Review

Developing Chemical Literacy in Non-Formal Learning Environments: A Systematic Literature Review

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Abstract

The study examines the development of chemical literacy in non-formal learning environments based on a systematic literature review conducted between 2010 and 2023. Non-formal education serves as a valuable complement to the formal school system, enabling the exploration of topics often overlooked in formal curricula due to rigid regulations or teachers' lack of expertise. The review included 236 primary articles, of which 19 met strict inclusion criteria. The results indicate that the most employed approaches in non-formal education are inquiry-based learning, laboratory work with an emphasis on independent experimental activities, and science camps. Non-formal education significantly contributes to the development of chemical literacy, fosters interest in science, and improves attitudes toward chemistry. The authors highlight the need for further research in this field and greater integration of non-formal approaches into formal education to enhance the scientific literacy of young learners.

Keywords: Chemistry; natural sciences; non-formal education; inquiry-based chemical education.

1. Introduction

Interest in specific forms of learning, such as formal, non-formal, and informal, emerged in the 1960s with the onset of the 'World Education Crisis'.[1] Since then, the interest in non-formal and informal forms of education has continued to grow, and in recent decades, these learning modalities have become a new area in both general and natural science education.[2] While formal education remains a fundamental pillar, the world is witnessing the development of numerous opportunities that complement formal education.[3] Schools are no longer the exclusive environments where students learn about natural sciences. Science centers, laboratories, and other educational environments, such as museums, botanical and zoological gardens, research institutes and univeristies are evolving to provide additional value to formal education. These environments offer young generations opportunities during sensitive developmental periods to express their interests, discover their passions, develop skills, and become responsible, scientifically literate citizens.[4]

Distinguishing between formal, non-formal, and informal education is not always straightforward. The terms non-formal and informal education are often used interchangeably, despite having official definitions.[4] The Organization for Economic Co-operation and Development (OECD)[5] defined formal education in 2012 as an intentional, time-bound, institutionalized activity, typically resulting in a publicly recognized qualification. Formal education is usually provided by a school institution, structured, planned, and leads to the recipient receiving a publicly recognized diploma upon completion. Formal learning is intentional from the learner's perspective. Non-formal education is also intentional, time-bound, and institutionalized, but it does not necessarily conclude with the acquisition of a publicly recognized qualification. It is structured and planned (with goals, duration, and a teacher), but participants do not receive a publicly recognized diploma upon completion. Non-formal learning is intentional from the learner's perspective. On the other hand, informal learning is intentional, time-bound learning that does not occur in a designated institution and does not result in a publicly recognized qualification. It takes place in everyday life, work, family, leisure time, is unstructured and unplanned, and does not lead to a certificate. It can be intentional, but mostly it is not accidental.

Some rearchers have highlighted several advantages of non-formal education, including the flexibility of program implementation, greater adaptation to individual abilities, easier selection of materials based on the learner's interests and abilities, and more freedom in guiding the learning process. They also emphasize the possibility of addressing topics not found in the formal education curriculum, related to current scientific issues that enhance students' chemical literacy, which plays a crucial role in our modern society, influencing everything from health and medicine to technology and the environment. Yet, despite its significance, many individuals lack a fundamental understanding of chemical principles and their real-world applications.[6–8]

In an era where scientific advancements are rapidly shaping our lives, fostering chemical literacy is more important than ever before. Chemical literacy encompasses a basic understanding of chemical concepts, including the properties, behaviors, and interactions of substances. It involves recognizing the role of chemicals in everyday life, from the composition of household products to the mechanisms underlying biological processes. Chemical literacy is a critical component of scientific literacy, encompassing an understanding of chemical concepts and their real-world applications. In the context of education, fostering chemical literacy is essential for equipping students with the knowledge and skills needed to navigate an increasingly complex world shaped by chemical principles. Numerous studies underscore the importance of chemical literacy in education.[9] Chemical literacy enables students to critically evaluate information about chemicals and make informed decisions. Additionally, chemical literacy is fostering scientific inquiry and problem-solving skills among students.[10] Several challenges hinder the development of chemical literacy in education. Lack of qualified teachers, outdated curricula, and limited resources are common barriers identified in the literature.[11] Moreover, misconceptions and negative attitudes toward chemistry often deter students from engaging with the subject.[3]

