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Special Collection:
Equity in Co-Production

Mahi Tahi - Rū Whenua: Tangata Whenua & Kairangahau Pūtaiao. Reflective Learnings on Partnering With Indigenous Māori Communities in Field-Based Scientific Research

Eleanor R. H. Mestel[1], Bubs Smith (Ngāti Tūwharetoa)[2], Kelvin Tapuke (Te Atiawa, Ngati Tama, Ngati Mutunga, Ngai Tai, Ngai Tai ki Tamaki, Ngati Porou, Te Whanaua-a-Apanui, Te Aitanga-a-Mahaki, Ngai Tuhoe, Te Whakatohea, Ngai Tahu, Ngati Maniapoto, Ngati Raukawa, Toa Rangatira)[3], Finnigan Illsley-Kemp[1], Lucy Kaiser (Kāi Tahu, Kāti Māmoe, Waitaha)[3,4], Ian Connon[5], David Johnston[3†], Colin J. N. Wilson[1], Graham Leonard[4], Mary Anne T. Clive[4], and Martha K. Savage[1]

[1]Te Kura Tātai Aro Whenua School of Geography, Environment and Earth Sciences, Te Herenga Waka Victoria University of Wellington, Wellington, New Zealand, [2]Ngāti Tūwharetoa, Tūrangi, New Zealand, [3]Joint Centre for Disaster Research, Te Kunenga ki Pūrehuroa Massey University, Wellington, New Zealand, [4]Te Pū Ao GNS Science, Lower Hutt, New Zealand, [5]Taupō District Council, Taupō, New Zealand

Kupu Whakataki

I timata ai tēnei rangahau I te tau 2018. I tūtakitaki ai I ngā kairangahau a Eleanor Mestel me ōna hoa mahi nō: Te Whare Wānanga o Te Herenga Waka; Te Whare Wānanga o Te Kūnenga ki Pūrehuroa; C.D.E.M. Taupō. I kōrerorero tahi ki ngā tangata o ia whenua ki te kaupapa matua me ngā wawata o te rangahau - Ahi Tupua. Mā ngā mihini rū whenua e kitea te katoa o tōna āhua. Ōna hōhonu, ōna whānui. Ōna nukunuku, ōna nekeneke. Mā reira kua whakatō ngā mihini ine rūwhenua ki rō whenua. Kua oti ai te mahi rangahau ine rūwhenua I te tau 2022. Ka āta wetewete e Eleanor i ngā tātai rāraunga. Mā reira kua kitea te āhua nei o Ahi Tupua. Ko te ngako o te rangahau, me pehea te hohonutanga o te Mātauranga Māori ki te putaiao pakeha kia noho whānau ai. A tōna wā ka hoki mai a Eleanor ki te iwi ki te whakatakoto i ngā kōrero whakaputa I tōna rangahau.

Abstract

Between 2018 and 2022, representatives of local Indigenous Māori communities and emergency management worked in partnership with physical and social scientists during the planning, deployment, and management of a temporary seismometer network around Taupō volcano. This deployment formed part of the Eruption or Catastrophe: Learning to Implement Preparedness for future Supervolcano Eruptions (ECLIPSE) project designed to increase understanding of the large caldera volcanoes in the central North Island of Aotearoa New Zealand. Here we critically reflect on this co-production approach to geophysical network deployment and associated volcano research. We identified a central theme of the creating and holding of space for researchers and communities to engage in the activities through adopting a co-production approach, that embeds representatives of local Iwi (tribal groups) Te Arawa and Ngāti Tūwharetoa as key researchers within a broad project team. We worked to ensure we were respecting communities' time, protocols, and decisions; and to exchange knowledge about the research and results with landowners, community leaders, schools, and young people. Time spent kanohi ki te kanohi (face-to-face) built relationships and trust within and outside the research team that have lasted beyond the scope of the ECLIPSE program. We detail our experiences in the hope of demonstrating that this approach to research is a possible and desirable path for future fieldwork-based research.

Plain Language Summary

Conducting scientific research with local communities that are affected by the research increases the usability and relevance of scientific outcomes. This collaboration is particularly important when researching natural hazards, where shared knowledge can improve awareness, knowledge, and resilience of communities. Between 2018 and 2022, representatives of local Indigenous Māori communities and emergency management worked in partnership with physical and social scientists to study Taupō volcano in North Island, Aotearoa New Zealand, including installing a temporary network of instruments around the region to monitor for earthquakes. After the removal of the network, the research team (including community members) discussed and reflected on our research approach. We found that it was key to build the partnership into the project, especially including people with the mandate from the local communities to represent those communities. It was important to work with respect for different communities and approaches to research, and

Key Points:

- We reflect on our research partnership between local Indigenous Māori researchers, emergency managers, and physical and social scientists
- Co-production research approach included meaningful communication; building relationships and trust; and respect for people and communities
- We offer suggestions and recommendations for researchers aiming to co-produce field-based scientific research in the future

Supporting Information:

Supporting Information may be found in the online version of this article.

Correspondence to:

E. R. H. Mestel,
eleanor.mestel@vuw.ac.nz

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Author Contributions:

Conceptualization: Eleanor R. H. Mestel, Bubs Smith, Kelvin Tapuke, Finnigan Illsley-Kemp, Lucy Kaiser, Ian Connon, David Johnston, Colin

J. N. Wilson, Graham Leonard, Mary Anne T. Clive, Martha K. Savage
Data curation: Eleanor R. H. Mestel
Formal analysis: Eleanor R. H. Mestel, Finnigan Illsley-Kemp, Lucy Kaiser
Funding acquisition: Bubs Smith, Kelvin Tapuke, David Johnston, Colin J. N. Wilson, Graham Leonard, Martha K. Savage
Investigation: Eleanor R. H. Mestel, Bubs Smith, Kelvin Tapuke, Finnigan Illsley-Kemp, Lucy Kaiser, Ian Connon, David Johnston, Colin J. N. Wilson, Graham Leonard, Mary Anne T. Clive, Martha K. Savage
Methodology: Eleanor R. H. Mestel, Bubs Smith, Kelvin Tapuke, Finnigan Illsley-Kemp, Lucy Kaiser, Ian Connon, David Johnston
Project administration: Eleanor R. H. Mestel
Supervision: Finnigan Illsley-Kemp, Colin J. N. Wilson, Martha K. Savage
Writing – original draft: Eleanor R. H. Mestel, Bubs Smith, Kelvin Tapuke, Finnigan Illsley-Kemp
Writing – review & editing: Eleanor R. H. Mestel, Bubs Smith, Kelvin Tapuke, Finnigan Illsley-Kemp, Lucy Kaiser, Ian Connon, David Johnston, Colin J. N. Wilson, Graham Leonard, Mary Anne T. Clive, Martha K. Savage

to communicate about research and results with landowners, community leaders, schools, and young people. We built relationships and trust between people within and outside the research team that have lasted beyond the end of this research project. We hope that detailing our experiences will support others to take a similar approach to future research.

