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Geoscience communication: a content analysis of practice in British Columbia, Canada, using science communication models

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Abstract. Geoscience communication, an emerging discipline within the geosciences, faces a scarcity of theoretical grounding despite abundant practical perspectives. This paper addresses this gap by investigating the application of science communication models (deficit, dialogue, participatory) in geoscience communication, specifically in British Columbia, Canada. The overarching aim is to determine if the deficit-to-dialogue shift often discussed in science communication literature is reflected in geoscience communication practice. Using a content analysis approach, data were collected from publicly accessible websites to qualify and quantify how (activities) and why (objectives) geoscience communication practitioners communicate. The activities and objectives were coded based on terms associated with each model that closely aligned with those described by Metcalfe (2019a, b). Findings reveal a persistence of the deficit model in practice (76 % for objectives, 61 % for activities) with limited adoption of dialogue and participatory approaches. This suggests a discrepancy between theoretical advancements in science communication and their application in geoscience contexts. The study highlights disparities in the use of communication models across target audiences, regions, and venues. While communication with K–12 (kindergarten–grade 12) audiences (students, educators) utilizes dialogue-based approaches, participatory activities are underrepresented, particularly in regions with high population densities (e.g. Lower Mainland/Sea to Sky is 0 % participatory) and areas where geoscience intersects with public interests (e.g. northern British Columbia is 3 % participatory). By shedding light on the current landscape of geoscience communication in British Columbia, this research informs future endeavours in theory development and practice improvement within the broader field of science communication. However, it also acknowledges the need for localized studies to capture the diverse contexts of science communication practices worldwide.

1 Introduction

Geoscience communication has increasingly been recognized as a subset of science communication (Gani et al., 2024). The geosciences face unique communicative challenges, such as communicating the subsurface, addressing public audiences' lack of geologic understanding, and communicating risks associated with natural hazards (Drake et al., 2014; Stewart and Lewis, 2017). However, geoscience communication also has many commonalities with communication in other scientific fields. Although many scientific disciplines have successfully incorporated science communication principles and theory (e.g. Phillips and Beddoes, 2013; Varner, 2014), few examples exist in geoscience contexts (e.g. Illingworth et al., 2018; Stewart and Lewis, 2017). This imbalance between practical and theoretical approaches in geoscience communication literature, particularly within a Canadian context; undermines the field's credibility, creates potential for unforeseen issues and misconceptions; and limits the depth, nuance, and applicability of findings to effective practice (Gani et al., 2024). The field of science communication spans diverse contexts and research trends (Dudo and Besley, 2016; Schiele et al., 2012), encompassing initiatives ranging from citizen science projects to combatting misinformation during the COVID-19 pandemic (Halliwell et al., 2021; Rzymski et al., 2021). One enduring and prominent research trend focuses on science communication models, which provide frameworks for understanding how science communicators engage with their audiences (Macq et al., 2020; Metcalfe, 2019b; Nisbet and Markowitz, 2016). These models, including the deficit, dialogue, and participatory models, offer insights into the diverse approaches used by science communicators, shaped by contextual factors such as socio-economic, cultural, historical, and geopolitical influences.

A gradual shift in rhetoric from the deficit model toward dialogue and participatory approaches has been observed, reflecting broader advancements in the field (Reincke et al., 2020). However, this transition remains unexplored in geoscience communication, a critical domain in addressing pressing global challenges such as climate change, resource management, and natural hazard mitigation. This gap in understanding has significant implications for geoscience communicators' practice, the design of training offerings for practitioners, and the development of effective communication strategies.

To address the identified theoretical gap in geoscience communication and contribute insights applicable to diverse practitioners globally, this study investigates the following research questions:

1. To what extent does geoscience communication practice in British Columbia, Canada, demonstrate a transition from deficit-oriented approaches to dialogue and participatory models?

2. How do science communication models vary based on the target audience, geographic location, and venue?

3. Do practitioners align communication activities (deficit, dialogue, participatory) with their corresponding goals or employ activities from one model to address objectives associated with another?

By identifying alignments or misalignments between communication objectives, models, and practices, this research provides crucial insights into the consistency, effectiveness, and credibility of geoscience messaging. Furthermore, it highlights gaps in current practices that may hinder meaningful public engagement. Specific factors such as the types of audiences being targeted, the venues in which communication occurs, the regions and communities being served, and the mediums utilized for outreach are vital for ensuring equitable and impactful communication.

This paper addresses these considerations by integrating science communication models into the analysis and discussion of geoscience communication practices in British Columbia, Canada. The province's unique geoscientific context, characterized by its diverse population centres, varied geographies, and dynamic socio-economic landscape, offers an ideal case study for examining how theoretical models translate into practice. By bridging the theoretical gap in the application of science communication models to geoscience, this research contributes to advancing the field and supporting the development of more effective and inclusive communication strategies globally.

2 Literature review

2.1 Geoscience communication

The term geoscience communication has gained increasing traction within the field of geoscience, and Illingworth et al. (2018) underscore its aim of raising awareness of and stimulating discourse on geoscience topics. For this discussion, we adopt the broadest interpretation, referring to it as communicating geoscience information with non-specialist audiences. Such communication encompasses various initiatives, including UNESCO Global Geoparks, geoscience museums, informal education programs, outreach initiatives, geoheritage projects, and more.

The role of geoscience in addressing society's most pressing challenges is increasingly acknowledged (Stewart and Lewis, 2017; Stewart and Nield, 2013). For instance, some have emphasized geoscientists' role in supporting the United Nations Sustainable Development Goals, encompassing sustainable development, food security, education, energy, and land use (Franks et al., 2022; Gill, 2017; United Nations, 2015). Considering these significant issues, enhancing geoliteracy through geoscience communication is becoming more crucial (Stewart and Gill, 2017). This importance was underscored in Canada's Pan-Canadian Geoscience Strategy, which highlighted increasing geo-literacy as a key recommendation (National Geological Surveys Committee of Canada, 2022). Moreover, discussions surrounding declining enrolment in geoscience departments in Canada have also emphasized the importance of geo-literacy (Council of Chairs of Canadian Earth Science Departments, 2022).

Although calls for improved geoscience communication with the Canadian public date back several decades (e.g. Carleton, 1976), scholarly attention to Canadian geoscience communication remains limited, primarily focusing on broad forms of practice. In designed settings, such as public and university museums, efforts to communicate geoscience are evident through permanent exhibits, while the expansion of geotourism, particularly with the establishment of UNESCO Global Geoparks (Canadian Commission for UNESCO, 2025), has further bolstered engagement with geoscience (Blackwood, 2009; Royal Ontario Museum, 2021). Additionally, programs aimed at science learning, including outreach activities by university departments and informal education organizations, as well as ongoing support for educators, contribute to the dissemination of geoscience knowledge and skills (Bank et al., 2009; Dillon and Lipkewich, 2002; Onstad, 2021; van der Flier-Keller, 2011; van der Flier-Keller et al., 2011).

2.2 Science communication

The definition of science communication has undergone various interpretations as its study and practice have progressed (Bucchi and Trench, 2021; Burns et al., 2003). For this paper, we have adopted Besley and Dudo's (2022) definition of "communication conducted within the context of scientific issues", adding the qualifier of non-specialists being a key audience. Practitioners who facilitate science communication include scientists, academics, institutions, individuals, and not-for-profits (Roedema et al., 2022), while target audiences are individuals or groups engaged with scientific discourse (Ridgway et al., 2020).

Various typologies, frameworks, and models have been proposed to understand the multifaceted nature of science communication activities (Del Carmen Sànchez-Mora, 2016; Wilson et al., 2016). Of these, the most notable conceptualization is the science communication models (deficit, dialogue, participatory), which delineate practitioners' objectives, activities, tactics, and the level of stakeholder and practitioner engagement (Besley and Dudo, 2022; Metcalfe, 2019b; Nisbet and Markowitz, 2016). Trench and Bucchi (2010, p. 2) note, "The near-20 years of discussion of models of science communication – since the naming of the 'deficit model' – is the most solid thread of theoretical work in this field". These models have evolved within diverse contexts, serving varied objectives and catering to diverse audiences (Dudo and Besley, 2016; Horst, 2012).

The deficit model, often associated with early forms of science communication, aimed to address what was perceived as the public's lack of knowledge about science (Irwin and Wynne, 1996; Nisbet and Scheufele, 2009; Millar and Wynne, 1988). Within this model, the public is perceived as misinformed, leading to distrust in scientific endeavours' credibility (Bucchi and Trench, 2016). Scholars initially believed rectifying this deficit could be achieved through the one-way transmission of scientific knowledge from experts to the public (Gross, 1994; Irwin, 2006; Nisbet and Scheufele, 2009). However, subsequent research has debunked the idea that mere information provision could effectively change attitudes toward science, revealing the multifaceted nature of attitude formation influenced by factors such as belief systems, interpersonal interactions, and existing knowledge (Bucchi and Trench, 2008).

In contrast to the top-down approach of the deficit model, the dialogue model advocates for a two-way conversation between scientists and the public (Irwin, 2006). Central to this model is the acknowledgement and incorporation of public concerns, opinions, and knowledge into the discourse (Metcalfe, 2019b). The participatory model, in theory, emphasizes a relatively equal standing between the public and scientists (Metcalfe, 2022). Unlike the deficit and dialogue models, the participatory model envisions a process where decision-making power and knowledge are shared between the scientists, policymakers, and public (Schrögel and Kolleck, 2019).

2.3 (Geo)science communication

The prevalence of the deficit model in geoscience communication is evident in current literature, with objectives such as increasing public knowledge about topics such as "rock formation, plate tectonics, earthquakes, and volcanic activity" and raising awareness of "stress on forest ecosystems under climate change" (Mölg et al., 2023; Todesco et al., 2022). Common activities associated with this model include communication through social media platforms such as X (formerly Twitter) and lectures (Mölg et al., 2023; Wellman et al., 2025).

In contrast, the dialogue model emphasizes objectives such as supporting decision-making related to geological hazards and discovering public opinions on geoscience (Müller and Döll, 2024; Schneider et al., 2024). Activities aligned with this model include workshops on volcanic risk and training initiatives that "foster climate literacy" (Todesco et al., 2022; Wellman et al., 2025).

