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Managing and Governing Integrated Research Programmes: Lessons from Theory and Practice

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Abstract: Researchers are increasingly working in large, integrated science programmes. This is supposed to lead to several benefits, including creating and enhancing synergies amongst projects, improving collaboration and knowledge exchanges amongst researchers from different disciplines, and generating a higher return on investments in R&D. In practice, though, these benefits are often not fully realised, and large-scale integrated programmes can become frustrating for researchers. Additionally, they can result in insufficient integration and collaboration, and incur high overhead costs. In the present paper, the authors share their experience and insights on how to structure, manage and govern integrated programmes more competently. They do so by reflecting on their own practical experience in designing an integrated programme, and by drawing valuable insights from the literature on governance, management studies and organisational economics. The authors suggest that many problems can be linked to the implementation of programme management systems and coordination mechanisms that are poorly aligned with the unique characteristics of integrated programmes. They provide guidelines for programme managers to use systems that are a better fit, which can help researchers collaborate in a more engaging and productive manner while reducing the overhead costs associated with programme administration.

Keywords: integrated research programmes; programme management challenges; governance; management; transdisciplinary collaboration

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1. Introduction

The sustainability challenges confronting humanity are incredibly complex and are thought to necessitate integrated, transdisciplinary approaches [1,2]. Consequently, scientists are increasingly being asked by funding bodies to develop large, integrated research programmes [3]. These integrated programmes are expected to encompass multiple projects, involve various disciplines and stakeholders, and work towards a common goal (e.g., [1,4,5]). However, managing and governing integrated research programmes is far from being a straightforward task and is fraught with numerous challenges [6].

"Integrate" comes from the Latin word "integer", which means "whole". Integrate, as a verb, is the process of combining or fusing "things" so that they form a coherent whole [7]. "Integration" has of course different meanings depending on the context in which it is used and the type of "things" that are being integrated. In the context of research programmes, researchers most often use the term to refer to the integration of different epistemics (so-called "epistemic integration"); i.e., combining or fusing different forms and types of knowledge to construct new knowledge [1,8]. This includes knowledge from different disciplines, but also from different modes of thought (including non-science) and cultures [9]. Integration is crucial to interdisciplinary and transdisciplinary work [4].

Besides epistemic integration, several other forms of integration can be distinguished [7], such as normative and functional integration [5,10]. By normative integration, we refer to the integration of purpose, which is realised when participants share a common aim or vision. Functional integration refers to the integration of workstreams. This includes integration of vertical workstreams (project, programme, supra-programme), as well as integration of horizontal streams (across different projects within the programme). In this case, integration is successful when researchers cooperate in a coordinated manner across the programme. The type of integration that funding agencies have in mind when they request proposals for integrated research programmes is not always well-specified. However, implicitly at least, often all three of the above-mentioned forms of integration are assumed to some degree.

Combining different projects into one integrated programme is expected to have several benefits such as avoiding duplication of efforts, creating synergies among projects, achieving better collaboration among researchers, realising efficiency gains and obtaining higher returns on invested funds [11]. In addition, the sum is supposed to be greater than the individual parts. However, in practice, these benefits are often not fully realised. Collaboration between different disciplines can be challenging and synergies between projects hard to manage. Moreover, large-scale integrated programmes can become expensive (e.g., by incurring high overhead costs), while they often fail to deliver the desired outcomes for stakeholders [12,13]. Communication problems, politics, power imbalances and hidden agendas can all form major obstacles.

In the present paper, we contribute to addressing the challenge of how to structure, manage and govern integrated research programmes. We do this using an ongoing research programme, which some of the authors are involved in leading, as an example. We reflect on the challenges we faced in designing the programme and discuss what steps we are taking to address them.

The remainder of the paper is organised as follows. In Section 2, we briefly explain the core problem this paper focuses on, the question of how and when to realise the different forms of integration, as well as how to manage the relationships between them. In Section 3, we discuss the programme we are involved in as a case study to explore some of the problems that result if different forms of integration are not explicitly acknowledged, and the relationship between them is not well managed. Section 4 of this paper details how insights from the literature on governance, management studies and organisational economics can be used to tackle these problems. Section 5 identifies lessons of the study for the design and management of integrated research programmes. Section 6 concludes the paper.

