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Enhancing STEM Education through Effective Science Communication: A Comprehensive Review

Mejorando la Educación STEM a través de la Comunicación de la Ciencia: Una Revisión General

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Abstract: This work reviews the evolving connection between science communication and STEM (Science, Technology, Engineering, and Mathematics) education, highlighting its significance for students and teachers. It includes a comprehensive literature review of the challenges and opportunities of integrating education and science communication and covers the history and evolution of science communication models, communication strategies, teaching methodologies, and engagement, motivation, diversity, equity, and inclusion. Additionally, this review discusses the impact of science communication practices on both informal and formal environments and considers the role of emergent technologies. The review underscores the increasingly strong relationship between science communication practices and STEM education, emphasizing their critical role in shaping the future of STEM education research and praxis.

Keywords: STEM education, science, communication

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Resumen: Este trabajo presenta una revisión de la conexión en evolución entre la comunicación de la ciencia y la educación STEM (por las siglas en inglés de ciencia, tecnología, ingeniería y matemáticas), resaltando la importancia para estudiantes y docentes. Incluye una revisión general de la literatura sobre los desafíos y las oportunidades de integrar la educación y la comunicación de la ciencia, la historia y evolución de los modelos de la comunicación de la ciencia, estrategias de comunicación, metodologías educativas, y la participación, motivación, diversidad, equidad e inclusión. Además, la revisión discute el impacto de las prácticas de la comunicación de la ciencia en ambientes formales e informales, y considera el papel de las tecnologías emergentes. La revisión recalca la cada vez más fuerte relación entre las prácticas de comunicación de la ciencia y la educación STEM, enfatizando su pertinencia en la formulación de la futura investigación y praxis de la educación STEM.

Palabras clave: educación STEM, ciencia, comunicación

Introduction

Science communication is recognized as an interdisciplinary field of theory and practice (Borowiec, 2023). Illingworth and Prokop (2017) emphasize that science and its education benefit society through their connections to culture and policymaking. “Science communication and education are two sides of the same coin” (Illingworth et al., 2015; Clark et al., 2016; Illingworth & Prokop, 2017, p. 6). Similarly, Design et al. (2024, p.1) state that “[e]ffective STEM teaching and learning is dependent on effective science communication.”

Webb et al. (2012) argue that scientists must improve their communication skills to inspire future generations. This reinforces the role of science communication in formal and informal education, the latter including activities outside the classroom such as talks, festivals, museums, and podcasts (El-Adawy et al., 2024). Science communication is also described as a third mission in academia (Fecher et al., 2023). However, Schaefer (2024) warns that many scientists are not adequately trained for this societal demand. Webb et al. (2012) therefore advocate for integrating informal science education and communication into formal learning goals.

Gelmez-Burakgazi and Reiss (2024) highlight the overlap between science communication and education strategies: building trust, fostering dialogue, and increasing engagement. Wilkins et al. (2024) suggest that STEM teachers are underutilized science communicators, as they are uniquely connected with students, understand their backgrounds, and collaborate with scientists in outreach efforts.

Hendrickson et al. (2020) propose incorporating outreach into curricula via service-learning, while Wood (2023) calls for university-level science communication training to develop skills such as critical thinking, digital literacy, and interdisciplinary collaboration. Enzingmüller and Marzavan (2024) emphasize that STEM research, education, and communication are interconnected and should be designed collaboratively. Nemadziva et al. (2023) echo this, recommending science communication to improve STEAM teaching and to inspire young students to pursue STEM careers.

This review analyzes the current literature regarding the intersection between science communication and STEM education, and identifies effective strategies, challenges, and emerging trends, while highlighting how science communication practices can enhance STEM teaching and learning. The review aims to inform future science education research and educational practices by offering a comprehensive synthesis of theoretical frameworks, findings, and applications that support the integration of science communication into formal and informal STEM education contexts

Literature review

The role of science communication in education

Nowadays, there is a broad spectrum of science communication modes and target audiences. However, science communication is based on three basic communication models (Llorente & Revuelta, 2023; Lorke et al., 2024). The first is the traditional model of science communication, which is based on filling the gaps in scientific knowledge. This model is called the *deficit model* or *one-way* model (Illingworth & Prokop, 2017), which appeared during the 1960s (Kessler et al., 2022). This model is also called the *dissemination model* (Llorente & Revuelta, 2023). Pilt and Himma-Kadakas (2023) expand the deficit model to include the public deficit in scientific literacy and knowledge, the proper attitudes toward science, and trust in scientists and scientific processes, and the role of scientists is to fill these gaps.

The second model of science communication is known as the *two-way model* (Illingworth & Prokop, 2017) or the *dialogue model* (Llorente & Revuelta, 2023). In this regard, science communication and informal practices in STEM outreach are examples of the two-way model of science communication, in which the active participation of the public or group of students offers the possibility of a more dynamic exchange of ideas and messages (Frachiolla et al., 2024).

