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Review Article

The landscape of science communication and public engagement in UNESCO Global Geoparks

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ABSTRACT

UNESCO Global Geoparks are unique platforms for communicating science and geoscience, especially in the context of contemporary environmental challenges. These territories are outstanding models for promoting environmental stewardship and fostering community engagement. To address a research gap in understanding science communication within geoparks, this study explored the theoretical framework behind science communication, discussing key principles and strategies. The results revealed a diverse landscape with a wide spectrum of approaches, showing progress and opportunities, yet challenges persisted, including inconsistent frameworks and the prevalence of deficit model thinking. Trends indicated increasing adoption of participatory and community-focused initiatives, although these were unevenly implemented. The study concluded that while geoparks had made significant contributions to science communication and sustainability, their impact could be enhanced through more consistent and participatory strategies that actively involved communities, strengthening their role as global models for environmental stewardship and public engagement.

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1. Introduction

As UNESCO-designated sites, UNESCO Global Geoparks (UGGps) are dedicated to protecting geoheritage while promoting local development (UNESCO, 2015; Zouros, 2004). They protect valuable heritage while engaging the public to appreciate their significance, raising awareness of geodiversity's role and its connection to human well-being and natural systems, serving as platforms for science and environmental communication (Brilha, 2018; Eder & Patzak, 2004). Effective communication strategies are essential for bringing geoscience, geodiversity and geoparks to the forefront of public and media attention, fostering discussions on Earth's processes, geoconservation, and environmental challenges, while calling for societal action for Earth's sustainability (Rodrigues et al., 2023a).

UGGps are currently at the forefront of geoscience communication, but the formalization of science communication as a practice and research field remains underdeveloped in these contexts, leading to ambiguity and a lack of clarity regarding the definition and scope of science communication within geoparks. While there is a growing commitment to communicating science,

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perspectives and approaches adopted do not always align with the latest trends or those considered most effective by research (e.g., Bucchi & Trench, 2021; Davies, 2021).

The diversity of terminology, perspectives, and practices in geoparks underscores the need for further study to refine communication strategies and align them with best practices, prompting the question: What does science communication mean in the context of geoparks? To address this question, this conceptual research article aims to contextualize what science communication is and how it is practiced in UGGps. Specifically, it seeks to: (i) examine the role and significance of science communication in geoparks, (ii) identify the terminology commonly used in this context, and (iii) analyze how the communication strategies and perspectives adopted by geoparks align with established theoretical models of science communication.

To explore this, a comprehensive review of existing literature on geoparks was conducted to identify science communication practices, combined with an in-depth analysis of official documents and grey literature to identify frameworks, concepts, as well as communication strategies and engagement initiatives, as further described. The results were critically analyzed and interpreted within the established body of science communication research, namely in terms of science communication models and paradigms, as further elaborated.

Over time, science communication has moved from deficit models focused on addressing public misconceptions, to dialogue models that prioritize two-way communication and public engagement, and more recently, to participatory models that emphasize collaboration and co-creation of knowledge, empowering society (Bauer, Allum, & Miller, 2007; Bucchi & Trench, 2021; Davies, 2021). This theoretical article seeks to fill a research gap and enhance the formalization and laying the groundwork of science communication in the context of geoparks, providing a foundation for further studies in this area.

1.1. Framing science communication: from definitions to purposes

Science communication is a multifaceted field, both of research and practice, that spans diverse definitions, forming an umbrella term that includes its broad spectrum of meanings and applications. Burns, O'Connor, and Stocklmayer (2003) summarized "science communication" as the use of appropriate skills, media, activities, and dialogue to evoke personal responses to science, including awareness, enjoyment, and other emotions. It also aims to generate interest through voluntary engagement, shape opinions about science-related attitudes, and enhance understanding of content, processes, and social factors. Modern perspectives emphasize public engagement, recognizing the importance of bidirectional dialogue and participatory processes (Bucchi & Trench, 2016, 2021), and align with the need to empower society to actively engage in decision-making about the governance of science and the preservation of shared heritage (Davies, 2021).

"Science communication" is a generic and non-universal term, frequently employed as a wide-ranging concept, encompassing several related terms, such as science dissemination, popularization, or outreach, frequently used interchangeably. However, these terms are not synonymous. Although they share common goals and have indistinct boundaries with some areas of overlap, each term reflects unique contexts and approaches. These have evolved over time in tandem with the development of communication models and paradigms (Bauer et al., 2007; Bucchi & Trench, 2016; Burns et al., 2003; Trench, 2008). Terminology varies not only across countries but also within countries. Beyond definitions, there is a broad spectrum of practices under the scope of science communication, which also differ based on specific national or cultural contexts (Davies et al., 2021; Gascoigne et al., 2020).

As a field of study, science communication has experienced exponential growth over the past two decades. Moreover, it has garnered substantial investment, exemplified by significant funding commitments such as those from the European Union. The traditional concept of science communication emerged from scientists' recognition of noticeable gaps in public knowledge, prompting the need to address and bridge these informational disparities, with the overall aim of promoting "scientific literacy." For this reason, reducing the deficit of knowledge was the main priority for a very long time (Bauer et al., 2007; Miller, 1983).

Research has revealed that increased scientific knowledge does not always lead to greater engagement or confidence in science (e.g., Francisco & Gonçalves-Sá, 2019); consequently, strategies promoting dialogue and active participation between society and scientists have been pursued (Katz-Kimchi, Martin, Weber, & Taylor, 2011; Simis, Madden, Cacciatore, & Yeo, 2016).

