Educational Innovation in Science Communication: Enhancing Public Understanding of Environmentally Friendly Nuclear Technology in Indonesia

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Abstract

This study investigates educational innovations in science communication aimed at enhancing public understanding and acceptance of environmentally friendly nuclear technology in Indonesia. As global energy transitions increasingly highlight the importance of low-carbon alternatives, nuclear power has re-emerged as a viable option. However, public skepticism and limited scientific literacy pose significant challenges to its acceptance. This research focuses on how nuclear power plants are represented within educational and public discourse, emphasizing the role of nuclear scientists not only as technical experts but also as educators and communicators. The Indonesian Nuclear Society Association (Himpunan Masyarakat Nuklir Indonesia/HIMNI) is examined as a case study, representing a professional community actively involved in public education and outreach. Through activities such as webinars, workshops, media campaigns, and informal learning events, HIMNI seeks to build trust and foster informed dialogue on nuclear issues. Anchored in a constructivist paradigm and utilizing a qualitative case study approach, data were collected through interviews, observations, and document analysis, applying triangulation to ensure credibility. The findings reveal that the use of innovative communication tools—including interactive digital technologies, infographics, animation, and social media platforms—plays a vital role in enhancing nuclear science literacy and increasing community engagement. Moreover, integrating artistic and visual elements into educational content contributes to making complex nuclear concepts more accessible and relatable. The study concludes by emphasizing the importance of rethinking science communication as a form of public education and calls for interdisciplinary strategies merging scientific content with effective pedagogical and media practices in the context of nuclear energy development.

Keywords: educational innovations, science communication, public understanding, nuclear technology, scientific literacy, HIMNI, public education, community engagement

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Introduction

In essence, science is not only knowledge but also a way of thinking. Science, in this case, must be applied effectively in society, as it is not solely the preserve of scientific groups like scientists, but also belongs to the wider public. In this regard, members of the public who are unfamiliar with science cannot understand explanations by scientists using scientific, rigid, and seemingly complex language. This can lead to the public not achieving the results they expect from science itself. Therefore, such conditions can lead to a loss of trust in science (and the emergence of anti-science) if they consistently occur, due to the failure to meet the public's high expectations for science. This situation can also be exacerbated by the rapid spread of fake news (hoaxes) due to the lack of a comprehensive understanding of science among the majority of the public. Science communication, in this regard, is crucial for the scientific community, as scientists act as science communicators and negotiators in informing and educating the public about research results and various scientific issues, as well as for policymakers to gain a more comprehensive understanding.

In today's digital era, science communication plays a crucial role in maintaining the public's ability to think intelligently and distrust fake news (hoaxes). It is crucial for the public to receive information from reliable and trusted sources, including credible and accountable scientists. This aligns with the interconnected communication between scientists, the public, and the government. Scientists, with their expertise, are expected to be able to explain their research findings related to scientific issues to the public and provide important recommendations to the government. Furthermore, the success of science communication can also be influenced by the cultural context of society, including how they understand science. This understanding of science, in this context, also includes scientific literacy, where scientists make a significant contribution to economically competitive development (Stilgoe et al., 2014). Therefore, scientists, as practitioners and communicators of science, must be equipped with the skills to engage with the public and convey findings and innovations to the public. Furthermore, the adoption of technology and aesthetic values, such as popular science or fiction, is also necessary (Gregory & Miller, 1998).

Science communication is the science of communicating scientific topics in a popular style from scientists to scientists and the public. Practically, this is often done through journalistic media (blogs, social media, and television), exhibitions, and public policy mapping with science as a primary element. From the perspective of governments and scientists, science communication is crucial for determining the effectiveness of science communication to the public on environmental science issues, specifically regarding environmentally friendly nuclear technology, through public media. Science communication to the public can be conducted through three media groups: mainstream media (such as magazines, television, and radio), face-to-face events, and online interactions (Bultitude, 2011). However, in the modern era of advances in communication technology, we are faced with the proliferation of social media platforms, making social media science communication a complementary tool.

The concept of science communication in English is a modified form of the terms science and communication. The history of science communication can be traced back to ancient times, but its development became more structured and focused in the 19th century and flourished in the 20th century (Nielsen, 2022; Schneider & Heinecke, 2019). The history of science communication reflects a gradual evolution from elite intellectual exchange to broad public engagement. It began during the Age of Enlightenment (17th–18th centuries), when thinkers such as Galileo, Newton, and Descartes promoted rational inquiry and the scientific method.