The participatory model further advances engagement by promoting objectives such as active audience participation in "climate change adaptation processes" and co-designing community hazard initiatives with stakeholders (Cumiskey et al., 2019; Müller and Döll, 2024). Activities characteristic of this model include enabling audiences to collect data during geomagnetic storms, building capacity for risk communication, and facilitating collaboration between audiences and geoscientists (Cumiskey et al., 2019; Grandin et al., 2024).

Though Sect. 2.1 and 2.3 show that there have been significant efforts to communicate geoscience to the public, few of these instances explicitly connect these practices to established science communication theory. There are, however, exceptions to this (see Illingworth, 2023, and Stewart and Nield, 2013, for examples), with increasing acknowledgement of the importance of basing geoscience communication within the theoretical frameworks of science communication (Gani et al., 2024; Illingworth et al., 2018).

3 Methods

This research aims to qualify and quantify geoscience communication activities and objectives in British Columbia by employing a content analysis methodology. Data collection involved retrieving information from publicly accessible websites via Google searches, with data then organized into a database which included names of practitioners, target audiences, venues, and other pertinent factors for 146 organizations (also referred to as sampling units). A subset of these data ($n = 81$), specifically from practitioners maintaining public websites, underwent content analysis. Referencing established science communication models (Bauer et al., 2007; Bucchi and Trench, 2008; Metcalfe, 2019a, b), the content extracted from geoscience communication practitioners' online platforms was subject to systematic coding. Qualitative data were also compiled during the content analysis to provide evidence of what practice entails relative to the science communication models.

3.1 Database compilation

Initial data collection involved the identification of relevant terms and keywords associated with the research topic. Combinations of two keywords such as geoscience, Earth science, geological, and communication, outreach, informal education, museums, and engagement, along with geographic modifiers such as British Columbia or Vancouver Island, were entered into Google. All combinations were entered until no new relevant results were identified. This search was initially conducted in April of 2022, with websites revisited in March 2024 to perform the content analysis. Only practitioners linked to publicly available websites were included, excluding social media accounts, a common platform for science communication (Huber et al., 2019; Wilson et al., 2016); policy engagements; and other relevant avenues. This criterion was necessary for the content analysis since practitioners' objectives and activities are often explicitly stated on their websites. However, it is worth noting that content analysis of geoscience communication through social media or alternative channels remains feasible, albeit beyond the scope of this study.

The database encompasses various pieces of information regarding the target audiences, the resources offered, the primary venue, and the primary geographic location of services offered among other variables not of focus to this study. Venues were classified based on existing literature definitions and natural breaks within the data. Some categories were self-evident, such as museums, which were further classified into history museums and science museums based on distinct objectives. Natural physical sites, identified by Spector et al. (2012), encompassed locations such as bodies of water where citizen science programs often occur, or areas utilized for field trips by rock and mineral enthusiast groups. Parks, including UNESCO Global Geoparks, aspiring UNESCO Global Geoparks, and national/provincial parks, were considered distinct from natural physical sites due to their managed nature and human-enhanced elements. K–12 schools and universities were identified as venues for programs for science learning (National Research Council, 2009). Online platforms were used as a venue for organizations whose services were available through publicly accessible websites. It was noted that individual practitioners often operated in multiple venues, and for analytical purposes, a primary venue was assigned based on where the majority of their activities were conducted. This process is considered subjective and constitutes a limitation of the study.

Incorporating the primary geographic location of services offered and primary venues addresses crucial inquiries regarding accessibility. To achieve this, the locations were classified based on a regional map of British Columbia. It was chosen for its relatively small number of geographic areas ($n = 7$) and its ability to distinguish between geographically distinct and population-distinct regions. Organizations outside British Columbia were included only if they offered online resources accessible to all, excluding those tied exclusively to other provincial or territorial curricula as such resources would not be relevant to British Columbia's curriculum. The database discussed in this section can be made available upon request.

3.2 Content analysis

In general, this study adopts a problem-driven analysis approach to content analysis and adopts the approach outlined in Chap. 14 of Krippendorff (2019). Systematic content analysis was conducted on a subset of data extracted from the database discussed in the prior section. The codebook and all data (Onstad, 2025) associated with the content analysis can be accessed through the Federated Research Data Repository. As mentioned, only geoscience communication practitioners with publicly accessible websites were included in the analysis. Additionally, geo-art was excluded from the data subset due to the lack of available information regarding the artists' objectives, which readily translate to science communication models.

This analysis employed a deductive approach due to the content's strong theoretical foundation (i.e. science communication models). Despite adopting a deductive approach, the data (inductive) partly influenced the creation of categories. The key terms associated with each model were notably informed by the work of Metcalfe (2019a, b; Table 1).

The coding involved two stages: one focusing on practitioner objectives and the other on activities. Regarding the coding of activities, three supplementary categories (medium, resource, audience) were devised to better depict the prevalence of models utilized in specific contexts, with particular resources, and for distinct audiences. While coding activities, it was impossible to include the related objectives since goals were not commonly mentioned on websites associated with activities, target audiences, or resources.

The development of the medium category drew heavily from established informal education literature and includes designed spaces, programs for science learning, and science media (Fig. 1; The National Research Council, 2009). Science media encompasses many traditional and digital media formats distributed across all science learning venues. Programs for science learning typically occur within educational institutions and community-based organizations that prioritize science education. Designed settings are intentionally crafted environments curated to facilitate learning and foster self-engaging experiences (The National Research Council, 2009).

The medium categories were each further sub-categorized: science media (traditional print media, traditional broadcast media, and new media), programs for science learning (workshops/training, supplemental resources, and festivals/-

Table 1. Simplified codebook with key terms used to code sampling units into corresponding model categories. Terms were directly used and adapted from Metcalfe (2019a, b). The key terms below were used as a guide for coding, but exact term matches were not required.

Focus	Deficit model	Dialogue model	Participatory model
Objectives	– raise awareness – educate – inspire/excite – promote geoscience careers	– help people make decisions – make connections between people – discover public opinion – debate/discuss issues	– solve problems – co-produce new knowledge – participate in research with geoscientists – participate in democratic policymaking
Activities	– practice one-way communication – put up a display/exhibit – use formal education to engage – use online means to communicate – use traditional mass media	– participate in an activity involving people in geoscience – train/develop skills to participate in geoscience – workshops – provide access to geoscientists	– collect data/do research – jointly produce new knowledge – participate with geoscientists in an activity

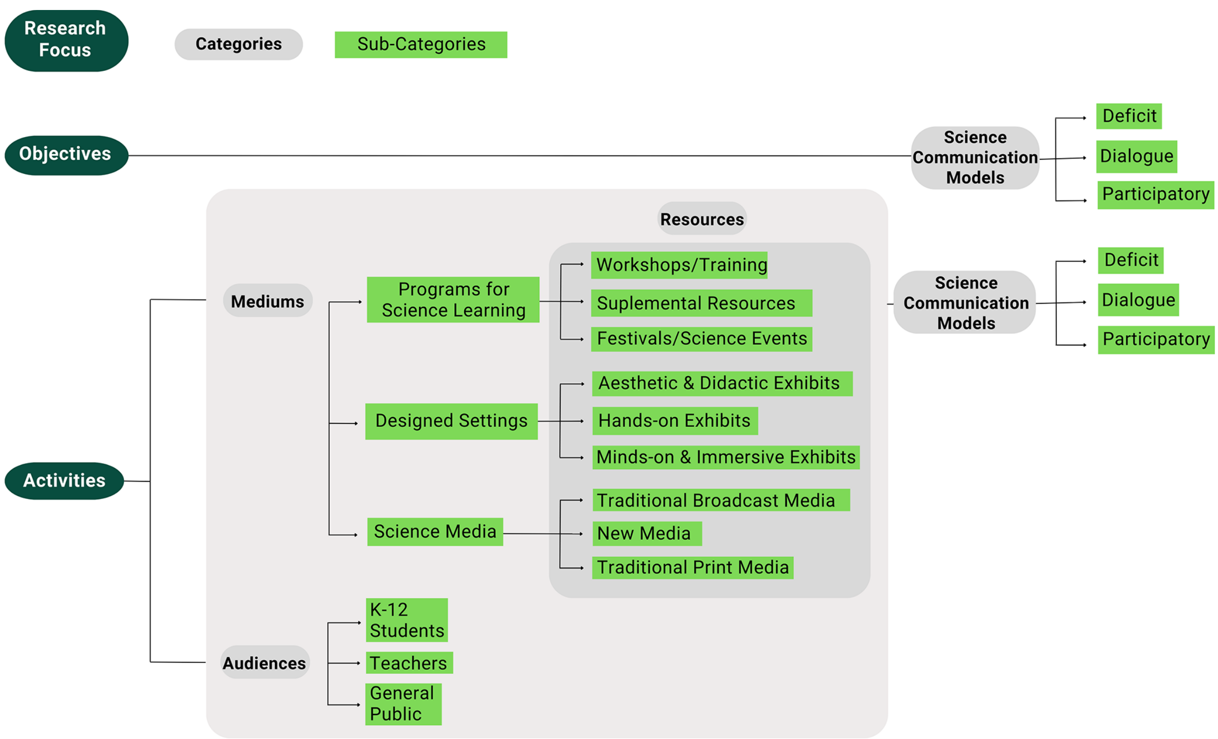

Figure 1. Concept map highlighting the relationships between the categories, sub-categories, and research focuses.

science events), and designed settings (aesthetic and didactic, hands-on, minds-on, and immersive). These sub-categories were partially influenced by the existing literature and natural breaks in the data (e.g. Ahmad et al., 2015; Rajendran and Thesinghraja, 2014). Lastly, the audience categories directly reflected those audiences described on websites. They comprise K–12 students (generally referring to youth between the ages of 5 and 18), teachers (those who teach K–12 youth either formally or informally), and the general public (a broad, non-specialist audience or instances where the audience is unspecified). To aid in understanding the complex interrelationships between multiple categories and sub-categories, a concept map illustrating these relationships has been provided (Fig. 1). The definitions for all categories and subcategories can be found in the codebook in Onstad, 2025.

3.2.1 Recording/coding

The data recording process, completed by the principal investigator, entailed multiple iterations to define the semantics of the data. This involved documenting words, phrases, images, and contextual observations pertaining to the activities and objectives of practitioners. The categories delineated in Fig. 1 emerged as the outcome of these observations, evolving until they became exhaustive and mutually exclusive. Data were systematically approached through a codebook, which served as a written protocol instructing coders how to assign values to the content (Lacy et al., 2015). The final version of the codebook (version 6; Onstad, 2025) was used to develop the test, reliability, and full samples. In this study, the process can be divided into two components.