Public engagement with science fosters a stronger connection between society and science, focusing on how the public raises concerns, asks questions, and participates in decision-making (Bauer et al., 2007; Bucchi & Trench, 2016; Trench, 2008; Bucchi & Trench, 2021). It is also an overarching concept, encompassing non-linear communication approaches, though less commonly applied within geoparks.

1.2. Science communication in UNESCO Global Geoparks

1.2.1. The emergence and scope of the UNESCO Global Geoparks

The geopark concept found its roots in Europe in the late 1980s and in the Declaration of the Rights of the Memory of the Earth (Digne Declaration, 1991), which marked a pivotal moment for the recognition of geological heritage (Brilha, 2014, 2018). The movement took shape in the 1990s, with efforts from Gerolstein Geopark (Frey, 2012), Chinese geoparks (Chen, Lu, & Ng, 2015), and UNESCO (Patzak & Eder, 1998; UNESCO, 1999). This led to the establishment of the European Geoparks Network (EGN) in 2000 with four pioneer territories (Zouros, 2004) and the Global Geoparks Network (GGN) in 2004, progressively expanding to 213 UNESCO Global Geoparks across 48 countries by 2024 (Du & Girault, 2018; Jones, 2008).

In 2015, UNESCO established the "UNESCO Global Geoparks" label under the International Geoscience and Geoparks Program (IGGP), endorsing governmental recognition for geoconservation. UGGps became "UNESCO Designated Sites," alongside World Heritage Sites and Biosphere Reserves, collectively celebrating and conserving the world's cultural, biological, and geological

diversity and promoting sustainable economic development. UNESCO, as the only United Nations (UN) agency for geoscience research under IGGP, fosters scientific cooperation on sustainable resources use, risk reduction, and geoheritage (Adiyaman et al., 2018).

UGGps are defined as "single, unified geographical areas where sites and landscapes of international geological significance are managed with a holistic concept of protection, education and sustainable development" (UNESCO, 2015).

Geoparks are multifaceted initiatives combining the safeguarding and promotion of geoheritage with local sustainable development (Eder & Patzak, 2004; Henriques & Brilha, 2017; McKeever & Zouros, 2005; Zouros, 2004). They are a mechanism for international cooperation, using bottom-up approaches to conserve geoheritage, with sustainable development dependent on local community participation and empowerment (UNESCO, 2015).

Geological heritage conservation is central to geoparks, serving as the foundation of their existence and a tool to foster sustainable development (Brilha, 2018). Since geoparks are not protected areas or formal designations, safeguarding geoheritage depends on local, regional, or national frameworks, requiring active engagement and participation of communities and stakeholders in management processes. By recognizing the importance of geoheritage in geoparks, visitors can develop bonds with Earth's history, fostering responsible environmental attitudes and supporting geoconservation (Gou et al., 2024).

While geoheritage is central, geoparks go beyond geology by integrating natural, cultural, and intangible aspects, raising awareness and encouraging engagement with global challenges and strengthening the bond between local communities and their land (UNESCO, 2015).

1.2.2. Science communication in geoparks: From branding to environmental awareness, and public engagement

Achieving UGGps status requires four key features: geoheritage of international value, effective management, visibility, and networking (UNESCO, 2015). Communication, in its broadest sense, is a crucial element interconnected into the multifaceted missions and activities of these territories, encompassing dimensions such as institutional communication, marketing, community engagement, public relations, environmental advocacy or science communication.

1.2.2.1. Visibility. Science communication is key to shaping geopark's branding and marketing, enhancing its identity by establishing the geopark as a credible and authoritative source for scientific research, engaging visitors and building a connection that boosts the geopark brand.

Visibility is a key aspect of the geopark strategy, rooted in its corporate identity, ensuring recognition and enhancing engagement with local communities and visitors. To be effective, the geopark brand must reflect a sense of place, aligning with a territorial marketing strategy that highlights geoheritage as the defining element in place branding (O'Loughlin & Lemon, 2006; Van Geert, 2019).

Several approaches emphasized branding's role in shaping the geopark's vision and boosting public visibility, particularly from a tourism perspective (Lee & Jayakumar, 2021; Mohd Yusof, Ismail, & Ahmad, 2019; Nantakat & Vorachart, 2021; Van Geert, 2019; Mawaddah, Prasetyo, & Hussein, 2024). Additionally, research on name branding for geotourism destinations highlights its contribution to conveying the sense of place and territory (Pamungkas, Sujatna, Darsono, & Haron, 2020; Sujatna, Pamungkas, & Sugianto, 2022).

The limited awareness of the geopark concept increases the responsibility of geoparks to promote their brand while broadening recognition of geoparks globally (Mohd Yusof et al., 2019). Studies highlight the economic benefits of UNESCO labeled territories, including geoparks (Portuguese National Commission for UNESCO, 2020; UK National Commission for UNESCO, 2020; Lee & Jayakumar, 2021). The UK report (2020) notes that geoparks significantly support green, inclusive economies and act as heritage guardians, knowledge hubs, and innovation drivers, fostering connections between people, culture, and nature to enhance community well-being.

The geopark brand also benefits from the UNESCO label, bringing global recognition, credibility, and visibility from the UNESCO label, highlighting its geoheritage's international significance. From a corporate communication perspective, it's important to highlight UNESCO's global role as the UN agency responsible for the IGGP. However, UGGps are the most recent UNESCO sites, established in 2015. This contrasts with World Heritage Sites and Biosphere Reserves, which were created in the 1970s, and their global recognition is still growing. A more coordinated effort involving geoparks, member states, GGN, and UNESCO could enhance worldwide visibility and promote sustainable development.

