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How is Technology Positioned in the Implementation of SSI-Based Learning?

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Abstract: How is Technology Positioned in the Implementation of SSI-Based Learning? Objectives: Socio-Scientific Issues (SSI)-based learning is an educational approach that combines scientific content with ethical, social, and real-world issues. This learning model is significantly influenced by technology, which enhances student engagement, facilitates access to a variety of information sources, and offers interactive and immersive experiences. This research endeavors to conduct a comprehensive analysis of the position of technology in SSI-based learning, with a particular emphasis on its functions, forms of application, and effects. **Methods:** The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) method was employed to conduct the Systematic Literature Review (SLR). Keywords associated with "Social-Scientific Issues" and "technology in education" were implemented during a literature search of Scopus-indexed journals from 2016 to 2025. The initial search identified 399 articles, which were subsequently filtered through the identification, screening, eligibility, and inclusion processes, culminating in 39 eligible articles. Articles published in English, indexed in Scopus, and specifically addressing the intersection of SSI and technology are included in the inclusion criteria. In order to investigate patterns, keyword trends, and thematic clusters, articles were subjected to bibliometric analysis using RStudio–Biblioshiny and VOS viewer. **Findings:** These findings categorize the role of technology in two main ways: (1) Direct implementation in SSI-based teaching, such as Augmented Reality (AR), Virtual Reality (VR), Artificial Intelligence (AI), web-based platforms, and educational games; and (2) Integration of technology in broader pedagogical approaches, including STEM, STEAM, STS, and Computational Thinking (CT). **Conclusion:** Technology serves variety functions: it acts as a source of information, a collaborative tool, a platform for virtual experimentation, and a medium for communicating ideas. This review highlights the growing significance of technology in shaping effective, critical, and contextually rich SSI-based learning in the digital age.

Keywords: socio-scientific issues (ssi), technology, digital application, systematic literature review.

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INTRODUCTION

The emergence of science was a response to the numerous scientific challenges that had evolved into social issues during its era. This is due to the fact that certain curricula are taking the initiative to return to the core of science by emphasizing the significance of contextualizing science in relation to socio-scientific problems in the real world (Mang et al., 2023). A variety of scientific issues are becoming issues and problems at the same time, such as pollution caused by waste plastic, polluted air, acidification of the sea, global pandemic, policy vaccination, engineering genetics, lack of resilience in food, global warming, and sustainability (Baran et al., 2021; Danielson et al., 2022; Reis et al., 2020; Yanti et al., 2024). Currently, the socio-scientific or socio-scientific issues (SSI) are "science knowledge that is currently warm" due to the fact that the meaning of scientific literacy is shifting from the comprehension of the products and processes of science to the comprehension of the complex interaction between science and technology, and it is encouraging society students to engage in critical analysis and actively participate in the breakdown of socio-scientific issues (Pedro Reis et al., 2020).

Socio-scientific problems or socio-scientific issues (SSI) are typically associated with complex and unstructured social issues that are defined in the real world and are full of value and relevance in a social manner that is either informed by science or has a foundation in basic science (Constantinou & Rybska, 2024; Ke et al., 2021). According to Mang et al. (2021, 2023), SSI-based learning is the intersection of science and society, in which students investigate scientific content in relation to social issues in order to serve as resources for dialogue, discussion, debate, and action as "activists" in environmental and social issues. Constantinou and Rybska (2024) propose that students be engaged in socio-scientific issues through the learning of SSI-based endeavors, which will motivate them to resolve cognitive and moral dissonance in the social and environmental domains. In addition to comprehending scientific concepts, students must also take into account ethical, social, and environmental factors when formulating judgments and suggesting solutions (Ke et al., 2021).

Filter et al. (2020) and Wahono, Narulita, et al. (2021) have proposed that learning that reviews and discusses a variety of socio-scientific problems in order to make science learning more relevant and meaningful for students, as well as to establish a sustainable, objective, supportive education development. This approach equips students with the knowledge, skills, values, and attitudes necessary to become solutions to a variety of social issues and problems. The acquisition of SSI can enhance the student's comprehension of the fundamental nature of science and technology, cultivate the ability to communicate and argue effectively in order to negotiate a variety of viewpoints, and instill the character and values that are essential for being a responsible citizen (Erna et al., 2023).