The third model is the *conversation-participation model* (Llorente & Revuelta, 2023).

Scotti (2020) and Kessler et al. (2022) identify the deficit model of science communication with the Public Understanding of Science, which aims to increase science literacy among the public (Kessler et al., 2022). The Public Engagement with Science model is identified with the two-way model (Scotti, 2020), which emerged after 2000 (Kessler et al., 2022). Public participation is traditionally limited to engaging with the science being communicated rather than with the design process of the science communication products (Enzingmüller & Marzavan, 2024).

Frachiolla et al. (2024) argued that the traditional one-way model of science communication may reinforce power dynamics, as the deficit model separates the public from scientific discourse and prevents the public from influencing it (Kessler et al., 2022). On the other hand, a two-way exchange can be extended to the design process of outreach activities with the public participating in the design stages, providing helpful information about their needs, preferences, and behaviors (Enzingmüller & Marzavan, 2024).

The deployment and conceptualization of science communication models have evolved. Metcalf (2019), as referenced by Lorke et al. (2024), proposes the *rosette model*, in which the dissemination, dialogue, and participation models coexist and complement each other as part of a spectrum (figure 1).

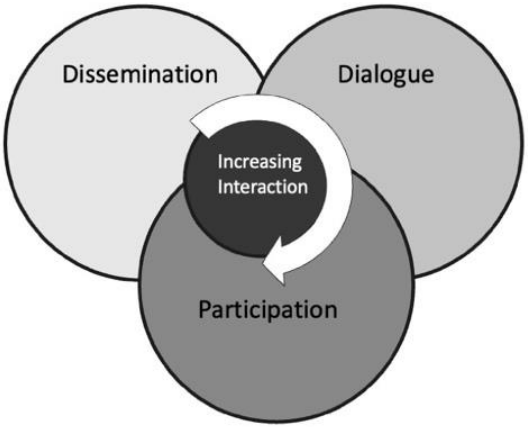

Figure 1. Representation of public increasing participation in the rosette model of science communication. Adapted from (Metcalf, 2019; Lorke et al., 2024).

Recognizing science communication as a part of STEM education, Ishmuradova et al. (2023) conducted a literature review study to evaluate the scientific output of science communication in the SCOPUS database for articles published between 2000-2022. The results show that science communication studies in STEM education have increased since 2018, underscoring the growing importance of studying science communication practice in STEM education. Using the exact keywords as in (Ishmuradova et al., 2023), we conducted an updated search on the Web of Science database on the topics (searches in title, abstract, keyword plus, and author keywords) for "science communication" and "STEM education" or "science education" or "mathematics education" or "technology education." The search produces 263 records published from 2000 to 2023, as shown in Figure 2. These results are consistent with what Ishmuradova et al. (2023) found.

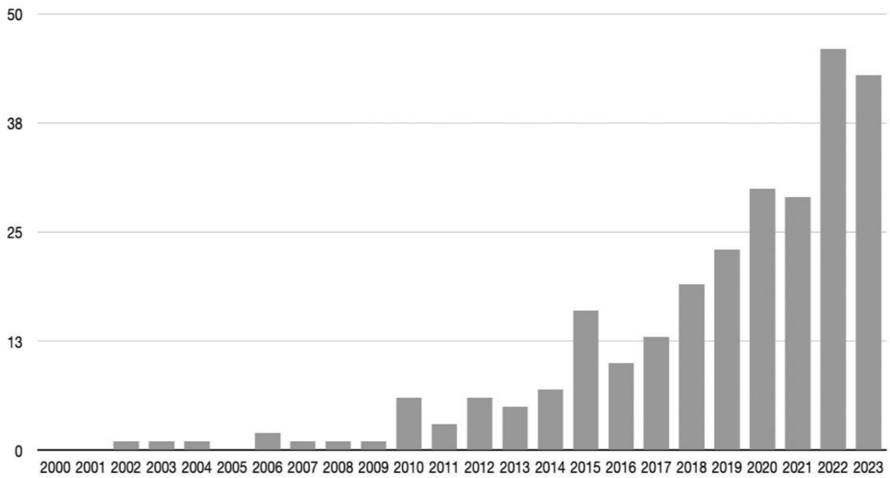

Figure 2. Distribution per year of articles published between 2000 and 2023 with the keywords described in the main text. The figure was obtained from the Web of Science database analytics.

Science Communication strategies

As part of the current science communication practices, Llorente and Revuelta (2023) mention *citizen science* projects in which scientists participate in research activities collecting, analyzing, or categorizing scientific data. These projects require some training from scientists for citizens, for which the potential to combine the two-way and participatory models exists.