GGN, aligned with UNESCO, connects geoparks globally, promoting networking and collaboration to enhance global quality standards (Zouros, 2016). It is organized into regional networks and thematic groups, including a communication committee that coordinates both internal communication to facilitate streamlined collaboration and external communication with a focus on promoting the concept, its scope and the territories. Key channels include websites, social media (Facebook, YouTube), newsfeeds, newsletters, videos, maps, brochures, publications and magazines. A tourism working group also promotes the geopark concept and brand. On a regional level, since 2000, the EGN magazine has been published annually as a key communication tool, providing updates and insights on a wide range of topics and initiatives within the geoparks and the network (European Geoparks Network, 2024).

Efforts to increase visibility within geoparks and globally are significant, but uncertainty remains about their effectiveness. Recent research shows a preference for traditional printed materials over digital tools and a reliance on classic social media platforms (Facebook, Instagram, YouTube), with limited focus on broader-reaching networks across different demographics (Molokáč, Kornecká, Pavolová, Bakalár, & Jesenský, 2023). More strategic and targeted approaches could broaden the scope, extend the reach, and amplify the impact of communication.

Table 1
Number of non-indexed data sources.

Type of source		Number
Abstract books	International conferences on UGGps	8
	Regional conferences on UGGps	13
Books and special volumes		9
Thesis		10
Newsletters	GGN	28
	EGN	22
EGN magazine		20

1.2.2.2. The significance of science and geoscience communication within Geoparks. Science communication aligns with the core mission of geoparks, which serve as research hubs for geosciences and platforms for educating the public on geological landscapes and environmental issues (Patzak & Eder, 1998). They bridge academia and the public through formal educational programs (e.g., Catana & Brilha, 2020; Fernández Álvarez, 2020), and recreational settings, such as geotourism (Dowling & Newsome, 2006; Hose, 1998). Geoparks offer unique opportunities to communicate earth sciences and geoheritage to non-specialists, fostering deeper engagement with these topics (McKeever, 2010).

It is worthwhile to bear in mind that "within the UN family, UNESCO maintains and operates the largest site designation schemes, and these sites help to advance human understanding of the values of diversity and heritage, and bring profound changes in human attitudes, behaviors and the social transformations required for achieving the Sustainable Development Goals (SDGs)" (UNESCO, 2018, p.126). In line with the 2030 Agenda, geoparks are committed to the SDGs (McKeever, 2018; UNESCO, 2016b), focusing on areas such as science and research, sustainable development, geological hazard risk reduction, natural resource management, climate change awareness, education for sustainability, geoconservation, and promoting local and indigenous knowledge, cultural heritage, gender equality, and women's empowerment (UNESCO, 2016a).

As a collaborative network, GGN promotes joint celebrations of UN International Days, including International Geodiversity Day, Disaster Risk Reduction Day, Earth Day, World Environment Day, World Soil Day, World Water Day, International Mountain Day, and World Clean Up Day. These coordinated initiatives raise awareness, encourage engagement, and emphasize the importance of these events in advancing global understanding of scientific and environmental issues. They also involve activities with schools, local communities, families, and stakeholders. GGN also publishes materials on topics like geodiversity, which highlight geoparks' role as distinctive heritage territories, as well as on oceans, addressing how geoparks contribute to tackling ocean challenges (Global Geoparks Network, 2024).

The European Geoparks Week, organized by EGN, is an annual public engagement event held in geoparks across Europe to celebrate geoheritage, natural beauty, and cultural significance through activities like tours, exhibitions, and workshops. In 2019, 73 geoparks hosted about 1,100 events, attracting nearly 430,000 people (Korbély & Ramsay, 2020).

Despite limited understanding of geoscience's significance (Rogers et al., 2024), it plays a vital role in global development frameworks like the SDGs, Sendai Framework and Paris Agreement on Climate Change (Gill & Bullough, 2017). UGGps build on geoheritage, integrating it with natural and cultural heritage to drive awareness, understanding, and action on key issues such as sustainable resource use, climate change mitigation, and natural hazard risk reduction. They are dynamic platforms for promoting education and dialogue, highlighting the link between geological, environmental, and cultural factors for sustainable development in alignment with the SDGs. Geoparks also foster local pride and connection to the area's international value as a universal and shared legacy.

Committed to their mission, UGGps look for the best ways to communicate geoheritage by developing frameworks and guidelines (Drifting Apart, 2018; Modrej, Fajmut Štrucl, & Hartmann, 2018). The COVID-19 pandemic also encouraged the innovation and adoption of digital tools (Fassoulas, Nikolakakis, & Staridas, 2022; Frey, Schmitz, & Weber, 2021).

In conclusion, geoparks not only communicate science but also serve as vital platforms for engaging society in geosciences, addressing environmental challenges and promoting sustainable development.