Socioscientific issues-based learning approaches are now increasingly incorporating digital technologies, including artificial intelligence (AI) and virtual reality (VR), to enhance the profundity and engagement of student learning. Innovative teaching strategies are necessary to enable students to comprehend diverse viewpoints on intricate issues, including global pandemics, climate change, and environmental degradation, which are emerging socioscientific challenges. For instance, virtual reality (VR) technology has the capacity to replicate real-world scenarios, enabling students to investigate ecosystems, observe environmental effects, and participate in immersive virtual discussions (Newton & Annetta, 2024). This technology not only enhances students' comprehension of the scientific foundation of a problem, but also prompts them to contemplate the moral implications of human actions, including the overexploitation of natural resources that can result in ecological catastrophe.

By offering advanced data visualizations, personalized feedback, and adaptable learning environments, artificial intelligence (AI) has substantial potential. Students have the opportunity to investigate the molecular processes that underlie phenomena such as global warming through AI-powered simulations. For example, AI can assist students in comprehending the greenhouse effect by absorbing infrared radiation at 2,349 cm{ ^{1}, which is a result of the asymmetric vibrations of CO, molecules (Yuniarti et al., 2024). These instruments encourage the development of empirical reasoning, evidence-based decision-making, and inquiry-based learning.

In spite of these advantages, there are numerous obstacles that must be resolved prior to the complete integration of digital technologies into educational environments. Limited digital literacy among educators, disparities in access to digital infrastructure, and the absence of pedagogical models that effectively integrate emergent technologies into SSI contexts are among the challenges. Additionally, there is a possibility that technology may be perceived as a novelty rather than as a valuable instrument to facilitate scientific comprehension. It is imperative to evaluate the current function of technology in SSI-based learning in order to determine whether it is being used to transform student engagement with socioscientific issues or to enhance content delivery. Consequently, the objectives of this investigation are to investigate the subsequent research inquiries: What is the role of technology in the implementation of Socio-Scientific Issues (SSI)-based learning?

■ METHOD

Research Design and Procedures

This study employed a Systematic Literature Review (SLR) approach to comprehensively examine how technology is positioned in SSI-based learning. The review followed the **PRISMA 2020 guidelines** (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), ensuring transparency, replicability, and rigor in identifying, screening, and analyzing the relevant literature (Haddaway et al., 2022).

Search Strategy

The search was conducted through the Scopus database due to its broad coverage of high-quality, peer-reviewed journals. The search used the following Boolean keywords: ("Socio-Scientific Issues" OR "SSI") AND ("technology" OR "digital learning" OR "virtual reality" OR "AI" OR "STEM"). The publication window was limited from 2016 to 2025 to capture the latest trends in educational technology integration within SSI. Initially, 399 articles were identified. After duplicate removal and relevance screening based on titles and abstracts, 39 articles were selected for full-text review and analysis.

The metadata from the articles was processed using RStudio with Biblioshiny for bibliometric analysis. Keyword co-occurrence and thematic networks were further visualized using VOSviewer, providing insights into the trends and relationships within the literature. Figure 1 shows the trend of cumulative keyword appearance over time, while Figure 2 illustrates the PRISMA flow diagram of article selection.

The image is a chart trend of cumulative keyword occurrence in a study from 2020 to 2024. The horizontal axis (X) shows the year, while the vertical axis (Y) represents the amount of emergence cumulative a keyword in research. Each colored line in the chart represents different keywords, which reflect various field studies like education, technology, science, sustainability, and social issues. In general, graph this shows that part big keyword experience improvement emergence from year to year, which signifies that Topics the the more lots studied. Some underlined keywords, such as computing, computer-aided instruction, social media, and e-learning, indicate improvement relevance in research, especially in field education based on technology and social media. Thus, the graph describes development trend research and how the topic certain become more popular over a number of years.

