS projects reveals a consistent focus on environmental and natural sciences over time, as depicted in Fig. 5. Additionally, due to the nature of these projects, educational themes are also prominently featured. Notably, there is a substantial emphasis on competencies, particularly the sub-competency of critical thinking and other thinking-related skills, indicating their importance in the context of CS projects.

MQ7 Who are the most prominent authors, which countries are most active, and what are the key areas of knowledge in the field?

Figure 6 illustrates the connections between authors, the most salient topics of the analyzed CS projects, and the

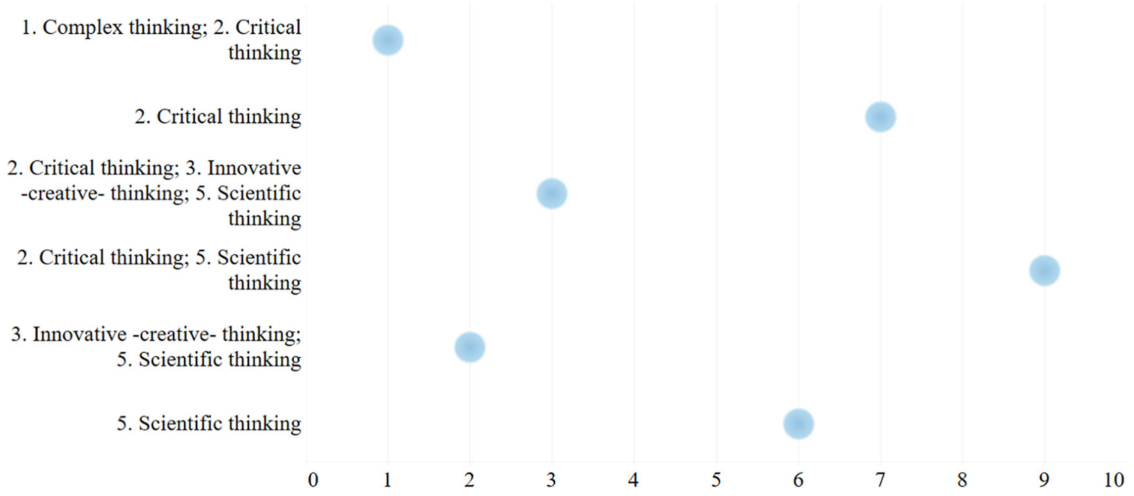


Fig. 2 Sub-competencies addressed in CS projects. Type of competencies and their recurrence in projects.

Table 2 List of projects that contributed to its educational purpose.

Number	Title	Author
1	Promoting Scientific Literacy in Evolution Through Citizen Science	Brandt et al., 2022
2	ICT Tools and Citizen Science: a Pathway to Promote Science Learning and Education for Sustainable Development in Schools	Rodríguez-Loinaz et al., 2022
3	Inquiry Through Industrial Chemistry in Compulsory Secondary Education for the Achievement of the Development of 21st-Century Skills	Ojeda et al., 2021
4	Lessons Learned Through Listening to Biology Students During a Transition to Online Learning in The Wake of the Covid19 Pandemic	Humphrey and Wiles, 2021
5	The Roles and Value of Citizen Science Perceptions of Professional Educators Enrolled in a Postgraduate Course	Aristeidou et al., 2021
6	Leveraging Citizen Science in a College Classroom to Build Interest and Efficacy for Science And The Environment	Smith et al., 2021
7	The Educational Community and its Knowledge and Perceptions of Native and Invasive Alien Species	Sosa et al., 2021
8	Educational Design Framework for a Web-based Interface to Visualize Authentic Cosmological Big Data in High School	Salimpour et al., 2021
9	Bridging the Gap: Bringing Professionals into the Classroom to Effectively Teach Environmental Science Concepts	Ware et al., 2019
10	Getting Messy with Authentic Data Exploring the Potential of Using Data From Scientific Research to Support Student Data Literacy	Kjelvik and Schultheis, 2019
11	Socio-scientific Reasoning and Environmental Literacy in a Field-based Ecology Class	Kinslow et al., 2019
12	Investigating Introductory Astronomy Students' Perceived Impacts From Participation in Course-based Undergraduate Research Experiences	Wooten et al., 2018
13	Authentic Science with Citizen Science and Student-driven Science Fair Projects	Koomen et al., 2018
14	Establishing Enabling Conditions to Develop Critical Thinking Skills: a Case Of Innovative Curriculum Design in Environmental Science	Belluigi and Cundill, 2017
15	School of Ants Goes to College: Integrating Citizen Science into the General Education Classroom Increases Engagement with Science	Vitone et al., 2016
16	Outcomes of a Self-regulated Learning Curriculum Model Network: Analysis of Middle School Students' Views of the Nature of Science	Peters-Burton, 2015
17	Teaching Socio-scientific Issues: Classroom Culture and Students' Performances	Tal and Kedmi, 2006