1. Introduction

It is increasingly recognized that by involving communities in scientific research that affects them, the usability and applicability of scientific results is increased (Nature Editorial, 2018). Unfortunately, local communities are often excluded from research on and about their own land. This is sometimes termed "parachute" or "parasite" science, where research is conducted in an extractive way without engaging with or acknowledging local communities, researchers, and experts (EGU, 2023; Genda et al., 2022; North et al., 2020; Stefanoudis et al., 2021). The ongoing legacy of colonialism means that this inequitable research approach is a particular issue for Indigenous communities (Smith, 2012; Willyard et al., 2018; Yua et al., 2022). Across a range of disciplines, co-produced research, which builds partnerships between researchers and communities, results in improved research impact, greater trust in results, more applicable outputs, and builds networks and capacity (Meadow et al., 2015; Nature Editorial, 2018; Norström et al., 2020; Willyard et al., 2018). In this paper, we discuss our recent work planning, deploying, and managing a temporary seismometer network around Taupō volcano in Aotearoa New Zealand. This project involved partnership between community members (including Indigenous Māori researchers), physical and social scientists, and staff involved in local emergency management and national geohazard monitoring in a co-produced research approach by partnering with the communities affected by the research to undertake the research.

Our seismometer project was one part of the ECLIPSE (Eruption or Catastrophe: Learning to Implement Preparedness for future Supervolcano Eruptions) program, a six-year Endeavour Fund research program that ran from 2017 to 2023, funded by Aotearoa New Zealand's Ministry of Business, Innovation and Employment. The ECLIPSE program was designed to provide the scientific basis for the interpretation and response to unrest (and possible eruption) from Aotearoa New Zealand's caldera volcanoes within Ahi Tupua (the ancestral name for the central Taupō Volcanic Zone supervolcano system from Te Arawa and Ngāti Tūwharetoa; see Table 1 for full glossary) achieved through co-production of research with local Iwi (tribal groups), emergency management, and national geohazard monitoring (e.g., Illsley-Kemp et al., 2020). The program was trans-institutional and trans-disciplinary, with substantial parts of the program focussed on education (Saha et al., 2023), decision-support (Scott et al., 2022) and hazard mitigation (Craig et al., 2021), as well as physical sciences (e.g., Barker et al., 2021; Mestel, 2023; Muirhead et al., 2022).

Ahi Tupua lies within the rohe (region) of Te Arawa and Ngāti Tūwharetoa in the central North Island, Aotearoa New Zealand. Taupō volcano lies beneath Taupō moana (Lake Taupō, Figure 1) in the south of Ahi Tupua (Wilson et al., 1995). The most recent eruption was approximately 1800 years ago, and there are periods of volcanic unrest on roughly a decadal timescale (Barker et al., 2015, 2021; Hogg et al., 2019; Potter et al., 2015). Taupō is of great inter-generational importance to many Iwi lands, waters, economic interests, and people. Community understanding and preparedness for eruptions can be life-saving (Kitagawa, 2015; Van Manen et al., 2015), and even small eruptions or non-eruptive volcanic unrest can have a significant effect on those living around the volcano, causing injury, loss of life, property damage and severe economic effects (Johnston et al., 2002; Loughlin et al., 2015; Potter et al., 2015). Monitoring volcanic activity and researching past events are important for forecasting and mitigating risk. This often requires installation of temporary or permanent networks of diverse specialized instrumentation on, under, or above the ground (Jolly, 2015; Matoza & Roman, 2022; Poland & de Zeeuw-van Dalfsen, 2022).

In this paper, we critically reflect on the co-production approach that we, the research team, took to the planning, deployment, and management of the ECLIPSE seismometer network. This network used 14 seismometer sites deployed in the Taupō region (on the rohe of Ngāti Tūwharetoa and Ngāti Rereahu) between October 2019 and May 2022. The aim was to learn more about Taupō volcano and share this knowledge in partnership (Ngāi Tai Ki Tāmaki Tribal Trust v Minister of Conservation, 2018). The deployment of temporary seismometer networks in Aotearoa New Zealand is very common (International Federation of Digital Seismograph Network Codes, 2023),

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Table 1
Glossary of Te Reo Māori Words Used Throughout This Manuscript

Te Reo Māori	English
Ahi Tupua	The ancestral name for the central Taupō Volcanic Zone supervolcano system from Te Arawa and Ngāti Tūwharetoa
Hapū	Sub-tribal group or groups
Hui	Gathering, meeting
Iwi	Tribal group or groups
Kanohi ki te kanohi	Face-to-face, in person
Koha	Gifts
Kōrero	Discussion
Kura kaupapa Māori	Māori-language immersion schools
Mahi	Work, activity
Mana	Authority, status
Māori	Indigenous person of Aotearoa New Zealand
Marae	Traditional meeting place
Mātauranga Māori	The body of knowledge originating from Māori ancestors, including the Māori world view and perspectives, Māori creativity and cultural practices (in our case within Ngāti Tūwharetoa, Te Arawa, and Ngāti Rereahu)
Maunga	Mountain or mountains
Pākehā	Aotearoa New Zealand person of European descent
Pōhiri, Pōwhiri	Welcoming ceremony on a Marae
Pūrākau	Myths, stories
Rangatiratanga	Ownership, authority, self-determination
Rohe	Region
Taupō moana	Lake Taupō
Te Ao Māori	Māori world and world-view
Te Reo Māori	Māori language
Tikanga Māori	Māori customs, protocol
Tūpuna, tupuna	Ancestors, elders, grandparents
Wāhi tapu	Sacred sites
Wānanga	Discussion, conference
Whakapapa	Genealogy
Whakawhanaungatanga	Process of establishing relationships
Whenua	Land, provides nourishment (birth sac of a newborn baby)

and, while efforts have been made in education and communication, we are not aware of previous network deployments that incorporated cross-cultural collaborative research with local and Indigenous communities as we have. We aim to record our approach to co-produced seismic network deployment and research, reflect on what worked well, identify improvements that could have been made, and offer recommendations for future approaches to such field-based research. Most of our engagement was with Māori communities; however, we also worked with other end-users of our research, including entities involved in local and national emergency management (e.g., the Caldera Advisory Group) and geohazard monitoring (GNS Science and GeoNet). The learnings that arise from our mahi (work, activity) can help inform future efforts to co-produce Earth science field research with Iwi and Hapū (sub-tribal groups) in Aotearoa New Zealand. While we acknowledge that the relevancy and applicability of these learnings will be influenced by the differing social, political, and cultural contexts across communities, we present our recommendations with the intent that they can be shaped to achieve meaningful collaboration and impact across settings other than our own.