By the early 19th century, science gained recognition as an independent discipline through the rise of scientific magazines and newspapers. Advances in printing and illustration expanded public access to complex scientific ideas, while the establishment of museums and exhibitions in the 19th century made scientific knowledge more tangible and publicly accessible (Bauer & Bucchi, 2008; Bucchi, 2013; Nielsen, 2022).

The popularization of science continued into the 20th century, exemplified by figures like Carl Sagan, whose media presence bridged science and public imagination. The emergence of mass media—radio, television, and later the internet—transformed science communication into a global phenomenon. Educational institutions and scientific organizations such as the American Association for the Advancement of Science (AAAS) and the British Science Association (BSA) strengthened the field through publications, conferences, and outreach programs. Finally, the digital and social media revolution in the late 20th and early 21st centuries enabled scientists to directly engage with audiences worldwide, marking a new era of participatory and democratized science communication. This development demonstrates that science communication is the result of a variety of interrelated factors, including the development of science itself, the development of communication technology, and the efforts of individuals and organizations dedicated to disseminating scientific knowledge to the public (Bucchi & Trench, 2014).

Several influential figures have contributed to defining and shaping the concept of science communication. Carl Sagan viewed science not merely as a body of knowledge but as a *way of thinking*, emphasizing the transmission of scientific reasoning to the wider public (Davidson, 2000). Alan Alda highlighted the relational dimension of science communication, stressing the need to bridge understanding between scientists and lay audiences through clear and empathetic interaction (Weiss, 2011). Neil deGrasse Tyson advocated that science must be accessible to everyone, underscoring the importance of explaining scientific concepts in a simple and engaging manner (Elshahed & Tyson, 2020; Tyson, 2020). Meanwhile, Sandra Knapp emphasized the role of science communication in raising public awareness of biodiversity and environmental conservation (Wheeler et al., 2012).

It is important to remember that the definition of science communication can vary between individuals and can depend on the context. Each individual might highlight specific aspects of science communication based on their experience and understanding of the relationship between science and society. In its developmental context, science communication has evolved rapidly along with technological advancements and changes in access to information.

Contemporary science communication is shaped by several key developments. Social media platforms such as X (formerly Twitter), Facebook, Instagram, and YouTube enable scientists to share research findings and interact directly with the public. Podcasts and videos make complex topics more accessible, while infographics and data visualization enhance public understanding through visual clarity. The growth of scientific blogs and websites allows researchers to reach wider audiences, supported by stronger collaboration with science journalists to ensure accuracy and accessibility. Public education programs—including workshops, exhibitions, and museum initiatives—foster direct engagement, while online communities facilitate discussion and knowledge exchange. Increasing scientist participation in media and public events strengthens outreach, and amateur science initiatives contribute valuable data, particularly in fields like astronomy and ecology. These developments collectively create an environment in which science communication can reach a wider audience

and ensure that scientific information is more openly and easily understood by the general public.

From a Science Communication perspective, science communication can be grouped into several contexts that encompass the dimensions of communication and interaction between scientists, research institutions, and the public. Science communication can be broadly categorized into interrelated domains that together form a comprehensive framework for understanding how scientific knowledge is created, shared, and received (Kappel & Holmen, 2019; Mulder et al., 2008). The first domain is public scientific communication that includes both formal and informal channels. Formal communication refers to the dissemination of research findings through scholarly journals, academic conferences, and professional presentations, while informal dissemination focuses on sharing scientific information with the general public via traditional media outlets, press releases, and public events. The second domain is communication in science education that encompasses pedagogical and outreach-oriented interactions. Within formal education, scientific learning takes place in classrooms and laboratories, emphasizing the structured transmission of scientific concepts. Beyond formal settings, public education initiatives—such as workshops, training programs, and community-based learning activities—extend the reach of science to broader audiences, promoting lifelong engagement with scientific ideas.

The third domain involves mass media and science journalism, which play an essential role in translating complex scientific developments into accessible narratives for public consumption. This area also emphasizes the importance of collaboration between scientists and journalists to ensure that scientific reporting remains accurate, engaging, and socially relevant. Another critical aspect is risk communication and scientific ethics, which focus on how information about environmental, technological, and health-related risks is conveyed to the public. This dimension also highlights the ethical responsibilities of scientists in communicating research processes and implications transparently and responsibly.