countries where these studies were published. This visualization helps pinpoint the specific interests of these countries in particular subjects and discern the current trends and themes related to CS. For instance, projects focused on developing new antibiotics or addressing antibiotic resistance were predominantly spearheaded by researchers in Switzerland. Meanwhile, the United States concentrated on CS as an approach to address environmental and educational issues.

Scientific production by countries and regions was identified; Europe and North America led the project count. The United States held the majority with 48.1% of the projects, followed by Spain at 18.5% and Switzerland at 7.4%. Other countries such as Argentina, the Czech Republic, Israel, Norway, Portugal, South Africa, and Sweden each contributed 3.7% to the total project count (see Fig. 7).

It is also crucial to identify the primary sources for disseminating scientific research. In this line, the journals that feature a concentration of these publications, with *Citizen Science: Theory and Practice* (three publications) being the foremost, indicating a trend among authors to publish on these topics, followed by *Environmental Education Research* (2), *Fems Microbiology Letters* (2), and the *Journal of Biological Education* (2). Other journals considered in the study included only one publication.

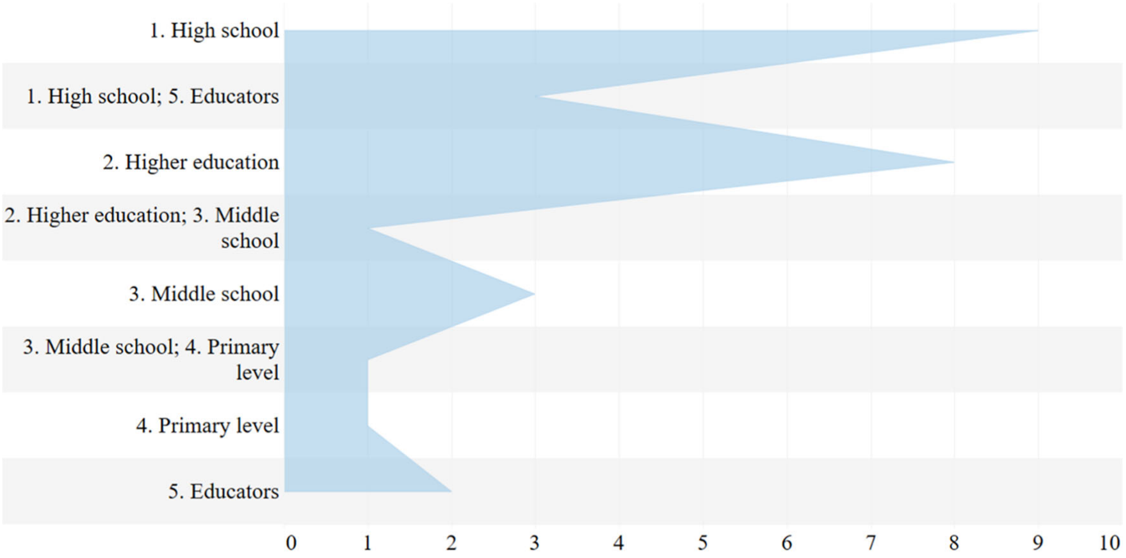


Fig. 3 Educational level addressed by CS projects. Different educational levels and their recurrence in projects.