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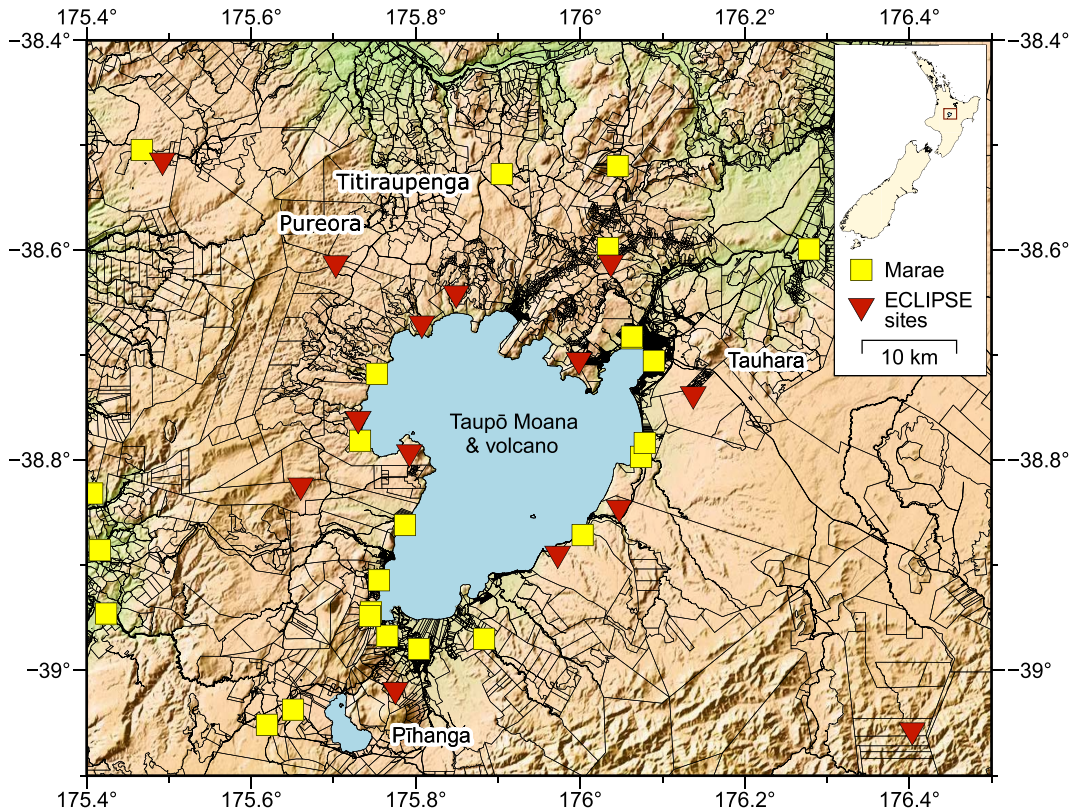

Figure 1. Summary map of the Taupō region, with land tiles from Land Information New Zealand marked as black lines, Marae (traditional meeting place) marked as yellow squares (Māori Maps, 2023), and ECLIPSE seismometer sites as red triangles. Maunga (mountains) are labelled.

1.1. Positionality

This paper is collectively presented from the position of the entire research team, but we acknowledge that each participant has their own diverse perspectives and experiences that have contributed to this position. The manuscript was primarily written by the lead author as part of their doctoral research (Mestel, 2023). Members of the research team have a wide range of backgrounds, experience, and expertise. The team comprises Māori, Pākehā (Aotearoa New Zealand person of European descent) and international researchers (from the United Kingdom and United States of America). Some are based in Wellington (southern North Island), whereas others are based locally in the central North Island. We have included Māori co-author's Iwi affiliations in the authorship list. The research team's expertise spans earthquakes, volcanoes, disasters, Mātauranga Māori, social science, emergency management, and school and community outreach. Our reflections were discussed in a semi-structured focus group format that may have affected what people felt comfortable sharing.

Indigenous ECLIPSE leaders brought extensive local wisdom and local knowledge of the Indigenous people of Ahi Tupua to the ECLIPSE program along with Earth science. Indigenous ECLIPSE leaders are mandated and entrusted to hold their position: upholding ancestral values of respect for the lands and waters of the area. Indigenous cosmogeny of Ahi Tupua is of central importance and volcanoes are seen as respected tupuna (elders). A central aim of this research was to ensure that our Indigenous researcher and community voices were at the forefront of this research. Anecdotally, Indigenous and community perspectives are rarely named in publications, let alone have an active role in authorship. Bringing the team together as a mixture of Indigenous and non-Indigenous researchers was a purposeful effort to decolonize the volcanology space. By including direct quotes of the reflections of our team members, it is our hope that readers may gain a better understanding of the challenges and successes of conducting this type of work.

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2. Co-Production of Earth Science Research With Māori

Research co-production, co-creation and co-design encompasses a wide and inter-locked range of participatory approaches where end-users and people affected by research are included in the research. This can take a range of different forms from discussion with community members to fully community led and co-led research. Participatory research approaches are often used in disciplines that directly involve people, including policy (Brandsen et al., 2018), health and medicine (Bell et al., 2023; Beresford et al., 2021) and the humanities (Durose et al., 2012). They are also increasingly being used in environment and Earth science disciplines (Bremer & Meisch, 2017; Djenontin & Meadow, 2018; Gabrielsen et al., 2018; Herman-Mercer et al., 2023; Liboiron et al., 2021; Meadow et al., 2015) that have historically often been considered disconnected from human experience. The geosciences have an association with colonialism and the exploitation of land and resources (Dowey et al., 2021; Monarrez et al., 2022). Inclusion of Indigenous peoples in leadership of research activities happening on their lands and waterways contribute toward increasing global calls for the decolonization of science (Klymiuk, 2021; Liboiron, 2021; Smith, 2012; Yua et al., 2022) and opposition to ongoing poor practice (Cisneros et al., 2022; Kahanamoku et al., 2020).

Historically, the government of Aotearoa New Zealand has exclusively supported science with an epistemological approach based in western philosophical ideas (western science; for discussion of this term see Mercier, 2018). This included dismissing and actively suppressing Mātauranga Māori (defined as "the body of knowledge originating from Māori ancestors, including the Māori world view and perspectives, Māori creativity and cultural practices" by Te Aka Māori Dictionary (Moorfield, 2023); see also Broughton et al., 2015; Walker, 2004). Today, Mātauranga Māori is increasingly being partnered with western science (Hikuroa, 2017; Macfarlane & Macfarlane, 2019), and Māori researchers have outlined the value in partnering with and empowering Indigenous communities in managing volcanic events (Gabrielsen et al., 2018).

A key signifier of the shift of the government's approach toward engaging, supporting and recognizing Māori research and knowledge was the 2007 introduction of the Vision Mātauranga (VM) policy "to unlock the innovation potential of Māori knowledge, resources and people to assist New Zealanders to create a better future." VM is defined as "to envision knowledge, to think about new ways of doing things, to find answers, to solve problems" (Ministry of Research Science and Technology, 2007). Consideration of VM is now a part of research funding applications by the Ministry of Business, Innovation and Employment (2021) and the Royal Society Te Apārangi (Marsden Fund Council, 2021).