Furthermore, communication in collaborative research addresses internal communication among researchers, including teamwork, coordination, and interdisciplinary dialogue across different scientific domains. Effective communication within and between research teams fosters innovation and strengthens the integrity of collaborative inquiry. In addition, social media and online scientific communities have transformed the contemporary landscape of science communication. Through digital platforms, scientists, students, and the public can now engage directly, share information, and participate in ongoing discussions, creating new forms of interaction that transcend traditional institutional boundaries. Finally, scientific marketing activities—including research promotion and scientific branding—have become increasingly significant. These activities help communicate the societal value of research outputs, enhance institutional visibility, and establish a recognizable identity for individual scientists, research teams, or scientific organizations.

Taken together, these interconnected categories illustrate that science communication today is not merely a linear process of information transfer, but a multidimensional and participatory practice that bridges scientific communities, educators, media, and the wider public. By grouping science communication within the framework of Science Communication, it is easier to understand the various aspects of scientific communication that involve various parties and contexts.

Science communication uses a multidisciplinary approach reflecting the understanding that science and communication are interconnected, and that combining approaches from various disciplines can enhance the effectiveness and impact of scientific communication. Science communication is inherently multidisciplinary, drawing insights and methods from a wide range of academic fields. From the natural sciences, it adopts principles of scientific communication and cognitive psychology to understand how individuals process and interpret complex scientific information. Within the field of communication studies, theories of communication, media, and journalism provide frameworks for effectively transmitting scientific messages and engaging the public through mass media channels (Mulder et al., 2008; Wood, 2023).

The domain of education contributes through instructional design and health education, emphasizing the creation of accessible learning materials and the integration of science into everyday contexts. Anthropology and sociology offer perspectives on cultural values, social behavior, and group dynamics, helping communicators understand how societal factors shape the reception and acceptance of scientific knowledge. Meanwhile, information technology and graphic design enhance science communication through the use of visualizations, infographics, and interactive digital platforms that promote participation and engagement. The arts and humanities add creative and narrative dimensions—using visual art, storytelling, and literary techniques to make scientific ideas more relatable and emotionally resonant (Scrimshaw, 2019; Tuveri et al., 2024; Zallio, 2021).

Ethical and legal considerations emerge from the fields of law and ethics, which emphasize responsible communication, respect for scientific integrity, and awareness of policy frameworks influencing public discourse (Medvecky & Leach, 2019; Priest et al., 2019). Lastly, economics and marketing contribute strategies for promoting scientific initiatives, analyzing the efficiency and impact of communication efforts, and ensuring that resources are allocated effectively. Together, these disciplines form an integrated foundation for science communication, positioning it as both a scientific and cultural endeavor that bridges knowledge production and public understanding. A multidisciplinary approach enables science communication to be more holistic and adaptive to various challenges and contexts. By combining diverse perspectives and skills, science communication practitioners can reach a wider audience and optimize the impact of scientific information (Davies, 2022; Stengler, 2020).

Science topics are often raised through various media platforms within the four groups mentioned above. Currently, one hot topic is environmentally friendly nuclear technology. Based on the application of environmentally friendly nuclear technology, we recognize two sectors: the energy sector (Nuclear Power Plants/NPP) and the non-energy sector (agriculture, animal husbandry, health, industry, etc.) (Murakami & Anbumozhi, 2020). At least the government must fulfill three important things for the smooth development of nuclear power plants in Indonesia: (1) There is a strong commitment from the President regarding the realization of nuclear power plants; (2) The realization of this Presidential commitment by the House of Representatives (DPR) together with the National Energy Council (DEN) through changes to the National Energy Policy (KEN) to make nuclear energy a top priority energy and no longer a last alternative; (3) Public campaigns by the government to increase the level of public acceptance (public acceptance rate) towards the use of nuclear power plants (Hariyadi, 2017). This third point is a crucial point in shaping mindsets and educating the public.

In the Outline of A Theory Practice, it is stated that habitus is related to knowledge resources (Bourdieux, 1977). This is correlated in the form of inhibiting factors for scientists in the context of science communication, namely: language problems (translating the complexity of science from scientific language into semi-popular language that is easily understood by the public), perception problems (tendencies towards various theoretical scientific data and focus on accuracy rather than readability), and value problems (the media's assumption that science does not have enough news value). According to the government's energy roadmap through the Indonesian Ministry of Energy and Mineral Resources (ESDM), it is known that the target for new nuclear needs will begin in 2040, where the demands for the government's seriousness in building a nuclear power plant are very high. In addition, the government will form a Nuclear Energy Regulatory Agency that is directly responsible to the president.