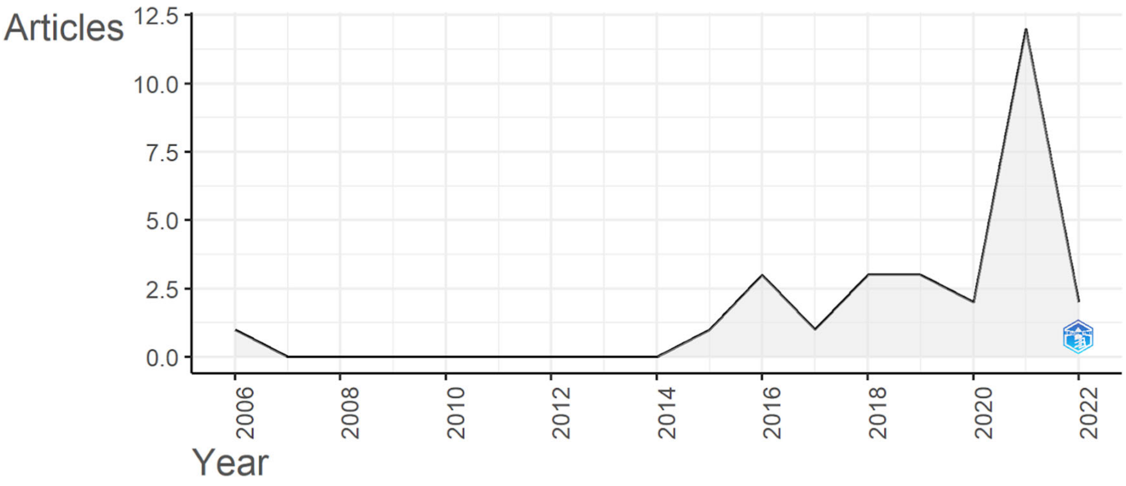


Fig. 4 Annual scientific production. Number of articles and years of publication.

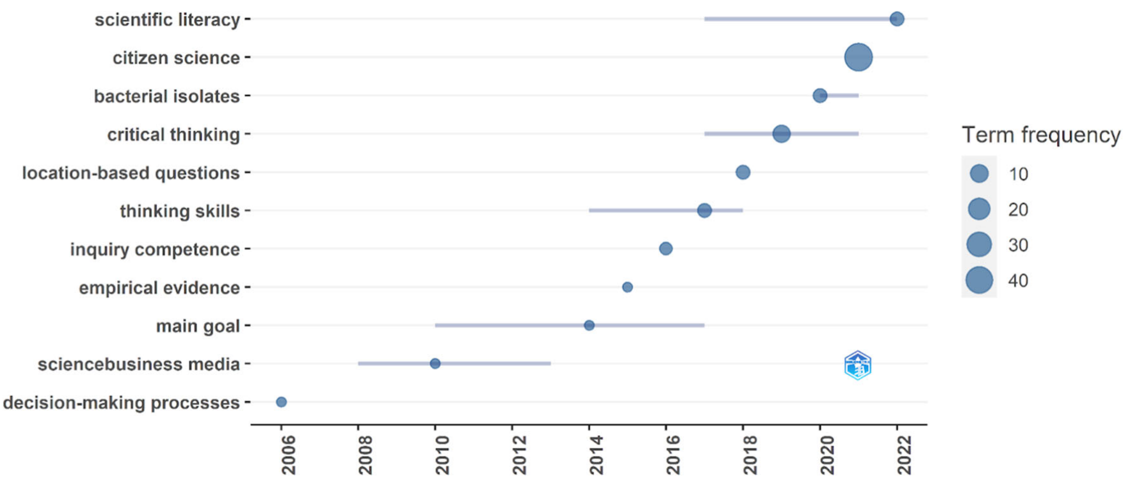


Fig. 5 Trend topics. Frequency of occurrence of topics per year in the journals.

