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Science communication in unexpected places

ARTICLE

Cultural and communicative pathways in grassroots science and innovation: field research learnings from under-resourced rural India

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Abstract

This article examines grassroots innovation in under-resourced regions of rural India, where science communication emerges through culturally resonant and locally grounded practices in informal settings. Drawing on fieldwork with youth and students in underserved communities, the study foregrounds human ingenuity and participatory engagement that organically co-create context-specific solutions. Challenging linear, expert-driven paradigms, it advances a community-centered framework and highlights the potential of informal contexts — marked by linguistic diversity, trust deficits, and infrastructural limitations — to foster alternative modes of science communication. Informed by Indigenous methodologies and decolonial insights, the research critiques top-down models of knowledge transfer and advocates for inclusive, dialogic, and place-based approaches. Integrating insights from communication, cultural, and design studies, the article positions science communication as an equitable and co-creative process. By centering marginalized voices and alternative epistemologies, it reimagines science engagement as a transformative and empowering practice that connects scientific inquiry to lived experience in unexpected yet vital ways.

Keywords

Decolonising science communication; Science communication in the developing world; Public engagement with science and technology

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1 ▪ Introduction

This article explores grassroots science and innovation in under-resourced rural contexts through cultural and communicative perspectives. Moving beyond linear, top-down models of technology transfer and innovation diffusion, it adopts a participatory, community-centered grassroots innovation approach grounded in Indigenous methodologies and decolonial insights [Chilisa, 2019]. It demonstrates how local and Indigenous knowledge, creativity, and ingenuity generate sustainable, cost-effective solutions rooted in human agency, self-reliance, and contextual relevance. Integrating insights from science communication, design studies, and communication for social change, the study reimagines communication of science as equitable, dialogic, and culturally grounded.

The paper is motivated by an urgent need to revalue the communicative dimensions of science communication [Druckman et al., 2025] and innovation in the Global South — especially in spaces marked by extreme poverty, geographic isolation, caste-based discrimination, and the erosion of indigenous knowledge systems. The broader relevance of this study lies in its redefinition of "innovation" as a socially embedded and culturally mediated process by challenging dominant assumptions about where science happens and who its legitimate actors are.

Drawing on field research across four rural regions in India with youth and students, this study examines grassroots innovations[1] that emerge amid geographic isolation, resource scarcity, and infrastructural challenges, alongside sociocultural barriers such as trust gaps, literacy divides, linguistic diversity, and political marginalization [Canfield & Menezes, 2020; Kang, 2016]. The communities under study experience severe economic constraints, often earning less than USD 1.00 per day, and face limited access to education, systemic neglect, and social exclusions, including caste-based untouchability and discrimination [Chanchal & Lenka, 2023]. Additionally, the erosion of traditional knowledge and environmental stressors further shape the fragile landscape in which grassroots science and innovation emerge in these under-resourced rural contexts [Singh et al., 2022].

The findings underscore the need for culturally resonant and community-engaged methodologies. Integrating science communication with critical cultural perspectives, the evidence-based study shows how locally developed solutions bridge gaps between scientific knowledge and public engagement, positioning science as a co-creative and accessible endeavor [Jensen & Gerber, 2020; Newman et al., 2024].

Informed by field learnings, the paper advances a local-centric human ingenuity perspective that critiques top-down models of knowledge production, which often marginalize local perspectives [Bjögvinsson et al., 2012], and thereby promotes people-centered approaches that legitimize place-based knowledge and enable transformative interventions.

This study contributes to existing scholarship by advocating creative, community-led engagement specifically tailored to under-resourced and disenfranchised rural contexts in India and most South Asia. Challenging expert-centric models [U. Dutta, 2019], it advances culturally informed, decentralized strategies that empower marginalized voices and recognize

1. Grassroots innovation refers to locally driven problem-solving and inventive practices emerging from underserved communities, often outside formal institutions. Rooted in experiential knowledge and necessity, these innovations reflect creativity, autonomy, and context-specific adaptation grounded in local culture and everyday challenges [Kumar & Namrata, 2024].

diverse epistemologies. Drawing on detailed field-based insights, the research empirically demonstrates how communities facing extreme poverty, limited formal education, and systemic neglect mobilize local knowledge, social networks, and intermediaries to co-create inclusive spaces for scientific practice and grassroots innovation. By reconceiving science communication as a collaborative and participatory process [Metcalfe et al., 2022], this work highlights how communication functions both as a resource and a catalyst for community-driven problem-solving in resource-constrained settings.

The article situates these arguments within the broader landscape of informal science communication. It begins with a review of relevant literature representing interdisciplinary perspectives, explores contextual realities and challenges faced by marginalized communities [Dawson et al., 2022], describes field processes and four illustrative cases, and concludes with reflexive insights and implications for reimagining science communication from the margins.

2 ▪ Literature review

2.1 ▪ *Critiques of one-way science communication*

Conventional science communication often relies on one-way information transfer, wherein knowledge flows unidirectionally from experts to lay audiences, often without fostering genuine dialogue or engagement [Biermann et al., 2025; Stocklmayer & Rennie, 2017]. The "deficit model," assuming a lack of scientific literacy among laypeople, has been critiqued for its externally-driven paternalistic orientation and failure to acknowledge the diverse perspectives and lived experiences of various communities and cultural contexts [Wang, 2025]. In contrast, dialogic and participatory approaches, valuing situated needs, belief systems, forms of knowledge, advocate for co-creation of knowledge between science and society, fostering trust, inclusion, and mutual learning [Falk et al., 2011; Momme et al., 2025]. Science communication also reproduces disciplinary and institutional hierarchies that privilege Eurocentric norms while erasing Global South voices [Chakravartty et al., 2018; Rasekoala, 2023]. Re-centering plural epistemologies challenges these hierarchies and creates room for equitable knowledge exchange.

Combining an Indigenous studies framework with decolonial insights offers a robust and complementary foundation for examining grassroots science and innovation in under-resourced rural India. Both perspectives challenge colonial epistemic dominance and resist Eurocentric universalism [M. Dutta et al., 2021] by centering pluralism, community-driven knowledge, and participatory, non-extractive research methods. While the decolonial approach interrogates structural inequalities and global power hierarchies, Indigenous perspectives foreground lived experiences, local epistemologies, and ethical reciprocity. Indigenous scholars have critiqued conventional "scientific research" and "science communication" for perpetuating epistemic violence [Smith, 2012], advocating instead for community ownership and alignment with local values. For studies of grassroots innovation in rural India, the synergy between these two approaches — where decolonial critique illuminates what must change and Indigenous epistemologies guide how to change — proves especially valuable for research that seeks not merely to analyze but to co-create sustaining, justice-oriented solutions with communities.

