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Original research article

Perceptions of co-design, co-development and co-delivery (Co-3D) as part of the co-production process – Insights for climate services

A. Fleming [a,f,*], E. Bohensky [a], L.X.C. Dutra [a], B.B. Lin [a], J. Melbourne-Thomas [a,f], T. Moore [a], S. Stone-Jovicich [a], C. Tozer [a], J.M. Clarke [a], L. Donegan [h], M. Hopkins [d], S. Merson [c], T. Remenyi [a,b], A. Swirepik [e], C. Vertigan [g]

[a] *CSIRO, Environment, Hobart 7005; Brisbane 4000; Aspendale 3195; Townsville 4814, Australia*
[b] *University of Tasmania, Hobart 7005, Australia*
[c] *Parks Australia, Canberra 2601, Australia*
[d] *Centre for Applied Climate Sciences, University of Southern Queensland, Australia*
[e] *Department of Climate Change, Energy, The Environment and Water, Canberra, Australia*
[f] *Centre for Marine Socioecology, University of Tasmania, Hobart 7005, Australia*
[g] *Port Arthur Historic Site Management Authority, Port Arthur 7182, Australia*
[h] *Fremantle Prison, Western Australia 6160, Australia*

A R T I C L E I N F O

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A B S T R A C T

Co-design, co-development, and co-delivery (Co-3D for short) are activities within the co-production research pathway that are increasingly being used in climate change science and adaptation projects. However, the research community is still coming to understand how best to incorporate Co-3D in practice, as each project has a specific context around stakeholder relationships, governance arrangements, and capacity to actively participate. This paper outlines five case studies from Australia as examples of different projects engaging with Co-3D in different ways in order to explore how Co-3D is being used and might be improved. Crucially, we include the perceptions and experiences of researchers, funders and end users, as well as our own critical reflections. Each of the projects self-describes as using ‘co-production’, but the extent and format varies widely with different combinations of co-design, co-development and/or co-delivery used in each. Our findings show that without clear understanding of Co-3D within the co-production process, aspects of Co-3D may not be properly considered in planning or implementation. Co-3D activities are not completely distinct, rather they form a continuum of engagement and integration across phases of project work. Thus, the specific definitions and delineations between these terms may not be required for them to be applied. However, practical and explicit negotiation of what ‘co-production’ means in different project contexts is needed so that all parties understand their roles and responsibilities. Further, more evaluations of outcomes and stakeholder experiences are required. We provide seven principles of Co-3D that should be considered when embarking on co-production projects.

Introduction

No single group in society holds the diversity of contextual and technical knowledge, insights and experiences required to develop holistic, equitable, and effective adaptation responses to climate change. Participatory processes in climate change science agendas, planning and policies are thus instrumental to ensuring the integration of different roles, relationships, practices, and purposes to achieve meaningful climate adaptation action (Collins and Ison, 2009; Colloff et al. 2021). Through public engagement of multiple groups of stakeholders, participatory processes have a long history in empowering people to address political, economic, and social problems (Collins & Ison 2009; Lauria & Slotterback 2021; Williams & Jacob 2021). These processes can be wide ranging, with a plethora of ‘co–’ terms including co-design, co-management, co-evaluation, co-innovation, co-implementation, co-construction, co-production among others occurring across a wide range of science and other disciplines (e.g. Kliskey et al. 2021; Steger et al. 2021). The increase of ‘co–’ terms signifies the growing importance of

* Corresponding author.
E-mail address: Aysha.Fleming@csiro.au (A. Fleming).

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partnership, collaboration and sharing power for decisions and processes that have multiple and diverse stakeholders (Dalal-Clayton & Bass 2002). All of these 'co' terms may be interpreted differently and used in different ways, and we see this diversity as something to encourage, as long as the terms and purposes are explicit in their own context.

Co-production is important for climate science in many ways, such as the development of scenario planning to explore different possible climate adaptation options (e.g. Butler et al. 2020), approaches tailored to specific stakeholders or industry areas of interest, such as hazards, or thresholds (e.g. Vincent et al. 2020; Craddock-Henry et al. 2021) and community-led climate initiatives such as local conservation or restoration efforts (e.g. Kelly et al. 2020). In the context of climate services (development of new projections and new tools to help users make decisions based on projections) collaborative approaches are also gaining popularity because it increases the relevance and applicability of climate science to many different problem areas (Daniels et al. 2019; André et al. 2020; Bojovic et al. 2021; Neset et al. 2021).

However, researchers can face significant challenges in integrating co-production approaches in projects. Part of the challenge is the 'conceptual plurality' (Hakkarainen et al. 2021, p.2) of co-production activities and their underpinning theories. Confusion around expectations, requirements and outcomes of co-production is accentuated by projects bringing together people across different disciplines, worldviews and power dynamics, often without accounting for these explicitly or reflexively (Chambers et al. 2022). Co-production is always political and must be acknowledged as such, not as a step to 'resolution' but as a process that allows for greater transparency and for true to life contexts to be part of the discussion (Turnhout et al. 2020). For many scientists this presents a new way of thinking and a new skill set to explicitly acknowledge the role of power and the reflexive and critical reimagining required of researchers when inviting communities and other groups to actively contribute to the design of the research, the production of science activities and outputs, and the delivery of benefits.

Examples of sharing power for successful outcomes of projects using different types of co-production, to different extents, especially in local, Indigenous and cultural settings are starting to emerge (e.g. Taboada et al. 2020; Maclean et al. 2021; Barnes et al. 2021; Mustonen et al. 2022). For example, participatory work with Indigenous people requires a reflexive and critical reimagining of how non-Indigenous researchers engage with place, leading to a change in pace and a shift in different ways of relating people and Country (St John and Akama, 2022). Co-production is also increasingly important for global initiatives like the IPCC (Beck and Forsyth, n.d) and the Sustainable Development Goals (Dannevig et al. 2022) because it improves legitimacy and allows for diverse and multiple perspectives of environmental sustainability to be considered within the same framework.