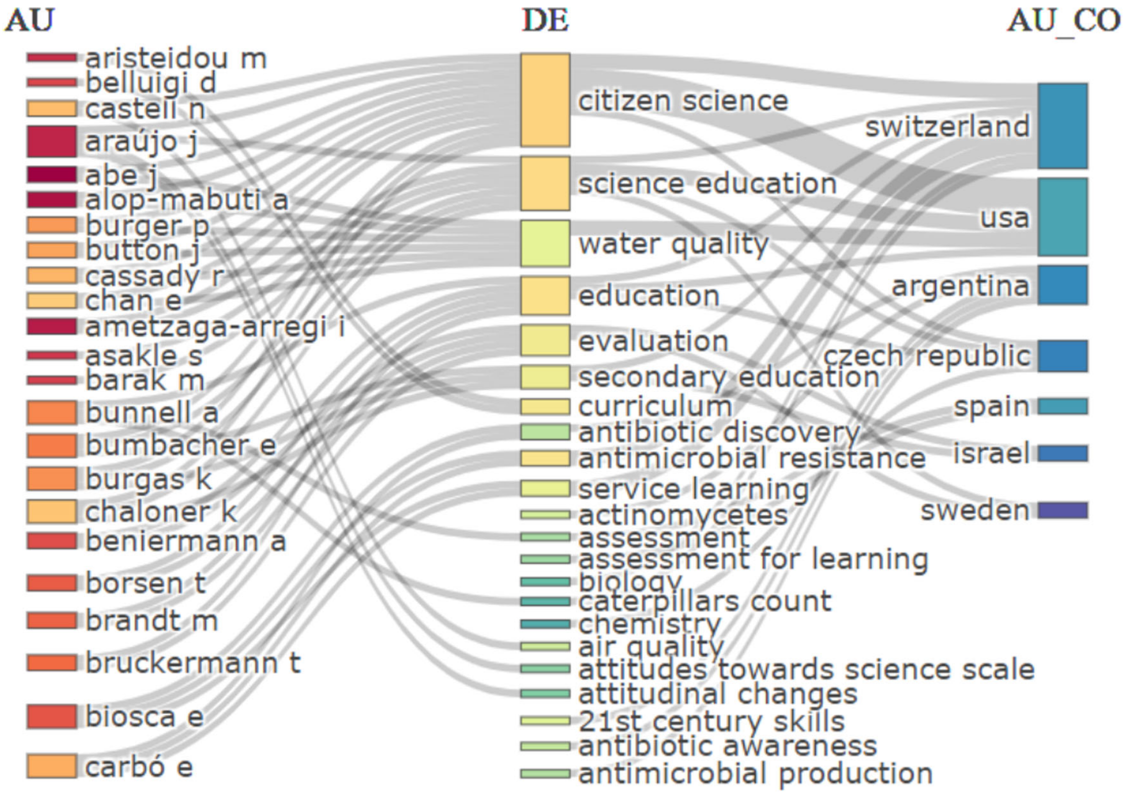


Fig. 6 Authors, areas of knowledge, and countries of publication. Three-column Sankey diagram.