2.2 ▪ *Reimagining science communication in informal settings*

Informal science communication redefines how science is practiced and shared beyond formal institutions. It foregrounds meaningful, community-based learning that occurs across everyday settings — homes, marketplaces, or community centers [Diamond & Rosenfeld, 2023]. This approach integrates insights from science, social sciences, and the arts [Stocklmayer & Rennie, 2017], reframing science as an inquiry-driven, transformative practice [Pandya et al., 2025].

The Public Engagement with Science (PES) framework marks a shift toward dialogue, reflexivity, and co-production, replacing passive dissemination with collaborative knowledge-building [Potochnik & Jacquart, 2025]. In the Global South, scholars emphasize participatory and context-sensitive approaches to science communication, critiquing top-down, expert-driven models that overlook local knowledge and linguistic diversity. Valdez-Ward et al. [2024] calls for culturally grounded community narratives, while Marsh et al. [2023] stresses the inclusion of regional languages and diverse voices. Together, these perspectives advocate for a more equitable and responsive science communication paradigm — one that values local epistemologies, amplifies marginalized perspectives, and fosters genuine co-production between communities and institutional scientific practices.

2.3 ▪ *Communication and science engagement*

In doing so, the paper underscores the relevance of human communication not merely as a tool of dissemination but as a transformative social practice that builds trust, and nurtures co-creative processes across cultural and epistemic divides in informal contexts. Critical intercultural communication frameworks enable dialogue across worldviews and bridge structural and cultural/communicative barriers that limit participation [U. Dutta, 2018]. Structural constraints — including limited resources, inadequate infrastructure, and technological disparities — often hinder access to informal science learning [McCallie et al., 2009]. Equally significant are communicative challenges, such as language barriers, varying literacy levels, educational inequities, skepticism toward scientific information, and culturally rooted attitudes, all of which influence how science is conveyed, interpreted, and acted upon in everyday life. The dominance of English further restricts inclusivity, often marginalizing non-English-speaking populations and Indigenous knowledge systems [Márquez & Porras, 2020]. Empathetic and participatory communication practices — active listening, open dialogue, and amplifying community voices — counter deficit-based narratives and foster equitable and inclusive participation [Mazzurco & Jesiek, 2017]. Such communicative ethics transform science communication into a relationship-based and socially responsive practice.

2.4 ▪ *Insights from design studies and humanitarian innovation*

Furthermore, insights from design studies enhance informal science engagement by promoting cross-disciplinary participation and co-creation [Enzingmüller & Marzavan, 2024]. Through iterative and dialogic processes, design transforms communities from subjects of intervention to co-producers of knowledge [McMahon & Bhamra, 2015]. Critical and social design perspectives interrogate underlying power structures and position design as a catalyst for social change [Moritz, 2005]. The social turn in design thinking reframes communities as co-producers, emphasizing shared ownership and reflexive dialogue [Dunne & Raby, 2013].

Similarly, humanitarian engineering and innovation frameworks emphasize co-defining problems, building local capacity, and fostering self-reliance rather than imposing external solutions. These approaches resonate with the understanding that we inhabit a society where everybody designs [Manzini, 2014], positioning community members as active agents of innovation [Colledge, 2012] and aligning scientific engagement with goals of sustainability, equity, and resilience.

2.5 ▪ *Methodological and applied aspects*

Participatory methodologies such as public engagement and participatory action research embed science communication within community contexts, involving participants in co-creation and evaluation [Gould et al., 2023]. Innovation and design thinking tools — collaboration, iteration, and visualization — support inclusive and user-centered participation [Enzingmüller & Marzavan, 2024].

Informal science communication thereby becomes action-oriented, situating learning within lived experiences and aspirations. Spaces such as community labs and makerspaces enable experimentation and iterative learning through hands-on engagement [Chick & Micklethwaite, 2011]. These user-driven processes empower participants to move from passive consumption to active co-creation.

While this research resonates with the principles of approaches such as Community-Based Participatory Research (CBPR) — notably participation, co-learning, and shared ownership of knowledge — it departs in its epistemological focus and practical orientation. The study highlights communicative pathways of innovation, ingenuity, and material improvisation in contexts of scarcity, advancing a communication-centered and culturally attuned model of grassroots innovation. It shows how communities co-create knowledge and innovate organically through informal, situated, and iterative practices beyond formal research frameworks.

Embracing a transdisciplinary essence, this study integrates Indigenous perspectives, decolonial insights, and participatory methodologies to examine grassroots science and innovation in under-resourced rural contexts. Guided by participatory action research (PAR) principles, the research prioritized community-led engagement, positioning participants as co-researchers, evaluators, and local knowledge holders throughout all stages. Drawing on insights from design studies and humanitarian innovation, the research recognizes that creativity, imagination, inquisitiveness often arises under material and infrastructural constraints. Also, informed by principles of communication for social change, the study situates communication as a relational and dialogic process rooted in trust, cultural sensitivity, and everyday interaction. The approach emphasized informal science communication, using locally resonant languages, storytelling, and participatory demonstrations to foster trust, engagement, and iterative learning. Building on the preceding theoretical and methodological insights, this study conducted in rural India advances empirical understanding of grassroots innovation processes that unfold amid social hierarchies, infrastructural constraints, and epistemic exclusions.

The article offers a field-immersive account of grassroots innovation in under-resourced regions of Global South — where participants with limited educational access, and face intersecting barriers of caste, class, and geography and structural constraints such as

untouchability, patriarchal restrictions, limited education, and environmental adversity. Empirically, the paper illustrates how communities innovate despite near-total infrastructural absence — no incubators, science networks, or procurement channels — and with minimal seed capital.

Accordingly, the following research questions guide this inquiry:

RQ1: How do dialogic, participatory, and culturally grounded communicative strategies — together with local epistemologies and intermediary actors — facilitate community-led grassroots innovation and the co-creation of inclusive spaces for marginalized groups?