Although progress is being made in understanding the importance of inclusion and power relationships in co-production processes (Norström et al. 2020, Chambers et al. 2021, Hakkarainen et al. 2021), putting this into practice remains a challenge. The complexity involved in climate science, the range and scale of competing power relationships, conflicts between diverse benefits and trade-offs, as well as the novelty and extent of behaviour changes required, have made this area of study rich with lessons learned (Kolstad et al. 2019), exploring the complexities (Lemos et al. 2018), as well as the shortcomings of such processes (Turnhout et al. 2020; Karcher et al. 2021). There has been progress on examples comparing and evaluating different modes of co-production, including exploring the alignment (or lack thereof) of world views, perspectives and expectations from researchers, funders and end users, as well as learning from what works and does not, (Schuck-Zöller et al. 2022) but more are still needed as this work is so context dependant and dynamic (Taboada et al. 2020). To understand how to implement different modes of collaborative research approaches more effectively, empirical studies of climate science projects that have embedded different types of co-production are essential to support the jump from theory to practice and knowledge to action.

In this paper, we use the combined concepts of co-design, co-development, and co-delivery (Co-3D) to discuss the diversity of ways in which people can participate in co-production processes within climate science projects. The Co-3D concepts represent related, but different, phases of the co-production process and each plays an important role toward guiding the interaction and discussion of information across parties at different points. However, the research community is still coming to understand how best to incorporate these into co-production projects in practice. We build on decades of work looking into participatory models of science, questions around knowledge, power and inclusion and different actor roles and levels of agency for the purpose of serving society and building science legitimacy to consider how the Co-3D concepts can be implemented to allow for shared knowledge production and ownership (Jasanoff 2004; Bremer & Meisch 2017; Carter et al., 2019; Norström et al. 2020; Chambers et al. 2021; Kliskey et al. 2021). While a comprehensive review of co-production is out of scope here, and our conceptual model is not new, we aim to add insights targeted towards practical applications of co-production for climate science and climate services.

To better understand the contributions of Co-3D in the delivery of desired outcomes and goals of climate science projects, we examine five examples of co-production climate science and service projects. This paper contributes to our collective understanding of the practical application of Co-3D by examining the role of different types of Co-3D in delivering satisfactory outcomes from different projects based on the goals and outcomes of the various stakeholders involved. Through interviews with researchers, funders and end–users, we develop an understanding of the expectations of co-production, whether and how Co-3D was utilised, and how the implementation of Co-3D activities contributed to collaborative efforts and positive outcomes for all involved.

The paper begins with a description of definitions of the key Co-3D terms: co-production, co-design, co-development, and co-delivery in Box 1, as defined from our conceptual framework (see supplementary material) and the context of our research, as well as related concepts of engagement and participation, collaboration and end users. It then outlines the methods used for data collection and analysis, including case study analysis, qualitative interviews and critical reflection (see Fig. 1). Next, we summarise our results, and identify overarching principles for improving Co-3D, highlighting the importance of intentional matching of different Co-3D activities for different project objectives. We also consider the relational concepts of Co-3D, including trust and communication. We conclude our paper with a discussion of our findings in relation to relevant literature and considerations to address the gaps in research practice that our work identifies, particularly in terms of valuing and supporting interpersonal skills and reflexivity as essential components of science delivery to inform decision-making processes, and the need to allow for flexibility in funding and project design.

Box 1. Key definitions of terms used in the paper in the context of this project (participant interviews and the synthesised analysis). Note: We recognise there are multiple definitions of these terms and thus recommend projects should define these terms in their own context and focus on outcomes, rather than debating definitions.

Stakeholders: Stakeholder refers to anyone who has a 'stake' in the work, such as researchers or scientists, end users (people who use the outputs, or benefit in some way) funders (who pay for the work), rightsholders (who have a claim to any aspect of the work), or collaborators (who participate in the work). A stake may be a professional interest in the outcomes, the information used to produce the outcomes, the network, or any other aspect involved in the work.

Collaboration: Working closely with others to create or achieve a shared objective, project or output.

Co-production: An umbrella term for research engagement (which typically incorporates some or all of co-design, co-development, and co-delivery, often sequentially) that brings diverse knowledges together to create new knowledge, tools or products, activities, processes and/or outcomes.

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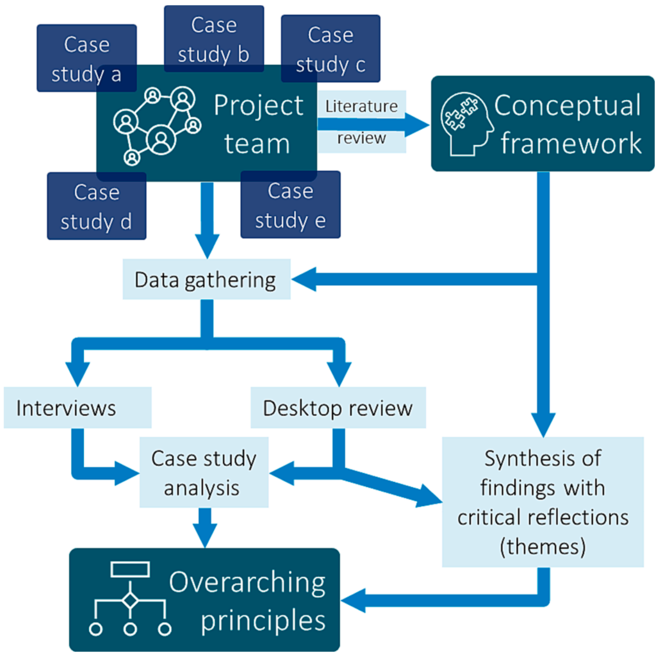

Fig. 1. Graphical summary of the approach for data gathering and analysis for the five case studies. The conceptual framework derived from a literature review (see supplementary material) informed the approach for data gathering (i.e. interview questions) and underpinned the synthesis of findings. Data from interviews as well as a desktop review of secondary data (reports and websites) were combined in the analysis, the results of which fed into the development of overarching principles.