Nelson et al. (2017) explain an educational example in which science communication models can be combined, as proposed in the rosette model (Metcalfe, 2019; Lorke et al., 2024). Nebraska STEM for You is an after-school outreach program in which undergraduate students mentor and engage middle school students with experiments and hands-on activities to motivate them to pursue STEM careers. The undergraduate students present these activities, help select topics, teach lessons on those topics, and design and present experiments (Nelson et al., 2017). This combination of science communication models in informal and formal settings allows the dissemination of information, the identification of and engagement with specific audiences, and the active participation of the public in the research/outreach activities that affect it (Holford et al., 2023; Steward, 2024).

Storytelling is one of the key tools in science communication. Tirumalai (2024) emphasizes using Campbellian presentations —in which characters embark on journeys and adventures— about science to connect with audiences. Shivni et al. (2021) proposed a storytelling-based framework for effective science communication, which encompasses four strategic storytelling categories, as shown in Table 1.

Strategic Categories of Storytelling	Description
Who	Identify and understand the intended audience and their degree of pre-existence knowledge.
Why	Identify the purpose and intended outcome of the main scientific message.
What	Situate the communication content in a relevant context considering the audiences' social, political, and cultural characteristics.
How	Encourage two-way communication and promote engagement with science

Table 1. Essential elements for effective science communication. Adapted from (Shivni et al., 2023).

Shivni et al. (2023) state that "[a]n important early step in creating effective and efficient curricula is understanding what baseline skills students have prior to instruction." In this regard, Shivni et al. (2023) assessed student baseline skills via an assigned plan and execution of science communication products in an undergraduate environmental science course. Their results show that the majority described the scientific content, the platform to be used, the mode of science communication, and the target audience in their plans. However, only some students included situational content stylistic elements such as humor, anecdotes, analogies, and metaphors. Also, it is important to note that students originally planned to share information via the one-way model but frequently involved two-way dialogue (Shivni et al., 2023).

Components of effective science communication

Engagement and motivation

As mentioned, narrative structure has been recognized as essential in effective science communication, with storytelling being a basic form of human communication (Cheu, 2020). Cheu (2020) has discussed the tensions between explaining physics concepts for their own sake in contrast with how this knowledge of physics fits in a larger narrative, highlighting the importance of relating concepts to the audience. The proposed structure components of effective science communication are (Cheu, 2020):

1. *Exposition*, in which the conflict or motives are presented.
2. *Rising action,* in which the conflict deepens.
3. *Recapitulation*, which corresponds to the rise to the dramatic climax.
4. *Climax*.
5. *Dénouement*, in which the resolution or catastrophe is reached.

Cheu (2020) demonstrates the approach by structuring the double beta decay physics at the SNO+ experiment. Also, storytelling as a science communication tool has shown that narrative increases comprehension, interest, and engagement (Dalhstrom, 2014; Green et al., 2018; Borowiec, 2023).

Inclusivity and accessibility

In recent years, science communication has been recognized as an interdisciplinary field in which experts in science, education, pedagogy, diversity, equity, inclusion, and public engagement work collaboratively to foster a supportive environment, seeking to improve a diverse pool of people in STEM fields (Frachiolla et al., 2024).

Alderfer et al. (2023) state that inclusive science communication in STEM education supports diversity, equity, inclusion, and justice while helping students develop communication and collaboration skills necessary for their future careers, where they will work in diverse groups.

Vickery et al. (2023) have studied the presence of inclusive science communication in science communication curricula from STEM students and scientists. The authors define the *inclusive model* as public participation in a social network approach, in which it is recommended to incorporate cultural sources of knowledge and value the diversity of disciplines and levels of expertise. Vickery et al. (2023) analyzed the literature of published (from 2000 to 2022) trainings in science communication for STEM undergraduate and graduate students. They found that less than 20% (out of 81 published trainings) indicated the inclusive model.

Tandori and Favilla (2024) have addressed inclusion in science communication for audiences with members who are blind, have low vision, or have diverse needs. The authors recommend auditory and haptic techniques to facilitate information access and propose joint efforts of art and science to generate theme-specific content that provides multisensory experiences of research products while procuring the evaluation of its effectiveness in conveying valid scientific information. For example, Favilla et al. (2024) discussed using inclusive multisensory science books to communicate immunology data to blind, low-vision or diverse-needs children.

Judd and McKinnon (2021) presented an analysis of science communication literature, consisting of articles published between 1985 and 2020, about how diversity and inclusion are defined and implemented in science communication practice and research. The study shows that the science communication literature has increased its attention to equity, diversity, and inclusion. However, the study also found that girls and women are centered disproportionally compared to the attention paid to historically underserved and minoritized audiences (Judd & McKinnon, 2021). In this regard, Polk and Diver (2020) recognize inclusive science communication through an equity lens that acknowledges underlying inequalities in social groups. Regarding gender disparity in STEM, Parité Sciences is a Canadian initiative in which a diverse team of scientists, teachers, and specialists in diversity, equity, and inclusion provides training to high school students in science, mathematics, physics, and computer science. The main goal of this program is to convey a scientific identity to girls and young women participating in the program (Fines-Neuschild et al., 2024).