The first focuses on the practitioners' objectives, where coders were instructed to locate the home or about page on a practitioner's website and identify keywords associated with each model. For each occurrence of an objective per practitioner (to a maximum of three per model), coders checked off a box under the associated model in the coding database. The second part of the process centred on practitioners' activities. Coders examined all other pages on the website, starting from the home page and navigating through each tab. They noted keywords associated with each model and determined each activity's target audience and resource. Coders were given a list of keywords associated with each model derived from Metcalfe (2019a). Coders coded once for every unique combination of a resource–audience–model activity identified on a website.

3.2.2 Reliability

Given the subjective nature of applying codes to qualitative data, reliability was achieved through intra-coder agreement (stability) and intercoder reliability (replicability). The intracoder agreement was facilitated by several measures, including ensuring coder familiarity with the science communication models, note taking throughout the coding process, and encouraging breaks between coding of each sample unit. Additionally, the data were coded multiple times, and adjustments were noted before commencing inter-coding.

Before conducting the intercoder reliability check, a reviewer was engaged to assess the readability of the coding instructions and the categories and sub-categories used in the database. While independent coders are typically involved in intercoder reliability checks, this study followed Lorr and McNair's (1966) cautionary note regarding the potential for coder bias. Thus, the reviewer was not engaged in the reliability check to avoid influencing the results.

An advertisement was circulated to the undergraduate Earth science program at Simon Fraser University, listing attention to detail, ability to follow rules, familiarity with Excel, and English as a first language as requirements. In retrospect, it is acknowledged that knowledge of science communication models should have been a prerequisite for this study, as discussed later in this section. A single independent coder (Coder 2) was hired due to budgetary and logistical constraints, and basic knowledge of science communication and informal education was considered in the hiring process.

The test sample

Before conducting the intercoder reliability tests, Coder 2 underwent a training session to ensure consistency in coding practices. While knowledge of the study material is commonly recommended for intercoder reliability checks, this was not a qualification for coders in this study. The time needed to train Coder 2 to thoroughly understand the science communication models was not feasible for this study. Consequently, disagreements discussed in the subsequent section stemmed from misunderstandings of science communication models. Following the training, both coders coded eight recording units (ID: 1, 2, 27, 45, 48, 57, 66, and 72) to populate the test sample.

An intercoder reliability check was conducted on the test sample, with relatively high simple agreement but insufficient agreement in Cohen's kappa and Gwet's AC1. The primary limitation of simple agreement lies in its failure to account for the potential random selection of codes (Carletta, 1996). While Cohen's kappa addresses this concern by incorporating chance into its computation, some scholars have raised reservations about its application when dealing with data featuring extreme marginal distributions (Dettori and Norvall, 2020; Wongpakaran et al., 2013). Conversely, critiques of Gwet's AC1 highlight its leniency, its fundamental methodological challenges, and the absence of a standardized classification system for its values (Vach and Gerke, 2023). This ongoing discourse underscores the need for context-specific guidelines to aid in interpreting statistical agreements, as emphasized by Geiß (2021). In our analysis, we relied on Cohen's kappa statistics and its established thresholds (> 0.80 or > 0.70 for exploratory studies) to inform our reliability assessments (Intercoder Reliability, 2010; Landis and Koch, 1977).

Given the low Cohen's kappa values observed in the test sample and the high number of potential categories for a code to be applied to, combined with Coder 2's lack of prior knowledge of science communication models, achieving excellent intercoder reliability was deemed unfeasible. An alternative approach known as double coding was adopted where both coders code all data in the sample twice (Bogen et al., 2021; Fleerackers et al., 2022; Krippendorff, 2004, p. 250). This method was adopted to populate the reliability sample, considering its applicability to categorically complex cases (Spooren and Degand, 2010).

The reliability sample

The reliability sample used for intercoder reliability calculations comprised 729 objectives and 6561 activities from a total sample size of 81 websites. The reliability sample was generated using the procedure outlined in the previous section. Table 2 presents the simple agreement, Gwet's AC1, prevalence (the number of "present" agreements between Coders 1 and 2 calculated as a percentage of the total of the marginals), Cohen's kappa, and Krippendorff's alpha for the three science communication model objectives. The data exhibit the kappa paradox, where imbalanced marginal distributions and issues with agreement prevalence led to low kappa and alpha values (Delgado and Tibau, 2019; Tan et al., 2024; Wongpakaran et al., 2013; Zec et al., 2017). In this specific case, interpretations of reliability should primarily rely on Gwet's AC1 due to its adjustment for chance agreement and its avoidance of the paradoxical behaviour of kappa. However, there are currently no proposed benchmarks for interpreting the level of reliability of Gwet's AC1, and using the benchmarks proposed by Landis and Koch (1977) for Gwet's values is not appropriate.

Within science communication objectives, the deficit model exhibited 72 % observed agreement and a Gwet's AC1 value of 0.46 (Table 2). The dialogue model showed 86 % observed agreement and a Gwet's AC1 of 0.83, while the participatory model demonstrated 88 % observed agreement and a Gwet's AC1 of 0.85. In science communication activities, there were 81 unique categories, and the intercoder reliability statistics can be found in Table A1. Gwet's AC1 values for all categories ranged from 0.56 to 1.00 (mean = 0.92, SD = 0.10).

Despite the agreement results presented here, it is important to note that 100 % agreement is reached during double coding. In this case, we used a tie-breaker approach. Consequently, agreement results from the full sample are typically not presented in discussions surrounding reliability, as all disagreements are resolved. However, the relatively high values of Gwet's AC1 achieved at most categorical levels in the reliability sample indicate a relatively high level of agreement between coders.

The full sample

The full sample represents the definitive dataset utilized in the subsequent results section and serves as the basis for all interpretations. Transitioning from the reliability sample to the full sample involved enlisting an external expert to resolve 558 discrepancies between Coders 1 and 2, employing a resolution by a tie-breaker approach (Lombard et al., 2002). Due to budget constraints, the external expert was the supervisor of Coder 1 (the lead researcher). To mitigate potential bias, the expert was blind to which coder had assigned a specific code.

There were 134 disagreements on objectives and 432 disagreements on activities. External agreements on objectives with Coder 1 were as follows: 86.2 % for the deficit model code, 72.7 % for the dialogue model, and 62.5 % for the participatory model. For activities, external agreements with Coder 1 were 95.6 % for the deficit model, 97 % for the dialogue model, and 90.9 % for the participatory model. There was a pronounced tendency of the external expert to align closely with Coder 1 and exhibit fewer disagreements with them.

The full sample encompasses a total of 155 objectives and 363 activities based on the following: (A) agreements between Coders 1 and 2 (596 for objectives, 6137 for activities), (B) agreements between the external expert and Coder 1 (63 for objectives, 283 for activities), and (C) agreements between the external expert and Coder 2 (14 for objectives, 11 for activities). Disagreements between the external expert and either Coder 1 or Coder 2 (12 for objectives with Coder 1, 30 for activities with Coder 1, 45 for objectives with Coder 2, and 107 for activities with Coder 2) were excluded from the full sample as they indicated discrepancies between at least one coder and the external expert.

4 Results

Out of the 155 geoscience communication objectives identified in the coding process, an overwhelming 76 % ($n = 118$) was deficit, while objectives aligning with the dialogue and participatory models constituted 11 % ($n = 17$) and 13 % ($n = 20$) of the data, respectively (Fig. 2). Within the deficit model, objectives relating to education were predominant. Conversely, among those coded as dialogue, objectives focused on fostering connections between individuals. Lastly, within the participatory model, objectives centred around problem-solving emerged as the most common. In terms of geoscience communication activities, out of the 363 identified, a majority (61.4 %, $n = 223$) was coded as deficit, with dialogue activities comprising 33.3 % ($n = 121$) and participatory activities making up 5.3 % ($n = 19$) of the total (Fig. 2).

The deficit model was used mostly for activities targeting the general public, representing 71 % ($n = 134$) of all activities, while it was least utilized for K–12 students, accounting for 48 % ($n = 61$) of activities (Fig. 3a). Dialogue model activities were predominantly employed for K–12 students (48 %, $n = 61$) and utilized the least for the general public (23 %, $n = 44$). Notably, the participatory model only comprised 4 %–6 % of all activities and was most commonly used for K–12 students ($n = 6$) and general public audiences ($n = 11$). In Fig. 3b, it is evident that science media predominantly featured deficit model activities, encompassing 83 % ($n = 126$) of all activities coded. Programs for science learn-

Table 2. Intercoder reliability statistics of science communication objectives in the reliability sample.

Model objectives	Ratings by Coders 1 and 2				Prevalence	Observed agreement	Gwet's AC1	Cohen's kappa	Krippendorff's alpha
Deficit model		Present	Absent	Marginals	25 %	72 %	0.46	0.42	0.41
	Present	61	18	79					
	Absent	51	113	164					
	Marginals	112	131	243					
Dialogue model		Present	Absent	Marginals	2 %	86 %	0.83	0.19	0.19
	Present	6	23	29					
	Absent	11	203	214					
	Marginals	17	226	243					
Participatory model		Present	Absent	Marginals	5 %	88 %	0.85	0.38	0.38
	Present	12	18	30					
	Absent	12	201	213					
	Marginals	24	219	243					

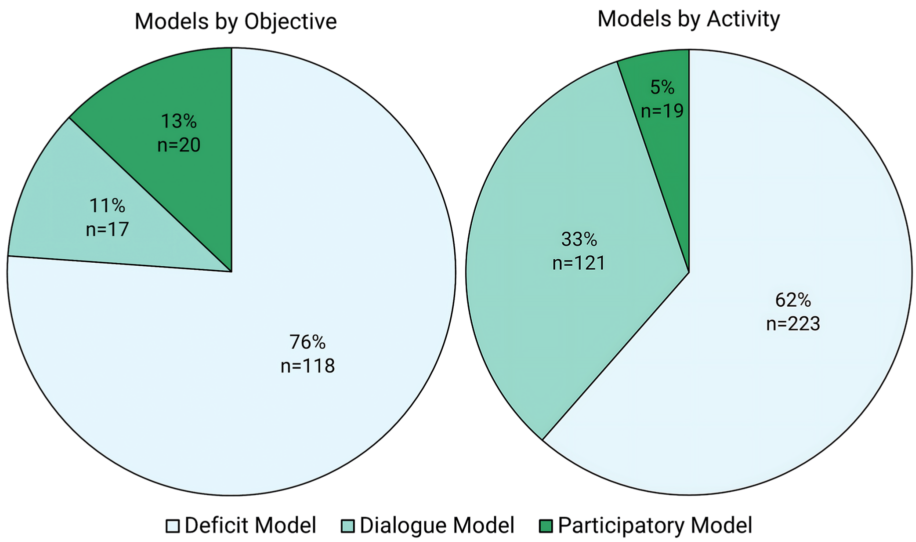

Figure 2. Pie charts visualizing relative proportions of deficit, dialogue, and participatory model codes applied to objectives and activities.

ing exhibited the highest proportions of the dialogue (53 %, $n = 72$) and participatory models (10 %, $n = 13$), while designed settings were relatively evenly distributed between the deficit (60 %, $n = 45$) and dialogue models (39 %, $n = 29$).