Globally, the development of nuclear power plants for Indonesia as the largest archipelagic country is very much in line with the energy transition in order to achieve the target of zero carbon emissions by 2060, because nuclear is one of the clean energy sources. However, economically, nuclear power plants are considered expensive to maintain, and Indonesia's limited nuclear scientists' ability to produce uranium as fuel is also questionable. These political and economic factors have led to a lack of media coverage of nuclear issues, leading the Indonesian public to become less informed and perceive nuclear issues not only as uninteresting but also as frightening (Massagony et al., 2025; Rahmanta et al., 2023; Santosa et al., 2023).

With regard to the application of environmentally friendly nuclear technology, this study focuses on the energy sector in environmentally friendly nuclear technology through the representation of nuclear power plants (NPP). Furthermore, one key point reinforces the role and urgency of science communication in educating the public about environmentally friendly nuclear technology, which correlates with the government's crucial commitment to ensuring the smooth development of nuclear power plants in Indonesia. This is the urgency of public campaigns by the government to increase public acceptance of nuclear power plants.

This study is to explore the practice of communicating environmentally friendly nuclear technology, particularly through the representation of Nuclear Power Plants (NPP) to the public by nuclear scientists enabling educational innovation in science communication that can foster more effective public engagement in Indonesia’s transition toward clean energy. Hence, this study answers one main question: how do nuclear scientists communicate nuclear power plants (NPP) in Indonesia to the public as the innovation of science communication, which in turn forms public understanding and acceptance?

With the constructivist paradigm and the qualitative approach, this study has some significances as the effective communication strategy for the government in educating the public related to nuclear issues, and the support of policy-making strategy by the government and actors in the issue of NPP development in Indonesia.

The Diffusion of Innovations Theory

In science communication, gaps and innovations reflect the dynamics of developments in conveying scientific information to the public. Therefore, this study utilizes the diffusion of innovation theory, developed by Everett Rogers. This theory is a conceptual framework that explains how, why, and how quickly innovations or new ideas are accepted and spread in society (Rogers et al., 2014).

Rogers's diffusion of innovations theory discusses the process of innovation diffusion from initial discovery to widespread acceptance, using several key concepts:

1. Innovation: Refers to ideas, practices, and objects perceived as new by a particular individual or group. Innovations can be technologies, products, services, or other ideas.
2. Communication: The process of conveying information about innovations. Communication plays a crucial role in shaping individual perceptions of innovations.
3. Communication Channels: The pathways used to convey information about innovations to individuals or groups. These channels can include mass media, interpersonal communication, or even live presentations.
4. Time: The theory of innovation diffusion identifies five categories for measuring diffusion time: innovators, early adopters, early majority, late majority, and lagging majority. Each group has a different level of openness to innovation.
5. Social System: Refers to the social group within which the innovation diffusion process occurs. Social systems can involve smaller groups, such as family or friends, to larger groups, such as communities or organizations.
6. Adoption Decision: The process by which an individual or group decides to accept or reject an innovation. This decision is influenced by various factors, including the characteristics of the innovation and the characteristics of the recipient.
7. Factors Influencing Diffusion: Rogers identified several factors that influence the speed and extent of diffusion, such as the perceived benefits to the recipient, the complexity of the innovation, compatibility with existing values, demonstrability, and limited trials that can be conducted before full adoption.

In this regard, this theory can provide important insights for researchers in understanding how an innovation can be successfully implemented and spread in society, where gaps and innovations in science communication reflect the dynamics of developments in conveying scientific information to the public.

Methodology

This study used a case study method studying a particular phenomenon in a real context—usually complex and multidimensional, particularly a single case with the classification of scientists as the main actors delivering messages within the Indonesian Nuclear Society Association (HIMNI), especially affiliated with the National Research and Innovation Agency (BRIN) as the home to government nuclear scientists—previously, the home for Indonesia nuclear research was the National Nuclear Energy Agency (BATAN). For collecting data, this study applied a triangulation encompassing interview, observation, and document analysis:

1. Interview with nuclear scientists from HIMNI inside and outside BRIN;
2. Participatory observation through the HIMNI webinar series as a form of communication activity;
3. Document analysis related to communication materials in practice carried out by HIMNI as well as BRIN and BATAN as the former entity of nuclear research before BRIN.