RQ2: How do communities innovate with limited resources amid structural constraints (poverty, limited formal education, infrastructural gaps) and socio-cultural hierarchies (caste, class, gender, local power relations)?

RQ3: What community-centered processes and mechanisms — such as public engagement, informal learning, and in-situ ingenuity — enable communities to build context-appropriate innovation ecosystems despite systemic neglect?

3 ▪ Context

3.1 ▪ *Science communication and informal science education in rural India*

Science communication and informal science education in rural India have relied on a diverse array of participatory and culturally embedded avenues, such as print materials, community radio, performances (e.g., folk performances, theater, puppet shows), traveling exhibitions, and hands-on demonstration activities, to spark curiosity, enhance scientific exposure, and foster awareness among rural and marginalized populations [Malik & Dhiman, 2022]. Many of these efforts have been facilitated by governmental and non-governmental organizations (NGOs) and voluntary science communication networks that develop outreach models for training teachers, youth leaders, and community volunteers. Although these programs often take place in and around schools, some have successfully extended to community spaces, enabling broader inclusion. However, challenges persist — ranging from uneven training quality, short engagement durations, and inadequate funding to infrastructural limitations and restricted geographic coverage [Patairiya, 2016]. While recent years have witnessed the introduction of digital and online avenues for science learning, their reach and effectiveness remain limited due to connectivity and infrastructural gaps, economic disparities, and linguistic diversity in rural India. Collectively, these conditions underscore the need for context-sensitive, dialogic, and sustained models of science communication that align with local epistemologies and community practices in rural India.

3.2 ▪ *Field contexts and realities*

This study examines grassroots science and innovation in under-resourced rural regions of West Bengal, Maharashtra, Mizoram, and Arunachal Pradesh, based on multi-year fieldwork across India. These culturally diverse regions- with more than 450 tribal languages [Das, 2024] - sustain rich traditional knowledge systems[2] and demonstrate community-driven resilience, creativity, and ingenuity amid persistent adversity [Yerramilli, 2025].

2. Traditional Knowledge Systems (TKS) are cumulative bodies of knowledge, practices, and innovations developed and transmitted across generations within specific communities. Rooted in local culture, spirituality, and lived

Many of the communities studied operate under conditions of acute poverty, with daily incomes often falling below USD 1.00 per person. Such economic precarity significantly limits access to scientific materials, infrastructure, and opportunities for experimentation [Prajapati, 2023]. Field observations revealed that formal education in these regions is frequently confined to the elementary level, with high dropout rates driven by situational and familial pressures — such as the necessity of contributing to household labor or migrating in search of livelihoods. The scarcity or complete absence of modern technology and formal scientific resources perpetuates structural inequities and obstructs the development of scientific engagements.

Participants primarily belonged to Indigenous tribal communities, including the Santhal, Korku, Mara, and Adi (Abor) communities, with some representation from Dalit families. In the sites located in West Bengal and Maharashtra, participants attended from multiple neighboring villages, whereas the field sites in Arunachal Pradesh and Mizoram involved participants from a single village, owing to the regions' geographic remoteness and limited transportation infrastructure. These contextual variations underscored the significance of place-based realities in shaping community-led scientific activities.

Along with geographic remoteness, the systemic neglect further compounds these challenges. Moreover, investments in science and innovation within these underserved regions are minimal or nonexistent, while institutional support structures — such as incubators, procurement mechanisms, and seed funding — remain largely unavailable [Bhaduria, 2023]. Beyond infrastructural constraints, entrenched social exclusions, including caste-based discrimination and the marginalization of Indigenous groups, continue to impede participation in knowledge creation. The erosion of traditional knowledge and Indigenous technologies has further endangered local epistemic systems that once sustained community resilience and innovation, threatening the cultural identity of rural communities [Gual & Das, 2025].

Again, environmental stressors, including climatic variability, soil degradation, and access to water, exacerbate the precarity of scientific engagement. Both material and communicative barriers are pervasive: limited access to infrastructures (incl. transportation and electricity), tools and materials intersects with linguistic and literacy divides, producing layered challenges for science communication and collaboration [Sindakis & Showkat, 2024]. Linguistic and cultural diversity shape grassroots science and innovation in rural India, where hundreds of languages — many without written scripts — limit access to scientific knowledge, which is often shared in Hindi or English. Low literacy (41% illiteracy among Indigenous people as per census) rates further widen this gap, distancing communities from formal science [Registrar General and Census Commissioner of India, 2011].

Equally vital is trust: historical exploitation and top-down interventions fostered skepticism toward external actors and top-down interventions. Building meaningful engagement thus requires sustained, transparent collaboration that values local knowledge, supports community-led initiatives, and is sensitive to existing power dynamics, social hierarchies, and cultural norms.

This context offers a critical entry point to examine how grassroots innovation, rooted in indigenous knowledge and practices, can generate sustainable, context-specific solutions.

experience, TKS guide sustainable ways of interacting with the environment and social life [Berkes, 2017].

4 ▪ Fieldwork

4.1 ▪ *Fieldwork preparation and community engagement*

The groundwork for the research project was rooted in building relationships with local communities and organizations through a culturally sensitive and dialogic approach. Initial outreach involved contacting academic institutions and non-governmental organizations via telephone and email to communicate the research objectives and seek guidance and support. These early exchanges established trust and facilitated access to local communities.

Following affirmative responses from community representatives, the research team visited the communities in person. These visits enabled face-to-face introductions with community members and situated the research within their lived experiences. The project team presented its objectives in an accessible and participatory manner, creating a conversational environment where community members could share their expectations, concerns, and suggestions. This dialogic process framed the research as a collaborative endeavor grounded in mutual respect.

During fieldwork, I spent a minimum of four weeks at each research site, residing primarily within village peripheries and integrated into the rhythms of daily life to closely observe and engage with local practices. Through shared meals, conversations, and routines, a foundation of relational trust was cultivated. All innovation and science communication activities took place in situ, emerging through everyday interactions and community-led initiatives.

To support the fieldwork and encourage participatory engagement, the project recruited interns and local volunteers. Key community members, including seniors, educated youths and teachers, served as facilitators and cultural mediators, bridging academic goals and local realities. Concurrently, internship opportunities were shared through university mailing lists and academic networks in India, emphasizing experiential learning and ethical fieldwork. Shortlisted applicants were interviewed to assess their commitment to community-based research.