4.1 Model activities in resources

This section is structured to emphasize the distribution of deficit, dialogue, and participatory models across resources and mediums: science media (Table 3), programs for science learning (Table 4), and designed settings (Table 5). Qualitative data (e.g. words, images) associated with the theoretical models, gathered during the coding process, provided more profound insights into their practical implementations. Each model and resource is accompanied by examples of excerpts for coding-specific models. The absence of a model for a resource indicates that no activities were coded to that particular model.

4.1.1 Science media

In most cases, traditional print media activities were coded as the deficit model, accounting for 96 % ($n = 52$) of observed codes (Fig. 3c). Two activities employing a co-creation approach were also coded as participatory. These activities encompassed lesson plans, books, newsletters, and other written media forms (Table 1). The deficit and dialogue models, respectively, accounted for 92 % ($n = 36$) and 8 % ($n = 3$) of activities coded to traditional broadcast media (Fig. 3c), with YouTube videos, movies, and slideshows being the most

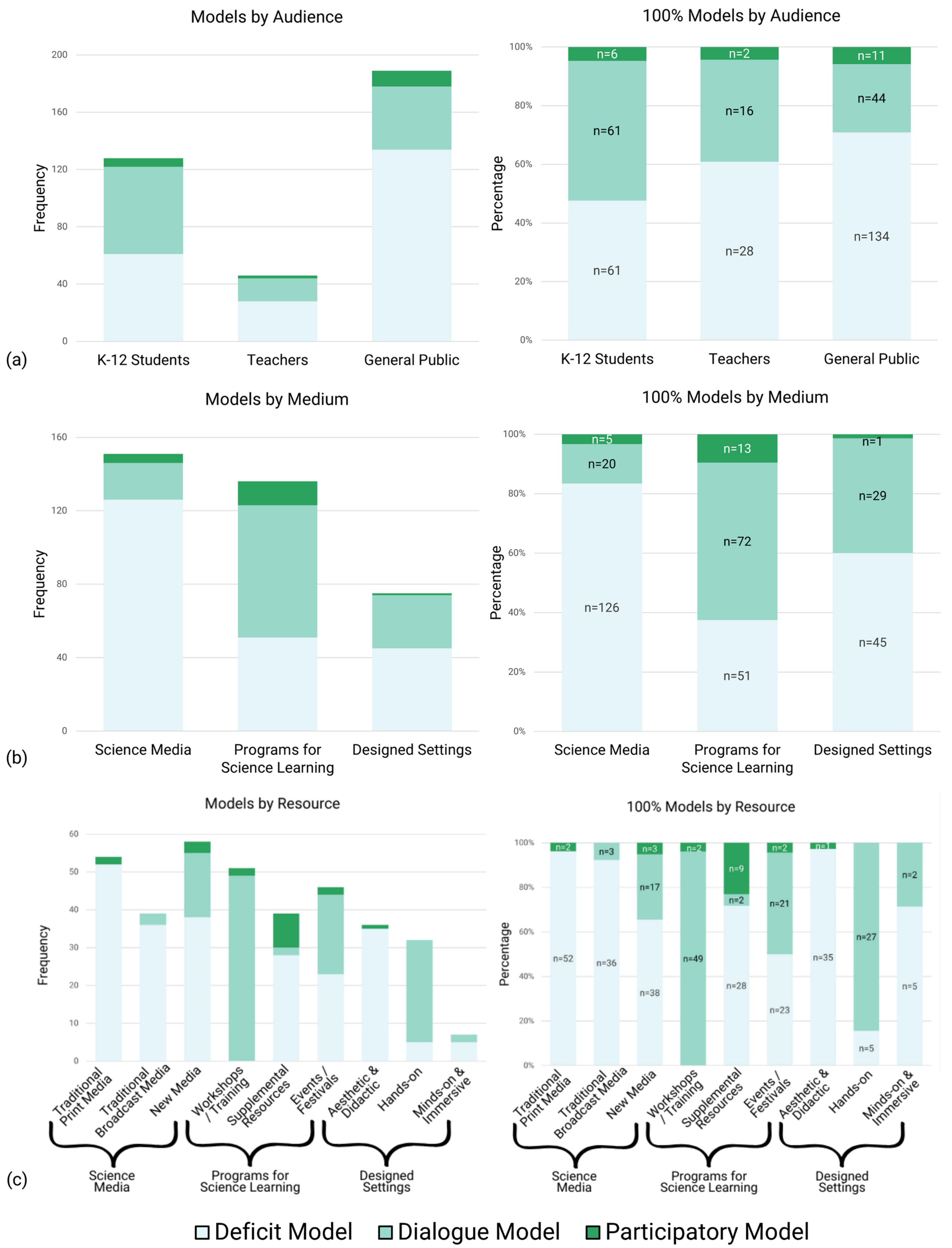

Figure 3. Respective frequencies and distributions of model activities used **(a)** when communicating with target audiences, **(b)** in science communication mediums, and **(c)** in resources.

Table 3. Common activities coded and examples of data used to code models within resources of science media. Bolded text in the example column corresponds to words/phrases associated with key terms for coding models and relevant anchor samples for determining the corresponding resource. An asterisk (*) in the example column is derived from coder observations.

Resource	Model	Activities	Example
Traditional print media	Deficit	– lesson plans – books – newsletters	"The new *Mining Matters* **Activity Book** for youth ..." – Mining Matters
	Participatory	– co-created print media	"Ocean Sense core modules, **co-created** by ONC and Indigenous community partners ... download **lesson plans** and activities, and browse connections to curriculum" – Ocean Networks Canada
Traditional broadcast media	Deficit	– YouTube videos – slideshows – movies	Canadian Mining **Videos** (*various videos relating to mining in Canadian society) – Mining Association of Canada
	Dialogue	– training videos	"Our Deeper and Deeper **video tutorials** are now available!" (*within a tab related to resources for teachers) – Mining Matters
	Deficit	– podcasts – blogs – apps – websites/platforms	"epicentres of local earthquakes as they are detected and located, are illustrated on a simple **web interface**" – SchoolShakes
	Dialogue	– virtual workshops – virtual field trips/tours – virtual training	"We are offering both in-person and **virtual outreach** for the 2023–2024 school year. All **workshops** are approximately ..." – Let's Talk Science (UBC Okanagan)
	Participatory	– citizen science apps/platforms	"Welcome to our **data platform**! **Collect and share water quality data**" – Water Rangers

common (Table 3). If any of these resources were used for training, they were coded as dialogue. Activities coded to new media were primarily deficit (66 %, $n = 38$) and followed by dialogue (29 %, $n = 17$) and participatory (5 %, $n = 3$) models (Fig. 3c). Deficit activities included podcasts, blogs, apps, and websites/platforms. If activities were coded to workshops/training within programs for science learning or hands-on exhibits within designed settings and were offered virtually, they would additionally be coded as dialogue. Lastly, any apps or data/web platforms that were used for citizen science were coded as participatory (Table 3). Concerning audiences, traditional print media activities were distributed relatively evenly among the general public, K–12 students, and educators, while traditional broadcast media and new media activities were most frequently coded for the general public (Fig. 4a).

4.1.2 Programs for science learning

Primarily, workshops/training inherently involves a certain level of interactivity, explaining the higher prevalence of activities coded as dialogue (96 %, $n = 49$; Fig. 3c). Workshops, field trips, courses, and hands-on activities were the most common examples of the dialogue model in practice, catering to the general public, teachers, and K–12 students (Table 4; Fig. 4b). Additionally, two activities (4 %) classified under the participatory model were identified, including a participatory professional development workshop and a community training initiative offered by the same practitioner (Table 4). Within supplemental resources, activities were coded to all models, with the deficit and participatory models accounting for 72 % ($n = 28$) and 23 % ($n = 9$), respectively (Fig. 3c). Deficit model activities included test/sample kits and games, while participatory activities solely included citizen science initiatives (Table 4). Furthermore, two dialogue model activities (5 %) were coded, including a poll researching public opinion on mining and a virtual research challenge on climate change (Table 4). Events/festivals were evenly distributed between the deficit (50 %, $n = 23$) and dialogue models (46 %, $n = 21$; Fig. 4b), constituting guest speakers for the former and camps and interactive community events for the latter (Table 4). Two par-

Table 4. Activities and examples of data used to code models within resources of programs for science learning. Bolded text in the example column corresponds to words/phrases associated with key terms for coding models and relevant anchor samples for determining the corresponding resource. An asterisk (*) in the example column is derived from coder observations.