2. Methodology

To analyze the terminology science communication and map existing practices, we conducted a broad literature review. Using an open, non-systematic review approach allowed for greater flexibility and adaptation to the research context, which facilitated the gathering of rich and varied data. The focus of the review was on extracting and synthesizing insights and perspectives from the literature, illustrating with significant examples, rather than quantifying information. Thus, bibliometric method was not chosen, as the categories studied overlapped and were not mutually exclusive, obstructing the clear distinctions required by this methodology. Due to the recent recognition of geoparks and the lack of formalization and framing on this specific topic, scientific literature on science communication and public engagement in geoparks is very limited in specialized journals because research and scientific publications in this area are still emerging. Furthermore, existing studies predominantly rely on case studies, which often do not comprehensively explore fundamental research or theoretical approaches in science communication.

On the other hand, beyond the theoretical aspects, this study focused on mapping real practices, which were more extensively documented in non-academic publications or non-published research. Therefore, the current research included not only papers

Table 2
Science communication terminology within the scope of geoparks.

Terms	Definition	Examples within geopark context
Science literacy	It represents what the general public should know about science (Burns et al., 2003; Miller, 1983)	Buhay & Best, 2015; Justice, 2023
Dissemination	It is the process by which information from science is moved into the public or practice domains (Kerner & Hall, 2009)	Li, Tian, Li, Shi, & Zhou, 2015; Fernandes, Castro, Tracana, & Fernandes, 2023
Science divulgation	It is a term borrowed from the Latin languages and is used in a broad sense to refer to a wide range of strategies for bridging the gap between science and non-specialist audiences (do Livramento Chaves & Alvarez, 2023; Schiele, Gascoigne, & Schiele, 2021)	Amato et al., 2013; Santagati et al., 2019, Santangelo, Amato, Ascione, Russo Ermolli, & Valente, 2020; Van Geert, 2022
Science popularization	It refers to strategies that simplify technical information and make science accessible (Bucchi & Trench, 2016; Hilgartner, 1990)	Yang, Chen, Wu, Tian, & Li, 2013; Li, Tian, Li, Shi and Zhou, 2015; Moliner & Mampel, 2019; Frey et al., 2021
Knowledge transfer	It is the process by which knowledge is transmitted to a user and absorbed by a user (Garavelli, Gorgoglione, & Scozzi, 2002)	Farsani, Coelho, Costa, & Amrikazemi, 2014; Frey, 2021
Knowledge diffusion	It is a term most often used to refer to the dissemination of information about innovations (Backer, 1991)	Moliner and Mampel, 2019; Santangelo et al., 2020
Outreach	It means the unidirectional discourse where scientists communicate their research to the broader public, with a specific emphasis on school children and young individuals (Illingworth, Redfern, Millington, & Gray, 2015)	McKeever and Zouros, 2005; Zouros, 2016; Frey, 2016; Bollati, Rossi, & Viani, 2023
Public education	It is the process of giving the public information or training about a particular subject (Oxford Advanced Learner's Dictionary 2024)	Zouros, 2004, Eder & Patzak, 2004, Azman, Halim, Liu, Saidin, & Komoo, 2010, Martini et al., 2022
Informal education	It is the lifelong learning that occurs naturally in everyday life, where learning can happen without intentional effort (Commission of the European Communities, 2000)	Buhay & Best, 2015; Stolz & Megerle, 2022
Popular science education	It refers to the activities to promote science to the general public (Chen, Ng, Zhang, & Tian, 2020)	Xu & Lei, 2010
Public awareness/ raising awareness	It involves processes aimed at fostering enlightenment, demonstrating the relevance, and cultivating positive attitudes towards science (Burns et al., 2003)	Eder & Patzak, 2004; Zouros et al., 2011; Santangelo et al., 2020; Lee & Jayakumar, 2021
Interpretation	It is an activity that seeks to reveal meanings and relationships by the use of original objects, by firsthand experience, and by illustrative media, rather than solely transmitting factual information (Tilden, 1957)	Xu & Lei, 2010; Modrej et al., 2018; Ciobanu, 2016
Consultation	It is a dialogue set up on a relatively restricted agenda, for a specific purpose (Trench, 2008)	Halim & Ishak, 2017, Pásková, 2018
Participation	It is a stronger form of engagement by the public both with scientific ideas and with the governance of science, under participatory democracy and participatory communication (Bucchi & Trench, 2016)	Azman et al., 2010; Geraldine, Hashim, & Aziz, 2011; Halim, Liu, Yussof, & Sian, 2011; Septiana, Samodra, & Lamatenggo, 2023
Deliberation	It is a democratic pathway to consensus-building, where the public's contributions help set the agenda for science (Hagendijk & Irwin, 2006; Trench, 2008)	Geraldine et al., 2011; Halim et al., 2011
Empowerment	It refers to the ongoing ability of individuals or groups to take action independently to attain a higher degree of control over their lives and futures (Staples, 1990)	Geraldine et al., 2011; UNESCO, 2015

published in indexed journals but also a broader range of sources such as official documents (e.g., the UNESCO Operational Guidelines for UGGps), conference proceedings, theses, books and special volumes, magazines, and newsletters (detailed in Table 1). These sources, in which geoparks share their best practices and experiences, provide a wealth of valuable insights and information.

The review began with the Web of Science and Google Scholar databases. Google Scholar enabled a more extensive exploration of geoparks research that may not be fully represented in traditional indexed databases. Given the multidisciplinary and practical aspects often present in geoparks studies, utilizing both Web of Science and Google Scholar ensured a thorough examination of relevant literature. Strategically combined keywords spanning the full range of the 16 terms under examination were employed to ensure comprehensive coverage of the subject matter (see Table 2). A total of 33 examples were selected to illustrate the analysis, as referenced in the table.