The research was designed by the corresponding author, who contributed to all phases of the project. Research assistants affiliated with Indian universities, played a central role in data collection and the facilitation of field research activities. Following data collection, research assistants in post-fieldwork phase contributed to the processes of data analysis and interpretation of findings. Importantly, senior community members actively participated in collaboratively evaluating and validating the relevance and effectiveness of the research outcomes.

A total of 108 participants from four regions of rural India took part in the study, comprising 56 males and 52 females between the ages of 12 and 25 years. Of these, 28 participants had discontinued formal schooling, 51 were currently enrolled in school, and 29 had completed higher secondary education (Grade 12) or above. For participant recruitment, public announcements about the research initiative were shared through informal, locally resonant channels such as word of mouth, home visits, and telephone conversations led by community volunteers. Posters written in the local language were displayed in public spaces — schools, marketplaces, and community centers — ensuring visibility and accessibility. These culturally grounded communication strategies played a vital role in generating interest, fostering participation, and embedding the project within everyday community life. All interactions and discussions were conducted in participants' native languages and regional dialects.

4.2 ▪ *Fieldwork phases in informal science engagement*

Fieldwork was conducted in six structured yet adaptable phases designed to promote grassroots innovation and community engagement in informal science settings. The approach emphasized collaborative learning, hands-on experimentation, and democratized problem-solving, positioning science as an accessible and meaningful part of daily life.

Phase one — workshop and foundational learning. The fieldwork began with a hands-on workshop introducing participants to fundamentals to design thinking and problem-solving. Invitations were extended personally or via telephone, and attendees joined a two- to three-day session. Inclusive and accessible participation was ensured through provision of breakfast, lunch, and all necessary materials. Core modules covered basics of design processes, principles of innovation, and context-specific problem-solving strategies, illustrated through accessible case studies and videos from institutions such as India's National Innovation Foundation (NIF), India. Interactive activities — such as building structures with sticks, soil, and plastic — encouraged creativity and use of local resources. Participants also gathered local materials, engaged in critical discussions about their uses and potential alternatives, and took part in group brainstorming exercises aimed at identifying and articulating everyday challenges within their communities. These initial activities laid the groundwork for preliminary solution ideation and development.

Phase two — local problem identification and immersive engagement. Following the workshop, participants identified at least three local challenges they personally faced. While most returned to the workshop site to refine ideas, the research team sometimes visited participants' communities to deepen engagement and understandings. This phase was designed to enhance contextual awareness and strengthen the connection between scientific knowledge and participants' experience. Emphasis was placed on selecting problems familiar to participants, ensuring relevance and authenticity in the innovation process, laying a foundation for meaningful co-creation rooted in lived realities.

Phase three — team formation. Participants then formed teams to collaboratively develop solutions. Team formation was guided by social and logistical considerations — participants often grouped with others addressing similar or overlapping challenges or nearby neighbors for ease of collaboration. In some cases, geographical proximity played a decisive role, as working with neighbors or those living nearby allowed for greater continuity and ease of collaboration. Gender dynamics also influenced team composition, with some participants choosing to form gender-specific teams for reasons of convenience, safety, or prevailing social and cultural norms. Importantly, participation was open — any community member could join a team or initiate one, regardless of whether they attended the original workshop, community-driven approach to science engagement.

Phase four — ideation and collaborative refinement. In this phase, teams generated ideas and explored multiple approaches, regardless of whether their ideas were fully developed or still emerging. The facilitation team played an active role in these ideation sessions, offering targeted feedback and research support to guide the problem-solving process. They oftentimes shared global examples of low-cost, locally adapted solutions that tackled similar challenges using context-specific resources. These discussions, iterations and collective reflection helped teams refine ideas and develop feasible prototypes. For example, several models of the community fertilizer unit, varying in size and shape, were proposed for both single-family and multi-family use as alternative options. To design a

manual weed-cutting device, several options were explored to determine the appropriate materials, length, and blade angle. All costs were covered, and participants received financial incentives in the form of prize money or tokens of appreciation, towards removing economic barriers and reinforcing the value of community-driven innovation.

Phase five — prototyping. With solution ideas finalized, participants advanced to the prototyping phase. Teams started to building tangible prototypes, collaborating with local artisans, craftspeople, and research facilitators. This phase integrated new skills with indigenous knowledge and traditional craftsmanship, highlighting the initiative's collaborative ethos. We offered continuous mentorship, technical guidance, and moral support, while also documenting the innovation journey. This phase provided valuable insights into participants' creative processes, supported material selection and fabrication, and helped identify implementation challenges.

Phase six — public presentation and demonstration. Four to five weeks after the initial workshop, participants reconvened for a public event to present their innovations. These gatherings served as moments of recognition and learning as well as platforms for public science communication. Participants showcased their prototypes, articulating the problems they addressed, the solutions they devised, and the iterative processes that informed their final designs. These events provided participants with the opportunity to communicate their work to peers and community members, fostering broader community engagement and recognition. In doing so, they helped position science and innovation as relevant, accessible pursuits in everyday life.

5 ▪ Examples from the field

The following examples illustrate how science communication emerges in informal settings through everyday problem-solving in under-resourced contexts. Each highlights youth- and student-led innovations that address urgent environmental, health, and infrastructural challenges using culturally resonant and resource-efficient approaches. Collectively, they underscore the transformative potential of science engagement beyond formal institutional frameworks.

5.1 ▪ *Community fertilizer: a waste-to-compost initiative*

In a remote village without formal waste management, household waste often accumulated in shared courtyards, attracting birds and domestic animals and posing health and environmental risks, particularly during monsoons. Responding to this problem, three students adopted a community-based ideation and co-creation approach, engaging residents through regular interactions to integrate situated knowledge and everyday waste practices into the design process. Leveraging the spatial configuration of shared courtyards — commonly used by multiple families — the students designed a low-cost polygonal waste collection unit positioned at strategic, easily accessible locations. Each face of the polygon corresponded to a participating household and featured a foldable waste drawer, minimizing litter while fostering hygienic and collectively managed disposal practices.