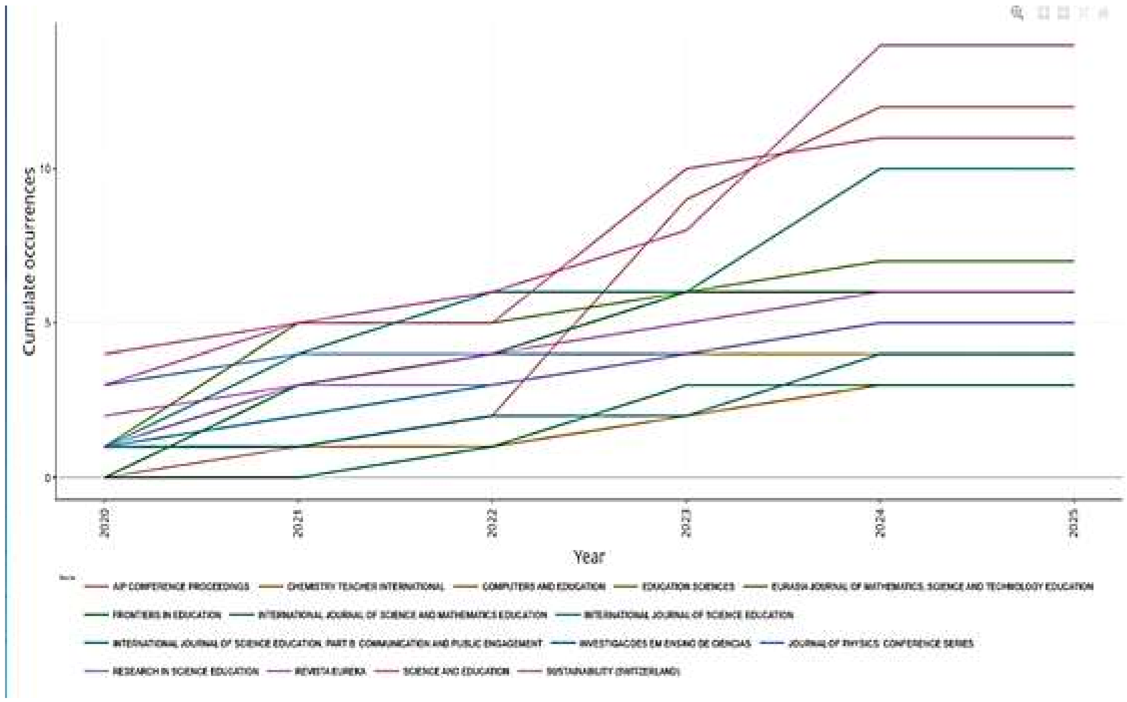

Figure 1. Trend of cumulative keyword occurrence from Biblioshiny-Rstudio

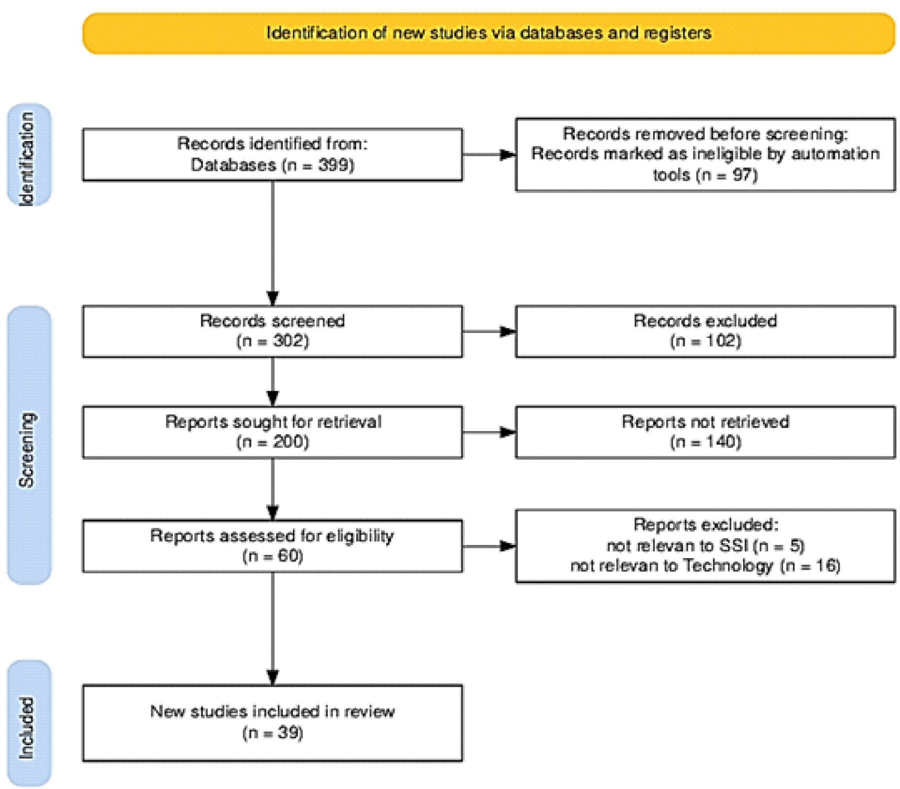

Figure 2. Systematic review flow diagram of SSI and technology or digital learning. Caption: the PRISMA flow diagram (Haddaway et al., 2022) for the systematic literature review detailing the database searches, the number of abstracts screened and the full texts retrieved

Inclusion and Exclusion Criteria

To ensure focus and quality, the inclusion and exclusion criteria were defined as follows:

Data Analysis

A combination of quantitative bibliometric mapping and qualitative thematic analysis was employed to analyze the final 39 articles. Themes related to technology functions, learning model integration, and pedagogical outcomes were extracted from each article. Two researchers conducted independent categorization to guarantee data validity, and they then conducted cross-checking to achieve consensus. The thematic synthesis was subsequently organized to address the primary research questions, and the results section includes figures and tables to substantiate the findings.

Table 1. Inclusion and exclusion criteria

Indicators	Inclusion Criteria	Exclusion Criteria
Period	Journals published in 2016 - 2025	Journals published outside 2016-2025
Indexed	Scopus-indexed international journal	Non-Scopus-indexed international journal
Language	English language journal	Non-English language journal
Article Type	Original research article, Review article	conference proceedings, book, book chapter, book series, editorial, etc
Topic of Discussion	The article's content is relevant to SSI and technology.	The article's content is not relevant to SSI and technology.

RESULT AND DISCUSSION