(*continued*)

Co-design: Process of working with clients, stakeholders and collaborators to design the objectives, activities and scope of a project before commencing. It can extend beyond the initial phases in some cases where the design is adaptive to feedback.
Co-development: The process of working with clients, stakeholders and collaborators to develop new knowledge, tools, activities, products or outcomes.
Co-delivery: Process of collaborating with clients, stakeholders and end-users to apply and maintain aspects of the completed project in industry, government or community.
Engagement: Any activity where people interact for the purposes of a project, such as interviews, workshops, meetings, webinars etc. Engagement is a two-way interaction and involves both the process of interaction and the motivation.
Participation: Any activity where there is interaction between scientists and people, including multiple groups of stakeholder types, for varying purposes and through a range of methods, including when information only flows one way (e.g., seminar or presentation).

Methods

To learn from past experiences and evaluate practical applications of Co-3D, five projects which had set out an explicit aspiration for 'co-production' were selected (what 'co-production' meant in each case was part of the study). The case studies were chosen based on: 1) ability to identify and contact project teams and partners 2) recently completed or at least a year of work conducted, 3) a diverse range of users, approaches, and potential insights. The case studies selected included both marine and terrestrial focused projects, used different climate data products at different scales, involved different stakeholder and rightsholder groups, and involved different levels of resourcing (team size and funding level). The case studies were all based in Australia to be more comparable in terms of political, social and economic context. The five case studies are summarised in Box 2.

Box 2. Case study descriptions.

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(a)Climate Services for Agriculture (CSA) is a $29 M project funded by the Australian government from 2020 to 2024.
The **key objective** is to help Australian Farmers to adapt to changing climate and (especially longer-term) weather-related conditions and thereby increase the viability of farm businesses by providing insights that are based on localized and contextualized climate and weather-related information (see Climate Services for Agriculture – DAWE).
The **stakeholders** include farmers, farm advisors, agricultural industries, consultants, government departments and others with an interest in climate and agriculture.
The **scientific partners** are the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Bureau of Meteorology.
The **sector** is Australian agriculture.
(b)Climate Vulnerability and Adaptation Tools for Protected Areas (Protected areas) project was funded by the Australian government from 2020 to 2021.
The **key objective** was to develop tools to help protected area management take into account the risks of climate change.
The **stakeholders** include protected area managers, indigenous groups and others with an interest in protected areas and climate change.
The **scientific partner** was CSIRO.
The **sector** was government.
(c)Victorian Climate Projections 2019 (VCP19) project was funded by the Victorian Department of Environment, Land, Water and Planning from 2017 to 2022.
The **key objective** was to produce a set of high-resolution climate projections for Victoria to supplement previous projections and to develop a tailored climate projections and guidance package see: Victoria's changing climate (climatechange.vic.gov.au) and https://www.climatechangeinaustralia.gov.au/vcp19/.
The **stakeholders** include local government and others with an interest in climate change in Victoria.
The **scientific partners** were CSIRO.
The **sector** was government.
(d)Electricity Sector Climate Information (ESCI) project (2019–2021) was funded by the Department of Industry, Science, Energy and Resources.
The **key objective** was to improve planning and investment decisions on energy infrastructure by developing methods to better access, analyse and use climate risk information. See: About ESCI (climatechangeinaustralia.gov.au).
The **stakeholders** were the Australian Energy Market Operator (AEMO) and electricity sector stakeholders.
The **scientific partners** were the CSIRO and the Bureau of Meteorology.
The **sector** was energy.
(e)Guidance on Adaptation of Commonwealth Fisheries management to climate change (Fisheries) project was funded by the Fisheries Research and Development Corporation (FRDC) via the Australian Fisheries Management Authority (AFMA) from 2016 to 2018. The key objectives were assessment of how the existing Commonwealth fisheries management framework will cope with climate change impacts; development of a methodology and approach for AFMA and other fisheries to adapt their regulatory environment to climate change impacts; and strategies and priorities to account for climate change in the management of Commonwealth fisheries. See: Managing fisheries in a changing climate – CSIRO
The **stakeholders** were AFMA and FRDC, fishers and industry as well as others with an interest in fisheries and climate change.
The **scientific partners** were CSIRO, the University of Tasmania and the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES).
The **sector** was fisheries.

Interviews and case study analysis

A desktop case study analysis and 23 interviews with experts and case study stakeholders, including five end-users, were conducted in 2021 to gather insights, reflections, and experiences of co-production design in practice as well as principles or requirements for co-production and specific points about Co-3D that participants felt to be important. 18 interviewees were linked to case studies, and additional individuals were invited because of expertise in the theory or practice of co-production as well as their peripheral knowledge of these projects. Nine participants were from the authors' organisation (CSIRO) and 12 were from other Australian organisations. We note that researcher and client perspectives are more strongly represented than end users due to greater ease and ability to identify and access these participants. The small number of end users is a limitation of this work and an area for further exploration. However, the interview participants were able to provide a well-rounded understanding of the stakeholders involved in each project to describe if and how the components of Co-3D were enacted in the projects.

Participants were deliberately targeted based on their involvement in a case study as a researcher or key partner, or referred by participants for their expertise in Co-3D. The interviews were sourced from contacts involved in the case studies (snowballing) and contacted via email. 34 people were invited, of which 23 completed an interview. See Table 1.