Over a period of six to eight months, biodegradable waste was converted into compost, accessed through a metal gate at the base of the unit. Families managed compost

distribution, ensuring equitable use for agricultural purposes. Built from locally available materials such as bricks and iron, the system exemplifies resource-constrained innovation as well as participatory governance. A vented chamber at the top allowed the release of gases during decomposition, which could be ignited for light, demonstrating a multifunctional design emerging from informal experimentation. By transforming waste into fertilizer, the initiative mitigated neighborhood environmental health risks while fostering grassroots innovation processes grounded in collaborative learning, science communication, and everyday practice.

5.2 ▪ *Portable privacy unit for open defecation awareness*

Despite governmental efforts to construct household toilets, open defecation remains a public health challenge in many rural areas. This practice not only endangers community health but also undermines culturally and gender-sensitive notions of privacy — particularly for women. In response to this dual challenge, two students, through collaborative brainstorming and iterative prototyping, designed a portable and cost-effective unit that functions both as a privacy shield and a medium of public health communication. Repurposing the reverse sides of discarded vinyl banners and using bamboo sticks fitted with iron stakes, they developed lightweight, collapsible enclosures that are easy to transport, assemble, and disassemble, thereby demonstrating innovation within socio-cultural and resource constraints.

The outer surfaces of the vinyl sheets feature printed and illustrated messages highlighting the dangers of open defecation, the importance of sanitation infrastructure, and the availability of government support for toilet construction. These culturally sensitive strategies draw on local knowledge systems to address both health awareness and privacy concerns. The iron-tipped bamboo fixtures allow the unit to be securely installed in soil and conveniently removed after use, enabling informal communication of knowledge in everyday settings. This low-cost, context-specific intervention demonstrates socially responsive innovation at the intersection of sanitation/WASH, gender equity, and safety, illustrating how locally grounded approaches can generate adaptive science communication outcomes and contribute to collective awareness.

5.3 ▪ *Sound-based animal frighteners in forest-edge agriculture*

In a tiger reserve forest in Central India, persistent threats from wildlife and recurrent crop damage often discourage community members — particularly women and children — from tending agricultural fields. Traditional scarecrows have proven largely ineffective under dense forest canopies, limiting farmers' ability to protect their livelihoods. Addressing this challenge through community deliberations and experimentation, four girl-students reimagined the conventional scarecrow by integrating acoustic deterrent mechanisms using empty metal tins, lightweight rods, and glass bottles suspended from trees. Activated by wind, these locally assembled components generated unpredictable, loud sounds that deterred birds and wild animals.

This approach directly addressed structural and environmental constraints by relying exclusively on locally sourced, low-cost materials and culturally familiar practices, requiring no specialized skills. The solution exemplifies grassroots innovation, where informal,

adaptive design responds to risk, gendered labor concerns, and livelihood insecurity, demonstrating how communities articulate problems, test solutions, and circulate knowledge in-situ. Finally, the iterative and context-driven nature of the process highlights how local innovation emerges, producing adaptive ecological solutions that enhance resilience, protect crops, and sustain income in forest-edge agricultural regions.

5.4 ▪ *Harnessing bicycle dynamos for off-grid mobile charging*

In regions where electricity is intermittent or unavailable, charging mobile phones poses a daily challenge. In one such village, students identified a routine commuting activity — bicycling — as a practical and locally sustainable solution for energy generation. Through iterative prototyping and experimentation, they repurposed discarded bicycle dynamos to convert kinetic energy from daily commutes into electrical energy, thereby directly addressing local infrastructural gaps.

To manage voltage fluctuations caused by uneven terrain and variable speeds, they integrated mini stabilizers through repeated rounds of testing, ensuring safe mobile charging while bicycles were in motion.

The innovation reflects adaptive responses to material and infrastructural constraints, relying on recycled components and locally sourced materials such as dynamos, wiring, and stabilizers. Although the system incurred a relatively higher cost than some of the grassroots examples discussed above, it remained economically accessible and contextually viable. By transforming routine mobility into energy production, the project illustrates how hands-on experimentation enables context-appropriate innovation, fostering everyday resilience and locally relevant energy solutions.

The cases examined in this manuscript illustrate diverse yet interconnected examples of grassroots science and innovation emerging from under-resourced rural India. Collectively, these cases exemplify necessity-driven innovation — solutions arising from contextual constraints, informed by local knowledge, and adapted iteratively from existing ideas potentially produce meaningful change under resource scarcity.

5.5 ▪ *Other projects and explorations*

Beyond the highlighted cases, numerous other student-led projects emerged over the course of the study. One explored incinerating sorted and categorized plastic wrappers to produce stone-chip-like construction material, but concerns about toxic emissions and pollution and their associated health and environmental risks limited its feasibility without further refinement. Other efforts included improving combustion of traditional *chulhas* (wood-burning stoves), developing better cleaning mechanisms for animal shelters, and converting animal waste to biogas for light and energy for nearby households. However, some initiatives were excluded from detailed analysis either due to resemblance to widely documented solutions or poor execution and not meeting the expected standards of quality and efficiency. Nevertheless, these efforts collectively reflect grassroots science-in-action, offering insights into how informal contexts foster creativity, knowledge exchange, and sustainable development at the margins. The aforementioned projects have seen small-scale local replication; however, without consistent funding, their reach has not extended beyond the local level.

6 ▪ Leanings and lessons from the field

This section presents insights from a multi-sited research initiative on grassroots science engagement in under-resourced rural Indian contexts. Based on fieldwork, the findings highlight the complex social, cultural, and communicative dynamics shaping how science is shared, adapted, and co-created outside formal institutional settings.

6.1 ▪ *Encouragement and engagements*

Encouraging participation was central throughout the various phases of this research. In the early stages, we organized open competitions in which community members served as jury members and evaluated participants' projects. However, this format — requiring participants to publicly present their projects before audiences — posed significant challenges. Younger participants and women, in particular, often felt uncomfortable or hesitant to speak in public due to prevailing cultural norms, limiting engagement. Following extensive deliberations and dialogue with participants, subsequent iterations of the program adopted more inclusive approaches. We introduced a format that ensured all participants received equal recognition and allowed individuals to opt out of public presentations if they preferred. To foster a more supportive and enabling environment and enhance participation and inclusivity, food and shared cultural rituals — such as communal meals and picnics held at the conclusion of research phases — emerged as powerful tools for engagement. These informal gatherings nurtured relationships and provided spaces for horizontal communication and community bonding. In several cases, follow-up conversations — conducted in person or by phone, sometimes months or even a year after the formal conclusion of the projects — proved instrumental in sustaining long-term relationships, generated valuable feedback for future improvements of the program.