Findings and Conclusion

The results of this study can be described as follows:

1. Interview with Nuclear Scientists. The researcher interviewed two nuclear scientists:
    a. Dr. Geni Rina Sunaryo, the nuclear scientist of HIMNI affiliated with BRIN. She is one of female nuclear scientists from BRIN, formerly BATAN. She has

only written in certain media: Detik, Media Indonesia, Senayan Post, Nawacita Study Institute, Istana Rakyat Magazine.
   b. Mr. Harun Ardiansyah, the freelancer as well as the PhD degree holder from the University of Illinois at Urbana-Champaign, USA. He wrote in scientifically certain media like The Conversation.
2. Observation: the researcher participated HIMNI webinar series as a form of communication activity organed regularly by HIMNI at least once a week.
3. Document Analysis: the researcher analyzed some documents related to communication materials in practice:
   a. Carried out by HIMNI through its official website (https://himni.org/), specifically displayed on "Berita" menu of the website (https://himni.org/category/berita/).
   b. Carried out by the National Research and Innovation Agency (BRIN) as the home to government nuclear scientists as displayed on its website, specifically at the Nuclear Energy Research Organization (https://www.brin.go.id/page/profil-pejabat).
   c. Popular nuclear media in BATAN era before merging into BRIN namely NUTECH (http://www.batan.go.id/index.php/id/publikasi-pdk).

Based on the collected data, the researcher found that HIMNI is still limited in innovation and use of digital technology as one form of digital transformation in the current era. Nuclear scientists in this regard have not been used to writing in various popular as well as online media. NUTECH was the pride of BATAN as a media for communicating nuclear science to the public, yet it is no longer published in BRIN era. In addition, the official website of BRIN as the home of nuclear research is lacking in nuclear-related educative content. BRIN displays minimum of specific content related to public campaigns about nuclear or dissemination of nuclear information to the public.

HIMNI is actually expected to play a strategic role in bridging the gap between nuclear scientists and the general public. Through its educational, collaborative, and open approach, HIMNI aims to establish a strong foundation for enhancing public understanding and acceptance of nuclear power plants (NPP) in Indonesia. This effort follows a structured communication strategy that emphasizes education and public literacy as the core pathways toward building trust. By involving experts directly in outreach and leveraging social media platforms as effective communication tools, HIMNI is hopefully capable of strengthening engagement and transparency. Ultimately, these integrated efforts are designed to foster greater public confidence and acceptance of environmentally friendly nuclear technology in Indonesia.

As the definition of science communication in this study as the science of communicating scientific topics in a popular style from scientists to scientists and the public. Practically, this is done through journalistic media (blogs, social media, and television), exhibitions, and public policy mapping with science as a primary element. Therefore, researchers can explore gaps that represent novelty in their research. Gaps and innovations in science communication reflect the dynamic developments in conveying scientific information to the public.

The following are some of the gaps observed in the context science communication in this study:

1. Language gap (scientific-public): the technical and complex language used in scientific publications can be a barrier to public understanding.

2. Demographic gap: ranges from limited access since not all groups in society have equal access to scientific information to generational gap since different generations may have different communication preferences that require diverse approaches.
3. Ethics and integrity challenges: how to respond to scientific uncertainty and how to communicate risks without causing panic or misunderstanding.
4. Issues of the politicization of science: political polarization in which science can be a source of political conflict, and scientific communication can be affected by this polarization.

In this study, various innovations in science communication are needed to address the gaps, and are designed to ensure that scientific information is more effectively accessed, understood, and appreciated by the general public. Here are the recommended innovations:

1. Interactive technology: using interactive technology to present scientific information in a more engaging way.
2. Social media and podcasts: using social media and podcasts as channels to share scientific information and interact directly with audiences.
3. Better data visualization (dynamic infographics and animations): using more dynamic and interactive data visualizations to explain scientific concepts.
4. Use of narrative (scientific stories): using narrative and story elements to make scientific information more engaging and easier to digest.
5. Scientist participation on social media (scientist's presence on social media platforms): scientists who are active on social media can directly interact with the public and disseminate scientific information in a way that is easy to understand.
6. Community engagement programs: programs that directly involve the public in the research or data collection process.
7. Collaboration with artists (arts and sciences): collaboration between scientists and artists to combine elements of art in the presentation of scientific information.
8. Increasing scientific literacy (public education): initiatives to increase scientific literacy among the public to be better able to access, understand, and evaluate scientific information.
9. Use of AI in content personalization: utilizing AI to create content that can be personalized according to the needs and level of understanding of individuals.

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