Any interested individuals who were not able to be interviewed were invited to provide feedback on interim findings. Interviews were conducted by one or two team members, on-line via video conference. The interviews were audio recorded and professionally transcribed, with participants able to receive and approve a transcript if so desired. The transcripts were used for qualitative thematic analysis, and where relevant, for analysis of case studies. This research was approved by CSIRO's Social and Interdisciplinary Science Human Research Ethics Committee (approval number (105/21). Interview questions were adapted to different case studies and client/researcher backgrounds as appropriate. Case study questions and interview questions were as similar as possible across example projects, but when interviewees were not familiar with a case study they were asked questions in a more general sense (see supplementary material). The interviews were semi-structured and started with some background context provided by the interviewee explaining their area of work and interest in climate services, for example. Through general questions about co-production we were able to elicit experiences and insights to Co-3D in fuller detail. Co-production was the most commonly used term by participants, to cover all aspects of Co-3D, which is reflected in the questions.

Case study analysis summary

The case studies were analysed from primary data (interview transcripts), secondary data (reports and websites) and critical reflections from the authors involved in the projects and the interviews. The analysis of interviews (inductive coding) and desktop analysis (content analysis) were conducted separately and then synthesised through project discussions and comparisons of experiences to formulate overarching principles and themes (see Fig. 1). The project team were interdisciplinary and had different experiences, epistemologies and expectations, from a mix of social and natural science backgrounds, but all from a white Australian context. This was useful to surface and discuss (and highlight limitations) during regular fortnightly meetings over the 12-month project of preparing this paper and added the richness of personal experience and group reflection to the analysis. Some of the case studies were on-going or had extensions and so the analysis is a snapshot of their progress. The analysis was qualitative (based on grounded theory) by individual team members assessing each case according to the questions below and then another team member reviewing and adding to the analysis. The case study analysis aimed to understand what Co-3D activities were undertaken and how, lessons and principles of successful Co-3D as well as opportunities and constraints. A graphical summary of the analysis approach is provided in Fig. 1, including how the analysis was informed by our conceptual framework, and how the analysis approach was synthesised into the development of overarching principles.

Table 1
List of participants included in each case study and their representative organisations.

CASE STUDY	Number of participants and role	Organisations
(a)CSA	4 (2 funders, 2 researchers) 4 co-authors involved in this case study	Government departments, academics, government researchers
(b)Protected Areas	5 (1 funder, 1 researcher. 3 end users) 5 co-authors involved in this case study	Government departments, protected area managers
(c)VCP19	2 (1 researcher, 1 end user) 2 co-authors involved in this case study	State government, government researchers
(d)ESCI	3 (3 researchers)	Government departments, government researchers
(e)Fisheries	4 (2 researchers, 2 end users) 3 co-authors involved in this case study	Government departments, government researchers, self-employed
Other	5 (all researchers)	Government researchers, academics, private business
Total	**23**	9 government researchers, 2 academics, 10 government departments, 2 private business.

Results

The case studies highlighted that there were often mismatches between objectives and the Co-3D methods employed, which constrained outcomes or added to the time and resources needed to achieve results (see Table 2). Table 2 shows the highlights for each case study that related to the aims and intended model of Co-3D; the processes and tools that were used; what worked well and not so well and why (enabling and constraining factors) and general lessons. These highlight themes arose from the synthesis of analysis approaches (see Fig. 1).

The case studies suggested that it can be helpful to understand Co-3D as distinct but overlapping stages of the engagement process that represent a continuum within the co-production process (Fig. 2 – which is derived from interview data, case study desktop analysis, and the authors' own interpretation). In any project or body of work, these stages may receive more, or less emphasis, in terms of time, resources and the number of people engaged – for the case studies considered here, five different combinations of stages were observed (see Fig. 2 below). This does not suggest a single 'right' way of combining these stages, but if the outcomes and requirements of different options can be considered in advance and negotiation of these stages can be discussed to bring clarity to the goals of each stage, then there may be benefits from more intentionally matching the design of Co-3D to the objectives.

As well as the different configurations of how projects planned or implemented the different stages of Co-3D, the synthesised analysis highlighted the importance of relationships and the development of trust. In addition, the longer time frames involved in planning, the higher levels of resourcing required and the need to respond to user needs even after project timelines had finished were identified in both the case studies and interviews as important for Co-3D. Interviews highlighted that the co-design stage particularly was often mistaken for a short, discrete process rather than just the beginning of interactions and iterations, and this assumption led to a truncated relationship-building experience across the project.

The interviews highlighted stakeholders viewed co-production processes as always being important, at least in some form, as without it the work risked being irrelevant. On the other hand, 'good' application of Co-3D concepts across the project can lead to longer term outcomes with clients and researchers, where project outputs continue to be used and trusted relationships persist. In addition, the interviews highlighted the need for strong leadership, interpersonal skills, the importance of early and inclusive work to frame the problem, as well as being empathetic, humble and realistic about how climate science fits in with real world decision contexts.

We identified five broad themes from our synthesis of both the case studies and interview results, with some quotes from interviews discussed in the broader context of the results below:

1. Definitions of co-production and Co-3D

Interviewees used co-production as an umbrella term for

Table 2
Case study analysis highlights from synthesised results.