To meet the needs of 21st-century learners, formal education must evolve by updating curricula to include critical thinking, problem-solving, digital literacy, and global citizenship. Integrating ICT tools and platforms like MOOCs can create interactive, personalized learning environments, making education more accessible and engaging. Both students and educators need advanced digital skills, supported by continuous professional development for teachers. A shift toward personalized and experiential learning, including project-based tasks and real-world problem-solving, caters to diverse learning styles and deepens understanding. Linking education with the labor market through internships and apprenticeships enhances employability. Overall, experiential learning fosters practical skills and prepares students for modern challenges.[12] Research in the field of non-formal education in science and chemistry indicates that non-formal learning experiences can increase students' scientific literacy, enhance students' interest and motivation for learning, provide enjoyable learning experiences, improve students' attitudes toward science and chemistry, support students' cognitive achievements, and promote learning with understanding and the development of social skills.[7,13–15] The goals of non-formal education are diverse and broad, with many forms and methods of such education. As one of the objectives of this paper is to analyse literature on non-formal education in chemistry. The aim is to identify examples of good practices in non-formal education that enhance the chemical literacy of participants. The research questions guiding the systematic literature review are as follows:

1. What are the basic bibliographic characteristics of all reviewed papers from 2010 to 2023 (publication year of reviewed papers, geographical areas of conducted research, scientific journals of published papers?
2. What research designs are used in the reviewed papers, and what methods are employed for data analysis?
3. What forms and methods of non-formal education are presented in the reviewed papers?
4. What are the main teaching methods described in the reviewed papers?
5. Which target groups are covered, or to what level of education do the reviewed articles focus on?
6. What are the main purposes of the reviewed papers?
7. How does chemical literacy develop in a non-formal environment in the reviewed papers?

2. Method

The literature review was conducted following the steps of systematic mapping, based on the PRISMA methodology (Preferred Reporting Items for Systematic Reviews and Meta-Analyses).[16,17] PRISMA is a structured framework designed to enhance the transparency, completeness, and reproducibility of systematic literature reviews. This methodology provides a checklist and a flow diagram to guide researchers in systematically identifying, selecting, evaluating, and synthesizing relevant studies. PRISMA ensures that systematic reviews are conducted rigorously and that findings are reliable and applicable to decision-making in various fields, including education and science. The framework emphasizes clear inclusion and exclusion criteria, comprehensive database searches, risk of bias assessments, and detailed reporting of results.[16,17]

Data analysis materials were searched in the electronic databases Web of Science (WoS) and Scopus.Command search was performed using keywords or phrases in the electronic databases WoS and Scopus. Keywords were used to form a search profile. Search profile for WoS is: chemistry, non formal education and for Scopus is: chemistry, non formal education. In the first step of the systematic literature review process, a total of 236 bibliographic units were obtained. 190 bibliographic units in database Web of Science (WoS) Core Collection and 46 bibliographic units in database Scopus.

Acquiring materials for analysis occurred in four phases, with individual steps presented in a prisma flow diagram (Figure 1), where the exclusion of specific units led to the final number of papers reviewed comprehensively. The process unfolded in the following steps: (1) analysis and selection of papers based on chosen keywords; (2) analysis and selection of papers based on additional inclusion and exclusion criteria; (3) analysis and selection of papers based on chosen titles and abstracts; and (4) analysis and selection of papers after reading the entire studies.