This qualitative approach enabled a deeper understanding of the diverse panorama of the science communication scope in geoparks. Additionally, to better understand the role of science communication in geoparks, as outlined in UNESCO's official guidelines (UNESCO, 2015), a detailed analysis was conducted on the official UNESCO self-evaluation documents (UNESCO, 2024), focusing on how the specific indicators relate to science communication.

3. Results: Science communication scope and practices in geoparks

3.1. Science communication terminology

As in other contexts, within geoparks, science communication is a polysemic term, frequently referred to in various ways, reflecting the developing and multifaceted nature of the field (Bucchi & Trench, 2016; Gascoigne et al., 2020; Schiele et al., 2021).

Table 3
Analytical framework of science communication models (redrawn and simplified from Trench, 2008; Bucchi & Trench, 2016; Stewart, 2024): Perspectives and applications within geoparks.

Prevalent communication models	Deficit/Dissemination model	Dialogue model	Participation model
Main goals	Transmission of scientific knowledge to improve perceived public lack of knowledge	Communication through dialogue involving scientists in public discussions	Collaborative participation, acknowledging that each agent plays a crucial role contributing to the outcomes of discussions and deliberations
Experts' perspectives on the public	They are hostile They are ignorant They can be persuaded	We see their diverse needs We find out their views They talk back They take on the issue	They and we shape the issue They and we set the agenda They and we negotiate meanings
Public uses	Information: awareness, learning	Questioning: opinion, discussion	Sharing: creating, enjoyment, critique
Communication flow	One-way	Two-way	Three-way
Social perspectives	Science literacy	Science in society	Society in science
Orientation			
Science communication applications	Deficit Defense Promotion Popularization Outreach Engagement Consultation Interactive Deliberation Co-creation Empowerment		
Approach	Top down	Dialogue based	Bottom up
Terms used within Geoparks	Science literacy, dissemination, science divulgation, science popularization, knowledge transfer, knowledge diffusion, outreach, informal education, public education, popular science education, public awareness /raising awareness	Outreach, public awareness/raising awareness, consultation, interpretation	Participation, deliberation, empowerment
Applications within Geoparks	Websites, apps, newsletters, social media, films and videos, maps, brochures, panels, guides and books, awareness-raising campaigns, press releases, news articles, public presentations/lectures, comic books, social media, guided tours, exhibitions, museums, interpretation centers	Public hearings, stakeholder consultation workshops/sessions, focus group discussions, capacity-building workshops, public conversations/dialogues, science café formats, surveys, questionnaires, games, social media, guided tours, interpretation centers, photo contests	Citizen science projects, art projects, volunteer and ambassador programs, working groups

The usage of the strict term "science communication" (e.g., Patrocínio et al., 2018; Justice, 2023) is limited in these scopes as in its related concepts "earth science communication" (e.g., Justice, 2018, 2023), "geoscience communication" (e.g., Quinzacara-Vicencio, 2023) or geocommunication (e.g., Carrión-Mero et al., 2024).

Table 2 compiles an overview of science communication terminology within the scope of geoparks, offering literature examples, selected balancing relevance, diversity, and representativeness, while also considering their illustrative value. It also includes formal definitions, but since authors commonly do not define the terms they use, their usage may not consistently align. For the same reason, this literature review does not provide information on the correlation between the chronological progress of theoretical frameworks or the evolution of paradigms in scientific communication. Also, some studies are found in more than one category because these categories are not mutually exclusive.

Generally, it is possible to observe an almost arbitrary use of terms, often employed interchangeably as synonyms. Certain terms are context-specific, reflecting social, cultural, and political influences, and their usage is also related to national trends. This conclusion is not unique to the geopark's context, but it reflects little connection between the geoparks' practices and scientific research in this field.

It's noteworthy that certain terms are commonly used alongside derivatives like "geoeducation", "geoliteracy," "geoknowledge," and "geointerpretation," suggesting a growing trend of incorporating 'geo' prefixes within geopark contexts.

Subsequently, we will examine and discuss the use of this terminology in the context of science communication models.

3.2. Science communication models: From dissemination to participation

To understand the range of science communication paradigms in UGGps, we analyzed geoparks' practices within dissemination, dialogue, and participation models.

For systematizing science communication practices in geoparks, a thorough analysis was conducted using a variety of sources, such as UGGps and EGN conferences' proceedings, EGN magazines, and GGN and EGN newsletters. From these sources, a wide range of approaches and initiatives were carefully extracted, analyzed, and systematically categorized, resulting in the practices included in Table 2, as examples for each model.

The analytical framework in Table 3 compiles the prevalent communication models according to the literature (Bucchi & Trench, 2016; Trench, 2008), framing geoparks' strategies and terminology. The intersection of these two perspectives revealed a diverse landscape of science communication, as further discussed.

3.2.1. Dissemination

In general, the dominant terminology, together with the identified practices, suggests that science communication in geoparks primarily focuses on the dissemination of knowledge. These deficit model approaches assume that the public's scientific knowledge gap acts as a barrier, where communication is a unidirectional process centered on knowledge transference, transmission, diffusion, translation, and dissemination to educate the audience and increase their scientific literacy.

In the context of UGGps, it is widely recognized that addressing the public's deficiency in scientific knowledge and environmental awareness is crucial to engage them in tackling environmental issues (Eder & Patzak, 2004; Escorihuela, 2017; Frey, 2021; Lima, Machado, & Nunes, 2013). Fauzi and Misni (2016) suggested that geoconservation effectiveness could be measured by assessing the awareness of the local community and tourists, which depends on their motivation and level of knowledge.