Case study analysis highlights	(a) CSA*	(b) Protected Areas	(c) VCP19	(d) ESCI	(e) Fisheries
Aims and intended model of Co-3D	Aims to be co-production, currently more engagement and co-design but still aiming to move to co-production.	No intended model originally although co-design and co-development were necessary to ensure the tools were designed and tested by end-users.	Engaging/co-designing.	Aimed to be co-designed. After initial engagement that took some time to settle, co-design was successful.	Co-design built into legislation and structure of funding agency that sits between science and industry.
Co-3D processes and tools	Interviews, on-line forms, presentations and discussions. Face to face engagements planned.	Interviews, phone calls, online and face to face workshops, Indigenous Reference Group.	Project inception and climate 101 workshops, follow up interviews and survey.	Workshops, webinars, training sessions, reference group.	Initial stakeholder workshop followed by smaller fishery specific working groups. Surveys of industry. Delivery via report, handbook and major conference.
What worked well	High level of interest & engagement generated. High levels of commitment and resourcing.	Working closely with protected areas led to buy in and high levels of engagement. Recognition of the value of co-development by stakeholders at the end of the project.	Workshop and associated engagement activities worked well to identify stakeholder needs.	Collaboration resulted in 'champions' in the sector to drive the work	The smaller, face-to-face groups with a steering group provided a different perspective. Long standing relationships, understanding, and trust between key champions.
What did not work well	Mismatch between funder and user needs. Some skill gaps in the team early on and resourcing constraints in terms of short time frames.	Not enough time and resources needed for full Co-3d model to be rolled out as stakeholders were not resourced with time to participate.	Expectations of co-design not matching the need for on-going and iterative process. Ongoing stakeholder needs not really accounted for in project design, required development of subsequent support project.	Late engagement of key stakeholders.	Not all participants had aligned view of how well structured the co-production was. Online surveys not an effective means for engaging with industry stakeholders.

* CSA was still ongoing at the time of assessment.

collaborative activities and had a broad range of definitions for co-production. Most defined co-production as a learning experience, about making something new, together. After co-production, co-design was the most frequently used term, and defined in relation to pre-project design or activity. Co-development and co-delivery were less frequently used terms, but described in terms of the outcomes achieved.

Co-production was seen to be important to increase stakeholder ownership of the work:

"So, co-production means that when your project ends someone else cares about it, and they'll keep it going." (Respondent #1, researcher) and was often described in terms of mutual understanding, learning and the design of projects:

"So, the first part of co-production is understanding what we all do and how to bring those things together." (Respondent #5, researcher).

We heard interviewees acknowledge that Co-3D exists on a spectrum, and there are many variants, and a lack of consistent definitions. Interviewees with considerable Co-3D experience noted that true Co-3D almost never happens, because it requires funders, researchers and end users to all be at the table from the very start, and more often this is not the case.

2. Motivations for Co-3D

The motivations for engaging in Co-3D were to improve the content and impact of projects. Interestingly, respondents mentioned that Co-3D is almost always useful at the early stages of any project and when projects relate to policy development (part of framing the problem). It can also be used to understand client needs and manage expectations. The reasons to use Co-3D include fostering stakeholder learning so they can change their own processes of doing things and understanding issues, and giving ownership of the process to stakeholders, as they are the ones that will identify issues and solutions; ownership empowers stakeholders to do something about the problem and move forward. While there may still be instances when Co-3D is not required (such as pure biophysical science research), and interviewees noted that poorly done Co-3D might be 'worse' than no Co-3D, stakeholders still viewed Co-3D as very important to science and research.

Some interviewees saw Co-3D as always being required in some form:

"I think, if humans are involved, it needs co-production of some sort." (Respondent #10, researcher).

However, participants thought that Co-3D wouldn't necessarily look the same in different contexts.

"I think the answer is, probably it's just that frequency of engagement that might change. You've got to find a frequency that works." (Respondent #21, researcher).

Co-3D was seen to be especially useful to frame the problem and make sure the right questions are being answered:

"I think if someone were to ask me a question – say, 'what is my climate risk?' – then the first part of it is co-design. Let's understand your thresholds. Understand your needs. Understand why you're asking. Why do you care?" (Respondent #4, researcher).

3. Participants in Co-3D

The interviews highlighted that who leads the process, who participates, when and how, are critical aspects of Co-3D. Interviewees highlighted that Co-3D can take a long time but is vital to building work that is useful and trusted.

"I learned long ago that, when you start something that's based on science and management and evidence and all that stuff and you put it through for implementation, it's a decade of work. And that's the other issue that arises. Who's going to be there for a decade?" (Respondent #16, end user).

Respondents discussed how Co-3D should start early and continue all the way through projects:

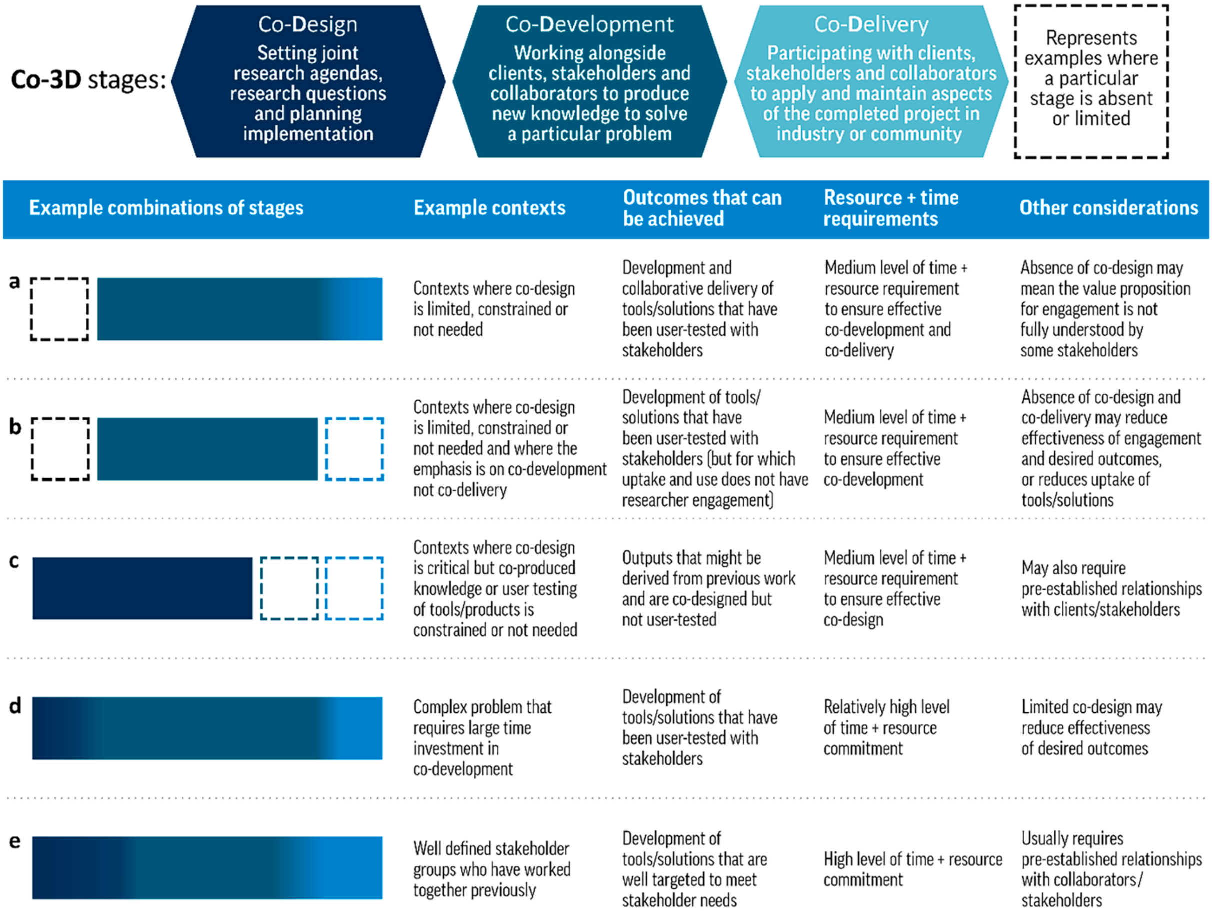

Fig. 2. Example combinations of stages for **co-design** (dark blue), **co-development** (teal) and **co-delivery** (light blue) derived from the case study analysis and participant feedback. Each case study placed different emphasis on each of the three stages: (a) CSA; (b) Protected Areas; (c) VCP19; (d) ESCI; and (e) Fisheries. The text in the columns outlines some further example contexts in which these different options for combining stages might be appropriate, together with the types of outcomes that might be achieved, comparative resource and time requirements, and other considerations for stakeholder engagement and the uptake of tools and solutions. Note that the colours of the stages do not have a hard edge, rather they flow into the next stage through a continuum, unless the other stages are not implemented. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

"Even in the proposal stage, I guess. There's no point delivering something that might be irrelevant. In part, it is very chunky research, but I'm sure you put everything into, I'm sure it's sitting on someone's shelf, which is unfortunate, but it happens. Yeah, and I think the client needs to be flexible throughout a project to be relevant." (Respondent #19, researcher).

Co-3D was seen to be a journey, and a mutual experience.

"I think that if you bring them along for the ride and explain it to them step by step, identify the issues and how it impacts them directly in that they might need to do something to change and they might also come up with issues and gaps that we hadn't thought of either as scientists or policymakers. So, it's really important to get them on board early and part of the process I think." (Respondent #15, end user).

4. Challenges and barriers to Co-3D

The interviews highlighted stakeholders often have difficulty matching available climate information to their needs to make management decisions. Furthermore, stakeholders may need to use climate information as evidence to support their approach and convince others, which is difficult when interpretations of the actions required are not necessarily clear or agreed.

"It's like having the right information at the right time to actually make some decisions is a bit of a challenge […] also when we actually get the information, communicating in a way to convince stakeholders and others that we need to respond to it and make a change." (Respondent #15, end user).

"There's actually a lot of information out there, but people struggle to access it and interpret it and find appropriate information for the types of decisions they're trying to make." (Respondent #10, researcher).

Climate is not always prioritised by stakeholders focussed on other, shorter-term, or more tangible aspects of decisions.

"The main challenges with people I've worked with have been how has climate stacked up against all the other things that make their lives complicated. In the case of fisheries, it's been things like overallocation, export problems, financial issues, finding a crew to do the jobs and so they're quite short term in some of their views but those short-term things just dominate their attention." (Respondent #1, researcher).

Common challenges around Co-3D processes identified by stakeholders include power relationships – who makes decisions, who is included, how contributions are valued – funding and time constraints. Respondents also referred to the lack of project continuity after the last milestone is delivered and the need to identify the right people to be involved in the process to enable the work to be taken up.

"The big challenge is getting the right people in the room in the first place and accepting that you will have missed someone and having a way [of] dealing with that when you do find out you've missed them, what are you going to do about it?" (Respondent #21, researcher).

5. Enablers for positive Co-3D outcomes

Interviewees highlighted that coming to a consensus on purpose was a crucial aspect of successful Co-3D. Understanding each other and reaching agreement could be hindered by a lack of trust, different language or disciplinary backgrounds, or a mismatch in institutional processes and arrangements as simple as preferring excel spreadsheets to maps and visualisations.

"So, the stuff we're deriving is quite specific to our needs, and I know that other people are deriving other things from the climate and applying them, and it's quite specific to their needs. So, I don't know how we do that collaboratively." (Respondent #19, researcher).

"And as I said, I think one of the lessons was don't underestimate your audience. Often, it's not they don't understand it, it's that you're using language that is not familiar to them. It's like don't try and teach – here's a lesson – don't try and teach them climatology language." (Respondent #4, researcher).

Differences are not necessarily difficult to overcome once they are apparent, but it can take a surprisingly long time to reveal the mismatches in what is assumed to be common understanding.