2. The Problem

The underlying objective of most research programmes is to address some type of problem through the creation of new knowledge (e.g., new theories, processes, tools, technologies, etc.). In an integrated research programme, participants attempt to do this through epistemic integration [6,9]. However, epistemic integration cannot be realised if it is not supported by adequate integration of purpose and functional integration. Without adequate integration of purpose, researchers will work at cross-purposes, addressing different, sometimes conflicting goals [10]. Without adequate functional integration, the various workstreams within a programme will not work in sync, leading for example to model and data incompatibility, duplication of efforts or unnecessary delays. However, to ensure all three types of integration are established within a programme, and are working in harmony, is complicated [14,15].

Integrated research programmes are usually concerned with complex, multifaceted problems. The participants come from widely different fields of research or practice and have, for example, different ideas about what constitutes science or have established different ways of working. To further complicate the situation, some of the participants may not be there completely by choice, as researchers need to fund their time. A catch-22 sort of

situation emerges; complex problems often require inter- and transdisciplinary teams (that is why they are complex), but such teams tend to find it hard to agree on problem definitions and problem-solving approaches. This is because they tend to bring different modes of thought, values, interests and ways of working into the programme [16,17]. The question of how to overcome such difficulties has been frequently raised in both the transdisciplinary (TD) and broader project management literature, still a satisfactory solution has yet to be found. We identify four primary reasons for this.

Firstly, and arguably most importantly, dependencies between different types of integration, and how they should be managed, have been insufficiently addressed. This is further discussed in Section 4.

Secondly, a number of these issues can be attributed to conflicts and disagreements among programme participants. Although the transdisciplinary (TD) literature acknowledges these conflicts, it does not provide clear guidance on how to address them efficiently and effectively. Specifically, the TD literature insufficiently considers how competent governance structures and processes can help to prevent or reduce these problems. However, it is important to consider these structures and processes as they can be instrumental in navigating the conflicts and disagreements that are bound to arise.

Thirdly, in the broader project management literature, project management approaches are frequently extended to the level of the programme [18]. Though some aspects of specialised project management methods may be valuable at the programme management level, there are additional coordination and collaboration challenges unique to that level that are not adequately tackled by project management methods and related literature (such as the Agile manifesto, PRINCE 2, PMBOK).

Fourthly, while a dedicated programme management literature has been in development for some time, there is still a significant amount of work that needs to be conducted in this area to adequately capture and study the messy nature of complex programmes [9]. For example, many studies in this field utilise a single theoretical approach. However, complex programmes involving multiple stakeholders tend to lead to a wide range of situations and problems. Making sense of these requires a plurality of theoretical perspectives.

When researchers from different disciplines are tasked with collaborating to develop integrated programs, there is often a phase in which integration appears impossible, and the participants struggle to agree on anything other than highly abstract goals and objectives. The level of abstraction embedded in these objectives is often too high to catalyse concrete decisions about how the programme should be designed. Some of the feelings that involved people express are, going in circles, indecision and paralysis, leading to frustration and impatience [19,20]. In the meantime, time keeps slipping away. Expressions such as "just tell me what to do then!" or "we need to get on with the real work" are often heard, and passive-aggressive attitudes emerge, as well as scapegoating, and tensions among the participants. At that point, only one way forward seems possible: to abandon any serious attempt at realising epistemic and integration of purpose, split the resources into individual pieces of research, only loosely related by some overarching objective, abstract enough to accommodate almost anything. Often, in such scenarios, this is performed in a tacit manner, by keeping functional integration in place. Sometimes it even involves just keeping up the appearance of functional integration (e.g., by keeping projects together, even if there is little actual collaboration taking place), which is the type of integration most clearly visible to funding bodies and other stakeholders [21]. However, keeping projects administratively together without real integration of the three types serves little purpose and is likely to lead to unnecessary coordination and administrative costs.