While this is a positive step, Rauika Māngai (2020) emphasized that there was still a long way to go in embracing Mātauranga Māori, building cultural competency, and supporting the Māori workforce within the science system. Māori scientists continue to be under-represented in Crown Research Institutes and universities (McAllister, Naepi, Wilson, et al., 2022), as well as at undergraduate and postgraduate level (McAllister, Naepi, Walker, et al., 2022; Naepi et al., 2021). Implementation of the VM policy has been patchy, often taking a surface-level and box-ticking approach to engagement (Rauika Māngai, 2020). Despite this, there has been increasing acknowledgment that incorporating different knowledge systems acts to strengthen research (McAllister et al., 2023; Mercier, 2018), and there are many projects that combine Mātauranga Māori and modern science approaches (Moller, 2009; Stevens et al., 2021; Wilkinson et al., 2020). We undertook collaborative research at one point upon the large continuum between research involving Māori and research being conducted by, for and with Māori (Ahuriri-Driscoll et al., 2007; Carson et al., 2022; Cunningham, 2000; David-Chavez & Gavin, 2018). The collection of seismic data, and the wider program, were conducted with a co-produced research approach in which the location and installation of our seismometer network was informed by Indigenous knowledge and tikanga (custom, protocol). The analysis of the collected seismic data used geophysical analysis techniques and a western science epistemology. This is not necessarily the approach that we endorse going forward, as we reflect upon later in this paper.

Working with communities to define and enact research increases the relevance and usability of science outputs (Beier et al., 2017; Norström et al., 2020). Knowledge sharing with communities throughout a co-production approach helps to contribute to awareness, knowledge, and resilience of communities to natural hazards in their respective areas. The relationships built can be leveraged in times of crisis for improved emergency response (Doyle et al., 2014). Within our project, we undertook a co-production approach that involves communities

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affected by the research in design and execution of the project. In our case, this included a particular focus on local communities including Iwi, Hapū, and Māori Trusts. As well as the benefits we listed above, the research institutions some of the team work within must honor Te Tiriti o Waitangi (Treaty of Waitangi) signed between the British Crown and most Māori chiefs in 1840 (Jennings, 2004). In co-producing research in partnership, we are working to offer a "seat at the table" to people previously left out.

3. Methods of Reflecting on Our Co-Production

We aim to critically reflect upon our mahi as a research group: what we planned, what happened, what went well, and what could have been improved. This reflection comes after initial discussions about our approach to co-production of research throughout the installation, management, and removal of the ECLIPSE seismometer network. By documenting and discussing our experiences, we hope to assist future research in taking a similar approach. To ensure that human ethics requirements were followed, a low-risk ethics notification was lodged via Massey University for this project (Ethics Notification Number: 4000026484).

A few months after the seismometer network was removed, the primary members of the research team (including Māori researchers, emergency management, social scientists and physical scientists) met to have a kōrero (discussion) around our thoughts in a semi-structured focus group format. Some initial open-ended questions were proposed based on previous discussions to elicit reflections upon our approach to network planning, deployment, and management (see Text S1 in Supporting Information S1 for questions). However, the discussion was allowed to adapt to the topics of interest and to evolve organically and reflexively. In the initial discussion session, we decided that it was important to have additional input from members of the wider ECLIPSE program who had been involved in the set-up and design of the program. Therefore, we had a similar kōrero 2 months later focussed on the early establishment phases of the ECLIPSE program (see Text S1 in Supporting Information S1 for questions). The combined 2.5 hr of semi-structured discussions were audio recorded, transcribed, and analyzed by the lead author for main ideas and themes using the approaches outlined in Saldaña (2021). The themes were then iteratively discussed and grouped by members of the research team. The key ideas, themes and recommendations are discussed in the remainder of this paper.

4. Creating Space (Key Themes From Our Reflections)

The central theme that emerged from our reflections is one of creating and holding space for researchers and communities to engage in this research. As a team, we approached the research thoughtfully and intentionally to avoid hierarchy and privileging one viewpoint to the detriment of others. We wanted all people involved to feel valued, comfortable, and to have a sense of rangatiratanga (ownership, authority, self-determination), as well as to feel respected as people and experts in their field. Therefore, we worked to have the humility and openness to learn, and to be aware of what we did not know. We tried to foster an environment where people felt willing and comfortable to ask questions of someone more knowledgeable. Some key ways we structured the research to ensure that we actively created and held this space were by:

- being flexible and adaptable
- adopting the co-production approach early (the ECLIPSE program was built from existing relationships and had VM and research with communities planned and resourced from the beginning)
- having people with the mandate from local communities to represent those communities as expert key researchers within the project
- supporting researchers to learn cultural competency and to make mistakes in a safe space
- trusting and respecting involved people and communities' time, rangatiratanga and decisions
- focusing on engagement and communication of research and results with landowners, community leaders, schools, and young people
- allowing time and space to build relationships and trust
- looking into the future, past the end of the project and to the lasting impacts of our mahi

Many of our actions throughout the research were linked to more than one of these interconnected ideas that we expand upon below.

4.1. Project Set Up and Early Planning

Built from existing relationships, the ECLIPSE program was designed to include co-production of research and partnerships with local communities, including Iwi researchers as paid, valued, and supported members of the research team. A program leader spoke about incorporating co-production into the program from the start:

> "whereas previously the tendency had been to write a research proposal and then- 'Oh dear, we better do the Vision Mātauranga section.' The idea grew to bypass that whole tokenism approach to, 'well, let's have Māori involved upfront as key researchers,' not just muck around with Vision Mātauranga as some kind of add on to a science programme."

A Māori researcher also spoke about the importance of having a seat at the table where Māori have been excluded for so long:

> "being at the table at the beginning is really important […] we were able to get real clarity around the purpose and to build confidence. […] Everybody has been really keen because they just haven't been at the table at all and so, for some of them, this is the first time that they've actually been able to engage fully. I think the investment's been really great."

An initial wānanga (discussion, conference) and overnight stay was held at the start of the program at Tangatarua Marae (meeting place), an institutional Marae at Toi-Ohomai Institute of Technology in Rotorua, to define the form of the project: what a co-production approach to research would look like within the ECLIPSE program, and what the engagement strategy and goals would be. One researcher involved in the program commented:

> "it brought all of the researchers together to have a conversation about values, the way we work together, and how to incorporate different perspectives in the work we do. I think it was a transformational moment for me as a researcher […] I've thought back to that often […] I think it started off the programme on the right foot to really immerse us in Te Ao Māori [the Māori world and world-view]."

A Māori researcher spoke about designing the experience with other program team members:

> "It wasn't really just the Marae experience. It was really just to locate it within tāngata whenua […] it actually spoke about not only Ngātoroirangi, but also the journey of Te Arawa into the Te Arawa-Tūwharetoa region […] all those things around identity and place and the significance of Maunga being Tūpuna rather than just the mountain from a modern science view and so it was really important to locate that […] in a very Te Arawa and Tūwharetoa way."