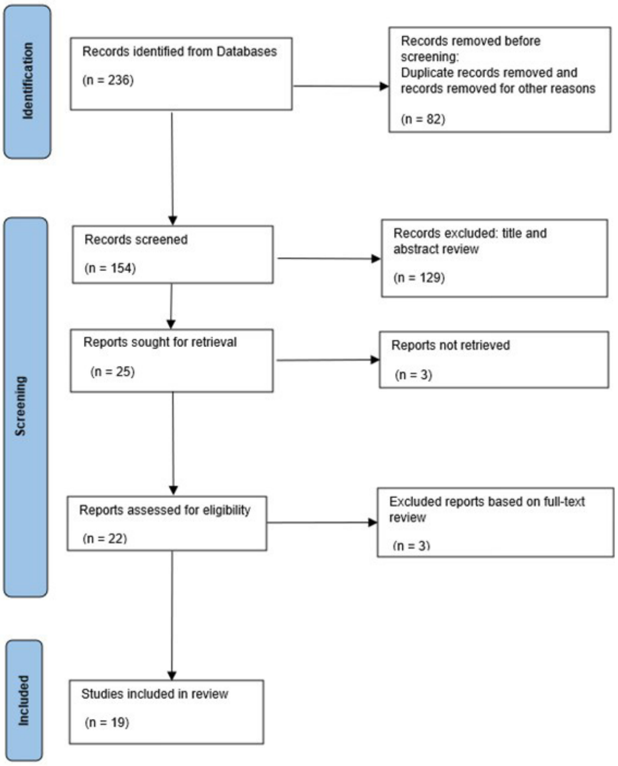

Figure 1: Prisma Flow Diagram for the selecton of papers.[17]

In the first step, the selected papers based on chosen keywords were analysed. The bibliographic databases Web of Science and Scopus, command searches were conducted using predetermined keywords or phrases, searching in the title, abstract, and keywords with the Boolean operator AND between keywords. In this phase, 236 bibliographic units were obtained. In the second step, the inclusion and exclusion process was conducted based on supplementary criteria. The search results were systematically filtered according to predefined additional inclusion criteria: a) Time period (2010–2022): 207 units; b) Paper type – research and review papers: 188 units; c) Language – English: 166 units. The obtained hits were merged into a common database, and 154 units were obtained for further analysis.

Exclusion criteria for bibliographic units were not specifically defined, so the only exclusion criterion was non – compliance with the inclusion criteria. In the third step, an analysis and selection of papers were performed based on the chosen titles and abstracts. Each bibliographic unit was reviewed based on its title and abstract, further assessing the relevance of the content. The inclusion criterion for the next step was that the title and abstract should relate to chemical content suitable for addressing elementary school students. At this point, 129 bibliographic units were excluded, leaving 25 bibliographic units for the next step, which were consolidated into a table. Three papers were further excluded from detailed analysis due to limited access, resulting in a total of 22 papers for comprehensive review. Based on the complete review of papers, three more papers were excluded due to content unsuitability. In the end, 19 units were included in the detailed literature analysis.

Six articles were found in Scopus,[6,19–23] and thirteen articles were found in the Web of Science (WoS) Core Collection.[7,8,24–34]

In the fourth step, an analysis and selection of papers was conducted after the entire studies were reviewed. Following the selection, a detailed content analysis of the full text for each chosen unit was performed based on predetermined criteria and research questions. The criteria were divided into 7 thematic categories. It includes basic bibliographic data (authors, title, journal, year of publication, keywords, and abstract), geographical details (region and country), research design (qualitative, quantitative, or mixed), data processing methods, and types of non-formal education (e.g., museums, science centers, camps). It also categorizes teaching methods (e.g., inquiry-based learning, teamwork, ICT) and target groups (e.g., primary, secondary, tertiary education). Lastly, it allows for the identification of the purpose of the contribution.

Following this comprehensive review, two additional papers were excluded due to content unsuitability. The exclusion was made because the content of these papers did not meet the expected standards and objectives, due to methodological limitations, irrelevant focus and insufficient detail regarding non-formal education in chemistry. As a result, a total of 19 papers remained for in-depth analysis. These 19 studies were deemed to offer valuable insights into the topic, fulfilling the criteria set forth for the systematic review.). The final selection represents a robust and relevant subset of literature that will provide the foundation for answering the research questions in this study.

3. Results and Discussion

The first research question addresses the bibliographic characteristics of all reviewed papers from 2010 to 2023, focusing on publication year, research region, and publishing journals. Adhering to the research questions formulated at the outset, a systematic review of 19 selected papers meeting the inclusion criteria revealed that studies in non-formal chemistry education began in 2014 (Figure 2).