Figure 3 delineates a network visualization produced via VOSviewer, elucidating the co-occurrence relationships among keywords identified in the 39 selected scholarly articles. Each node depicted in the visualization symbolizes a keyword, with the dimensions of each node reflecting the frequency of occurrence of the keyword throughout the corpus. The connections between nodes signify the intensity of co-occurrence, whereas the varying colors denote clusters of thematically analogous keywords.

Three predominant clusters are revealed in Figure 3, namely the crimson, azure, and verdant clusters. Terminologies associated with artificial intelligence, digital pedagogy, virtual environments, and technology are the primary focus of the crimson cluster. This cluster represents a growing corpus of scholarly research that investigates the direct application of digital tools to improve the interactive nature and efficacy of education that is based on socio-scientific issues (SSI). The contemporary literature emphasizes the critical role of technologies like artificial intelligence (AI) and virtual reality (VR) in the simulation of authentic socio-scientific dilemmas and the promotion of experiential learning opportunities. SSI concepts that incorporate socio-scientific issues, ethical considerations, argumentative discourse, and decision-making processes define the azure cluster. This cluster encapsulates scholarly work that emphasizes the original purpose of SSI education: to foster critical analytical skills, ethical deliberation, and social consciousness in students as they confront contentious scientific issues. Terminologies such as STEM, computational thinking, inquiry-based pedagogy, and problem-solving are included in the verdant cluster. This represents a paradigmatic shift toward the integration of SSI content into established educational paradigms and