Resource	Model	Activities	Example
Workshops/ training	Dialogue	– workshops – training/courses – field trips – hands-on activities	"An important component of each **workshop** is the package of resource materials provided to each participating teacher for use in the classroom" – EdGeo
	Participatory	– participatory teacher training – participatory training	"educators may also participate in at sea expeditions where they **work alongside scientists**, engineers, and technicians" – Ocean Networks Canada
Supplemental resources	Deficit	– test/sample kits – games – database	"this **kit** provides an introduction to the basics of geology. Supplied in the kit are over 40 mineral specimens, testing kits, and examples of prospecting equipment" – Rossland Museum and Discovery Centre
	Dialogue	– public polls – research challenges	"releasing a new **national poll** that finds high levels of support for Canadian mining and increased understanding on the role Canada's mining industry . . . " – Mining Assoc. of Canada
	Participatory	– citizen science	"**Citizen Science** Initiatives . . . The CNHR is pleased to work with interested members of the public to **answer research questions and develop tools** to enhance our understanding and ability to respond to natural hazards" – SFU CNHR
Events/ festivals	Deficit	– guest speakers	"Our outreach program **provides presenters to your classroom** to teach your geoscience curriculum" – Burgess Shale Foundation
	Dialogue	– camps – special one-off activities – interactive community events	"In Dinosaur Day **Camps**, kids (ages 7–13) learn the same skills used by actual paleontologists to find, clean, and learn about fossils!" – Tumbler Ridge UNESCO Global Geopark
	Participatory	– participatory events	"Our **private digs** are global adventures, so make sure you have your passport and a hunger for new experiences!" *Image of people **participating with scientists** during fossil dig – DinoLab

ticipatory activities (4 %) were identified: a private paleontological dig and a camp centred around integrating Indigenous and western science perspectives on water (Table 4). Notably, only one event targeting teachers was identified: a professional development opportunity held at a mining conference (Fig. 4b).

4.1.3 Designed settings

The phrase "put up a display/exhibit" was associated with the deficit model according to Metcalfe (2019a, b), which led to the majority of activities in designed settings being coded as deficit. Nevertheless, activities aligned with the dialogue model were also identified due to the interactive nature of many tours and workshops in designed settings. Aesthetic/-didactic exhibits were overwhelmingly coded as deficit activities (97 %, $n = 35$; Fig. 3c) with collections, displays, and interpretive signage being the most common activities, most of which were intended for general public audiences (Fig. 4; Table 5). A collection that was co-produced with members of the public was coded as participatory (3 %; Table 5). Hands-on exhibits were predominantly coded as dialogue (84 %, $n = 27$; Fig. 3c) since tours and workshops where participants were involved in science were common (Table 5). The deficit model accounted for 16 % ($n = 5$) of coded activities and included interactive displays utilizing low technology to communicate (Fig. 3c; Table 5), typically targeting K–12 students and the general public (Fig. 4). Lastly, minds-on and immersive exhibits were less frequently coded overall (Fig. 3c). Among those identified, 71 % ($n = 5$) were coded as deficit, including immersive displays and 29 % ($n = 2$) were coded as dialogue, which included immersive tours (Fig. 3c; Table 5).

Table 5. Activities and examples of data used to code models within the resources of designed settings. Bolded text in the example column corresponds to words/phrases associated with key terms for coding models and relevant anchor samples for determining the corresponding resource.

Resource	Model	Activities	Example
Aesthetic/didactic exhibits	Deficit	– collections – displays – interpretive signage	"six interactive posts with **educational panels** featuring the history of mining in the Elk Valley with imagery reflecting the geological roots of mining" – Tourism Fernie
	Participatory	– co-produced collections	"New specimens (FOSSILS) are added to the collection through museum-led field expeditions, **donated discoveries by residents** from across British Columbia ..." – Royal British Columbia Museum
Hands-on exhibits	Deficit	– interactive displays	"This spherical **interactive display** projects images and animations of planets, real time weather, ocean currents" – Pacific Museum of Earth
	Dialogue	– tours – workshops	"Dinosaur Trackway **Tours**: Experience 97 million year old dinosaur footprints up close in their natural environment!" – Tumbler Ridge Museum
Minds-on and immersive exhibits	Deficit	– immersive displays	"**Gaia Gallery** ... A trail of giant footprints leads you to an enormous, armoured Goliath that once walked these lands. **Immerse** yourself in this ancient world and imagine what it was like to live during this time" – the Exploration Place
	Dialogue	– immersive tours	"**Exhibits** ... BOOM! – a **live-action experience** inside the historic Mill ... will take visitors on thrilling visual journey exploring all 20 storeys ..." – Brittania Mine Museum

4.2 Model activities by region

While quantitative outcomes are presented, it is essential to exercise caution in interpreting these numbers, given that activities were solely categorized based on target audience, medium, and resource type. Therefore, precise figures and percentages should only be cited for these analyses. Nonetheless, general trends can still be explored as the regions where practitioners offered their services were documented during the database construction. Here, it is assumed that all activities a practitioner offers are delivered within their primary region of service provision.

Based on the primary region of services offered, the distributions of activities offered across British Columbia were as follows: Lower Mainland/Sea to Sky 28 % ($n = 101$), online only (available to all regions) 19 % ($n = 70$), Canada-wide (available to all regions) 12 % ($n = 44$), Vancouver Island 16 % ($n = 56$), Thompson–Okanagan 6 % ($n = 22$), Kootenays 8 % ($n = 28$), northern British Columbia 8 % ($n = 29$), Canyons and the Cariboo 2 % ($n = 7$), and north and central coast 1 % ($n = 5$). Across all geographic locations (excluding online and Canada-wide activities), the range in proportions of activities coded to the science communication models were deficit (46 %–66 %; $n = 3$–64), dialogue (31 %–55 %; $n = 2$–37), and participatory (0 %–5 %; $n = 0$–3). Deficit model activities were most frequently observed in northern British Columbia and online, while they were least prevalent in the Thompson–Okanagan region (Fig. 5). In contrast, the participatory model was most associated with Canada-wide and online activities. Region-specific participatory activities were identified exclusively on Vancouver Island and in northern British Columbia.

4.3 Models by venue

The identified venues were categorized using a combination of classifications found in the literature, as discussed in Sect. 3 (Methods), and categories that emerged from the data themselves. The distributions of activities based on their primary venue are as follows: 23 % ($n = 83$) are available online, 21 % ($n = 77$) in history museums, 17 % ($n = 63$) in science museums, 14 % ($n = 52$) at natural physical sites, 14 % ($n = 49$) in K–12 schools, 7 % ($n = 24$) in parks, and 4 % ($n = 14$) in universities. The deficit model's use ranged from 29 %–71 % ($n = 4$–59), the dialogue model from 22 %–71 % ($n = 7$–27), and the participatory model from 0 %–23 % ($n = 0$–9) across all venues. Deficit objectives and activities were most commonly observed in organizations associated with universities and parks, as illustrated in Fig. 6. Conversely, dialogue objectives and activities were predominantly found on online platforms and in university environments. Finally, participatory objectives and activities were most frequently encountered in organizations operating within natural physical sites for both examined cases.

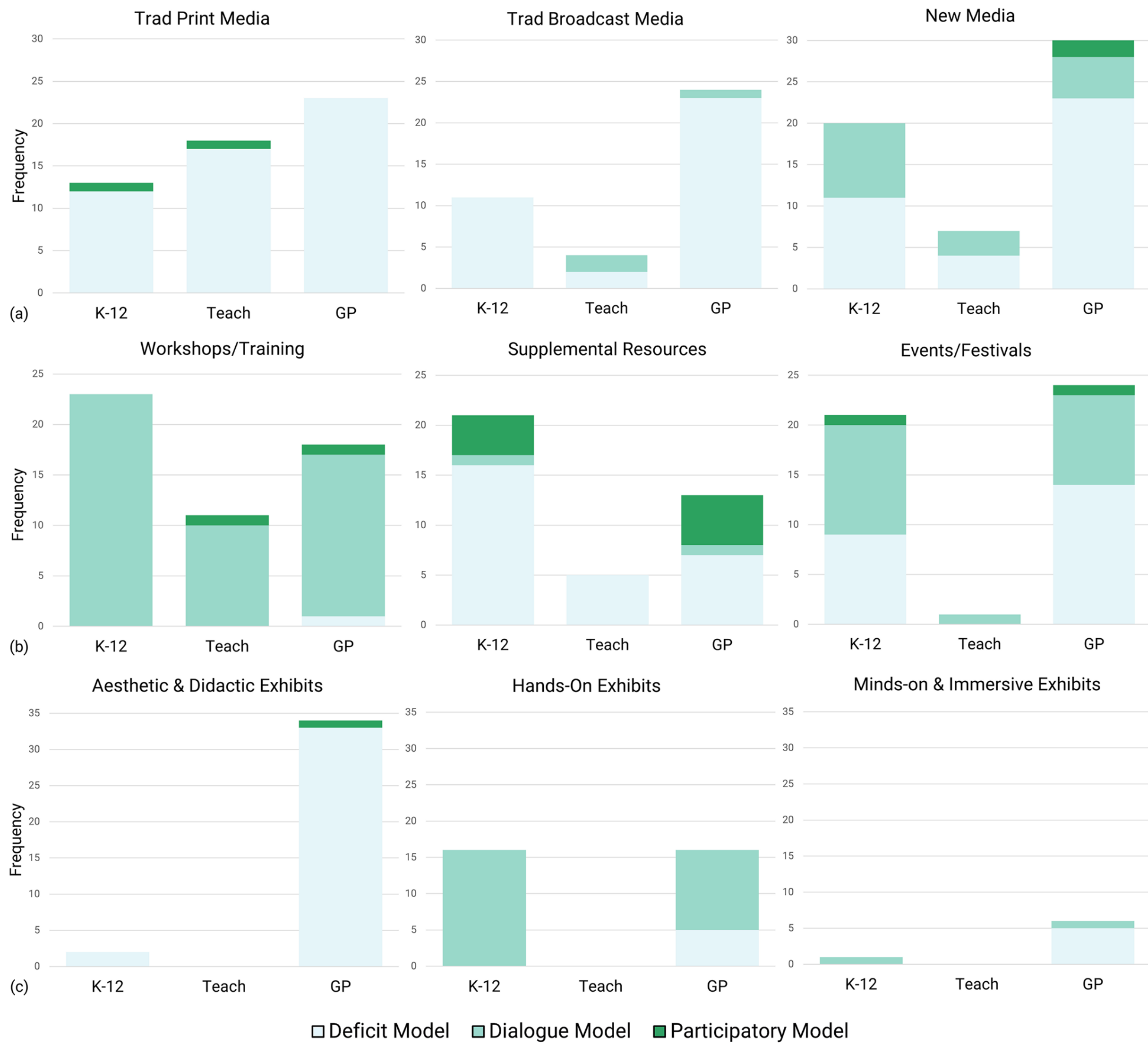

Figure 4. Frequencies (y axis) of deficit, dialogue, and participatory model activities identified in **(a)** science media, **(b)** programs for science learning, and **(c)** designed settings relative to target audiences.