Terms like "public education" and "popular science education" suggest geoparks' focus on knowledge transfer. Bibliometric analyses on geoparks research indicate the widespread use of "education" as a comprehensive mainstream term, including education in formal contexts, as well as in science communication and public engagement contexts (Herrera-Franco, Montalvan-Burbano, Carrion-Mero, Jaya-Montalvo, & Gurumendi-Noriega, 2021; Martínez-Martín, Mariñoso, Rosado-González, & Sá, 2023).

Moreover, the public demonstrates a keen interest in acquiring information, as evidenced by their knowledge-driven motivations studied in the geotourism context (Amaro, Chaves, Henriques, & Barroco, 2023). Further research shows that people are willing to pay more for high-quality guided tours with professional geological interpretation (Cheung, 2016). A comparative study on visitors' geoscience literacy in geoparks shows that, although they function as learning spaces, established and newly established geoparks exhibit similar levels of visitor knowledge and awareness (Buhay & Best, 2015).

Deficit model thinking tends to be a "default mode" in science communication, reflecting traditional top-down approaches (Stewart, 2024). Concerns regarding an under or misinformed public in participatory decision-making, where access to the best scientific information is crucial, are understandable; however, research indicates that merely correcting individuals' "knowledge deficits" may not be sufficient (Scheufele, Krause, Freiling, & Brossard, 2021).

Gonzalez-Tejada, Du, Read, and Girault (2017) defended that the prevalence of deficit models and the emphasis on fostering "geological literacy" within geoparks may be interpreted as the result of the prevalence of trained geologists in management teams, who bring their scientific experience. On the one hand, it is recognized that geology degree academic programs poorly prepare scientists for science communication (Rodrigues et al., 2023a). On the other hand, it is also acknowledged that personal and contextual factors influence geoscientists' perceptions and practices of science communication and public engagement, thereby conditioning the strategies implemented (Rodrigues et al., 2023a).

Geoparks often use modern, appealing digital techniques, sometimes with interactive tools, yet their main goal remains one-way knowledge transmission. While information-centered approaches are increasingly being replaced by more engaging models, linear strategies persist and are frequently an important part of participatory strategies.

3.2.2. Dialogue

Dialogical approaches advocate bidirectional communication flows, giving audiences an active role. Rather than simply transmitting information, a dialogue is established to promote exchanges that consider non-experts' concerns, beliefs, and expectations. Workshop consultations with local communities, interpersonal dialogues or capacity-building workshops are examples of dialogical approaches in geoparks, engaging the public in nature conservation and geotourism development (Geraldine et al., 2011; Halim et al., 2011; Pásková, 2018; Sanchez-Cortez, Jaque-Bonilla, Simbaña-Tasiguano, Astudillo-Bravo, & Cabascango-Chiliquinga, 2022; Septiana et al., 2023).

Strategies, which are anchored in the public's visions and perspectives, such as interpretation and awareness, and widely used in geoparks, stimulate people into action. By definition, interpretation is not instruction. Rather, it is a two-way strategy, provocative strategy designed to resonate personally with each audience, ostering relationships and significance (Tilden, 1957).

One of the early definitions of geotourism emphasizes providing interpretive and service facilities, going beyond mere appreciation (Hose, 1998). In line with this, geoparks prioritize the development of interpretation facilities, resources, and tools. In certain cases, strategic interpretation systems are implemented (Chen et al., 2020; Xu & Lei, 2010). Yet, several geotourism definitions have established a restrictive connection between tourism and a type of onsite informal education (Gonzalez-Tejada et al., 2017). This approach assumes geotourism as a mere form of educational tourism to instruct audiences outside the formal educational context.

Meanwhile, digital technologies have brought new forms and possibilities of interaction and dialogue, particularly regarding social media. A recent quantitative assessment of UGGps websites has highlighted opportunities for improvement regarding interaction. It could allow for more public engagement through online forms, citizen science tools, interactive maps, and even AR and VR interpretation immersive experiences such as virtual tours (Carrión-Mero et al., 2024).

In recent years, bidirectional and critical approaches have become prominent, with dialogical strategies shifting the focus from facts to concerns, fostering active public engagement and participation (Davies et al., 2021; Stewart & Lewis, 2017).

So far geoparks acknowledge the importance of fostering dialogues that extend beyond the mere dissemination of factual information; however, these strategies seem still to be reduced, with a strong attachment to conventional educational approaches.

3.2.3. Participation

While in dialogic approaches, non-experts' opinions are heard; in participatory strategies, their different perspectives are acknowledged, and non-experts are part of the decision-making and co-creation processes. Lately public participation has gained prominence with non-experts contributing to agenda setting, decision-making, and policy formation (Bucchi & Neresini, 2008; Bucchi & Trench, 2016).

Approaches like citizen science, consensus conferences, or citizen panels have been instrumental, promoting action to extend the reach of solutions for environmental and social challenges.

Geoparks face critical challenges such as water scarcity, geohazards, mining activities, climate change impacts, geological resources exploitation, illegal sale of geoheritage, among others, which require active participation and collaboration between empowered local communities, academy, stakeholders and authorities.