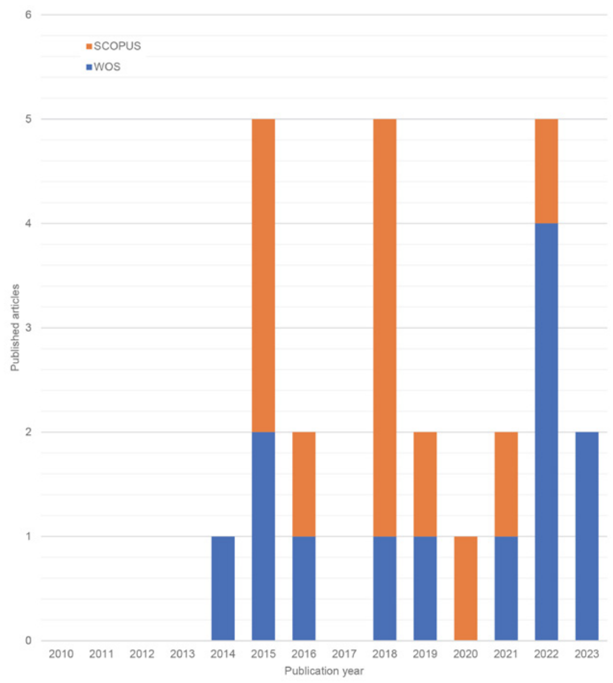

Figure 2: The number of published papers on the topic of non-formal education in the field of chemistry, from 2010 to 2023 in the searched databases.

Since then, annual publication rates have peaked at five papers per year. Germany[6–8,27,29,30,32] leads this research domain, followed by Finland[7,19,21] and Italy[26,28,31] which have developed best practices integrating non-formal and formal education.

Most studies have been conducted in Europe, with notable contributions from Brazil[20] and Indonesia.[23] Slovenia has produced only one paper[33] on non-formal chemistry education, highlighting an underexplored area, particularly in the context of ongoing educational reforms.[19] This indicates substantial potential for future research in this domain (Figure 3).

The reviewed papers were published across 15 different journals. The journal with the highest number of contributions is Education Sciences, featuring three papers. This is followed by three journals, each with two papers: Chemistry Education Research and Practice, Sustainability, and LUMAT.

Importantly, as of 2023, all these journals have high impact factors, highlighting their significant influence and relevance in the field.

The second research question focuses on the research designs used in the reviewed papers and the methods applied for data processing. Across all bibliographic units, statistical methods are consistently employed for

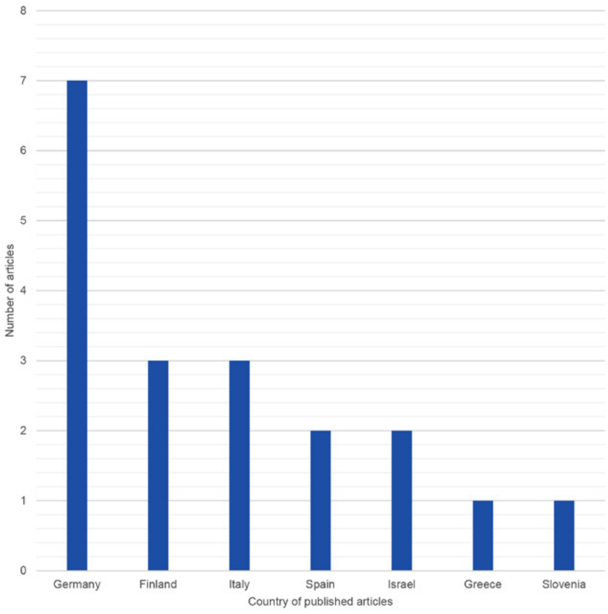

Figure 3: Geographical distribution of conducted research in the field of non-formal education in chemistry.

data processing. The most common research design is mixed methods,[7,19,21,22,25,26,29,30,32] which combines qualitative and quantitative approaches, typically integrating surveys with interviews or case studies. This is followed by quantitative research designs,[6,23,24,27,28,33,34] which primarily rely on survey questionnaires. Lastly, a smaller number of papers[8,20,30] employ qualitative research designs, utilizing methods such as interviews, case studies, or focus groups (Figure 4).