5 Discussion

5.1 Deficit model persists

This study found that the deficit model accounts for 61 % of activities and 76 % of objectives coded, suggesting its persistent influence in geoscience communication practices. Despite the identification of some promising participatory activities and objectives, constituting only 5 % ($n = 19$) and 13 % ($n = 20$) of the overall practice, respectively, it is evident that the deficit model overwhelmingly predominates, agreeing with other science communication studies (e.g. Metcalfe, 2019b; Vickery et al., 2023) and geoscience communication studies (Cook and de Lourdes Melo Zurita, 2019; Stewart and Nield, 2013). Our findings may offer a broad understanding of geoscience communication practices in Canada, but they are primarily representative of British Columbia. This study does not intend to represent global geoscience communication practices or broader science communication landscapes, which are shaped by a myriad of socio-economic, geopolitical, historical, and cultural factors (Bauer et al., 2007; Gascoigne et al., 2020; Horst, 2012).

In British Columbia, we found that the deficit model is used the most when communicating with general public audiences and the least with K–12 students. In contrast, the dialogue model was used the most with K–12 students. These findings align with the notion that hands-on activities are particularly effective in engaging youth in an educational context (Kyere, 2017). In this study, participatory activities, such as citizen science, were more frequently designed for general public audiences. This observation is consistent with other

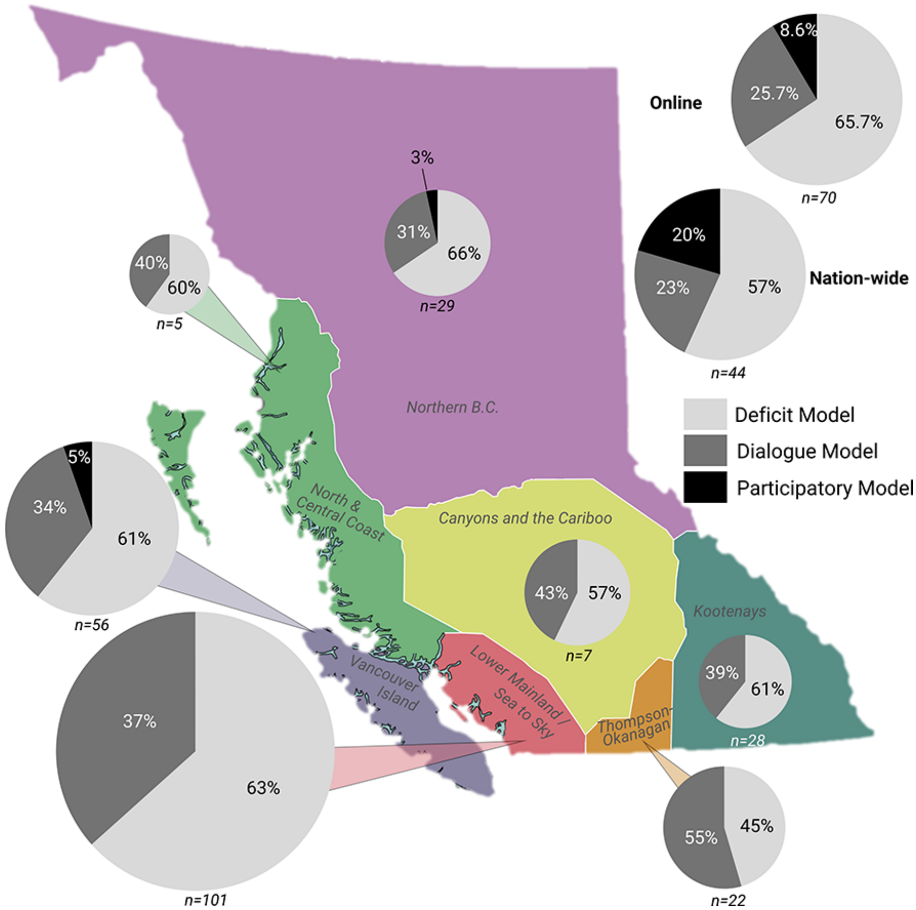

Figure 5. Map visualizing regions of British Columbia and corresponding deficit, dialogue, and participatory activities offered. Pie chart sizes are approximately proportional to the region's population. The n value corresponds to the number of recording units identified in respective regions.

research findings, highlighting the broader public as a typical audience for participatory science initiatives (Giardullo et al., 2023). Educators had limited opportunities to engage through the participatory model, and given that they regularly engage with diverse student cohorts, prioritizing participatory activities for educators could offer a promising avenue forward. However, it is essential to acknowledge that educators have specific learning outcomes required from the curriculum and other constraints (e.g. time, funding, resources) that should inform the development of suitable opportunities for them. These constraints may partially account for the prevalence of deficit and dialogue activities, where time considerations are less critical.

Programs for science learning exhibited the highest proportions of dialogue and participatory activities, constituting 63 % of all coded activities. These programs predominantly encompassed hands-on workshops and citizen science initiatives, respectively. Beyond citizen science endeavours, existing literature demonstrates the participatory model's capacity to engage diverse audiences within designed settings, as evidenced by fourth-generation science museums featuring co-created and equitable exhibits (de Oliveira and Bizerra, 2023; Pedretti and Iannini, 2020). Of the three designed settings, the finding that aesthetic and didactic exhibits were most prevalent is likely a result of the province's rich mining history, which often finds commemoration through museum exhibits and interpretive signage.

In this study, hands-on exhibits were often coded to the dialogue model, particularly when accompanied by interactive workshops and guided tours. Conversely, science media activities were predominantly coded as deficit, reflecting the inherent deficit orientation of traditional media formats (Metcalfe, 2019b). However, an amendment to the codebook facilitated the identification of additional dialogue and participatory activities within science media, underscoring the importance of contextual information in coding decisions. For example, the emergence of virtual workshops for K–12 students in new media formats, likely in response to the COVID-19 pandemic, contributed to the increased prevalence of the dialogue model in this medium. Our findings also suggest that new media formats offer more opportunities for interactive engagement than traditional media, which may ex-

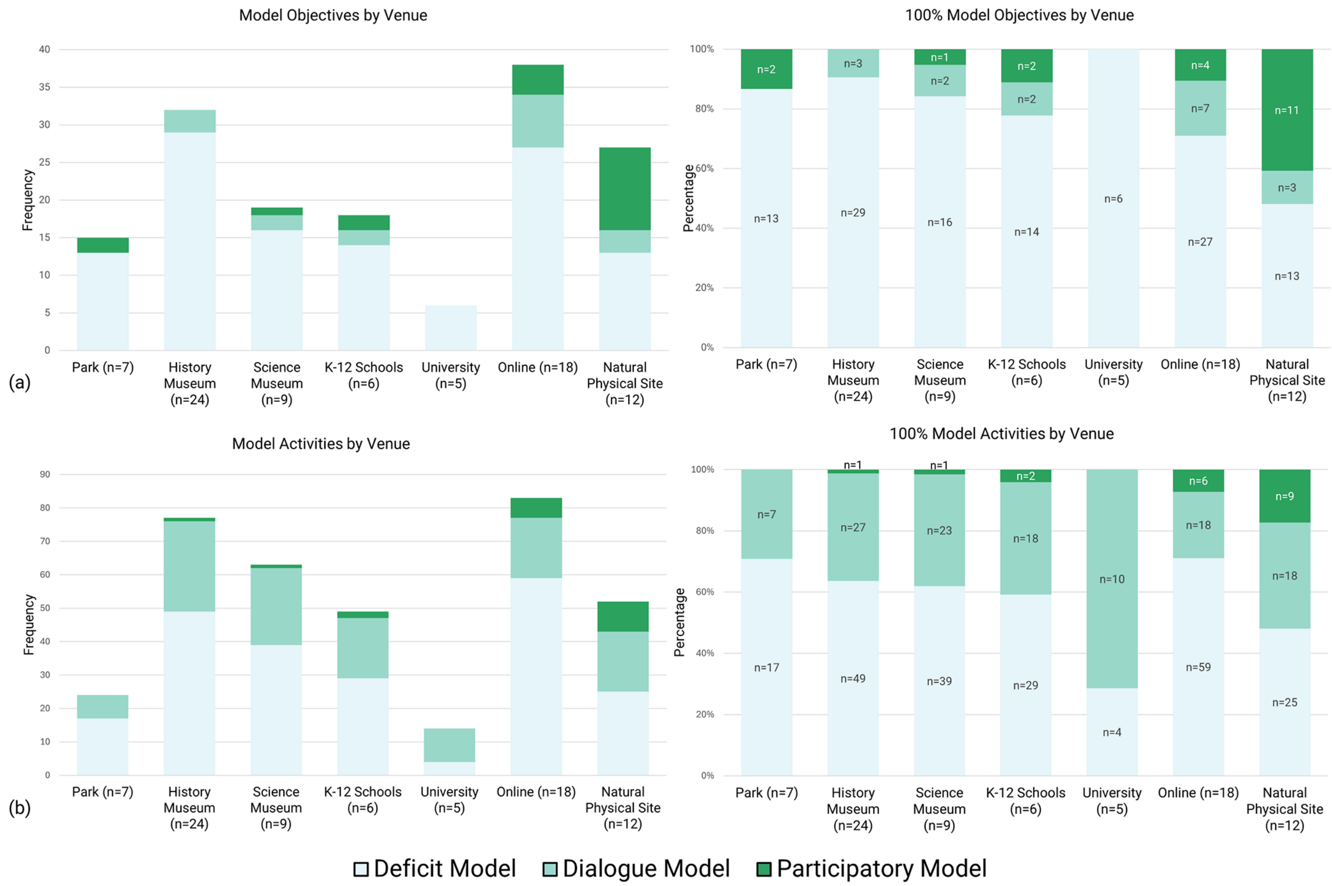

Figure 6. Respective distribution of model objectives **(a)** and activities **(b)** when communicating in select venues.

plain the higher frequency of activities coded to this category. Nevertheless, creating science media activities may be perceived as more straightforward, less time-consuming, and more cost-effective than developing activities within other mediums. These factors likely explain the high frequency of activities coded to science media relative to designed settings.

Regarding the primary geographic locations of services offered, we observed that targeted participatory activities were notably lacking. Most participatory activities originate from online-only or nationwide practitioners rather than region-specific initiatives within British Columbia. Despite an overall underrepresentation of the participatory model across all regions of British Columbia, the absence of targeted participatory activities in the Lower Mainland/Sea-to-Sky region, which boasts the highest population in the province, is particularly striking.