Case studies and best practices

Schmitt et al. (2024) propose that effective science communication can empower students through research-based teaching, striving to present complex ideas in an understandable language, thus facilitating the communication of educational content. In their proposal, the authors include implementing teaching modules and student laboratories, public presentations, and theatrical performances, in which an interactive and aesthetic dialogue can be established between students, scientists, artists, and the general public.

Fracchiolla et al. (2024) propose principles of effective public engagement for physicists, although these can be implemented in STEM disciplines in general. The principles are (Fracchiolla et al., 2024):

a) Goal and motivations: Physicists should clearly state whether they are motivated by personal reasons, a desire to share knowledge, support people pursuing STEM careers, or spark interest in physics and science.
b) Audience: A common principle of science communication is to understand the audience, their needs, interests, and perspectives towards science, knowing that these are directly linked to their religious, political, and cultural views, beliefs, and values.
c) Cultural relevance: Science communicators can serve as role models for students and audiences.
d) Logic model approach: The components of this approach can be summarized to clearly define the purpose of the science communication project, the people that will be involved, the activities of the project, the resources available, the desired outcomes, and the long-term impacts sought by the project and its activities.

Nemadziva et al. (2023) revise strategies for effective engagement from science communication and present recommendations to integrate science communication practices into formal STEM teaching by designing resources to enhance STEM learning and teaching. Specifically, the authors propose the adoption of tools and approaches that have proven effective in communicating science in informal environments - such as science centers and museums – via the *inquiry cycle*:

1. Presentation: A surprising phenomenon in an exhibit or demonstration is presented to the audience/students.
2. Exploration: The audience/students further explore the interaction or demonstration.

3. Explanation: The science related to the exhibit is explained to the audience/students.
4. Contextualization: The exhibit or demonstration is related to everyday situations.

The proposal also suggests using common materials as teaching tools and including science communication training in teacher development programs (Nemadziva et al., 2024).

Challenges and barriers in science communication

Fracchiolla et al. (2024) discuss that science communication faces skepticism towards science and scientists. The current state of science communication also faces a new post-truth normality, which is uncertain, politically and culturally polarized, and saturated by information and mediatization (Pilt & Himma-Kadakas, 2023).

Also, science communication practitioners need more financial resources, training in science communication (Llorente & Revuelta, 2023), time, staff, and equipment. These challenges are more significant for science communication actors in early career stages and members of underrepresented communities (Fracchiolla et al., 2024). The lack of external rewards and the additional workload are also obstacles for scientists who want to participate in science communication (Illingworth & Prokop, 2017). In this regard, Schaefer (2024) agrees that the outreach work needing compensation or support is a science communication challenge.

Déchène et al. (2024) found that social media can serve as a professional learning network. For example, the tweet analysis in their study found content about topics such as STEM education, digital educational tools, science, practice and knowledge transfer, educational materials, and educational legislation, among others. However, digital professionalization development in social media is informal and needs proper institutional recognition as valid training (Déchène et al., 2024). For this reason, unrecognized social media training remains a challenge in science communication and education.

At the student's level, Murphy and Kelp (2023) found that the student's lack of confidence in their communication skills, weak science identity, and self-efficacy correlate to the likelihood of engaging and participating in science communication activities. The authors define communication skills as the ability to communicate with peers and non-scientists verbally and in written form; science identity as the sense of belonging and self-recognition; self-efficacy as the capacity to conduct scientific research, solve scientific problems, and communicate effectively.

Evaluating the quality and impact of science communication activities is a significant challenge discussed in the literature (Illingworth & Prokop, 2017). Llorente and Revuelta (2023) argue that consistent evaluation criteria are needed to assess science communication activities systematically. This keeps the success and completion of the activities' objectives shrouded in uncertainty.

Another challenge in science outreach is that while it can improve short-term interest in science, the benefit does not necessarily translate to long-term interest (Hendrickson et al., 2020).

Impact of science communication training: Benefits and challenges

The literature documents the benefits and challenges of science communication training for STEM students, as discussed below.

Students participating in outreach activities in the Nebraska STEM for You program have reported significant organizational and engagement skills in their STEM knowledge (Nelson et al., 2017). Also, the results reported by Murphy and Kelp (2024) underscore the effects of science communication on learning outcomes in STEM education. A strong correlation exists between students' science communication skills, science identity, and self-efficacy. The study found that the students' perceived skills, identity, and self-efficacy significantly predict their behaviors toward science communication. A science communication training workshop for graduate STEM students consisted of interactive panels with invited science communicators, writers, academics, and filmmakers. In the study by O'Keefe and Bain (2018), the graduate students were asked to rank their confidence in communicating with scientists and general audiences and submitting work to popular science outlets. The survey results show an increase in the student's confidence in their science communication ability. The study authors mention that a limitation of their study was that the workshop consisted of a one-time event instead of a continuous training program (O'Keeffe & Bain, 2018).