6.2 ▪ *Gendered dimensions of participation*

Social norms and gendered expectations shaped participation. Female participants — particularly school-going girls — often encountered societal and institutional barriers that constrained their involvement, for example, they often needed repeated permissions from families and schools especially when the project extended beyond four weeks, reflecting broader societal gatekeeping.

Co-educational settings, comprising male and female participants from diverse age groups, also created discomfort. To address this, women-only sessions — especially for adolescent girls — among peers were organized, creating safer and more socially accepted spaces. This approach, rooted in cultural sensitivity, was necessary to navigate patriarchal norms that might otherwise restrict female participation. These gender-specific adaptations underscore the importance of designing informal learning environments that are attuned to intersectional barriers to inclusion, enabled deeper engagement and inclusion of marginalized female youth in various social contexts.

6.3 ▪ *Participant withdrawal — economic and educational realities*

Some participants, mostly young men from under-resourced backgrounds withdrew due to economic precarity stemming from complex, real-world circumstances or emerging

educational opportunities. Their withdrawal was not indicative of disinterest but rather a necessity driven by pressing livelihood concerns. Many were compelled to prioritize temporary labor opportunities or attend job interviews or enrolment in technical education programs to support their families, illustrating the broader economic crisis and uncertainties affecting underserved communities. These patterns underscore the importance of designing science engagement that are flexible and empathetic, attuned to the lived realities of participants in resource-constrained environments.

6.4 ▪ *Local elites and social criticism*

The project faced criticism and resistance from local elites, particularly upper-caste or socially dominant groups. First, the dominant stakeholders questioned the value of centering historically excluded communities in science-related activities. Second, the decision to involve Indigenous and Dalit elders as jurors — thereby prioritizing community-based and insider knowledge — provoked further contention. Elites, who are typically accorded prominent roles in public programs due to their educational qualifications or social standing, perceived this shift as a challenge to their authority. They questioned the legitimacy of jurors from so-called "uneducated" backgrounds, revealing entrenched caste-based prejudices. These tensions underscore the deeply political nature of science engagement and the critical importance of intentional and inclusive design in community-based science initiatives.

6.5 ▪ *Contributions from research associates*

Undergraduate and graduate associates from Indian universities enriched the research with interdisciplinary expertise in computer science, design, rural development, and linguistics. These associates played a vital role — not only organizing research activities but also serving as knowledge intermediaries to foster collaborative learning. They engaged directly with participants to review ideas and prototypes, offer constructive feedback, and facilitate iterative design processes. Acting as both facilitators and co-learners, their contributions focused on clarifying ideation processes, refining materials and methods, and identifying external resources — including navigating local markets and sourcing specialized services beyond village boundaries. Their work exemplifies collaborative and participatory knowledge-making, emphasizing horizontal collaboration and dialogic processes in informal science communication, thereby promoting deeper learning and enhancing community trust in the research process.

6.6 ▪ *Infrastructure constraints*

Participants in remote villages often faced infrastructural constraints, particularly in accessing tools, machinery, and services needed for project realization. During the initial ideation phase, they sometimes conceptualized tools or processes that were not easily available within the village context. In such instances, research associates accompanied participants to markets or industrial hubs in nearby towns or cities to procure the necessary materials or services. For example, one participant sought to incorporate a used dynamo into his project but was unable to find one locally; the team intervened by contacting urban suppliers to help source the component. In another case, a female participant's weed-cutting machine required high-quality welding services, which were unavailable in her village. The

team accompanied her to a nearby town where she was able to access skilled welding assistance. Such logistical support involves navigating both knowledge and infrastructural gaps was essential to bridge spatial disparities in material access becomes critical in enabling the translation of creative ideas into tangible implementations.

6.7 ▪ *Communicative aspects of informal engagements*

Communication played a pivotal role throughout the research process, serving both as a facilitator and a barrier. Shyness, particularly among younger participants and girls, many of whom were hesitant to share their ideas or uncertain about the value of their contributions. This reluctance was further compounded by a perceived expectation to please the researchers — a phenomenon scholars refer to as the "deference effect." Some participants attempted to replicate examples demonstrated during training sessions, assuming that imitation would be more favorably received. To mitigate this dynamic, we adopted intentional strategies centered on dialogue and reassurance, emphasizing that the objective was not to impress us but to address problems meaningful to them. These interactions underscore the significance of the relational and affective dimensions essential for authentic of science engagement.

6.8 ▪ *Cultural knowledge and local epistemologies*

Cultural and Indigenous knowledge systems, along with intergenerational wisdom, played a central role in shaping innovation processes. Participants frequently consulted community elders and knowledge holders for addressing local challenges. For example, in a project based in the mountainous regions of western India — an area grappling with chronic water scarcity — participants collaborated with scientists from the Indian Institute of Technology Bombay (where I was a team member). When renowned soil engineers proposed a construction strategy, local tribal elders intervened, drawing on Indigenous testing methods that revealed critical flaws in the proposed design. Specifically, through in-situ testing rooted in local practices, they demonstrated why the initial plan was likely to fail. Upon further investigation, the scientific team revised their approach, incorporating Indigenous insights into soil porosity and local ecological conditions. These experiences suggest that science engagement in informal contexts must not only respect but actively integrate local ways of knowing — both as a matter of equity and as an opportunity for reciprocal learning between institutional science and traditional ecological knowledge.

6.9 ▪ *Language and trust-building*

Language played a central role in fostering inclusivity and building trust. Many participants spoke Indigenous languages absent from formal education or mainstream science discourse. In contrast, educational and governmental communications typically occurred in Indic languages such as Bengali or Hindi. To bridge this linguistic divide, all posters, workshop materials, and verbal communications were delivered in the medium of instruction used in local schools. Local teachers and volunteers facilitated real-time translation, often enabling communication in participants' first languages. This multilingual engagement not only enhanced comprehension but also reduced participant anxiety and helped establishes rapport. In later stages of the project, presentations were made optional, and participants

frequently chose to speak in their mother tongue, with local volunteers providing translations. Although translation posed certain limitations, this multilingual approach helped build trust, reduce power asymmetries, and make the research process more participatory and emotionally accessible, demonstrating language's dual role as a technical and cultural resource in marginalized science communication contexts.