Across the venues analyzed, deficit model activities were most prevalent in parks and history museums, predominantly through aesthetic and didactic exhibits and traditional print media. Conversely, dialogue and participatory models were more common in natural physical sites and science museums, for which hands-on activities and citizen science programs are well suited. Our finding that the participatory model was most prevalent in natural physical sites aligns with prior research emphasizing the model's strength in facilitating place-based engagement (McEwen et al., 2022). Notably, many citizen science activities coded to the participatory model in this study were conducted at bodies of water, a pattern well documented in the literature (e.g. Brouwer and Maas, 2019). This further reinforces our understanding of natural physical sites as common venues for implementing the participatory model. This observation underscores the importance of considering different communication models' contextual relevance and effectiveness across diverse geoscience communication settings.

5.2 Misaligned objectives and activities

The data also show a misalignment between practitioners' stated objectives and the activities they design to achieve them. By misalignment, we mean model activities are not necessarily used to address corresponding model objectives. Deficit (76 %), dialogue (11 %), and participatory (13 %) objectives did not consistently translate into deficit (62 %), dialogue (33 %), and participatory (5 %) activities. While we highlight these misalignments, we do not necessarily view them as problematic, mainly when more participatory activities are used for less participatory objectives. Conversely, using less participatory activities to meet more participatory objectives may present more significant issues. For example, it is unlikely that lecturing (deficit activity) would allow practitioners to gain the public's involvement in democratic policymaking (participatory objective; Metcalfe, 2019b).

The misalignments discussed above are likely a function of multiple factors. We observed a significant misalignment when K–12 students were the target audience in that hands-on activities (coded as a dialogue activity) were often used to educate (coded as a deficit objective). While using hands-on activities to meet educational goals is a well-known pedagogical practice in formal education, the science communication models are conceptually distinct, especially when applied prescriptively through a content analysis approach. This constraint is discussed further in Sect. 6.

Regarding the overrepresentation of participatory objectives relative to activities, this could be due to (1) the comprehensive nature of many participatory activities, allowing one participatory activity to meet multiple participatory objectives, (2) a belief that deficit and dialogue activities can still achieve these objectives, and (3) a lack of science communication training and therefore understanding of the science communication models in general. Practitioners who do not understand the models are less likely to use specific model activities to meet specific objectives. Instead, they rely on already familiar practices, likely the deficit model (Simis et al., 2016).

5.3 Why does the deficit model persist?

The persistence of deficit model objectives and activities may imply that practitioners and organizations facilitating these opportunities are either unaware of participatory models, lack training in their utilization, or still prefer and prioritize the deficit model. Gascoigne et al. (2020) discuss the limited availability of science communication training in Canada, with only one master's program in Ontario and a few other universities offering courses as part of accredited programs. A recent study by Vickery et al. (2023) shared a similar objective that of to this research. Instead of quantifying the use of science communication models in geoscience communication practice, they assessed the models' utilization in science communication training for post-secondary STEM students. Through a coding process of published research on science communication training, they found that 40.7 % of the terminology reflected the deficit model, 39.5 % the dialogue model, and 19.8 % the participatory model. Comparing these results to our study, we observe a consistent trend of the participatory model being underrepresented. If the participatory model is marginalized in the training of science communicators, it follows that its representation in practice would be even further diminished. Research has demonstrated that scientists' attitudes toward communication often influence their communication practices (Besley et al., 2018; Kessler et al., 2022). For example, findings such as those reported by Calice et al. (2022), which indicate persistent deficit-oriented views of science communication, suggest that deficit activities are likely to prevail, thus providing further support for our findings. The prevalence of the deficit orientation is further accentuated by institutional structures and the model's utility for public policy purposes (Simis et al., 2016). Another consideration pertains to the challenges associated with implementing the participatory model in practice. Despite the numerous advantages of the participatory model, it is crucial to acknowledge its limitations. These initiatives are often characterized by their high costs, time-intensive processes, tendency to engage the scientifically literate, and limited reach, among other factors (Barbosa-Gómez et al., 2022; Nisbet and Scheufele, 2009; Powell and Colin, 2009). Most of the participatory activities identified in this research were associated with practitioners communicating on atmospheric science, hydrology, and oceanography, arguably having a more noticeable impact on people and everyday life. This finding aligns with existing literature, suggesting that the participatory model suits problem science rather than basic science (Callon, 1999; Metcalfe, 2019b). Simis and Madden's (2016) insights support our understanding and explore additional influences on the deficit model's persistence.

5.4 Moving forward

The shift from deficit-focused to more dialogical and participatory approaches in science communication is increasingly recognized in science and geoscience communication literature (Illingworth, 2023; Reincke et al., 2020; Stewart and Nield, 2013). A balanced integration of approaches may offer greater value rather than promoting a dichotomous perspective of these models. However, overreliance on the deficit model in geoscience communication may lead to unforeseen and potentially harmful consequences (e.g. Choi et al., 2023; Gustafson and Rice, 2016).

While a significant portion of the science communication literature portrays the deficit model in a negative light (Macq et al., 2020; Nisbet and Scheufele, 2009), others have highlighted its potential value in science communication practice (Stoker and Tusinski, 2006; Trench, 2008). For instance, Stoker and Tusinski (2006) propose that the deficit model can foster responsibility, diversity, and reconciliation. Furthermore, Trench (2008) highlights the success of Richard Dawkins through their bestselling book and other deficit-driven activities. The model's efficacy was also demonstrated in addressing the public's need for information, as exemplified during the COVID-19 pandemic (Zimmerman et al., 2024). On the other end of the spectrum, the participatory model is theorized to encourage inclusive involvement in science and democracy and build long-term relationships (Borchelt and Hudson, 2008; Schrögel and Kolleck, 2019). Recent studies, including Orthia et al. (2021), provide emerging practical evidence of the model's benefits. These studies illustrate how a co-design approach (where diverse stakeholders work together with equal power and say in an outcome) can enhance engagement and foster a sense of inclusion and shared identity. Moreover, community engagement can empower stakeholders to make informed decisions, while community partnerships can yield positive health outcomes.

Our findings indicate that deficit model communication remains prevalent in geoscience communication, while greater opportunities exist to incorporate dialogue and participatory models. To facilitate this shift, we propose several recommendations. Formal science communication training offers a promising pathway to equip practitioners with relevant and comprehensive skills (Gani et al., 2024). Training emphasizing science communication theoretical models and their practical applications could enable practitioners to pursue a broader range of objectives and activities beyond the traditional focus of the deficit model (Lewenstein and Baram-Tsabari, 2022). This would help practitioners choose appropriate approaches to meet specific communication objectives. Our content analysis revealed that practitioners often possess a simplified view of their audiences. The audience categories identified in our study (K–12 students, teachers, general public) directly reflect those listed on practitioners' websites. Providing practitioners with tools to better understand the complexities of individuals and groups could help refine their audience segmentation, leading to more targeted, relevant, and engaging communication activities for specific audiences (Lewenstein and Baram-Tsabari, 2022).

Besides training practitioners, we also believe that increasing the geographic reach of geoscience communication activities needs to be a priority for practitioners and ensuring that these activities are not just deficit activities. Focused participatory activities tailored to specific regions are likely to have a significant impact compared to online-only and nationwide initiatives. Furthermore, considering regions where geoscience intersects with the public, such as communities close to mining, oil and gas, land or water use issues, or those directly impacted by natural hazards, could enhance opportunities for targeted geoscience communication. Given that educators regularly engage with diverse student cohorts and considering the participatory model's potential for meaningful audience engagement, prioritizing participatory activities for educators could offer a promising avenue forward.

Finally, prioritizing efforts to address the barriers that hinder practitioners from implementing the participatory model, as well as the broader structural challenges of geoscience communication in Canada, is essential. Limited funding and time constraints create significant obstacles for practitioners attempting to engage in any form of geoscience communication. A comprehensive examination of these model-specific and systemic barriers would be a valuable next step to identify actionable strategies for mitigating these challenges. Such an analysis could not only help enhance the effectiveness and accessibility of geoscience communication but also highlight opportunities to expand the field's professional infrastructure and long-term success.

6 Limitations

Considerable limitations accompany this study and warrant acknowledgement. Firstly, the study was confined to publicly available websites, excluding initiatives without online presence. This decision to limit the study's scope disregards the impact of those practitioners and their offerings. Notably, social media influencers and geo-artists were excluded as a result.

The keywords used in the data search and database population may reflect biases, possibly omitting terms used in other countries. This inherently adds the possibility of certain practitioners not being included in the database in the first place. The database primarily encompasses practitioners in British Columbia, with the additional inclusion of practitioners from across Canada if they offered online resources or programs in British Columbia. While it is probable that some practitioners from Canada and British Columbia are not represented in the database, we believe that most organizations with a website presence (other than on social media), including both those with significant reach in terms of public-facing geoscience resources and those with more local and targeted reaches have been included.

Moreover, the study restricts itself to terms associated with science communication models based on Metcalfe (2019a, b). This narrow focus overlooks alternative terms linked to these models. This limitation also restricted the coding of particular resources and mediums. For example, according to the codebook, put up a display/exhibit was coded as a deficit activity, meaning every activity in designed settings and its corresponding resources should only be coded as deficit. Even with the rule to override a particular model code (if context from another model is provided, which in itself is a limitation), it is possible that the quantitative results collected were skewed toward those corresponding models.

Furthermore, concerning the coding of activities to a single model, it is probable that combinations of these models are employed in practice (Brossard and Lewenstein, 2010; Jensen and Holliman, 2016; Metcalfe, 2019b). While the science communication models serve as explicit frameworks for this research, they offer just one lens to analyze and interpret science communication practices. Many scholars have proposed continuums to capture these models' fluid and dynamic nature, recognizing that boundaries between them are often porous and subject to change (Trench, 2008). Embracing these continuums provides a more nuanced understanding of how science communication operates in real-world contexts (Metcalfe, 2019b). For instance, workshops for K–12 students typically begin with a lecture-based component followed by hands-on activities. However, in our analysis, a workshop was coded solely as a dialogue activity even though these workshops undoubtedly included deficit activities. This highlights a misalignment in categorizing activities, where the current coding scheme does not fully capture the multifaceted nature of science communication. Considering the shift from a deficit to a dialogue model, we implicitly assume that deficit model approaches primarily characterized historical geoscience communication practices. Although this study lacks a temporal dimension, we assume deficit model communication predominated in previous Canadian geoscience communication practices (e.g. Schiele, 2008).