For those who weren't from a Māori background, this was an early example of structured and intentional teaching of cultural competency through experience (Section 4.2).

During our reflections, one researcher said:

> "I think number one that I'd highlight was collective willingness from everybody that's been part of this."

It was important for the members of the research team to have a keenness and openness to learn, to ask questions, to share something of themselves, and to approach the research with a sense of humility. We aimed to listen to and learn from each other throughout the project: sometimes by listening and asking questions between the research team, but often by stepping back and listening to conversations with the people outside the project that we were engaging with.

Even those who were not named on the initial bid for funding were selected partially for their interest in the co-production part of the program. One supervisor spoke about recruiting their student:

> "when I was picking who to have as a PhD student, I factored that in. I wasn't just considering […] how good they were at maths […] but I was factoring in "are they as a student going to be enthusiastic about that and are they going to care about [co-production]?"

Within the final research team (Figure 2), we have a range of expertise in local knowledge, teaching, Mātauranga Māori, practical/civic knowledge, emergency management, social sciences, and physical sciences, as well as a balance of perspectives and experiences (Section 1.1). One of the social science team members remarked:

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Figure 2. A collage of images of the research team during the project. All photographs taken by members of the research team.

> "One of the best things about this project is just the variety of people and the expertise and what they've been able to bring to the table."

Coming from different backgrounds, there was a plurality of knowledge across the team from their own perspectives, experience, and strengths. This allowed people to step forward and speak to the parts of the project that they were expert in, while the others recognized where to step back to make space for them. Within the team, this encouraged us to hear different perspectives, learn from each other, work to avoid privileging one knowledge-set over another, and follow the lead of the most knowledgeable researchers across different situations. Outside the team, we were able to collectively answer questions people had about our mahi from many perspectives.

It was identified as especially important to have people within the research team with the mandate from the local community to represent that community (in our case, mandated Iwi representation). As well as their research expertise, their local and cultural knowledge, lived experience, whakapapa (genealogy) and mana (authority,

status) meant that we were able to engage appropriately with the appropriate people in local communities. When discussions entered "turbulent waters" they were able to recognize and understand unspoken social cues and take the lead to navigate the research team around them.

We had representation of local emergency management within the research team, as well as broader links to national emergency management and geohazard monitoring (GNS Science and GeoNet) across the program. This was another avenue to exchange knowledge with local communities, and to build relationships and understanding for the future (Section 4.6). The direction of the research was informed repeatedly by feedback from partners, usually through in-person conversations. This made the research more useful and interesting for those who will use the results in the future, now that the ECLIPSE program has finished.

4.2. "Wrapping Around" and Supporting Researchers

For some members of the research team, particularly those with an international background, the ECLIPSE program brought one of their first interactions with Te Ao Māori. For many others within the program, this was their first time working with a co-production approach. To ensure researchers were supported in this journey, one Māori researcher encouraged:

> "having a person to come alongside, and to guide them through that process. I think it's a critical part, and we can't just leave people to flounder."

Provision of this cultural support would not have been possible without local Iwi researchers with the cultural and local knowledge being actively funded as part of the program, as these comments from an international researcher emphasize:

> "All of the understanding I have of tikanga, of Te Tiriti, of co-production, of everything that we're talking about today has not come from my institution. It's come from the wider research team and interactions within that […] I think things have worked well having a broad research team and being in spaces where you feel comfortable to not know anything and to be able to ask any question and just learn as much as you can."

In our experience, institutional training and support for researchers was insufficient for our mahi, and in some cases wholly unavailable. However, a Māori researcher reflected that even if institutional training were available, it would not be a replacement for other experiences:

> "not too sure that we can learn those kind of things at institutional settings. They lack authenticity, you know. This is a real living, working Marae."

The initial wānanga and Tangatarua Marae stay (an institutional Marae) at the beginning of the ECLIPSE program (Section 4.1) was mentioned by multiple researchers as a pivotal moment that helped them to navigate into their roles within ECLIPSE, allowing a safe space for people to talk, grow, and make mistakes. Other experiences like attending Trust board meetings and Pōhiri (welcoming ceremony on a Marae) were also noted as particularly important. This reflects the fact that an active learning-by-doing approach, and having the experiences and interactions, is more valuable than a theoretical understanding. However, this approach comes with risks particularly for Māori researchers who are embedded in their own communities (insider research) and must deal with the consequences of the actions of outsider researchers should something go wrong (Smith, 2012).

4.3. Respect and Rangatiratanga

A central component of our reflections on our research was the importance of respect for and between people and their rangatiratanga. As we discuss below, this includes, but is not limited to, asking for permissions and respecting decisions; understanding and respecting tikanga Māori; respecting people's time and priorities; respecting different knowledge systems; and making space for community representation.

In the early stages of planning the seismometer network, Māori and physical science team members collaborated to find an initial plan for the network layout. This began with a desktop exercise to suggest a layout of the seismometer sites from a geophysical perspective, based on complementing the existing sites in the national seismometer network (Petersen et al., 2011) and the geology and geography of the region. The layout was then adjusted based on local and cultural knowledge of the appropriateness of different areas, and existing

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relationships with landowners and Trusts. This revised layout was then taken to local Hapū around the lake to speak to them about the project, answer their questions, and ask for permissions to install sites on their rohe. Engagement with Māori communities and asking for appropriate permissions acknowledges the pre-European Māori land systems of belonging to the whenua (land), rather than the private ownership of land blocks (Figure 1; Kingi, 2008), so we discussed with Hapū even when the sites were planned on private property. One of the physical scientists reflected:

> "right from the very start we were putting Hapū front and centre, making sure they knew what we were doing, why we were doing it and also getting their consent."

It is typical for individual landowners to be asked for permission when installing temporary deployments, but this wider approach is atypical. It was important to ask the right people in the relevant Iwi, Hapū or Trust for permission, and to follow tikanga Māori when doing so. The correct approach is not always apparent from outside a community, one of the many reasons why having members of the team from the local communities was and is so important.

We worked to follow the lead of the communities we were talking to in their spaces. Examples include attending Trust board meetings when asked, offering koha (gifts), introducing ourselves and our backgrounds in an appropriate cultural context, and attending a Pōhiri to be welcomed on to the whenua before work can proceed. By following tikanga, we were demonstrating that we were working on this project in a respectful way that built trust with the communities we were coming into and allowing research to continue to meaningfully benefit all parties.

While we worked to offer communities a seat at the table in our research, we needed to be patient and respectful of people's time. We worked hard to respect the fact that our project was unlikely to be a priority for communities and Trust boards with many competing demands on their time and resources, especially during the COVID-19 pandemic. This was achieved by having built-in time for engagement, visiting communities instead of asking them to travel, and accepting that there were periods of time when we were waiting for a response and the research was going to take longer. After it was clear that initial discussions on the seismometer network were going to take longer than planned, we requested an extension to the loan of our seismometer equipment to account for that time. Optimally, longer engagement times would have been built into the project from the start. We discuss how this need for flexibility interacts with research and funding timelines in Section 4.7.