The two tables are presented in the appendix of the article: Table 1 outlines the identified problems, the approaches adopted, and the outcomes for each case, while Table 2 illustrates the alignment between the research questions and the cases, with a focus on communication and collaboration.

7 ▪ Discussion

Scholars have increasingly emphasized the insufficient attention given to how communities in under-resourced settings engage with science-related issues in their everyday lives — despite their distinct perspectives, valuable experiences, and knowledge systems that can significantly enrich our collective understanding [Amazeen et al., 2024]. Recognizing the unique perspectives and lived realities of marginalized communities is essential, as these groups often face intersecting and perpetuating forms of exclusion, systemic oppression, poverty, and resource scarcity that shape their access to and participation in science learning and engagement [Dawson et al., 2022; Rodrigues et al., 2023]. The social challenges in developing countries are often complex and multilayered, including linguistic diversity and rich cultural heterogeneity, which complicate communication and engagement, and defy simplistic or linear solutions [Kang, 2016]. Therefore, the understanding of science communication in under-resourced contexts needs to be grounded in an awareness of environmental limits, resource constraints, and community capacities [McMahon & Bhamra, 2012].

To study Dialogic and Communicative Pathways in Grassroots Innovation (RQ1), this research situates grassroots innovation at the intersection of communication for social change, dialogic engagement, and community co-creation [U. Dutta, 2019]. It examines how culturally anchored communication practices — rooted in empathy, reciprocity, and mutual learning — enable inclusive and context-specific knowledge-making in under-resourced rural India. Grounded in immersive, place-based engagement within rural, under-resourced communities this research emphasize trust over extraction, fostering open dialogue, ethical and relational innovative processes.

Field observations revealed a dynamic communicative ecology [Baú, 2025] shaped by language, oral traditions, and participatory engagement. Local intermediaries — volunteers, teachers, and research associates — acted as translators between institutional science and local epistemologies, creating what scholars term infrastructures of communication: networks of co-learning and sustained collaboration bridging formal and Indigenous knowledge systems [Corchia & Borghini, 2025].

Dialogic strategies addressed linguistic and gendered inequities by translating workshop materials into local dialects that enabled safe and inclusive participation. Such practices make knowledge-making processes conversational and horizontal in which participants acted as co-authors of innovation.

Field initiatives exemplify these communicative pathways. The Waste-to-Compost initiative reflected collective problem identification and shared ownership; and community-led projects such as the Portable Privacy Unit and Fertilizer Initiative demonstrated how oral exchange and local semiotic systems adapted scientific knowledge to everyday realities.

To address Human Ingenuity, Scarcity, and Structural Marginality (RQ2), this study foregrounds human ingenuity under conditions of scarcity and marginality, showing how innovation from below arises amid persistent inequalities [Shaheen et al., 2022]. In rural India, necessity-driven innovation appears not as a linear or institutional process but as a social practice shaped by cooperation, care, and improvisation. Despite limited infrastructure, education, and resources, villagers transformed homes, courtyards, and fields into "living laboratories," where informal experimentation and peer learning substituted for formal support systems. These spaces cultivated ecological awareness and collective creativity.

Social hierarchies — especially of caste, class, and gender — profoundly influenced participation. Resistance from local elites when Dalit and Indigenous elders served as jurors revealed enduring epistemic hierarchies, while their inclusion enacted symbolic inversion and epistemic justice by re-centering historically marginalized knowledge holders. Gender-sensitive strategies, such as women-only workshops and inclusive design sessions, further opened avenues for women, and tribal youth to contribute meaningfully to innovation.

Field examples demonstrate how scarcity reconfigures rather than constrains creativity. Students designed sound-based animal deterrents from discarded materials; communities repurposed bicycle dynamos and vinyl banners to create solutions; and students developed a portable privacy unit linking sanitation with dignity. These practices reflect *design justice* and ethically charged process [Costanza-Chock, 2020], emphasizing local relevance, inclusion, and equity. The research foregrounds human ingenuity under conditions of scarcity and structural marginality, showing how innovation from below emerges amid enduring inequalities.

To examine RQ3 — Innovation Ecosystems and Praxis, this research advances conceptual discussions on innovation ecosystems at the margins [Vunibola & Scobie, 2022]. These ecosystems are sustained through social relationships and community-based experimentation, challenging the top-down models centered on institutional laboratories and state-sponsored incubators. At their core were iterative design cycles — problem identification, ideation, prototyping, trial, and presentation — that functioned as informal incubation pipelines. The six-phase participatory process documented in this study formed a process of peer-based learning and reflection.

Through immersion and co-habitation, communities mobilized embodied knowledge, material improvisation, and gendered collaboration to reimagine science as a lived, relational process. Public demonstration events extended these spaces into participatory validation forums, transforming spectators into interlocutors and democratizing evaluation.

The Bicycle Dynamo project epitomized this ethos by transforming everyday mobility into an energy-generation tool, demonstrating that sustainability depends more on cultural fit and community ownership than technical sophistication. Similarly, elders' soil-testing practices showed how Indigenous and formal sciences co-evolve through dialogue, producing hybrid epistemologies that blend local insight with scientific reasoning.

Methodologically, multi-sited ethnography and participatory action research, grounded in respect and epistemological humility, were guided by in-situ innovation across all stages from ideation to implementation. When indigenous elders served as jurors during innovation fairs, they enacted acts of epistemic reordering that embodied *epistemic justice* [Costanza-Chock, 2020] and affirmed the legitimacy of local expertise.

This bottom-up evaluative framework challenges conventional hierarchies of expertise and legitimizes alternate epistemologies, and the findings invite a redefinition of both science and the scientist. Grassroots science, in this sense, emerges as both a mode of survival and a pathway toward epistemic and social justice.

The following ideas are presented to envision the future of this research:

Fostering a grassroots science network. This research supported the formation of an alternative infrastructure of science — fluid, decentralized, and rooted in the margins. This network of science enthusiasts and indigenous problem-solvers operates beyond formal educational settings, sustaining a culture of curiosity, engagement, and shared inquiry. In this context, science becomes an emancipatory and participatory practice — shaped by, and accessible to, those historically excluded from its discourse.