The transformation of a continuous variable to a binary variable results in a loss of information. With this in mind, the quantitative data presented do not accurately represent all activities available. For example, if a practitioner had four books on different topics, this would only be coded once. It was often observed that this limitation occurred with deficit activities, potentially resulting in an underrepresentation of the deficit model. Although intercoder reliability on proposed categories is typical of numerous studies (Krippendorff, 2004), it was not conducted as part of the content analysis in this research.

Significantly more training would be necessary for the second coder to assess the suitability of applied categories, and with budgetary constraints, this was not deemed feasible. Coder 2's limited knowledge of science communication models was a significant constraint in achieving significant levels of intercoder reliability. Another limitation arose with the database structure when performing intercoder reliability tests. For instance, a website was coded with three participatory objectives by one coder but only two participatory objectives by the other coder. When discrepancies like this (via tie-breaker) are resolved, the external coder can only be guided by the qualitative data for the code of interest. Even if that code was applied already by the other coder under one of the two other columns for participatory objectives, it could still get coded again (if the external agreed), thus overrepresenting the coded model of interest. Lastly, the external expert, serving as the supervisor of Coder 1 (the lead researcher), may have been influenced in their perspectives on models due to their interactions with the lead researcher.

7 Conclusions

Findings from our content analysis of geoscience communication objectives and activities in British Columbia suggest that the deficit model persists, while the participatory model is significantly underrepresented in practice. Therefore, the shift from deficit to dialogue commonly referenced in science communication literature has not been reflected in geoscience communication practice, particularly in the context of British Columbia, Canada.

We theorize that the misalignments we identified between practitioners' objectives and activities may result from adherence to conventional objectives or a lack of formal training in science communication theories. Regarding the target audience, the deficit model is predominantly used for communicating with the general public, while the dialogue model is primarily employed for K–12 students. Few participatory model activities were offered for educators, indicating a significant opportunity for future work.

While limitations with the terms used to code activities in designed settings may have overemphasized the deficit model, it is evident that these settings predominantly host deficit and dialogue activities. Programs for science learning exhibited the highest proportions of dialogue and participatory activities, whereas deficit activities dominated science media.

From an accessibility standpoint, participatory activities are greatly underrepresented across British Columbia. Many participatory offerings were part of Canada-wide or online-only initiatives. We hypothesize that these would have less impact than targeted, community-specific, participatory programming; therefore, future practice has room for improvement. Lastly, concerning the venues where communication occurs, it was evident that parks (e.g. national, provincial, and UNESCO Global Geoparks) were dominated by deficit model communication, while natural physical sites (e.g. bodies of water and backyards) provided greater opportunities for dialogue and participatory model activities.

The above findings provide a theoretical framework for further research and practice in geoscience communication. Additionally, they highlight areas for increased attention moving forward, such as training for practitioners, which can enhance geoscience communication offerings. There are numerous opportunities to expand on the research findings presented here. For example, evaluating and assessing the impact of geoscience communication practice could lead to more effective communication strategies. Furthermore, understanding how institutional/organizational factors, resource allocations, audience perceptions, virtual versus in-person programming, and cultural/contextual factors relate to using particular science communication models would be valuable avenues for future research.

Appendix A

Table A1. Table of intercoder reliability statistics between Coders 1 and 2 for science communication activities for the reliability sample. Categories with an undefined or 1.00 statistic indicate no data were coded to this category.

Resource	Audience	Model activities	Prevalence	Observed agreement	Gwet's AC1	Cohen's kappa	Krippendorff's alpha
Traditional print media	K–12 students	Deficit	0 %	0.83	0.79	−0.04	−0.09
		Dialogue	0 %	1.00	1.00	undefined	undefined
		Participatory	0 %	1.00	1.00	undefined	undefined
	Teachers	Deficit	0 %	0.77	0.70	−0.05	−0.13
		Dialogue	0 %	0.99	0.99	0.00	0.00
		Participatory	0 %	0.99	0.99	0.00	0.00
	General public	Deficit	14 %	0.83	0.74	0.52	0.50
		Dialogue	0 %	0.96	0.96	0.00	−0.01
		Participatory	0 %	0.96	0.96	0.00	−0.01
Traditional broadcast media	K–12 students	Deficit	0 %	0.86	0.84	0.00	−0.07
		Dialogue	0 %	1.00	1.00	undefined	undefined
		Participatory	0 %	1.00	1.00	undefined	undefined
	Teachers	Deficit	1 %	0.96	0.96	0.38	0.38
		Dialogue	0 %	0.96	0.96	−0.02	−0.01
		Participatory	0 %	0.99	0.99	0.00	0.00
	General public	Deficit	5 %	0.73	0.61	0.17	0.11
		Dialogue	0 %	0.98	0.97	−0.01	−0.01
		Participatory	0 %	1.00	1.00	undefined	undefined
New media	K–12 students	Deficit	0 %	0.86	0.84	0.00	−0.07
		Dialogue	0 %	0.90	0.89	−0.02	−0.05
		Participatory	0 %	0.99	0.99	0.00	0.00
	Teachers	Deficit	0 %	0.93	0.92	−0.03	−0.03
		Dialogue	0 %	0.96	0.96	0.00	−0.01
		Participatory	0 %	0.99	0.99	0.00	0.00
	General public	Deficit	4 %	0.74	0.64	0.09	0.07
		Dialogue	1 %	0.89	0.87	0.15	0.13
		Participatory	1 %	0.94	0.93	0.26	0.26
Workshops/ training	K–12 students	Deficit	0 %	0.99	0.99	0.00	0.00
		Dialogue	7 %	0.79	0.70	0.34	0.29
		Participatory	0 %	0.88	0.86	0.00	−0.06
	Teachers	Deficit	0 %	0.94	0.93	0.00	−0.03
		Dialogue	5 %	0.88	0.85	0.38	0.38
		Participatory	0 %	0.94	0.93	−0.02	−0.03
	General public	Deficit	0 %	0.95	0.95	0.00	−0.02
		Dialogue	4 %	0.77	0.68	0.16	0.11
		Participatory	0 %	0.89	0.88	0.00	−0.05
Supplemental resources	K–12 students	Deficit	0 %	0.83	0.79	0.00	−0.09
		Dialogue	0 %	0.95	0.95	−0.02	−0.02
		Participatory	0 %	0.95	0.95	0.00	−0.02
	Teachers	Deficit	1 %	0.95	0.95	0.32	0.31
		Dialogue	0 %	0.99	0.99	0.00	0.00
		Participatory	0 %	1.00	1.00	undefined	undefined
	General public	Deficit	1 %	0.89	0.87	0.15	0.13
		Dialogue	0 %	0.94	0.93	−0.03	−0.03
		Participatory	5 %	0.93	0.91	0.53	0.53

Table A1. Continued.

Resource	Audience	Model activities	Prevalence	Observed agreement	Gwet's AC1	Cohen's kappa	Krippendorff's alpha
Festivals/ events	K–12 students	Deficit	0 %	0.88	0.86	−0.02	−0.06
		Dialogue	0 %	0.88	0.86	−0.02	−0.06
		Participatory	1 %	1.00	1.00	1.00	1.00
	Teachers	Deficit	0 %	1.00	1.00	undefined	undefined
		Dialogue	0 %	0.99	0.99	0.00	0.00
		Participatory	0 %	1.00	1.00	undefined	undefined
	General public	Deficit	0 %	0.83	0.79	−0.06	−0.09
		Dialogue	0 %	0.90	0.89	0.00	−0.05
		Participatory	0 %	0.99	0.99	0.00	0.00
Aesthetic and didactic	K–12 students	Deficit	0 %	0.94	0.93	−0.03	−0.03
		Dialogue	0 %	1.00	1.00	undefined	undefined
		Participatory	0 %	1.00	1.00	undefined	undefined
	Teachers	Deficit	0 %	1.00	1.00	undefined	undefined
		Dialogue	0 %	1.00	1.00	undefined	undefined
		Participatory	0 %	1.00	1.00	undefined	undefined
	General public	Deficit	20 %	0.75	0.56	0.46	0.44
		Dialogue	0 %	0.98	0.97	0.00	−0.01
		Participatory	0 %	0.96	0.96	0.00	−0.01
Hands-on	K–12 students	Deficit	0 %	1.00	1.00	undefined	undefined
		Dialogue	5 %	0.86	0.83	0.36	0.35
		Participatory	0 %	0.98	0.97	−0.01	−0.01
	Teachers	Deficit	0 %	0.98	0.97	0.00	−0.01
		Dialogue	0 %	0.98	0.97	0.00	−0.01
		Participatory	0 %	0.96	0.96	0.00	−0.01
	General public	Deficit	1 %	0.90	0.89	0.15	0.15
		Dialogue	0 %	0.89	0.88	0.00	−0.05
		Participatory	0 %	0.88	0.86	−0.02	−0.06
Minds-on and immersive	K–12 students	Deficit	0 %	0.99	0.99	0.00	0.00
		Dialogue	0 %	0.96	0.96	0.00	−0.01
		Participatory	0 %	0.99	0.99	0.00	0.00
	Teachers	Deficit	0 %	1.00	1.00	undefined	undefined
		Dialogue	0 %	1.00	1.00	undefined	undefined
		Participatory	0 %	1.00	1.00	undefined	undefined
	General public	Deficit	4 %	0.95	0.94	0.58	0.58
		Dialogue	0 %	0.95	0.95	0.00	−0.02
		Participatory	0 %	0.99	0.99	0.00	0.00

Data availability. The datasets and the codebook used for this study are published on the Federated Research Data Repository (https://doi.org/10.20383/103.01186, Onstad, 2025). The database with sampling units used as the basis for the content analysis can be made available by the authors upon request.

Author contributions. CCO and EvdFK completed the co-conceptualization of this research. Data curation/analysis and writing of the paper were performed by CCO. Review, editing, and supervision was undertaken by EvdFK.

Competing interests. The contact author has declared that none of the authors has any competing interests.

Ethical statement. The work performed in this study is original, reflects the authors' understanding, and does not require the involvement of human research participants.

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