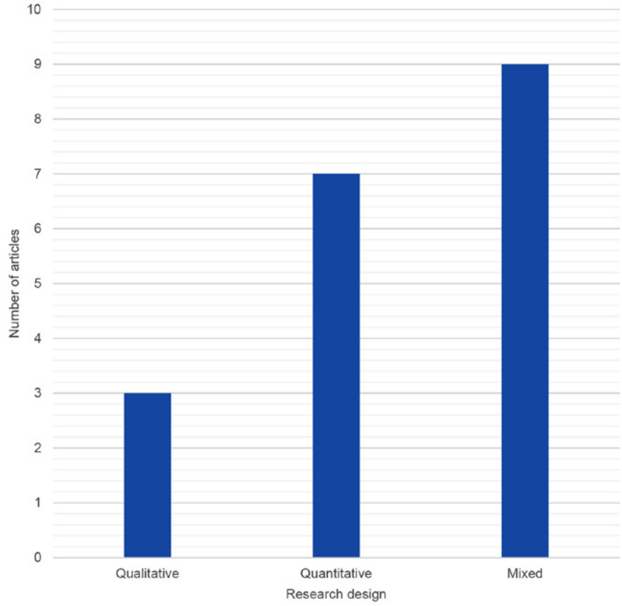

Figure 4: Research design employed in the meticulously reviewed papers.

The third research question addressed the forms and methods of non-formal education presented in the reviewed papers. Figure 5 outlines the forms and methods of non-formal education identified across all the reviewed bibliographic entries. The most frequently mentioned method is the non-formal laboratory,[6–8,29–32] followed by camps[19,21,22,25,27] and online courses.[23,33,34] Germany has conducted extensive research in the field of non-formal education, particularly in integrating non-formal laboratories (Schülerlabor) with formal education. The success of these initiatives is evident in recent studies.[19–21] Finland has focused on organizing camps with natural science content for gifted adolescents, but no further research has been conducted on these camps, which were once a prominent example of non-formal education in Finland, since 2014, signaling a cessation of both activities and research in this area. The Covid-19 pandemic accelerated the development and implementation of online courses,[23,33,34] which have proven to be valuable support for formal education. The reviewed literature indicates that these online courses yield favorable short-term outcomes. One paper[26] presents an individual case of non-formal education as part of afternoon activities for children or families, although these cases lack additional research support. Examples of integrating non-formal education with formal education, as described in the reviewed literature, include conducting activities in museums[20,28] and educational centers.[20,24]

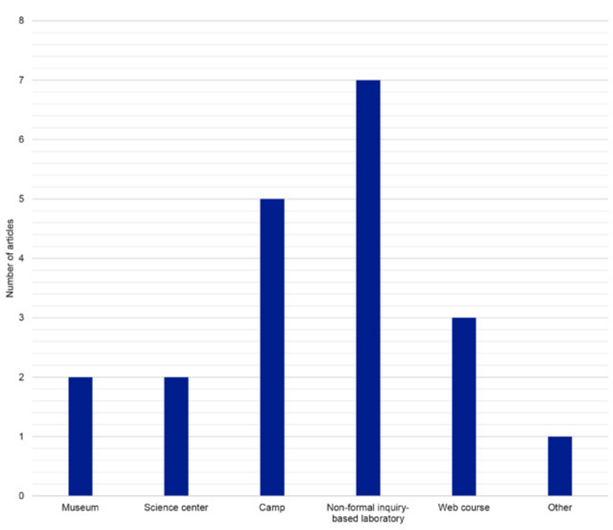

Figure 5: Forms of non-formal education presented in meticulously reviewed papers.

The fourth research question focused on identifying the main teaching methods described in the reviewed papers. Several teaching methods are discussed in the literature, and they often overlap and interrelate. As shown in Figure 6, the most prominent method is inquiry-based learning[6–8,20–22,24,26–32], which appears in 45% of the reviewed papers. This is followed by context-based learning, which accounts for 23% of the papers,[6,20,22,26,27,29,30] and experimental work,[6,19,21,27] representing 13% of all papers. Two papers discuss project-based learning.[33,34] One paper is attributed to learning through information and communication technology (ICT),[23] and one to learning through games.[25]