"I think we've had experience where we've said this is what we're going to do, every-one happy? Every-one says yes but they didn't get it, and so when you produce the answer it's still not going to be used because they realised, actually, we don't get it or that's not what we wanted. So how do you listen hard enough, and test 'are you really sure you know what we're doing here?' without insulting somebody or a group." (Respondent #1, researcher).

The strategies respondents identified to overcome the identified challenges prioritised interpersonal skills and broader considerations of issues and impacts. Capability to listen with empathy, genuinely care and try to understand the nature of the problem, at the same time as fostering mutual respect between climate scientists and stakeholders were seen as critical but often under-valued.

"So, I think involve them early. Take the time. Mutual respect. Check in frequently to make sure that you're still answering the right question. Because people's understanding changes as they become more educated or more understanding of the science of climate change. And their point of view changes as well." (Respondent #4, researcher).

"I've worked in much smaller projects that had some very strong personalities who felt that they were right and were not prepared to shift and adapt and produce [new knowledge] together." (Respondent #10, researcher).

Other key ingredients for success include inclusive, early engagement (larger vs smaller groups), building trust in the people and confidence in the process (listening, humility, curiosity, adaptive process), and scientists being aware that their own work is important but also be humble about its relevance to stakeholders to build partnerships to jointly 'own' commitment to the project.

"It's having the co-ordination and the relationships in place that will make trust." (Respondent #5, researcher).

"So, I would say the number one key ingredient is interpersonal skills. Whether you're working with colleagues from another discipline or domain or whether you're working with people who are not scientists, [you need] good people skills in order to be able to facilitate the conversations, the power dynamics." (Respondent #10, researcher).

"Trust is key, and listening." (Respondent #21, researcher).

Discussion

Our findings resonate with the literature on co-production (Beier et al. 2016; Vincent et al. 2018; Norström et al. 2020; Suhari et al. 2022; Schuck-Zöller et al. 2022; Bojovic et al. 2021), supporting the importance of incorporating diverse perspectives toward achieving solutions for complex problems in multiple contexts. How Co-3D influences knowledge production, uptake and 'legacy' is increasingly important for researchers, research organisations and funders interested in impact and systemic change as a response to complex issues, such as climate change. Therefore, understanding how shared knowledge can achieve impact beyond the defined time period of projects is an area that needs to be further examined.

A combination of multiple sources of information including the interview themes, the case study analysis (Table 2 and Fig. 2), our conceptual framework (see supplementary material) as well as our personal reflections as individuals and as a team were combined to develop several overarching principles that give practical insight into the implementation process of Co-3D. The combined learnings presented here can be taken up by any organisation that has a desire to learn and be more deliberate about applying Co-3D stages explicitly across a project. These recommendations build upon the analysis developed in this project as well as align with previous research. While not necessarily new to the literature, our insights from practice aim to help aid implementation in other contexts. Each principle is discussed below under separate headings to highlight key messages, although we recognise there is overlap and interconnection between these principles:

1. Frame the problem together
2. Allow time to build relationships, trust and understanding
3. Test and agree on expectations
4. Clarify key language and key outputs
5. Be inclusive and explicit
6. Support interpersonal skills and reflexivity
7. Be adaptive and match activities to objectives

Frame the problem together

The importance of collaborative problem framing is a well-supported principle for co-production. It is especially important at the co-design stage of Co-3D, and this has been discussed in the literature on climate science (Norström et al. 2020; Chambers et al. 2021). However, it is rarely a simple task to achieve consensus on the problem, the approach, and the outputs or projects. It takes time and open communication to learn from each other to establish needs, shared language, and a shared vision (Kelly et al. 2019; Fleming et al. 2021a). Terminology mismatches may hamper ability for scientists and clients to develop mutual understanding, as well as conflicts in perceptions (or lack of) legitimacy, saliency and credibility (Cash et al. 2003). Allowing partners to have flexibility on the project direction can help improve outcomes for all parties, however, this requires flexibility to be designed into the project and a shared understanding that allows for some aspects of the project to remain open. This also requires flexibility in how projects are funded (potentially requiring greater resources), as well as skills in project leadership and adaptive management (Lyall et al. 2013; Cvitanovic et al. 2016). Considering how project outcomes and impacts can have 'legacy' post project timeframes and resourcing (Reed et al. 2014) is important at early stages.

Allow time to build relationships, trust and understanding

Time to develop mutual learning and respect was a recurrent finding from the interviews and case studies. Relationship building is an essential foundation throughout co-production processes, and setting out time to work through Co-3D requires explicit planning and budgeting (Balakrishnan et al. 2022; Neset et al. 2021; Karcher et al. 2022). A strong relationship is a necessary foundation for achieving all of the other principles.

Test and agree on expectations

Clarity of expectations is a key part of framing the problem and determining the goals of the project, but it also includes surfacing power and values conflicts around who is driving the process and what types of knowledge are valued (Pielke & Roger 2007; Turnhout et al. 2020). In our interviews, this was described as ‘science arrogance’, where scientific knowledge was typically more valued than other stakeholders’ knowledge and scientists were more likely to make project decisions. Power and value conflicts cannot always be resolved, but they must be made explicit and openly addressed in some way (Turnhout et al. 2020), potentially through approaches such as a boundary manager who negotiates differences across groups (Suhari et al. 2022). Expectations around measures of success may also have to be negotiated as outcomes. For example, learning, empowerment and increased institutional capacity should be acknowledged as significant advancements (Bremer et al. 2019). Co-3D cannot be achieved if there are hidden agendas, partial commitment, or dishonesty – whether intentionally, or unintentionally (Pielke & Roger 2007).