In this context, public participation has demonstrated considerable advantages in management, geoconservation efforts, the coordination of mass visitation, or economic development (Azman et al., 2010; Geraldine et al., 2011; Halim & Ishak, 2017; Lee & Jayakumar, 2021; Vafadari & Cooper, 2020). Furthermore, the empowerment of local communities and their engagement with the sustainable development of geoparks, namely through geotourism services, may generate significant economic and social benefits (Sagala, Rosyidie, Sasongko, & Syahbid, 2018; Vafadari & Cooper, 2020).

Indigenous communities and indigenous knowledge have a relevant role in heritage conservation (Farsani et al., 2014; Halim et al., 2011; Pásková, 2018). It is crucial to respect and include the spirituality and cosmology beliefs and knowledge of indigenous communities into scientific methods for managing land and natural resources (Pásková, 2018). This fosters a collective understanding, promoting a balanced and more effective approach to environmental stewardship.

Azman et al. (2010) showed that community's engagement in geopark decision-making—when their real interests and needs are considered—leads to better attitudes towards geoconservation and helps to overcome the limitations that conservation strategies may impose. Benefits of negotiation and participation in geoparks planning have also been highlighted by Geraldine et al. (2011).

By definition, UGGps are established through a bottom-up process, calling local communities to action. Their internal network structures actively foster and encourage meaningful community participation. (Geraldine et al., 2011). With this purpose, geoparks implement public education programs, awareness initiatives, capacity-building workshops (Azman et al., 2010), working groups or action planning workshops (Septiana et al., 2023). Additionally, there are participatory collaborative management strategies (Septiana et al., 2023) and geopark (promotion) councils, incorporating different perspectives (Vafadari & Cooper, 2020).

Volunteer initiatives can foster deeper connections to the geopark and empower the community by encouraging active engagement, as successfully demonstrated by the Haţeg Geopark's award-winning 'Volunteers for the Geopark' program (Ciobanu, 2016; Ciobanu & Andrăşanu, 2020). In this example, volunteers play an active role in both developing interpretation facilities, games, and leading guided visits.

Despite these efforts on deliberation, participation, and empowerment, literature exposes a research gap concerning the role of communities in geoparks, alongside a tendency to undervalue their importance in territorial management (Stoffelen, 2019). The theme of "participation" conventionally encompasses a tension between declarations of intent and observable practices, emphasizing the anticipated paradox inherent in environmental mediation (Babou, 2019).

Many studies refer to public participation in geoparks as involvement in educational activities or awareness initiatives where the active roles of the public are not always perceptible. Further studies analyzing strategies are needed to assess the impact and effectiveness of these activities adequately.

3.3. Criteria and guidelines for science communication in geoparks implementation

The designation process for UGGps follows a rigorous application procedure with multiple phases, with strict protocols and criteria that evaluate various dimensions of the territory. This designation is not permanent; following formal nomination, it must be revalidated every four years to assess operational effectiveness and overall quality.

Both the first evaluation and following revalidation processes include the formal assessment of the performance of geoparks (or aspiring geoparks, aUGGps) through 252 indicators related to the 7 main criteria: (i) scope and mission, (ii) interconnection between different heritages, (iii) management structure, (iv) overlapping designations, (v) local and indigenous communities' participation, (vi) networking between geoparks, and (vii) the protection of geoheritage.

To understand the role of science communication in the designation process, we have performed a detailed analysis of the official UNESCO Self-Evaluation Form A (UNESCO, 2024), which serves as a self-assessment tool with the 252 specific indicators.

This analysis reveals that communication and public engagement are addressed across all main criteria in 121 (almost half). These indicators cover diverse dimensions to achieve multiple geopark's objectives, intersecting with all facets of geopark communication and engaging multiple audiences with topics like geodiversity, geoheritage (including other heritages), geohazards, climate change, and natural resources (see Supplementary Material). Beyond specific sub-criteria such as visibility (iF.1), infrastructure and facilities (iF.2), and communication tools (iF.3), many indicators are related to communication in a broad sense. Numerous parameters encompass specialized staff, strategic planning, branding, marketing, and tourism promotion, alongside aspects such as public information, visitor engagement tools, activities, and non-formal education. Furthermore, the criteria include community and stakeholder engagement, knowledge exchange, and broad environmental education efforts. Beyond these 121 indicators, 11 other indicators refer to internal communication, such as trainings, capacity building and exchanges; these incorporate science communication to some extent but are not aimed at broad audiences (see Supplementary Material).

4. Discussion and conclusions

Geoparks are taking the lead worldwide in advocating for geodiversity, protecting geological heritage and enhancing geoscience communication. Their prominent position regarding nature conservation, science communication, and sustainable development, together with their bottom-up approach, makes geoparks role models for fostering environmental stewardship and community engagement.

Our analysis reveals a diverse landscape of science communication, showcasing a spectrum of approaches and methods to engage with diverse audiences. In response to the initial question about the meaning of science communication within geoparks, we can summarize that it involves sharing scientific knowledge and insights with lay audiences, promoting environmental stewardship and engaging communities. Many different strategies are used to empower society to participate in decision-making processes and contribute to the protection of our planet's natural resources.

The intersection of the analysis of the terminology and practices within geoparks results in an analytical framework that reveals a diverse landscape of science communication, showcasing a wide spectrum of approaches, even if the theoretical positioning behind it is not always clear or consistent. At the same time, the prevalence of one-way approaches, primarily focused on translating and disseminating knowledge, is observed despite aiming to mobilize the public for action.

Acknowledging the geoparks' central concerns and endeavors to optimize opportunities and enhance impact, a strategic communication approach is vital, involving precise planning to achieve specific and targeted goals.