It is important to note that these methods are not strictly separate. For example, inquiry-based learning frequently appears alongside context-based learning. This interconnectedness suggests that a combination of approaches is often employed in practice. Inquiry-based learning is highly favored by both researchers and participants, showing positive effects for all involved. This method is effective in improving students' scientific literacy, enhancing conceptual understanding, and fostering a positive attitude toward science.[22–24]

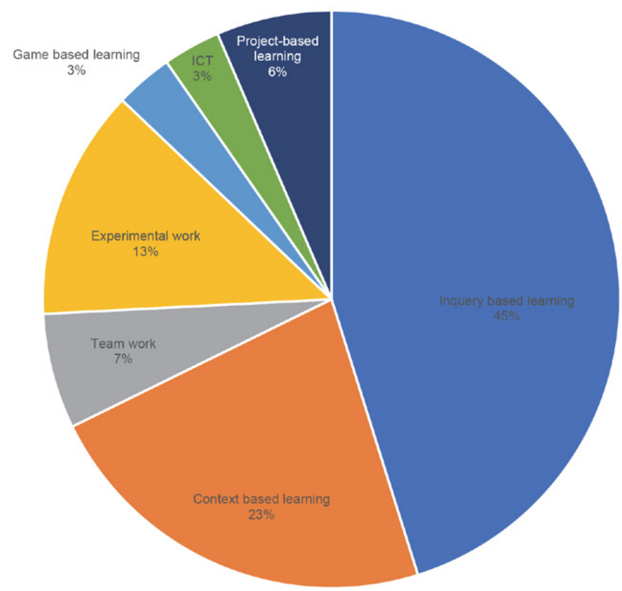

Figure 6: Teaching methods used in the reviewed literature.

The fifth research question focused on the target groups addressed in the reviewed papers concerning educational levels. Figure 7 illustrates the distribution of these target groups. More than half of the studies (58%) are directed toward students aged 12 to 18, who are actively studying chemistry within formal education settings.[6–8,21,24,25,27,29–32] Sixteen percent target younger students aged 6 to 11,[19,22,23] while only 10% focus on individuals aged 19 and older, such as university students.[28,33] Additionally, one study[20] explores teacher participation, and two studies[26,34] cater to an unrestricted age group, encompassing all educational levels.

The target group is a key factor in designing educational interventions as it determines the content's complexity, relevance, and delivery methods. Tailoring content to the developmental and cognitive abilities of the audience enhances engagement and learning out-

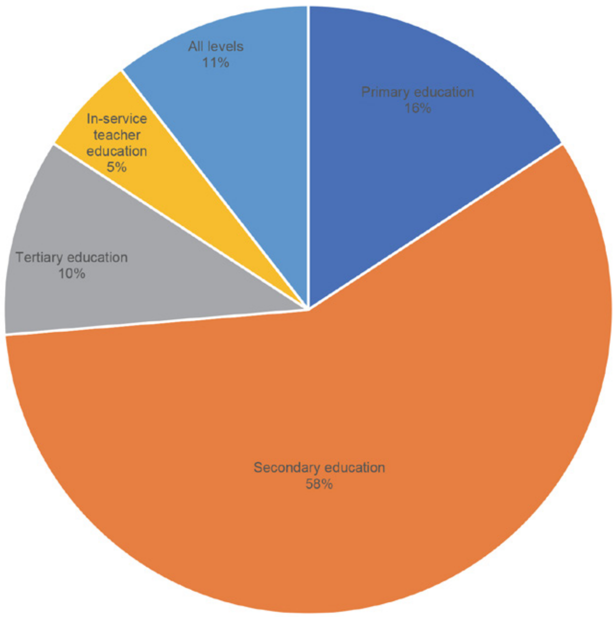

Figure 7: Target groups of conducted research in the reviewed papers.

comes. In chemistry education, addressing specific groups helps promote chemical literacy, improve conceptual understanding, and foster a positive attitude toward science.[9,10]

The sixth research question explored the main purposes of the reviewed papers, which are systematically categorized in Table 1. A detailed analysis of all the papers allowed for the compilation and organization of these purposes into distinct subcategories, as illustrated in Table 1. Notably, several papers exhibit overlapping or recurring purposes, which are reflected in their classification under multiple subcategories in the table. This systematic categorization highlights the diverse yet interconnected aims of the research studies, offering insights into their contributions to the field.