Once we had asked for permission, and communicated our intentions, we needed to respect people's decisions about their land. For example, some areas that we asked about were wāhi tapu (sacred sites), so were not appropriate places to have seismometer sites. The final layout of the seismometer network resulted from an iterative process of suggestion of possible locations, approaching and discussing with landowners, and adjustment of suggested locations either within that area, or moving to an entirely different, more appropriate area. Once the seismometers were installed, we continued to focus on working respectfully. This did not just include formal tikanga, but also maintaining relationships, following any rules regarding permits and health and safety, keeping up communication during fieldwork, as well as communicating about the data we were collecting.

At a Trustee meeting we attended, the issue of data sovereignty was raised. This was something that we had not previously considered and thus is a part of the research that could and should be improved upon in the future. Future work should consider the best approach to Indigenous data sovereignty when handling Earth science data in more detail and should optimally be a topic of discussion between researchers and communities in partnership before data collection has begun. There is an increasing move toward open data policies within the scientific community, exemplified by the increasingly widespread adoption of the FAIR data principles (Wilkinson et al., 2016). These open data policies have the potential to conflict with the rights of Indigenous people and interests with respect to their data (Rainie et al., 2019). However, through careful and considered data governance, the two are not necessarily at odds (Carroll et al., 2021). In our case, the data from the ECLIPSE seismometer network (Mestel et al., 2019) is stored by EarthScope, a USA-based organization, and became open-access after a protected period. This was part of the conditions of our borrowing equipment from the EarthScope Primary Instrument Center (formerly IRIS-PASSCAL), and we were open about this when communicating about potential sites. At the time of writing, we have included acknowledgment of the Iwi and Hapū on whose rohe the data was collected in the network's metadata, but this is not necessarily sufficient to adhere to the Indigenous data

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governance principles set out by Carroll et al. (2020), or the Māori data governance principles from Te Mana Raraunga (2018) and Te Kāhui Raraunga (Kukutai et al., 2023). Work is ongoing to formalize the inclusion of Indigenous data governance principles into geophysical data services (e.g., EarthScope, 2022), but this work is more advanced in other fields (e.g., Ambler et al., 2021; Walter et al., 2021; Williamson et al., 2023).

4.4. Communication of Research

Throughout the project, we prioritized communicating about our research. We wanted to be open about the project, the results, and the data. Our aim was to spread information while explaining it in a way that is interesting, relatable, understandable, and not overwhelming to a non-expert audience. One researcher said:

> "at the end of the day without that context, that data is just complete nonsense to people who aren't geoscientists. It's just a bunch of squiggles and lines. That communication is so crucial, showing its value for people and its relevance, and it's what gets people excited about it as well."

We wrote and distributed 1–3-page explainer documents throughout the project that we shared widely both by email and printed handout. These initially included introductions to the ECLIPSE program and seismometer project (included in Text S2 and S3 in Supporting Information S1, respectively) and a diagram of the site set-up to help to explain the planned project. Subsequent update documents included data and details of analysis. These documents were predominantly written by physical scientists, and we acknowledge that more co-development could have made them more widely useable. In one update, we focussed on some recent large earthquakes on the Kermadec-Hikurangi subduction margin that had been felt widely across the country and resulted in a tsunami alert (National Emergency Management Agency, 2021): describing what happened, showing what the shaking looked like at our sites, and discussing some of the difficulties in locating offshore earthquakes. One local researcher spoke about this update:

> "having a three-page explainer on this is what's happened, this is what was felt here. It's just hugely valuable. It got spread a lot wider than I thought it would."

Recording and sharing video was another method that we used to spread updates about our mahi, usually filmed on a smartphone to capture a moment when someone was explaining a concept or the equipment during a visit. One local researcher spoke about one of the many times that they posted a short video from one of the site visits to Facebook:

> "[they were] sharing how the [seismometer] worked and then how that particular seismometer that we were putting in was working as well, so that people who just don't have access, could have access to it."

In response to a request from a Trust board a few months before the seismometers were removed, we recorded more formal videos where we spoke about the research (e.g., ECLIPSE Programme, 2022). In addition to showcasing voices from within the research team, we also had some input from respected community members speaking about their experience of being involved. On reflection, we could have incorporated these longer and more complex videos earlier in the program, rather than just at the end.

While written documents and audio/video recordings are useful for spreading detailed information widely and without continual input from researchers, we concluded that communicating kanohi ki te kanohi (face-to-face) about the information resulted in the best information transfer. Another local team member said:

> "You shared the data […] printed out so we could see it and explained to us what it meant so we could understand it. You were open and sincere of the questions we were asking, and your answers were interesting and factual. That made the learning experience really worthwhile and gave us insight to the importance of the project […] from my point of view, it was brilliant."

We were able to adapt explanations and share knowledge in response to what people wanted to know, and it was easier to explain concepts with props or diagrams. For example, we found that bringing an example seismometer to meetings allowed people to get a better sense of what we were asking to do and how disruptive it would be. One local researcher said:

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> "This seismic machine, that's all they knew, it was gonna get buried in the ground. They're thinking how big the hole was. One of the guys saw it and goes "our posts are bigger than that, we put them in the ground right through our whole farm"

4.5. Engagement and Education

Spending time working kanohi ki te kanohi enables people to have conversations and learn from each other. Part of communicating about our research was a strategy of in-person engagement and education with landowners, local people, and schools. A local researcher commented:

> "The research that you're doing, you're involving the community, but you're going a little bit beyond that. […] You're giving back to the community, and by doing that you're giving them ownership as well, getting them involved and that's what's important."

When visiting our seismometer sites for installation, servicing, and removal, we invited people to join us to see and interact with the seismometer sites, learn about what we were doing, and build a sense of ownership of the sites. A Māori team member spoke about the installation of one seismometer:

> "We had some really significant people with us and I think that the opportunity to talk- especially with Tūwharetoa Trust board members was really critical, in terms of making sure that the leaders at the top of it were actually involved in it"

With the instrument set-up in front of us, it was easier to meaningfully discuss what we were doing and how it fit together. For example, we were able to show the data being recorded on their whenua and people could see the effect of their actions on the data. We could also discuss recent earthquakes people had felt and their effects. By having a broad range of expertise involved (Section 4.1), we were including multiple perspectives and knowledges for people, including those from Te Ao Māori. This included the postgraduate students that came with us (Section 4.7), in addition to landowners, community leaders, school-aged students and other young people involved in education and training programmes.