The effects of science communication on learning outcomes are not separated from the challenges faced by STEM students from lower socioeconomic status, first-generation college students, Black, Indigenous, and People of Color (Alderfer et al., 2023), as STEM professionals from these groups also face barriers and challenges (Gupta et al., 2024). In students from underrepresented groups, training on science communication definitions and models, analysis of case studies, role-playing activities, and peer discussions has been shown to increase their science identity: a study of student responses during pre- and post-workshop surveys showed a significant increase in student's self-efficacy and identity as scientist and science communicators, more markedly for marginalized students (Alderfer et a., 2023).

As Schiefer et al. (2024) mentioned, migrant students are underrepresented in STEM and likely to underperform. A science outreach after-school program consisted of inquiry-based, hands-on activities conducted by STEM professionals in the students' (ages 6-17) native language (Portuguese) in Germany (four schools) in the United Kingdom (two schools). An analysis of the pre-and post-training student's self-reports shows the students' positive response to the training and increases in STEM knowledge, intrinsic interest in science, attainment value towards science, self-concept towards science, and their willingness to partake in science in the future (Schiefer et al., 2024). These results underline the importance of considering audiences' and students' various cultural and linguistic backgrounds in science communication and STEM education.

Future trends in science communication and STEM education

One current trend in STEM education is using informal didactic videos on social media. The study by Lijo et al. (2024) analyzed a YouTube channel with content related to energy, electricity, and sustainability. The videos were classified as educational or for dissemination, i.e., audiovisual materials to satisfy curiosity about the topics and for entertainment. The study found that educational videos had more views, comments, and shares than dissemination videos. Compared to dissemination videos, educational videos offer a deeper focus on the topic paired with efficient explanations, animations and visualizations, and detailed mathematical explanations (Lijo et al., 2024).

Another current trend in STEM education is the educational approach called *evidence-based* teaching (Déchène et al., 2024). In this approach, educational methods incorporate empirical evidence and research findings so that scientific data guide instructional, curriculum design and development, and classroom interventions and activities. The study conducted by Déchène et al. (2024) analyzed the roles of educational Twitter (now known as X) communities in promoting evidence-based teaching approaches and science communication. The teacher survey results reveal that members in a particular Twitter community primarily use it as a digital development resource where teachers share and acquire ideas and materials. The study states that science communication on Twitter allows teachers to access the latest research findings and offers professional development opportunities such as resource sharing, participation in educational discussions, and continuous learning in a professional learning network.

The evidence-based approach from science communication and education is present in outreach efforts. For example, there is collaboration between scientists and science communicators at CERN, a leading institution dedicated to high-energy physics and fundamental research. CERN Science Gateway is an education and outreach center in which the exhibitions result from the collaboration of the exhibitor teams, CERN's researchers and technicians, visitors, designers, science communicators, and communications, natural and social science researchers (Dvorzhitskaia et al., 2024). The collaboration at CERN Science Gateway extends to research-based decisions about the exhibits, core messages, their planning and development, and considering the results from formative evaluations in which the participant's interactions with these exhibits are recorded (Dvorzhitskaia et al., 2024).

The use of virtual reality in science communication and education has also been reported. For example, the Virtual Reality Experiment discussed by (Graebling et al., 2024) implements an informal learning approach to communicate research in electoral resistivity tomography measurements in the Mont Terri underground research laboratory. The purpose of the research conducted at this facility is to study potential rocks as hosts for nuclear waste disposal. An evaluation of the quality and effectiveness of knowledge transfer showed that participants in the Virtual Reality Experiment highly enjoyed the experience, and the study reports high effectiveness in knowledge transfer (Graebling et al., 2024). The authors of the study spotlight that while the virtual reality approach is based on informal learning, some concepts, such as research methodology and its results, from formal learning are transferable in the virtual field trip experience.

Given that Externed Reality and Virtual Reality (XR/VR) technologies simulate physical environments in which users can interact with elements of those virtual spaces, a standard for science communication in XR/VR has been proposed by Rubio-Tamayo et al. (2024). The proposal aims to establish production and visualization standards for the XR/VR representation of scientific facts and research findings.

Another novel trend in science communication and education is Generative Artificial Intelligence (GIA). The development of critical and argumentative thinking in the age of GAI has been considered by Guerra (2024). The potential benefits and challenges of implementing GIA, specifically Chat GPT, in educational settings have also been considered (Albayati, 2024). Guerra (2024) highlights the crucial skills fostered by the STEM pedagogical interdisciplinary approach in the context of GIA:

- Critical thinking is related to objectively analyzing facts and evidence in diverse problems.
- Communication is listening, working collaboratively, and using media and technological means such as GAI.
- Collaboration is the capacity to work cooperatively and non-cooperatively to achieve team goals.
- Creativity is the ability to find novel solutions to diverse problems.