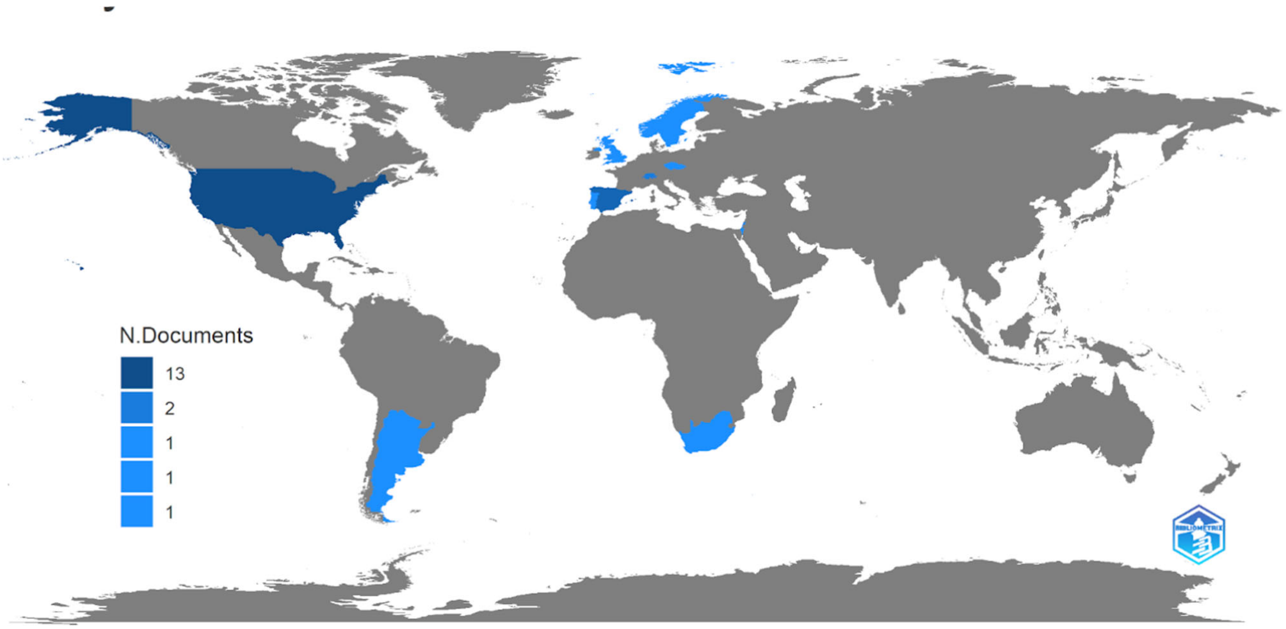


Fig. 7 Countries' scientific production. World map on which dark blue means higher production than light blue.

MQ8 Who are the authors with the greatest intellectual structure on the subject?. Figure 8 presents a visualization of the co-citation network among authors within the analyzed body of literature. This network was instrumental in pinpointing key thought leaders in CS as an educational strategy. Notably, Bonney emerged as a pivotal figure whose extensive and influential contributions to CS literature are critical for contextualizing its educational applications.

MQ9 What are the key terms most frequently used in these studies, and how are they interconnected?. In the analyzed articles, we discovered key themes by identifying the most meaningful keywords. Central to these themes were "education," "curriculum," and "evaluation," with secondary concepts including "higher education," "critical thinking," and "experiential learning" featuring prominently (see Fig. 9).