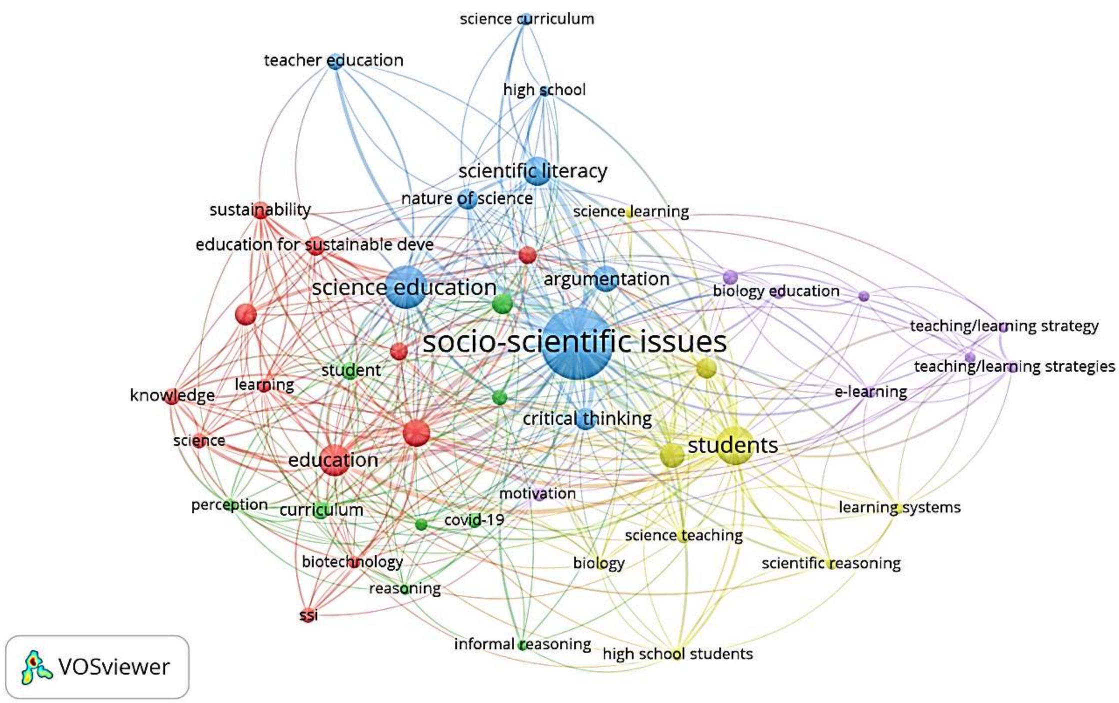

Figure 3. VOSviewer network visualization of research themes in ssi and technology

instructional frameworks. Within this framework, technology transcends its conventional function as a solitary instructional aid, transforming into a critical component of comprehensive curricular designs that are designed to cultivate interdisciplinary skills and competencies.

The term "socio-scientific issues" is centrally placed as a critical hub node, underscoring its fundamental significance in the connection of a variety of academic disciplines, including ethical considerations and technological instruments. Moreover, the robust connections between STEM, AI, and VR suggest that SSI learning is transitioning from a discussion-oriented instructional model to a pedagogical framework that is driven by models and integrated with technology. However, the network also demonstrates certain deficiencies. For instance, the terms "teacher professional development," "policy frameworks," and "curriculum design" are either absent or assigned a peripheral role. This discovery suggests that, despite the extensive documentation of technological innovation, the practical implications of its implementation are inadequately addressed.

Concurrently, Figure 4 displays the temporal progression of keywords through an overlay visualization that was generated by VOSviewer. The average publication year of the academic articles in which the corresponding keyword is mentioned is indicated by the color of each node in this graphical representation. The transformation of research themes over time is elucidated by a gradient progression from purple (representing earlier research) to yellow (indicative of more recent studies).

The overlay visualization emphasizes a significant transition in focus within the academic literature. The initial purpose of SSI learning as a means of fostering civic engagement and scientific literacy was reflected in the early studies (2016–2018), which were represented by purple nodes. These studies focused on foundational concepts such as science education, argumentation, ethics, and decision-making. Conversely, the keywords "virtual reality," "artificial intelligence,"