In the use of GAI to produce STEM content, Guerra (2024) recommends:

- Make explicit the use of GAI in products.
- Prevent the generation of illegal or protected content.
- Make known the copyrights of the data or resources used to produce content via GIA.
- Make explicitly known if the products generated with GIA have human supervision.
- Provide ethical recommendations for the use of the products.

Conclusions

This review highlights the relationship between science communication and STEM education, emphasizing the transfer of techniques and concepts from informal environments to formal ones and identifying the growing trend to incorporate in curricular design and research-based teaching. The aim of these practices is to improve critical thinking, digital literacy, and interdisciplinary competencies for future STEM professionals, educators, scientists, and science communicators.

Inclusive science communication models addressing diversity, equity, and inclusion in STEM are being implemented worldwide. Several science communication training evaluations stress the importance of fostering a science identity to empower students, especially those from underserved backgrounds. Examples discussed in this review explored the roles of students as science communicators, engaging with younger generations, serving as role models, and the benefits that science communication brings to participants, such as practicing their organizational and communication skills while promoting diverse participation and interest in STEM.

The benefits of science communication extend to teachers as well. Besides helping to improve their communication skills, social media platforms host development programs where teacher communities can share materials and ideas from the latest trends and technologies.

As discussed, science communication and STEM education still need to effectively address several challenges. Hopefully, this review will contribute to informing and redirecting efforts in effective science communication and education research to enhance STEM education.

Based on this review, it is evident that the main ideas can and should be adapted and implemented across diverse educational contexts, taking into account cultural, linguistic, socioeconomic, and technological differences in regions and institutions worldwide, particularly in Latin America. A concrete proposal derived from this review is to integrate science communication into STEM curricula through elective or mandatory courses focused on public science communication, hands-on outreach workshops, or community service activities with science communication goals. Such integration would enable students to develop not only technical competencies but also communication skills, critical thinking, and social awareness, which are key components in their formation as future professionals and engaged citizens.

References

Albayati, H. (2024). Investigating undergraduate students' perceptions and awareness of using ChatGPT as a regular assistance tool: A user acceptance perspective study. *Computers and Education: Artificial Intelligence, 6*, 100203. https://doi.org/10.1016/j.caeai.2024.100203

Alderfer, S., McMillan, R., Murphy, K., & Kelp, N. (2023). Inclusive science communication training for first-year STEM students promotes their identity and self-efficacy as scientists and science communicators. *Frontiers in Education*, 8, Article 1173661. https://doi.org/10.3389/feduc.2023.1173661

Borowiec, B. G. (2023). Science communication in experimental biology: experiences and recommendations. *Journal of Experimental Biology*, *226*(16), Article jeb245780. https://doi.org/10.1242/jeb.245780.

Cheu, H. F. (2020). Storytelling and science communication: how to turn (A,Z)->(A,Z+2_+2e$^-$+2$\overline{\nu}_e$ into a story. *Journal of Physics: Conference Series, 1342*, Article 012102. https://doi.org/10.1088/1742-6596/1342/1/012102

Clark, G., Russell, J., Enyeart, P., Gracia, B., Wessel, A., Jarmoskaite, I., et al. (2016). Science educational outreach programs that benefit students and scientists. *PLOS Biology, 14*(2), e1002368. https://doi.org/10.1371/journal.pbio.1002368

Dahlstrom, M. F. (2014). Using narratives and storytelling to communicate science with nonexpert audiences. *Proceedings of the National Academy of Sciences of the United States of America, 111*, 13614-13620. https://doi.org/10.1073/pnas.1320645111

Déchène, M., Lesperance, K., Ziernwald, L., & Holzberger, D. (2024). From research to retweets—Exploring the role of educational Twitter (X) communities in promoting science communication and evidence-based teaching. *Education Sciences, 14*(2), 196. https://doi.org/10.3390/educsci14020196

Desing, R. M., Pelan, R., Kajfez, R. L., Wallwey, C., Clark, A. M., & Gopalakrishnan, S. (2024). Identity trajectories of faculty members through interdisciplinary STEAM collaboration paired with public communication. *Education Sciences, 14*(454). https://doi.org/10.3390/educsci14050454

Dvorzhitskaia, D., Zamora, A., Sanders, E., Verheyden, P., & Clerc, J. (2024). Exhibition research and practice at CERN: Challenges and learnings of science communication 'in the making'. *Journal of Science Communication, 23*(02), N01. https://doi.org/10.22323/2.23020801

El-Adawy, S., Lau, A. C., Sayre, E. C, & Fracchiolla, C. (2024). Motivation and needs of informal physics practitioners. *Physical Review Physics Education Research, 20*(1). https://doi.org/10.1103/PhysRevPhysEducRes.20.01012

Enzingmüller, C. and Marzavan, D. (2024). Collaborative design to bridge theory and practice in science communication. *Journal of Science Communication, 23*(02), Y01. https://doi.org/10.22323/2.23020401