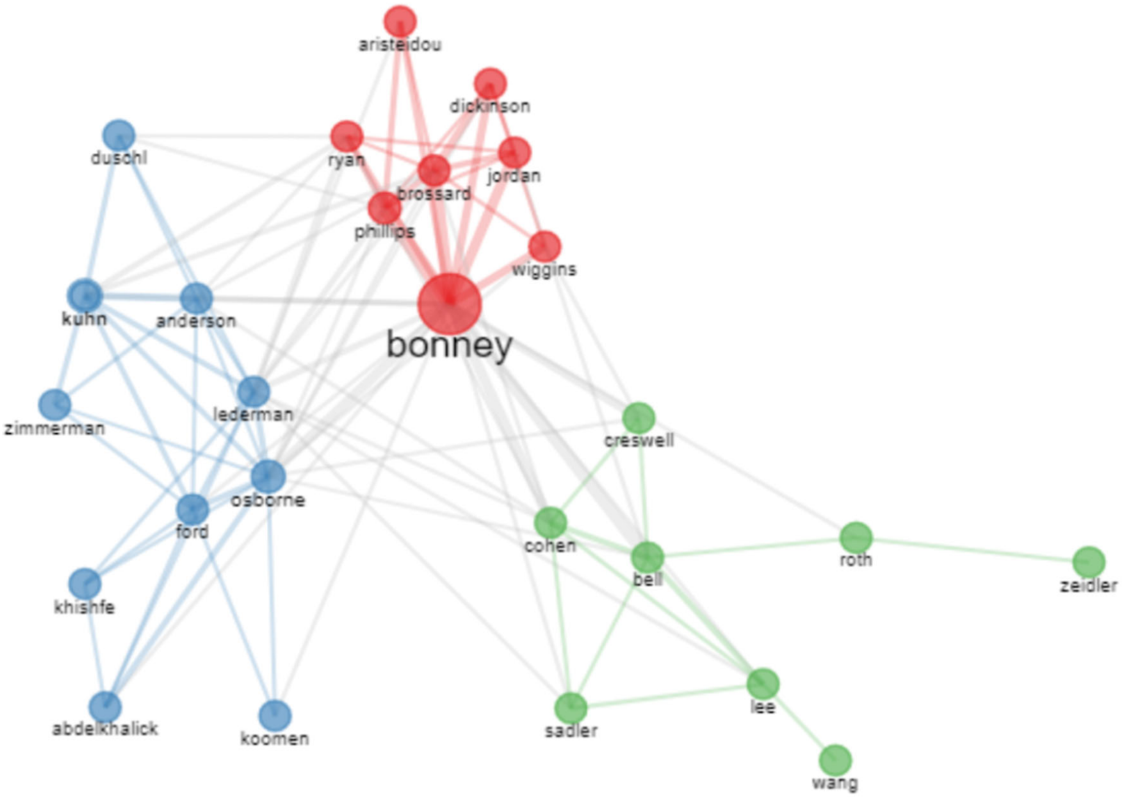


Fig. 8 Authors' co-citation network. Color groupings indicate clusters; thicker lines mean higher co-citation.

Fig. 9 Keyword cloud. The size of the words is proportional to their recurrence.

Following the identification of key concepts, their relationship with CS was analyzed. Figure 10 illustrates the development of these conceptual relationships, highlighting environmental, health, and educational issues as critically discussed concepts.

Discussion

The mapping review reports the following findings of interest, which are closely aligned with the mapping questions posed. Each finding is associated with the relevant mapping question, indicated in brackets at the beginning of each point.

a. [MQ1, MQ3] Most of the CS projects analyzed were of an educational type and demonstrated some relationship with complex thinking or its sub-competencies (Fig. 2). The predominant educational orientation of the analyzed CS projects directly connected to our intentional selection of projects designed with educational objectives in mind. This strategic approach aligned with our overarching educational goals, ensuring that participants were engaged in scientific or community-based research and on a platform that fosters essential sub-competencies, including critical and scientific thinking. This perspective was in harmony with