Clarify key language and key outputs

Being clear about terminology and outputs is again related to framing the problem and testing and agreeing on expectations, but it is specific to developing a shared language and understanding of the outputs (and beneficiaries). Disciplinary divides, different worldviews, and politics mean that language is easily taken to mean different things to different people (Turnhout et al. 2020; Balakrishnan et al. 2022). Rather than obsessing about definitions, clarifying language is more about sharing a ‘vision’ of the project, the approach, and the outcomes, and what constitutes ‘success’ (Bremer et al. 2019) which can sometimes be better achieved by embracing ambiguity or multiple meanings of particular words, rather than endlessly debating definitions (Fleming and Howden, 2016).

Be inclusive and explicit

Inclusivity is closely tied to clarifying key language and outputs, as well as testing and agreeing expectations, because it is about opening up the potential beneficiaries of the work (or those who might be negatively impacted) to participate and influence the approach. Being inclusive can be challenging if those who are involved in starting the project are not sure about who should be included, so it is important to start widely and then narrow down. Furthermore, it is important to think broadly at the outset about who might be potential end users, and who are not usually invited to participate in science co-production processes, for example, climate activists (Drake & Henderson 2022) or those in health or education. Being explicit about the roles and responsibilities, power and values, but also the decisions that are made throughout the project increases transparency and trust (Stilgoe et al. 2013), but this can be especially challenging to accomplish in privately funded work where an end goal is strongly suggested by the funder (Fleming et al. 2021b).

Support interpersonal skills and reflexivity

The case study and interview analysis strongly point to the need for interpersonal skills and reflexivity. The importance of skills such as patience, communication, relationship building, trust, facilitation, listening with empathy, willingness to learn, open-mindedness, curiosity, flexibility, sharing and humility, stood out as essential aspects of Co-3D (Bammer 2013; Tengö et al. 2014; Kelly et al. 2019; Neset et al. 2021). At the same time, these skills were often seen to be undervalued and under-resourced and rarely part of the explicit project negotiation process. There is a clear opportunity for science to move towards greater emphasis on capacity building and rewarding communication skills in science, including supporting broader career pathways in science for ‘translators’, ‘knowledge brokers’ and other intermediary and enabling roles (van Kerkhoff & Lebel 2015; Cvitanovic et al. 2016).

Be adaptive and match activities to objectives

Another clear finding from our research highlights that there is flexibility in how Co-3D activities might look in a project, but negotiation and discussion is required to determine how the project is run and how the Co-3D activities will be designed to match the intended objectives. This may need agreement from stakeholders as well as require time and resources from multiple parties that extend beyond the primary client and science organisations. If Co-3D is implemented after contracts are in place, there may be large mismatches in terms of funding and timelines. Co-3D should be incorporated into contracts to ensure it is recognised as part of the process and that appropriate contributions (time and resource commitment as well as inclusion of a project manager or facilitator role) are in place. This will allow for greater flexibility and integration of new ideas as the project progresses. Finally, while co-production was seen as important by stakeholders in all contexts, it should not become an end-goal itself, rather it should be carefully planned and designed and intentionally applied (Lemos et al. 2018).

Conclusion

We found that co-production is an umbrella term for many different understandings of collaborative research which are not necessarily made explicit or negotiated. To improve the outcomes of collaboration, what it involves and what the desired outcomes are, there needs to be clearly established understandings of how co-design, co-development, and co-delivery will be implemented at the outset. This may require some time and work to frame the problem and set expectations, even before the project begins. Explicit attention to Co-3D can help research to achieve impact, be more inclusive and produce relevant outputs, and increasingly climate science is funded specifically for these outcomes. Being intentional about how to achieve outcomes through different forms of Co-3D is important as there is no set process, rather a negotiated and context-specific set of activities. It is also important to evaluate different attempts at Co-3D so that knowledge can be more grounded in real examples and thus relevant to stakeholders. Active and honest reflexivity about the approaches, decisions, and outcomes Co-3D is trying to enable is an ongoing need for climate science.

Practical implications

Co-production plays an important role in the engagement and delivery of projects, but the planning and implementation around what form of co-production is used may depend on which stakeholders are involved and the project goals. Understanding co-production more specifically as various combinations of co-design, co-development and co-delivery (Co-3D) can lead to more deliberate consideration and planning of collaborative work through the course of a project. Starting with the mindset of inclusion and collaboration can also improve participation and collaboration in climate science and service projects and make the outcomes more effective, inclusive, relevant and fit-for-purpose.

Many climate service projects are increasingly cognisant of the need to collaborate across stakeholder groups to gain buy-in for additional actions or decisions which impact on different groups. However, institutions vary in the degree to which Co-3D is embedded in their practises, and the timeframes over which such arrangements have evolved. The principles provided in this paper provide a starting point for organisations which have not had a history in co-production to come to the table understanding what is required, or for organisations who are applying Co-3D but want to compare with other experiences. Over time, as organisations learn more about how they would like Co-3D to be implemented, their experiences can provide additional knowledge and guidance for others. For example, interviewees highlighted that co-design and co-development are effectively embedded in Australian Fisheries legalisation through the concept of the partnership approach supported by a consultative framework, so it is an overarching requirement that guides all projects and change processes that are undertaken. Over the 30-year history of developing the partnership, trust building, and long-term relationships have been especially important. Across the interviews and case studies, co-delivery was found to be less well understood and applied than co-design and co-development.

Capturing end-user evaluations of Co-3D processes and truly achieving transdisciplinary work that shares power and decision-making is still the exception rather than the norm. New approaches to indigenous-led research, such as that occurring in New Zealand, and institutional commitments to transdisciplinary research show us the way this work can be done. The future of complex system science requires more transdisciplinary approaches that are more iterative, self-reflective and inclusive. Developing a process in which to monitor and evaluate such learning can help the science community consider better methods for research practice and develop a stronger relationship with those who will implement the science.

Declaration of Competing Interest

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Data availability

The data that has been used is confidential.

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Appendix A. Supplementary data

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