Favilla, S., Tandori, E., & Marshall, J. (2024). Inclusive multisensory science and immunology books for blind, low-vision and diverse-needs audiences. *Immunology & Cell Biology, 102*(5), 358-364. https://doi.org/10.1111/imcb.12758

Fecher, B., Kuper, F., Fähnrich, B., Schmid-Petri, H., Schildhauer, T., Weingart, P., & Wormer, H. (2023). Balancing interests between freedom and censorship: Organizational strategies for quality assurance in science communication, *Science and Public Policy*, 50(1), 1–14. https://doi.org/10.1093/scipol/scac043

Fines-Neuschild, M., Hlavacek-Larrondo, J., & Arguin, J.-F. (2024). Empowering educators: The key to achieving gender parity in STEM fields. *Communications Physics, 7*(78). https://doi.org/10.1038/s42005-024-01574-0

Gelmez-Burakgazi, S., & Reiss, M. J. (2024). Perceptions of sustainability among children and teachers: Problems revealed via the lenses of science communication and transformative learning. *Sustainability*, 16, Article 4742. https://doi.org/10.3390/su16114742

Graebling, N., Ziefle, G., Furche, M., Nicol, R., Schefer, S., Ziegler, M., Jaeggi, D., Nussbaum, C., Annanias, Y., Goldstein, S., & Rink, K. (2024). VR-EX — An immersive virtual reality serious game for science communication about the electrical resistivity tomography measurements in the Mont Terri Rock Laboratory, Switzerland. *Environmental Earth Sciences, 83*, 318. https://doi.org/10.1007/s12665-024-11613-2

Green, S. J., Grorud-Colvert, K., Mannix, H., & Shanahan, M.-C. (2018). Uniting science and stories: Perspectives on the value of storytelling for communicating science. *FACETS, 3*, 164-173. https://doi.org/10.1139/facets-2016-0079

Guerra, E. (2024). The contribution of critical thinking to STEM disciplines at the time of generative intelligence. STEM Education, 4(1), 71–81. https://doi.org/10.3934/steme.2024005

Hendrickson, J. L., Bye, T. K., Cockfield, B. A. Carter, K. R., & Elmer, S. J. (2020). Developing a science outreach program and promoting "PhUn" all year with rural K-12 students. *Advances in Physiology Education, 44*(2), 212-216. https://doi.org/10.1152/advan.00196.2019

Holford, D., Fasce, A., Tapper, K., Demko, M., Lewandowsky, S., Hahn, U., Abels, C. M., Al-Rawi, A., Alladin, S., Sonia Boender, T., Bruns, H., Fischer, H., Gilde, C., Hanel, P. H. P., Herzog, S. M., Kause, A., Lehmann, S., Nurse, M. S., Orr, C., Pescetelli, N., Petrescu, M., Sah, S., Schid, P., Sirota, M., & Wulf, M. (2023). Science Communication as a Collective Intelligence Endeavor: A Manifesto and Examples for Implementation. *Science Communication, 45*(4), 539-554. https://doi.org/10.1177/10755470231162634

Ibragimov, G. I., Zhdanov, S. P., Volosova, N. Y., Knyazeva, S. A., Efimushkina, S. V., & Kochneva, L. V. (2024). The competence, interest, and perceived self-efficacy of undergraduate students in science communication. *Eurasia Journal of Mathematics, Science and Technology Education, 20*(1), Article em2387. https://doi.org/10.29333/ejmste/14118

Illingworth, S., & Prokop, A. (2017). Science communication in the field of fundamental biomedical research (editorial). *Seminar in Cell & Development Biology, 70*, 1-9. https://doi.org/10.1016/j.semcdb.2017.08.017

Illingworth, S., Redfern, J., Millington, S., & Gray, S. (2015). What's in a name? Exploring the nomenclature of science communication in the UK [version 2; peer review: 3 approved, 1 approved with reservations]. *F1000Research, 4*, 409. https://doi.org/10.12688/f1000research.6858.2

Judd, K., & McKinnon, M. (2021). A systematic map of inclusion, equity and diversity in science communication research: Do we practice what we preach? *Frontiers in Communication, 6*, 744365. https://doi.org/10.3389/fcomm.2021.744365

Kessler, S. H., Schäfer, M. S., Johann, D., & Rauhut, H. (2022). Mapping mental models of science communication: How academics in Germany, Austria and Switzerland understand and practice science communication. *Public Understanding of Science, 31*(6), 711-731. https://doi.org/10.1177/09636625211065743

Lijo, R., Castro, J. J., & Quevedo, E. (2024). Comparing educational and dissemination videos in a STEM YouTube channel: A six-year data analysis. *Heliyon, 10*, e24856. https://doi.org/10.1016/j.heliyon.2024.e24856

Llorente, C., & Revuelta, G. (2023). Models of teaching science communication. *Sustainability, 15*(6), Article 5172. https://doi.org/10.3390/su15065172