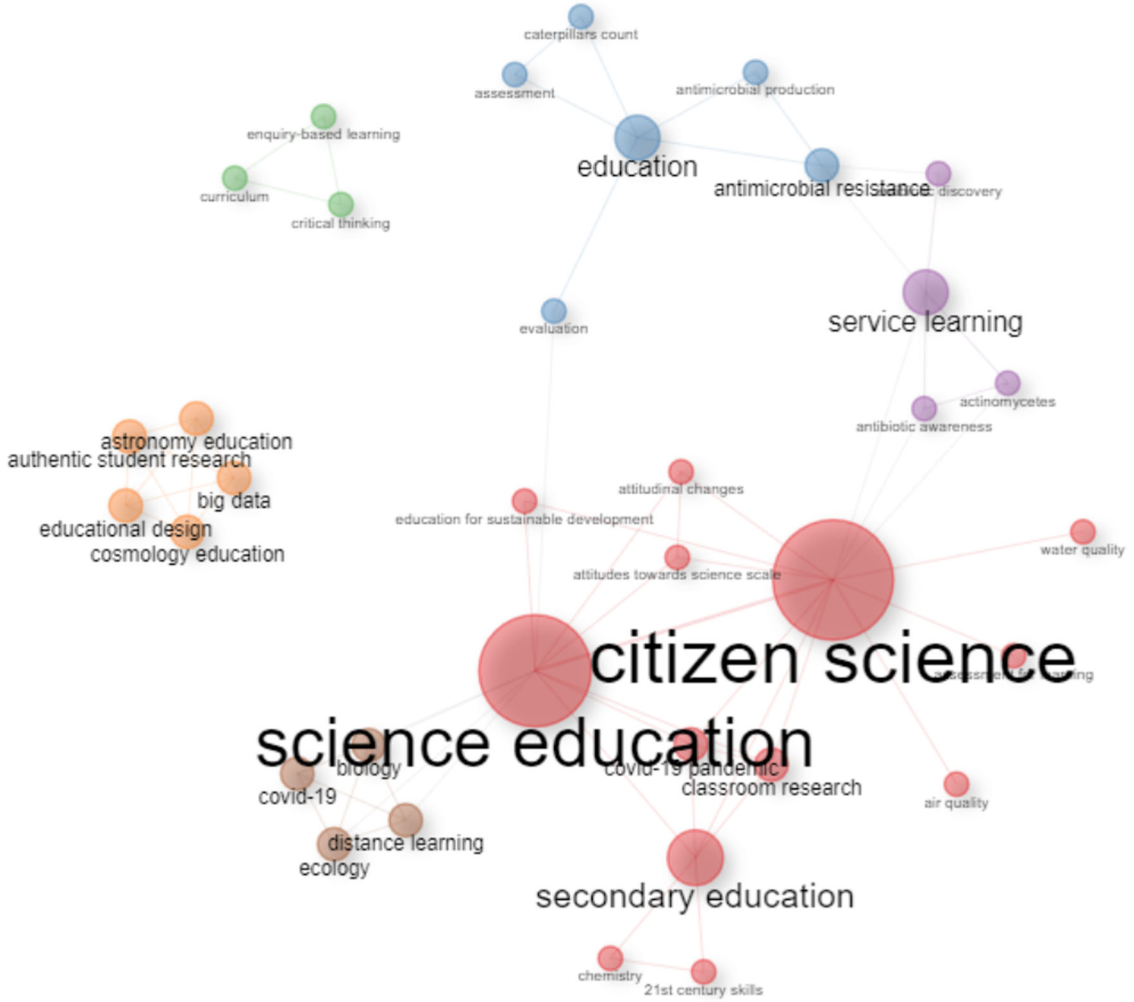


Fig. 10 Keyword relationship. Color groupings indicate clusters; thicker lines mean stronger relationship with CS.

the findings of Ramírez-Montoya et al. (2022) and the insights provided by Wiggins and Crowston (2011), both of which highlighted the vital role of CS projects in nurturing these cognitive skills, which are crucial for the participants' learning journey. Notably, a specific emphasis on cultivating systemic thinking was absent among the selected projects. Furthermore, there was a limited number of projects explicitly aimed at fostering innovative thinking. Nevertheless, it is essential to acknowledge that, despite the lack of explicit objectives in these areas, many CS initiatives indirectly contributed, to some extent, to the development of systemic and innovative thinking among participants.

b. [MQ4] The CS projects analyzed effectively achieved their objectives and added significant value to the participants' learning process (Table 2). The results consistently show increased participant engagement and interest across the board. For instance, the studies by Rodríguez-Loinaz et al. (2022), Ojeda et al. (2021), and Smith et al. (2021) provided clear instances of increased engagement and interest among participants.

   Our analysis underscores the capacity of CS projects to bolster the learning process, as demonstrated by initiatives such as those by Brandt et al. (2022). These projects stand out, mainly when they include clear learning goals in their designs to optimize their educational influence. Many CS projects primarily targeted high school education, with higher education following closely, as shown in Fig. 2. This trend suggests a promising area for additional research, especially within higher education, to investigate and enhance approaches that cater to students' distinct requirements and aspirations at this educational stage.

c. [MQ2, MQ3] The trajectory of Citizen Science (CS) research for educational purposes has been notable, highlighting a consistent interest in this pedagogical method (as illustrated in Fig. 3). The upward trend indicates a commitment to investigating CS's role in enriching participants' educational journeys. Moreover, the analysis of evolving themes within CS projects, as depicted in Fig. 4, shows a list of topics encompassing CS, natural sciences, education, and cognitive skills development. This integration indicates a comprehensive approach to CS projects, integrating scientific inquiry with the educational and cognitive growth of the participants. Our bibliometric analysis was instrumental in mapping the progression of these themes over time. In recent years, the focus has shifted toward the educational implications of CS and its influence on the learning process, as evidenced in Fig. 4. This shift highlights a growing recognition of the educational value of CS projects, particularly their effect on the learning outcomes of those involved.

d. [MQ7] From our analysis, we noted a prevalence of information society initiatives in Europe and North

America. Yet, this observation is based on a dataset limited to English-language publications. Hence, these results may not comprehensively represent the global landscape of information society participation. Populations such as Latin America, which may have significant CS activities, might be underrepresented in our study due to language restrictions. This constraint is particularly relevant given that the study focuses on articles written in English, and is recognized as a limitation in our findings.