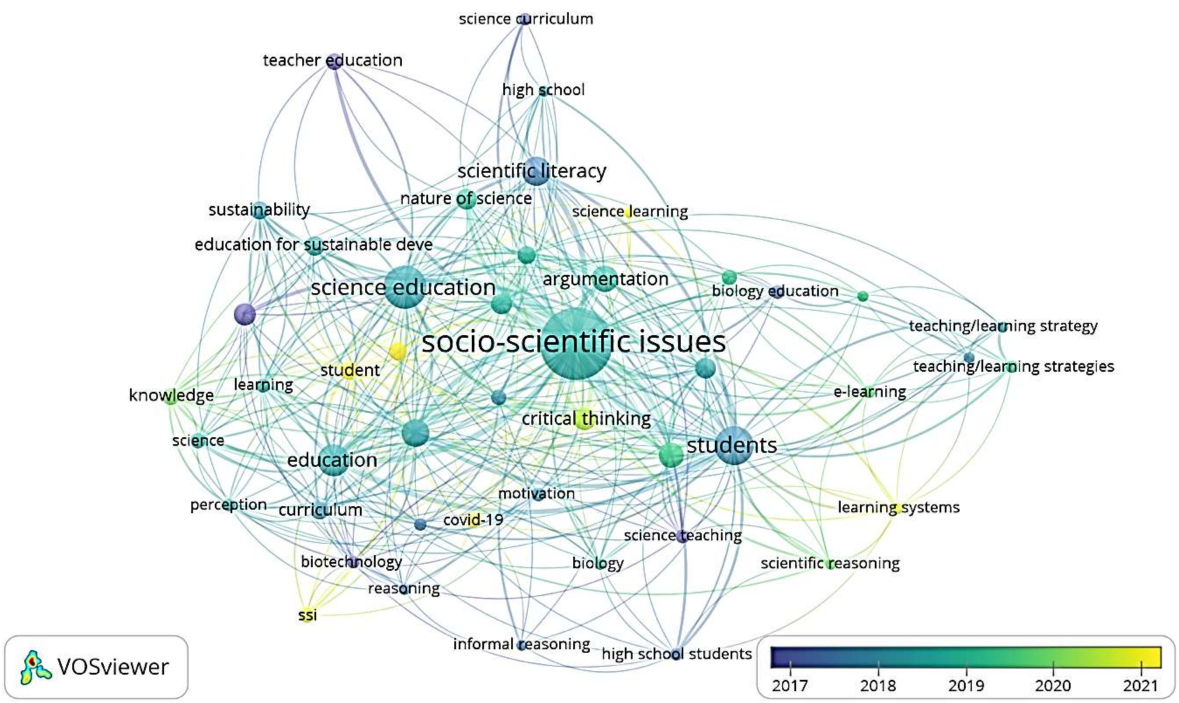

Figure 4. Overlay visualization of keyword trends in ssi and technology research (2016–2025)

"computational thinking," and "digital learning" are increasingly prioritized in more recent investigations (2021–2025), which are identified by yellow nodes. This change indicates a growing interest in the integration of state-of-the-art technologies into SSI-focused pedagogy to improve interactivity, engagement, and real-world simulations.

The integration of STEM within SSI frameworks has emerged as a persistent and expanding area of scholarly inquiry, particularly in the aftermath of the pandemic, which accelerated advancements in technological innovation within remote learning contexts. Additionally, the keyword STEM transitions from blue to green and yellow. This temporal trajectory illustrates that the academic discipline is transitioning from the development of conceptual frameworks to the implementation of technology-enhanced methodologies, which is consistent with the broader digital transformation that is taking place in the educational sector. It further emphasizes the importance of comprehending the contextualization of these technologies, whether they supplement, modify, or essentially alter the essence of SSI learning.

Figure 5 illustrates a density visualization of keyword co-occurrence, thereby clarifying the concentration and intensity of diverse research themes. In this representation, regions marked by heightened keyword frequency are depicted in yellow, while areas containing keywords of lower frequency are indicated in green or blue. This visualization serves to clarify both the dominant research domains and those that may be underrepresented in the academic literature. The most densely populated area in the figure is concentrated around keywords such as socio-scientific issues, technology, STEM education, and argumentation—implying that these subjects have attracted considerable scholarly attention and represent the nucleus of current research on SSI-based learning. Conversely, keywords such as virtual reality, artificial intelligence, digital simulations, and computational thinking appear in regions of moderate density, suggesting an