Lorke, J., Ballard, H. L., & Robinson, L. D. (2024). More complex than expected - mapping activities and youth's experiences at BioBlitz vents to the rosette model of science communication. *Frontier in Environmental Science, 11*. https://doi.org/10.3389/fenvs.2023.1270579

Metcalfe, J. (2019). Rethinking science communication models in practice [Doctoral dissertation, Australian National University]. Open Research Depository. https://openresearch-repository.anu.edu.au/items/a69d36ec-2bf6-4b67-9708-d1229e8bf28f

Murphy, K. M., & Kelp, N. C. (2023). Undergraduate STEM students' science communication skills, science identity, and science self-efficacy influence their motivations and behaviors in STEM community engagement. *Journal of Microbiology & Biology Education, 24*(1), Article 00182-22. https://doi.org/10.1128/jmbe.00182-22

Nelson, K., Sabel, J., Forbes, C., Grandgenett, N., Tapprich, W., & Cutucache, C. (2017). How do undergraduate STEM mentors reflect upon their mentoring experiences in an outreach program engaging K-8 youth? *International Journal of STEM Education, 4*(3). https://doi.org/10.1186/s40594-017-0057-4

Nemadziva, B., Sexton, S., & Cole, C. (2023). Science communication: The link to enable enquiry-based learning in under-resourced schools. *South African Journal of Science, 119*(1/2), Art. #12819. https://doi.org/10.17159/sajs.2023/12819

O'Keefe, K., & Bain, R. (2018). ComSciCon-Triangle: Regional science communication training for graduate students. *Journal of Microbiology & Biology Education, 19*(1). https://doi.org/10.1128/jmbe.v19i1.1420

Pilt, E. and Himma-Kadakas, M. (2023). Training researchers and planning science communication and dissemination activities: testing the QUEST model in practice and theory. *Journal os Science Communication, 22*(06), A04. https://doi.org/10.22323/2.22060204

Polk, E., & Diver, S. (2020). Situating the scientist: Creating inclusive science communication through equity framing and environmental justice. *Frontiers in Communication, 5*(6). https://doi.org/10.3389/fcomm.2020.00006

Schaefer, E. (2024). Evolving attitudes of science graduate students toward science policy and communication. Journal of Science Policy & Governance, 24(01). https://doi.org/10.38126/JSPG240114

Schiefer, J., Caspari, J., Moscoso, J. A., Catarino, A. I., Afonso, P. M., Golle, J., & Rebuschat, P. (2024). Science and Heritage Language Integrated Learning (SHLIL): Evidence of the effectiveness of an innovative science outreach program for migrant students. *Science Education, 119*(1/2), 1-32. https://doi.org/10.1002/sce.21860

Schmitt, FJ., Golüke, M., & Budisa, N. (2024). Bridging the gap: enhancing science communication in synthetic biology with specific teaching modules, school laboratories, performance, and theater. *Frontier in Synthetic Biology, 2*. https://doi.org/10.3389/fsybi.2024.1337860

Scotti, V. (2020). Social media and storytelling: Tools to raise engagement with physics. *40th International Conference on High Energy Physics - ICHEP2020*, July 28 - August 6, 2020, Prague, Czech Republic (virtual meeting). https://pos.sissa.it/

Shivni, R., Cline, C., Newport, M., Yuan, S., & Bergan-Roller, H. E. (2021). Establishing a baseline of science communication skills in an undergraduate environmental science course. *International Journal of STEM Education*, 8(47). https://doi.org/10.1186/s40594-021-00304-0

Stewart, I. S. (2024). Advancing disaster risk communications. *Earth-Science Reviews, 249*, 104677. https://doi.org/10.1016/j.earscirev.2024.104677

Tirumalai, M. R. (2024). Education and public outreach: communicating science through storytelling. *Journal of Microbiology & Biology Education, 25*(1), Article e00209-23. https://doi.org/10.1128/jmbe.00209-23

Vickery, R., Murphy, K., McMillan, R., Alderfer, S., Donkoh, J., & Kelp, N. (2023). Analysis of inclusivity of published science communication curricula for scientists and STEM students. *CBE—Life Sciences Education*, 22(1), ar8. https://doi.org/10.1187/cbe.22-03-0040

Webb A. B., Fetsch C. R., Israel E., Roman C. M., Encarnación C. H., Zacks J. M., Thoroughman K. A., & Herzog E.D. (2012). Training scientists in a science center improves science communication to the public. *Advances in Physiology Education, 36*(1):72-6, Article 2238418. https://doi.org/10.1152/advan.00088.2010

Wilkins, M. R., Rapciak, S. E., Goller, C. C., Weintraub, J., & Mikaelyan, A. (2024). Scaling the wall: Overcoming barriers to STEM knowledge mobilization. *Frontiers in Communication, 9*, 1366207. https://doi.org/10.3389/fcomm.2024.1366207

Wood, M. (2023). Science communication as interdisciplinary training. *Journal of Science Communication, 22*(6). https://doi.org/10.22323/2.22060401