Thus, although our results suggest regional affinities for CS projects in the data we analyzed, these findings should be interpreted with caution. They represent trends within the scope of the English-language scholarly literature and may not fully reflect the diversity and scope of information society activities around the world. This gap underscores the need for more inclusive research that spans a wider range of languages and regions, providing a more complete picture of worldwide information society engagement. This type of research could reveal unique educational initiatives and practices in non-English speaking regions, enriching our understanding of the global impact and reach of CS.

Conclusions

To synthesize these insights, we turn to the conclusions drawn from our analysis, reflecting on the educational potential of CS and the avenues for future research. The study's findings highlight the current state of CS in education and the need for further exploration, particularly in developing innovative and systemic thinking competencies through CS initiatives. Through this process, we aimed to provide an understanding of the current status of CS in confronting the ongoing challenges of developing complex thinking in higher education. The study focused on understanding the scope of CS research, the educational approaches and trends where CS and complex thinking converge, and the relevant metrics regarding authors and their publications. Among the findings, we identified (a) a clear relationship between CS and the sub-competencies of complex thinking, (b) how the role of CS projects contributes value to the learning process, and (c) the evident growth of CS projects in the academic community.

There are several implications for educational practice arising from this study. First, while there is a growing emphasis on developing sub-competencies of complex thinking through CS initiatives, there is still a need to strengthen innovative and systemic thinking within teaching-learning strategies. Additionally, the predominance of CS projects at the high school level, followed by higher education, suggests an opportunity to re-evaluate and tailor educational strategies at the tertiary level, focusing on the distinct objectives appropriate for each educational stage. Regarding the implications for CS research within educational settings, this study highlights a potential area for growth in Latin America. The unique characteristics of the teaching-learning context in this region warrant a detailed exploration. Furthermore, the study offers a framework for future research on developing complex thinking skills through social studies, capitalizing on the strong presence of environmental studies within the CS domain.

The methodology of this literature review had certain limitations. First, the study's focus on the constructs of complex thinking and its four sub-competencies—critical, innovative, systemic, and scientific thinking—may not align with the varied terminologies and frameworks used across different educational contexts. A more inclusive approach to identifying types of thinking could reveal different priorities and insights. Second, the exclusive use of the Scopus database may overlook relevant studies housed in other databases, particularly those prevalent in Latin America that offer more coverage in Spanish and Portuguese. This limitation also excludes "gray literature:" materials and research produced outside of traditional academic publishing and journals; these may offer insights more reflective of the on-the-ground educational environment where educators may not publish in high-impact journals. Additionally, the terms used to define the educational level and the concept of citizen science could be broadened to include synonyms and alternative expressions, potentially capturing a more comprehensive array of studies.

Future research could address these limitations by adopting a more expansive approach to complex thinking and its sub-competencies, incorporating various search terms, databases, and article analysis techniques such as digital semantic mining tools. Furthermore, a comprehensive study could also consider including platforms and dissemination channels commonly used by educators, particularly at the higher education level in Latin America, to share and promote CS projects.

Data availability

The database generated for this study is available on an open platform at this location: https://doi.org/10.5281/zenodo.10091107. The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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Author contributions

BA-P contributed to the study conception, design, and coordination. BA-P, RD, LM, and JS-Z contributed to the writing of the manuscript. BA-P developed the dataset and did the methodological analysis. All authors read and approved the final manuscript.

Competing interests

The authors declare no competing interests.

Ethical approval

Not required as the study did not involve human participants.

Informed consent

This article does not report experimental studies on human participants.

Additional information

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