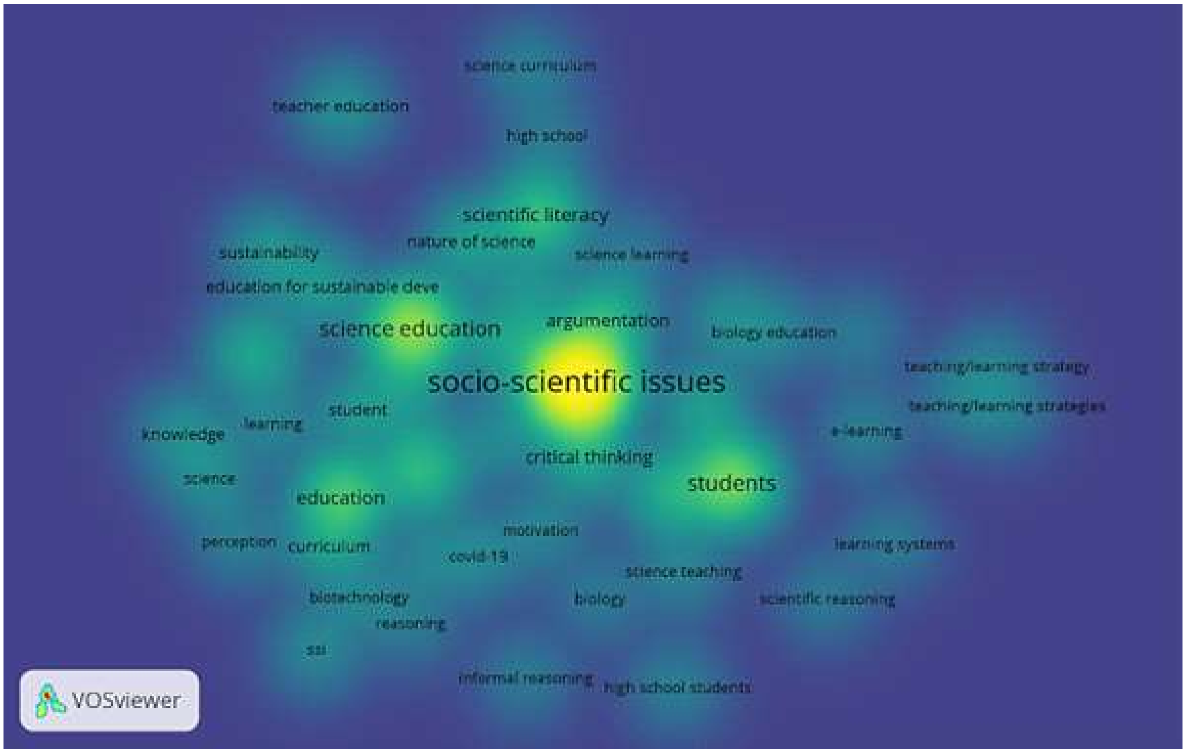

Figure 5. Density visualization of keyword distribution in ssi-based learning studies

emerging yet growing scholarly interest in these fields. These keywords are increasingly being explored to augment the pedagogical potential of SSI learning, particularly in cultivating systems thinking, immersive engagement, and data-informed decision-making.

In contrast, the peripheral and low-density regions signify a lack of research in areas such as teacher professional development, digital ethics, and policy frameworks. This revelation indicates considerable opportunities for future investigations aimed at reconciling pedagogical innovation with institutional and policy-level support. Overall, the density visualization enhances the preceding figures by confirming that while certain themes are comprehensively developed, others are only beginning to gain prominence. This highlights the importance of this systematic review in delineating current strengths and identifying research gaps within the integration of technology in SSI learning.

The findings derived from a systematic literature review encompassing 39 scholarly articles suggest that technology is manifested in two predominant forms within the context of SSI learning:

Technology Plays a Role in the Learning Process

Technology is directly involved in the learning process at SSI, as students utilize a diverse array of digital devices and media. The utilization of the web, online discussion media, simulation technologies such as Artificial Intelligence (AI) and Virtual Reality (VR), digital games, and specific devices or applications are among the implementations. Students' primary source of information and reference is web-based learning. Kruit et al. (2024) demonstrate how students independently investigate scientific social issues through the use of web-based digital platforms. Constantinou and Rybska (2024) have also created the STOCHASMOS platform, which enables students to explore the issue of microbial resistance by utilizing two primary features: the Inquiry Environment and the

Reflective Workspace. The platform has been demonstrated to enhance students' engagement and interest in SSI topics.

Devices such as the microbit are also employed directly in the learning process. López et al. (2024) employed micro:bit to comprehend the concept of pH and the correlation between chemical-physical phenomena and real-world applications. Students work collaboratively in a team to actively analyze and develop an understanding of the degree of acidity in an actual context using this tool. SSI's learning is also significantly influenced by online discussion and collaboration. Tsai (2018) and Chen & Tsao (2021) demonstrate that online platform-based discussions can enhance students' argumentative abilities and broaden their cross-perspective comprehension.. Online collaboration also facilitates the transmission of ideas between regions through virtual meetings, thereby enhancing productivity, creativity, and efficiency in learning, as per Stavrou et al. (2018).