Obviously, it is in society's best interest that such a scenario is avoided. But how? A key challenge that managers and designers of integrated programmes face is that little research has been conducted on the relationships between different forms of integration, and how they can enable or disenable each other. As a result, the existing literature on integrated research offers little insight into how these relationships need to be managed. Examples of unresolved or unaddressed questions on this topic include:

- What degree of functional and normative (purpose) integration is necessary within a programme to enable epistemic integration?
- At the outset of a programme, should programme managers or designers tackle all three types of integration simultaneously, or should they first start with one form?
- If the latter, what form of integration should be enhanced or promoted first?
- For example, do researchers need to first have a common vision before epistemic integration can be addressed or is it necessary for stakeholders with different modes of thought to first have at least some level of epistemic integration before a common vision can be realised (e.g., a common language or knowledge base needs to be established first)?

While these may seem like abstract questions, they are directly related to the more tangible questions of how to (1), establish consensus or to at least move forward from situations where this is lacking; (2), ensure various workstreams within a programme work in sync; and (3), manage and govern a large, complex programme effectively (towards the goals of the programme) and efficiently (i.e., with most of the funds going to science activities rather than the administration of the programme). These problems are especially daunting in the context of inter- and transdisciplinary programmes, where programme managers may not possess the requisite academic background to fully understand and review the performance of many of the projects. As is explained in the next section, we experienced these problems in our programme, where we grappled with the challenge of realising integration (in all its forms).

3. A Case Study

In this section, we reflect on our experience in participating in the planning of a large integrated research programme called New Zealand Bioeconomy in the Digital Age (NZBIDA).

NZBIDA is managed by AgResearch (Christchurch, New Zealand), the organisation for whom most of the authors of this paper were working at the time it was written. AgResearch is a research institute that is fully owned by the government and undertakes both public good research and contract-based research for commercial companies.

NZBIDA is a programme dedicated to exploring the ways in which digital technologies can enhance the sustainability (in its environmental, economic, social and cultural dimensions) and resilience of New Zealand's primary sector. In particular, NZBIDA's mission is as follows:

> *"To demonstrate how digital technologies can be harnessed to enable the transformation of New Zealand food systems to deliver: prosperous land-based enterprises; protected, enhanced and sustained natural resources; and added-value foods and bio-based products that meet consumer needs".*

The programme, up till the time of writing, has consisted of two phases. Here, we discuss the process undertaken to plan the second phase of the programme. Approximately 70 researchers are participating in this phase, with an expected total funding of $NZ 25M for a 5-year period.

3.1. Initial Developments

The NZBIDA leadership team was formed in March 2020. Co-design workshops were conducted with key internal and external stakeholders and five key themes were developed from these workshops. The NZBIDA leadership team initially decided to use a bottom-up approach to generate research ideas for these themes. A call to submit Expressions of Interest (EoIs) was sent out to all scientists working for AgResearch. This call contained the scope (five themes), selection and success criteria. Around 54 EoIs were submitted.

To evaluate these EOIs, a group was set up consisting of members of the NZBIDA leadership team and other managers and directors within AgResearch that were not directly involved with the NZBIDA programme. Around 25 EoIs were selected by this group.

Subsequently, the NZBIDA leadership team attempted to synthesise these ideas to develop an integrated programme based on them. However, it proved hard to develop an integrated programme from 25 scattered ideas and they made the decision to go back to the drawing board and follow more of a top-down approach. At that point, the NZBIDA leadership team established a design team to lead the design and planning phase. This phase lasted from September 2020 until February 2021. Four researchers were part of the design team, which was led by one of the authors of this paper.

The authors had the following roles within the programme: two of the authors formed part of both the design team (one of whom was the leader of the design team, and one of whom was also a module leader), and one of the authors was a science delivery team lead. Please see Section 3.3 for details about NZBIDA's management and governance structures, and where these roles fit into that structure.