The final research question examines how chemical literacy develops within non-formal environments as described in the reviewed papers. These environments foster chemical literacy through diverse approaches, including hands-on experiences, citizen science initiatives, online resources, informal discussions, popular science media, and everyday interactions. Collectively, these avenues complement formal education by providing accessible and engaging opportunities for individuals to deepen their understanding of chemical concepts. Non-formal environments, such as science museums, science centers, science camps, workshops and community science events, play a pivotal role in promoting chemical literacy. These environments feature hands-on activities, interactive exhibits, and demonstrations that make chemical concepts engaging and comprehensible for diverse audiences. For instance, participants can explore chemistry using comics in experimental instructions within a non-formal chemistry learning environment or through practical experiments or guided inquiries, sparking curiosity and fostering a deeper connection with the science. Citizen science initiatives represent another impactful approach, enabling individuals to actively contribute to scientific research while developing their chemical knowledge. Projects such as water quality testing or using modern technologies, such as mobile applications, to enhance learning effectiveness and concentration or air pollution monitoring involve non-experts in real-world scientific practices, thereby bridging theoretical concepts and practical applications. Online platforms and digital resources have expanded opportunities for self-directed learning in chemistry. Educational websites, videos, podcasts, and interactive simulations provide flexible, on-demand access to chemical information, catering to various learning styles and interests. Similarly, engagement in informal discussions–whether through social media, online forums, or peer networks-offers a platform for exchanging ideas, asking questions, and gaining diverse perspectives on chemical topics. Popular

Table 1: Purposes of the reviewed papers.

Purpose of the Paper	Paper references
Learning through research as the main learning strategy in non-formal learning environments	24, 28
Motivating students for further education in the field of natural sciences	6
Presenting non-formal learning environments to increase scientific literacy	6, 21, 30, 31, 33
Evaluating the impact of non-formal learning environments on student knowledge	20, 21, 33
Assessing the impact of online courses on chemistry learning outcomes	23, 34
Student, teacher, and parental perspectives on non-formal learning environments	19, 29
Introducing two non-formal learning environments in Germany and Finland	7
Enhancing scientific literacy through play	25, 28
Increasing interest in learning chemistry in non-formal learning environments	21, 24, 29, 32
Gaining a precise understanding of students' interest in formal and non-formal learning	8, 20, 27
Developing scientific literacy	21, 26, 28, 30, 31, 33
Significance of camps in motivating learning of natural science content	19, 21
Increasing environmental energy literacy	22, 26, 30
Relationship between formal and non-formal learning environments	20

science media further supports chemical literacy by presenting scientific content in an engaging and accessible format. Books, magazines, television programs, and documentaries introduce chemical principles and applications in a manner that is both informative and stimulating, often inspiring further exploration of the subject. Lastly, everyday experiences significantly contribute to chemical literacy. Encounters with chemicals in daily life, such as observing reactions during cooking, reading product labels, or understanding medication effects, provide practical insights into chemistry. These real-world interactions demonstrate the relevance of chemical concepts in personal and environmental contexts, fostering a more intuitive understanding of chemistry. Together, these non-formal environments and methods form a robust framework for enhancing chemical literacy, making chemistry more relatable and accessible to diverse populations. This multifaceted approach emphasizes the importance of integrating formal and non-formal learning opportunities to promote a comprehensive understanding of chemistry.[6–8,19–26,23–34]

Non-formal educational settings offer unique opportunities for experimental work, hands-on, inquiry-based learning, context based learning or team work. However, several limitations have been mentioned in the reviewed articles. Non-formal learning is often insufficiently integrated with formal education. While activities like field trips, science camps, and laboratory visits can boost student engagement, their potential is limited if they do not complement the formal curriculum. This disconnect can lead to missed opportunities for reinforcing key scientific concepts and building long-term retention through real-world connections. Furthermore, Measuring and assessing learning outcomes in non-formal settings also presents a challenge. Traditional assessment tools are often not applicable due to the flexible, spontaneous nature of non-formal learning. Without standardized evaluation methods, it becomes difficult to gauge the effectiveness of these experiences or track students' progress accurately. Furthermore, resources and accessibility issues can limit the reach of non-formal educational programs. These initiatives frequently rely on specialized facilities, equipment, and expert staff that may not be uniformly available across different regions. As a result, only a limited number of students, often those in urban or well-funded areas, can access these enriched learning experiences, potentially exacerbating educational disparities among socio-economic groups. Finally, the long-term impact of non-formal learning experiences remains uncertain. While such experiences can generate a short-term spike in motivation and interest, research indicates that without ongoing integration or repeated exposure, the durability of these effects may be inconsistent. Isolated events might not foster lasting retention of concepts or sustained influence on career choices.[6–8,19–26,30–34]