Virtual simulations and experiments enable students to encounter scenarios that are not feasible in the physical world. Newton & Annetta (2024) and Filter et al. (2020) discovered that AR and VR technologies can enhance students' learning experiences, particularly in the context of climate change and its consequences. This technology enhances students' ecological awareness, deepens comprehension, and provides access to realistic simulated scenarios. Additionally, AI is employed to create simulated solutions to intricate socio-scientific issues (Humburg et al., 2024).

Ideas or the outcomes of student discussions are communicated through digital presentation media. Students in the Promise Zone region of the United States developed digital posters to illustrate solutions to local issues in the study of (Songer & Ibarrola Recalde, 2021). Students' scientific communication abilities and creativity are fostered through the utilization of innovative formats, including interactive presentations, infographics, and videos. This research is consistent with international findings, including those of Kong et al (2022) and Ke et al. (2021), which indicate that technologies like VR and AI can enhance students' comprehension of the social and ethical aspects of science. Nevertheless, the articles examined in this SLR tended to emphasize the technological aspect as a medium of visualization and simulation, rather than as a means of scientific debate, in contrast to Ke et al., who emphasized social discussion. The utilization of this technology also enables students to cultivate the social skills that are essential for real-world social interactions. The incorporation of these technologies into the educational curriculum has the potential to enhance the efficacy of instruction and equip students with the skills necessary to confront future obstacles. Consequently, it is crucial to persist in the investigation and implementation of technologies that facilitate students' engagement and creativity in the educational process (Moin, 2022).

Technology as a Component in a Learning Model or Approach

Technology is not only a primary component of learning activities, but it is also a fundamental component of learning approaches such as STEAM, Computational Thinking (CT), STS, and STEM. In this instance, technology serves as not only an instrument, but also an element that contributes to the design and structure of the learning process. STEM and STEAM models are implemented to incorporate technology into SSI-based project learning, as demonstrated by numerous studies, including Altan et al. (2018), Danielson et al. (2022), and Wahono et al. (2021). Students not only comprehend the issues, but they also develop technology-based solutions, such as eco-friendly products or sustainability simulations.

Guerrero-Márquez & García-Carmona (2020) employ the STS (Science-Technology-

Society) approach to investigate the social and ethical implications of science through the lens of technology. Students develop a critical comprehension of the relationship between science, technology, and public policy by investigating digital news and online data. In the interim, Yanti et al. (2024) investigated the Computational Thinking (CT) approach, which they applied to the fundamental aspects of learning style and energy. Through the utilization of digital technology and simulation, CT instructs students on the processes of decomposition, pattern recognition, abstraction, and algorithm design, all of which are essential for problem-solving. Nevertheless, the effectiveness of long-term pedagogy, teacher readiness, or the evaluation of the impact of technology on student engagement were only examined in a limited number of studies. This is in stark contrast to international studies, such as Gray & Bryce (2006), which underscore the significance of professional development and institutional support in the implementation of technology in SSI.

CONCLUSION

Technology plays a strategic role in the implementation of learning that is founded on Socio-Scientific Issues (SSI). SSI learning has become more interactive, contextual, and pertinent to the challenges and knowledge development in social technology as a result of the presence of technology. Facilitate collaboration and discussion among participants, as well as provide access to extensive information, allowing for virtual simulations and experiments. Furthermore, technology can facilitate the dissemination of ideas and presentations, thereby enabling students to cultivate the ability to think critically and solve problems more effectively. Technology implementation in SSI-based learning can be accomplished through direct methods, such as the use of AR, VR, AI, and digital gaming applications, or through the integration of learning models such as STEM, STEAM, STS, and CT. By employing appropriate strategies, technology can assume a prominent role in the learning of SSI, thereby motivating participants to become more engaged in the understanding and pursuit of solutions to the intricate social and scientific issues of the digital era. In order to improve pupil engagement and comprehension of socio-scientific issues, educators must exhibit greater adaptability when implementing technologies. Moreover, in order to achieve adaptive, interactive, and pertinent SSI-based learning that meets the requirements of the digital generation, it is imperative to engage in curriculum development, longitudinal research, and collaboration among educational institutions, technology developers, and policymakers.

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