Access to science and reclaiming the practice of science. This research aimed to dismantle systemic inequities and poverty that often limit access to scientific knowledge and experimentation by enabling communities to engage directly in hands-on scientific inquiry. Villagers conducted experiments and completed science projects, gaining firsthand experience in problem-solving. Doing science at the margins became both a political and epistemological act — demonstrating that meaningful knowledge production can occur outside institutional walls and that innovation flourishes in unexpected places. These engagements fostered confidence, autonomy, and a renewed sense of agency. Moreover, they created space for reciprocal learning between local practitioners and formal scientists — demonstrating the power of plural epistemologies in addressing complex challenges.

Reframing innovation approaches. Accordingly, this work intentionally diverged from conventional top-down innovation models. It embraced three interwoven strategies: (i) one that harnesses place-based, intergenerational knowledge; (ii) another that limits external intervention while facilitating collaborative innovation; and (iii) one that embraces transdisciplinary approaches — i.e., valuing and rooted in grassroots science and praxis, while also drawing inspiration from science communication, innovation studies, and related disciplines such as communication studies, indigenous studies, and STEM subjects through reflexive dialogue. In both approaches, the emphasis remained on centering local expertise, concerns, and aspirations as the driving forces of the process.

Despite the promising outcomes, the initiative also faced significant challenges — particularly the lack of sustained financial, infrastructural, and institutional support. Future efforts should prioritize long-term resourcing for grassroots innovation ecosystems. Facilitating the transition of local innovators into entrepreneurs could further enhance resilience and bolster local economies. Importantly, such support must be designed to amplify, rather than override, community agency — ensuring that futures are shaped by local priorities and indigenous knowledge systems.

8 ▪ Conclusion

Conceptualizing science communication solely as transmission or translation is inadequate for understanding engagement in under-resourced and marginalized contexts [Bevan et al., 2020]. Drawing on immersive, place-based research in rural India, this study demonstrates that science communication at the margins functions as a dialogic, relational, and culturally embedded practice shaped by lived experience, scarcity, and local epistemologies, functioning as an enabling infrastructure for trust and collective problem-solving.

The findings show that dialogic and participatory communicative pathways support inclusive knowledge-making by mobilizing oral traditions, local languages, and intermediary actors who bridge institutional science and Indigenous knowledge systems. These practices disrupt hierarchical models of expertise, repositioning community members — particularly women, youth, and Indigenous elders — as co-creators rather than passive recipients of scientific knowledge.

The findings further demonstrate that grassroots innovation under conditions of scarcity and structural marginality emerges through cooperation, improvisation and care, producing contextually grounded, and ethically informed solutions. Innovation ecosystems at the margins are thus sustained not by formal institutions but by social relationships, iterative experimentation, and responsive to the lived experiences of diverse publics [Rodrigues et al., 2023].

Collectively, these insights challenge universalizing notions of science communication and innovation, emphasizing the need for approaches that are reflexive, place-based, and justice-oriented [Stocklmayer & Rennie, 2017]. Such an approach can guide initiatives to ensure that diverse voices are not only acknowledged but meaningfully integrated into the shaping of scientific discourse. Aligning research and practice as mutually informing processes strengthens the capacity of science communication to address real-world challenges [Stocklmayer & Rennie, 2017]. Recognizing this complexity supports ethically grounded and equitable forms of participation, fostering more inclusive modes of engagement — particularly at the margins.

A ▪ Case overview

Table 1. Case overview: problems, approaches, outcomes.

Cases	Problem / Challenge	Method / Approach	Outcome / Impact
Community Fertilizer (Waste-to-Compost Initiative)	Unsanitary waste accumulation in shared courtyards; environmental and public health risk	Community-based ideation and co-creation	Reduced scattering of waste; produced compost for agricultural use; multifunctional utility (vented gases for light); cleaner local environment
Portable Privacy Unit for Open Defecation Awareness	Lack of privacy and sanitation awareness; gendered health concerns	Collective brainstorm, iteration, community feedback	Enabled women to maintain dignity; disseminated sanitation awareness; low-cost, portable, easily replicable, leverages local and discarded materials
Sound-Based Animal Frighteners (Forest-Edge Agriculture)	Crop damage due to wildlife intrusion; traditional scarecrows ineffective	Field-based experimentation; Community deliberations;	Reduced crop damage; encouraged women and children to tend fields; uses local materials, low-cost wildlife deterrent
Bicycle Dynamos for Off-Grid Mobile Charging	Lack of electricity; Off-grid: no or limited charging	Repurposed technology; iterative prototyping and testing	Enabled mobile charging off-grid; energy production embedded in daily activity; locally maintainable, scalable and replicable

B ▪ RQ alignment

Table 2. Research questions — case alignment.

Cases	*RQ1 (Communicative strategies, local epistemologies)*	*RQ2 (Innovation amid constraints)*	*RQ3 (Processes enabling context-appropriate ecosystems*
Community Fertilizer: Waste-to-Compost Initiative	Dialogic and participatory approaches through community involvement, integration of situated knowledge and practices. optimizing shared community spaces	Shows resource-constrained innovation leveraging available materials and local spatial knowledge	Exemplifies context-appropriate innovation ecosystems via informal experimentation and public engagement. multifunctional design
Portable Privacy Unit for Open Defecation Awareness	Employs culturally sensitive, participatory communication strategies to engage the community in health awareness and to address privacy	Illustrates creative problem-solving within socio-cultural and resource constraints. Uses discarded materials	Context-specific and socially responsive innovation. informal learning and knowledge dissemination
Sound-Based Animal Frighteners	Integrates local needs and ecological knowledge, collaborative experimentation, and intermediary facilitation	Addresses structural and environmental constraints using Locally sourced materials and culturally informed strategies	Adaptive ecological solution, informal, context-driven innovation to enhance local resilience
Bicycle Dynamo for Off-Grid Charging	Demonstrates participatory experimentation, infrastructural gaps and practical knowledge transfer	Reflects innovation under material scarcity and infrastructural limitations. Use of recycled components	Hands-on experimentation for building locally relevant energy solutions and resilience

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