When we were reflecting upon the engagement within the project, we acknowledged that, while we would have liked to have even more engagement and people coming with us to sites, it does take time out of people's days. For lots of people, even though they are interested, engaged and keen to hear about the project, it was not their priority. For these people, we provided the written explainer documents and tried to offer face-to-face engagement again next time that we were visiting.

In addition to the visits to seismometer sites, we visited local schools to meet students and science classes (mainly of primary and intermediate school ages). The research team were all involved in a parallel Seismometers in Schools project that distributes Raspberry Shake seismometers (Christensen & Blanco Chia, 2017) to schools in the Taupō and Bay of Plenty regions, as well as other areas of Aotearoa New Zealand (Johnston et al., 2021). The importance of a team with varied backgrounds was particularly clear in these school visits, where different researchers could lead short activities or answer questions in their area of expertise and from their perspective. Some of these schools were kura kaupapa Māori (Māori-language immersion schools) and visits were only possible because of researchers who spoke Te Reo Māori (the Māori language). There, students asked questions in Te Reo that were translated by a researcher who spoke Te Reo. Having someone present who was familiar with pūrākau (stories) that often related to volcanic or earthquake phenomena particularly engaged the young people and ensured we were not just presenting one type of knowledge and perspective.

Reflecting on the lessons learned from this mahi, we propose that the engagement side of the project could have been improved by more extensive early planning to integrate the science and engagement throughout the program. We could have started public outreach earlier in the project, done some longer-term engagement, and perhaps invited interested students to the universities and institutions where we work. One team member remarked:

> "one thing we could do better is given more thought about how all of our interactions with communities do help shape those educational pathways for young people, whether they go into science or anything else"

We can plan to improve our approach in any future activities based on the outcomes and relationships built through this experience.

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4.6. Whakawhanaungatanga (Relationships and Trust)

The benefits of spending extended time kanohi ki te kanohi with people was not limited to just communicating about our research. These times were an opportunity to build and strengthen broader relationships by exchanging scientific and cultural knowledge, and to discuss other opportunities and projects.

Creating the space to build and maintain reciprocal relationships and trust between people has been foundational to our co-production approach: existing relationships that were built upon to set up the ECLIPSE program (Section 4.1); existing relationships between Iwi researchers and emergency managers with their communities; and new relationships that were built through an investment of time throughout the project.

The research team, many of whom did not know each other before the project, have built relationships with each other based on trust and transparency. One social science researcher talked about this during our reflections:

> "the central component is the trust between people involved in this project. Throughout the whole thing, I think everyone has come to this research with a real sense of humbleness which has been really useful for working together and leading into that adaptable nature of this project where you have to be humble, and you have to be flexible and work with the interests of the communities"

This openness and trust made it possible to navigate any difficult situations and ensure researchers felt safe and supported throughout their mahi.

Despite relationships being between individuals, it was important to be aware of the reputation, both positive and negative, that one carries with them when visiting a community. As researchers or members of a university or Crown Research Institute coming to a community, we represented a complicated legacy of trust issues between cultures (Hepi et al., 2007; Smith, 2012). On the other hand, building strong relationships can have a positive impact on those reputations of yourself and everyone associated with you moving into the future. One Māori researcher said:

> "it wasn't about scientists coming in, educating people and telling them, "these are where the machines are going. They're going to give us this information. It's going to go in your land. The end." So it's really breaking down those really quite negative perceptions, I think, of what scientists do and scientists as experts and actually really acknowledge some of the local experts in the communities that they're in."

The strong reciprocal relationships that we have built and maintained throughout the seismometer project can continue into the future. We anticipate that the relationships developed in this project will lead to future collaborative research which will help improve the community's preparation for, or response to, volcanic activity at Taupō. For example, in the year following the removal of the ECLIPSE seismometer network, there was an episode of volcanic unrest at Taupō during which the Volcanic Alert Level for Taupō was raised to Alert Level 1 for the first time (GeoNet, 2022; Lamb et al., 2024). Through the communication, engagement and education work that we did (Sections 4.4 and 4.5), improved community understanding led to a more resilient response to the 2022 unrest. Through the relationships built between members of the research team, we were able to make a central contribution to the communication and decision-making with emergency managers and Ngāti Tūwharetoa. An ECLIPSE program leader involved in the decision compared the 2022–23 activity response to a similar episode of unrest in 2019:

> "through the programme and the instrumentation, we've seen very different abilities to interpret that and to communicate off of it. That's directly off the back of the instrumentation and therefore the collaboration that led to it. […] It allows us to communicate in a more nuanced and probably useful way now"

4.7. Into the Future

As we came toward the end of the seismometer project, we had a forward-looking focus with a collective desire to keep moving onward and to ensure our relationships stretched into other opportunities. One local team member said:

> "working with you guys, and the relationship that we now have, has built other relationships […] and has also often opened up a lot of other opportunities"

We have seen researchers from across the ECLIPSE program begin to apply elements of this co-production approach to their planning for future research projects. When developing research, we should be asking and answering questions that are relevant and useful to the specific communities we are working with (Kaiser & Saunders, 2021). A Māori team member remarked:

> "from my perspective, I should be coming to a list and saying, 'hey, these are the questions we want answered. Do you have any students who can direct their study around finding out the answers to those?'"

We also discussed moving toward communities working on research questions themselves, including collection and analysis of data, and supporting young people in study toward this aim. As mentioned in Section 2, while our deployment was informed by local and Indigenous knowledge, the analysis of the collected seismicity data used a western science epistemology. Future research projects could embed Mātauranga Māori more deeply throughout the research. Examples include incorporating oral histories into wider understanding of hazards (e.g., King et al., 2020) and Mātauranga Māori volcano monitoring techniques (Gabrielsen et al., 2018).

We reflected on the realities of the academic and funding systems in Aotearoa New Zealand, which make it difficult for researchers to maintain relationships past the end of temporarily funded research programmes (Thompson et al., 2017). Actively maintaining relationships so they do not break down requires continuing support and resourcing for researchers, particularly for Iwi researchers, and while many of the permanent research staff will remain in their posts and be able to maintain relationships, early career researchers and postgraduate students may be forced to move on to other projects, jobs, or places where funding is available (Nissen et al., 2020).

Having the flexibility to respect communities' timelines (Section 4.3) can often be difficult within the rigid boundaries of academic and funding systems (Thompson et al., 2017), and this is one of the key reasons that it is important to build co-production and flexibility throughout research (Section 4.1). Short research timelines do not allow for researchers to be able to spend time building relationships, but having existing relationships is crucial for developing projects with communities that can run well within subsequent research timeframes. While interaction with end-users is becoming increasingly important, the success of research projects is often benchmarked on key performance indicators and critical steps that were set up at the beginning of a project and take no account of the complexities of associated relationship-building (Ministry of Business, Innovation and Employment, 2019). In addition, there is little consistency in assessing the VM aspect of a project across funding bodies (Rauika Māngai, 2020). This is part of a broader problem across the research landscape on how to acknowledge co-production (Durose et al., 2018).