4.1. Science (and geoscience) communication as a core mission of geoparks

Considering the current 213 UGGps,[1] every year, millions of residents and visitors from all over the world engage with science, thanks to innovative experiences. Geoparks have demonstrated significant efforts and investments, blending science, education, and entertainment through a myriad of strategies, bringing science from academia to the public over the past 24 years.

These territories have been at the forefront of global geoscience communication, carrying added responsibility in addressing sensitive environmental challenges, promoting sustainability, and empowering societal participation in decision-making. It is worth recalling the role of geoscience communication as a tool for sustainability, engaging society with geodiversity and geoconservation (Rodrigues et al., 2023a).

[1] Data source: https://www.unesco.org/en/iggp/geoparks/about. This is the total number of UGGps in 2024.

In a time of crisis for traditional journalism and media, marked by declining trust, social media dominance, polarization, and the extensive dissemination of misinformation, geoparks have a special responsibility to contribute to addressing environmental challenges and mobilizing collective action to protect the planet for future generations.

4.2. Conceptual framework

From a conceptual point of view, a notable inconsistency has been observed in the adopted terminology, characterized by a lack of formal and rigorous frameworks. The diversity of terms may be seen as simply a matter of semantics, but in fact, it reflects a low understanding of science communication perspectives. This inconsistency underscores a significant disparity between science communication research and the practical implementation within geoparks.

International geopark conferences, key for exchanging practices and advancing scientific knowledge, bring together researchers, professionals, and stakeholders. Science communication is regularly discussed in sessions like "education and interpretation," "geo-education and science popularization," or "education, public awareness and communication." Although there is a clear concern about addressing the subject, this structure reinforces the disparity in terminology and inconsistent conceptualization, assuming that science education and communication share similarities in their corpus and strategies, emphasizing educational and dissemination approaches. Public engagement topics are usually framed in sessions about "engaging communities" or "community participation," creating what seems like a disconnection between these themes, yet also encompassing topics related to science communication.

4.3. Science communication paradigms

Geoparks showcase a diverse spectrum of science communication strategies but as discussed earlier, the theoretical positioning behind them is not always understandable.

Our analysis, under the scope of science communication paradigms, reveals the prevalence of one-way models, focused on translating and disseminating knowledge, even while aiming to mobilize the public for action. Public engagement with science must always involve a common ground of knowledge so that there can really be dialogue that leads to participation.

While research acknowledges the devaluation of the role of scientific literacy, criticizing strategies that only focus on the public's knowledge deficits, it is recognized that unidirectional communication strategies cannot be abandoned. However, instead of an audience with little knowledge, the public should be seen as an asset that must be motivated and involved to be empowered to take part in long-term sustainable solutions and decisions. This approach perfectly aligns with the objectives of geoparks, which aim to contribute positively to local community sustainable development and enhance their well-being, making their active participation highly relevant.

Communication models, often perceived as antagonistic, can indeed work together effectively and it is not uncommon for a participatory three-way communication strategy to incorporate uni- or bi- directional approaches, which may coexist at different stages serving specific goals.

The global call for a paradigm shift, as advocated by the science communication community, should similarly be endorsed by geoparks, territories that are by definition committed to public engagement and participatory approaches. With their broad scope, geoparks are ideal hubs for co-designing strategies that incorporate local beliefs, empirical experiences, traditions, and development needs, together with natural and environmental protection.

The main takeaway should be that more dialogical, critical, and participatory approaches are needed to tackle sustainable development. Geoparks, intimately committed to the SDGs of the Agenda 2023, have the responsibility as well as the optimal conditions to implement these strategies.

4.4. Future paths

In recent years, science communication has evolved significantly, offering invaluable contributions to advancing science in society, yet these are often overlooked in geoparks strategies. One key shift should involve shifting from deficit-based framing, which views non-experts as a problem, to asset-based approaches that engage them in generating solutions. This transition calls for interdisciplinary teams, specialized training, dedicated science communication staff, and stronger connections with research. Additionally, geoparks' bottom-up approach underscores the importance of public engagement skills, such as active listening, negotiation, and collaboration.

Research on science communication in geopark contexts remains scarce, with the limited literature mainly consisting of case studies and lacking focus on core research areas. The landscape of communication practices in geoparks is fragmented, lacking large-scale, longitudinal studies and systematization. Gaining more detailed insights into these globally implemented practices would help identify strengths and challenges.

Lessons learned from methodical research can assist stakeholders in understanding science communication in geoparks and support the formulation of evidence-based strategies to enhance public engagement efforts.

Integrating the current findings with prior research—which identified challenges and opportunities in science communication (particularly in geoscience, geodiversity, and geoconservation) (Rodrigues et al., 2023a) and studied geoscientists as science communication practitioners (Rodrigues et al., 2023b)—is expected to advance science communication in UGGps.

CRediT authorship contribution statement

Joana Rodrigues: Writing – review & editing, Methodology, Formal analysis, Writing – original draft, Investigation, Conceptualization. **Elsa Costa e Silva:** Writing – review & editing, Supervision. **Diamantino Insua Pereira:** Supervision, Writing – review & editing.

Ethical statement

This study "The landscape of science communication and public engagement in UNESCO Global Geoparks" presents original research that has not been previously published or is currently under consideration elsewhere. The paper reflects the authors' own research and analysis, with all sources properly disclosed. Additionally, all authors have been involved in substantial work leading to the paper.

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Declaration of competing interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Appendix A. Supplementary data

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