4. Conclusions

The systematic literature review on non-formal education in chemistry highlights its pivotal role as a complementary approach to formal education, addressing limitations in traditional curricula and promoting the development of critical thinking, problem-solving, and practical skills. Through the examination of 19 selected studies, it becomes evident that non-formal education has steadily gained prominence since 2014, particularly in Europe, with Germany emerging as a leader in this field. Successful initiatives such as "Schülerlabor" exemplify the potential of non-formal inquiry-based laboratories to engage students actively, enhance their scientific literacy, and foster sustained interest in chemistry and related disciplines. Finland's adoption of science camps provided another innovative avenue, particularly for gifted students, although their discontinuation highlights challenges related to funding, applicability, and disruptions caused by the Covid-19 pandemic. Additionally, other forms of non-formal education, including museum visits, educational center programs, and online courses, offer versatile and effective means to make chemistry engaging and accessible to diverse audiences.

Inquiry-based learning stands out as the cornerstone of non-formal education, emphasizing student-centered exploration and active engagement in the learning process. This method fosters deep conceptual understanding, promotes independent learning, and instills curiosity, making chemistry more relatable and meaningful. It is frequently integrated with experimental work, project-based learning, and game-based methods, amplifying its impact and demonstrating its versatility in various educational settings. Furthermore, environments such as science centers and museums play a crucial role in bridging theoretical knowledge and practical applications, enabling learners to connect chemical concepts with real-world phenomena. Online platforms and digital tools, particularly significant in the post-pandemic era, further expand the reach and personalization of non-formal education through virtual laboratories, simulations, and citizen science initiatives.

Despite its evident benefits, the review identifies several limitations. The relatively narrow focus of existing studies, publication biases favoring statistically significant results, and the reliance on single author analyses present challenges to the field's comprehensiveness and objectivity. Most reviewed studies target secondary school students (aged 12 to 18), leaving gaps in understanding the impact of non-formal education on younger learners, tertiary-level students, and educators. Moreover, the limited geographical distribution of research and the lack of interdisciplinary approaches highlight the need for broader investigations.

By leveraging innovative methods like inquiry-based learning and integrating diverse non-formal environments–laboratories, camps, museums, and online platforms–educators and policymakers can create engaging, equitable, and impactful learning experiences. Such efforts will not only enhance scientific literacy but also inspire lifelong curiosity and equip learners with the skills necessary to address complex global challenges in a rapidly evolving, science-driven world.

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Povzetek

Študija obravnava razvoj kemijske pismenosti v neformalnih učnih okoljih na podlagi sistematičnega pregleda literature med leti 2010 in 2023. Neformalna izobraževanja predstavljajo pomembno dopolnilo formalnemu šolskemu sistemu, saj omogočajo obravnavo tem, ki jih formalni kurikulumi pogosto zanemarijo zaradi togih predpisov ali pomanjkanja znanja učiteljev. Pregled je zajel 236 primarnih člankov, od katerih jih je 19 izpolnjevalo stroge kriterije vključitve. Rezultati kažejo, da so najpogosteje uporabljeni pristopi v neformalnem izobraževanju raziskovalno usmerjeno učenje, delo v laboratorijih s poudarkom na samostojnem eksperimentalnem delu ter naravoslovni tabori. Neformalna izobraževanja pomembno prispevajo k razvoju kemijske pismenosti, spodbujanju zanimanja za naravoslovje ter izboljšanju odnosa do kemije. Avtorji izpostavljajo potrebo po nadaljnjem raziskovanju tega področja ter večjem vključevanju neformalnih pristopov v formalno izobraževanje za dvig znanstvene pismenosti mladih.