With an aim of growing capability and increasing the awareness of co-production among current and future research scientists, we brought undergraduate and postgraduate students with us as field assistants to check on the seismometers. This allowed those students exposure to the fieldwork and engagement approach we were using, and to gain experience sharing their work with the communities we were visiting. We have worked to introduce our approach to students and scientific colleagues by including details of our mahi within lectures and talks, and through this paper hope to share our ideas and experience further.

5. Conclusions and Recommendations

With its approach to co-production of research, the ECLIPSE seismometer project was novel in geophysical network deployment and in volcano-related studies in Aotearoa New Zealand. As one ECLIPSE program leader pointed out in our reflections:

> "it's especially new territory to think about physical science implementation and the collection of raw data. It's a lot less commonly co-produced compared to hazard scenarios or education materials."

By sharing our experience, we hope to demonstrate that it is possible and beneficial to engage in meaningful bicultural Earth science research in this fashion. We also hope that these reflections on our mahi will be useful and encouraging for others who endeavor to partner with Indigenous communities in field-based science research. In Figure 3, we summarize our discussions and conclusions about our co-production approach to research.

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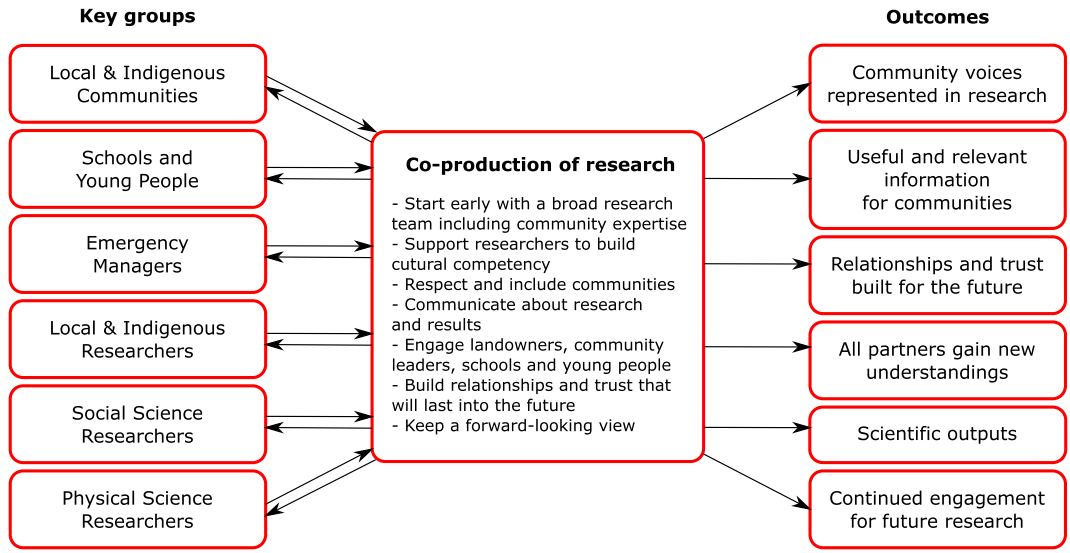

Figure 3. A graphical summary of our reflections about the key groups, ideas, and outputs of our co-production approach to research. All groups contribute to and benefit from research which leads to better outcomes for all. Many people within the research fall into multiple groups.

Below we list a set of recommendations, based on how our team worked together throughout our research to create and hold space for our co-production approach (Section 4). We emphasize that this is not an exhaustive list, nor will all these elements necessarily apply in all situations: successful co-production is not a box-ticking exercise. However, we aim for the recommendations to support future researchers who endeavor to co-produce Earth science research with Indigenous communities.

1. **Start early with a broad research team including community expertise**
   We have reflected on the importance of including a co-production approach from the start of the project, including community voices in the conceptualization and design of research, and situating the project within a local and Indigenous context. This means recruiting a broad research team, from existing relationships, with a plurality of knowledges across varied backgrounds, expertise, and experience, including people with the mandate from local communities to represent those communities as key researchers. We came together at the beginning of the research program to have conversations around values and the form of the project.
2. **Support researchers to build cultural competency**
   All members of the research team worked to develop their personal cultural competency and responsibility. However, many of the research team knew very little about Te Ao Māori before the start of this project. They were supported to learn, ask questions, and build their knowledge throughout the project. Iwi researchers within the team were key to leading others in navigating interactions with Māori communities like Trust board meetings and Pōhiri which have an authenticity that cannot be replicated in an institutional setting.
3. **Respect and include communities**
   We aimed to respect the communities we were working with by: prioritizing asking for permission from Iwi, Hapū and Trusts responsible for the land before installing sites and respecting the decisions that came back; adhering to communities' tikanga and processes; and respecting people's time and priorities. This required having flexibility in our research and fieldwork timelines and flexibility in the locations of potential sites, as well as the cultural capability within the research team to understand what the most appropriate route forward was. Once sites were in the ground, we continued to work in a respectful way, adhering to permits and health and safety, and maintaining communication.
4. **Communicate about research and results**
   We communicated about the aims and results of our research in a way that aimed to be understandable, relevant, and useful for people. This included using written documents, short informal and longer formal videos, and speaking kanohi ki te kanohi with members of communities. We found this last method of communication allowed the most openness and flexibility, especially when combined with one or more of the

other communication methods, allowing people to ask questions and engage with the research and researchers in front of them.

5. **Engage landowners, community leaders, schools and young people**
   During our fieldwork visiting the seismometer sites, we invited landowners, community leaders, school-aged students and other young people to come with us to see the sites, to discuss our research, and to share the results. We also attended Trustee meetings when invited and visited schools to meet students and science classes as part of a broader science education project. We suggest that the engagement part of projects would benefit from extensive early planning to weave the science and education threads of the mahi together.
6. **Build relationships and trust that will last into the future**
   Through our communication, engagement, and education work, we took time to build and strengthen relationships and trust between members of the research team, as well as with partners outside it. It would not have been possible for our mahi to go ahead without this basis of trust. Researchers should be aware of the positive and negative effects their actions can have in the long-term. Some relationships we built have already been leveraged during the volcanic unrest episode at Taupō in 2022–23.
7. **Keep a forward-looking view**
   We look to continue our relationships through ongoing opportunities and development of new research ideas that are relevant and important to the communities we are working with. These ongoing relationships can be hampered by the academic and funding structures that we work within, but we advocate for prioritizing continued support for Iwi researchers' mahi. We support efforts to increase flexibility in these structures to account for the importance of relationship building, with funding specifically to help build and maintain relationships both before and after research. Finally, we work to introduce the idea of co-producing research to students and colleagues, so that they can begin thinking about the possibilities it offers.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

The initial questions used to prompt discussion are included in Supporting Information S1. The seismic data recorded by the seismometer network (Mestel et al., 2019) are archived at the SAGE Data Management Center. The map in Figure 1 was created using Generic Mapping Tools (Wessel et al., 2019).

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