When the design team was established, the programme was already divided into several components. The design team was asked to focus on the largest of these components (see Figure 1), leaving the other components outside the scope of its brief.

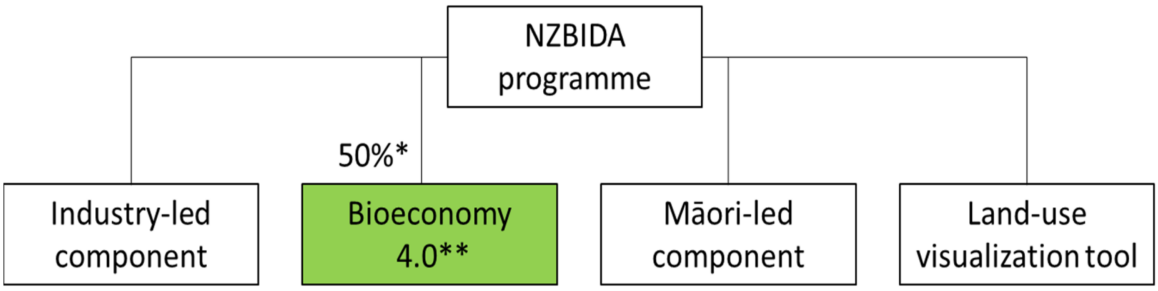

Figure 1. Components of the NZBIDA programme. * Percentage of total NZBIDA funding; ** The green marked component was the focal point for the design team. It is also the main component of the NZBIDA programme (in terms of allocated funding).

3.2. Our Attempt to Design an Integrated Programme

The design team had a very broadly defined problem space to work with—the role digital technologies can play in developing and enabling transition pathways for the agricultural sector—with disparate views of what should be performed and limited resources. As mentioned above, by the time this phase had started, the programme had already undergone a period of creativity and divergence. Now, a phase of convergence was required to produce a cohesive and integrated programme, and to scope a plan within the allocated budget.

A process was devised to aid such convergence, drawing on tools and ideas from engineering design methods [22]. One key element in any design process is the "client", which in this stage of the programme was the Programme Leadership Team (the client thereafter) who assigned the task to the design team. We also considered the demands and needs of a wider group of stakeholders (e.g., funders, farmers, agribusinesses, etc.).

The starting point for the design was a high-level programme logic for the programme that had already been developed. The role of the design team was to develop a more detailed research plan. The main phases of the process followed were:

- The task clarification phase involved getting more clarity and consensus about the responsibilities of the design team through an iterative process with the programme leadership team. This culminated in the creation of a "brief" for the design. The brief defined purpose, scope or system boundaries, priority areas and strategic choice of means (i.e., digital technologies as one key means for achieving the purpose).
- The high-level planning phase focused on programme-level planning and included the development of the programme into specific modules. The plan was created in several iterations with the client and led to the establishment of three initial modules. In parallel, the programme governance structure was set up.

- The detailed planning phase focused on module and project level planning, which led to the development of proposals and the creation of science teams to deliver on these proposals. In total, about 15 project plans were developed. A fourth module was set up to support and enhance the sharing of information across the other modules.

3.3. NZBIDA Management and Governance Structure

Part of the planning task included ensuring the design team would work in a participatory way with the larger delivery team, but that it, at the same time, would take leadership in the planning process. That meant momentarily shifting the 'bottom-up/top-down' balance in decision making within the programme somewhat towards the latter.

The plan was that the design team would coordinate the module leaders and would report to the client. The module leaders, in turn, would coordinate the project leaders, which would coordinate the delivery teams.

Further up in the hierarchy, the programme leadership team would report to a "governance group", which had an oversight and control function. The governance group in turn, would report to a "steering group", which also had an oversight and control function (although not just for NZBIDA, but also over other integrated programmes undertaken within AgResearch).

As the programme moved out of the design phase, the design team was dissolved with some of the members taking up roles as module leaders. Figure 2 gives an overview of NZBIDA's management and governance structure at that point in time, with Table 1 summarising the role of each of the layers in the hierarchy.

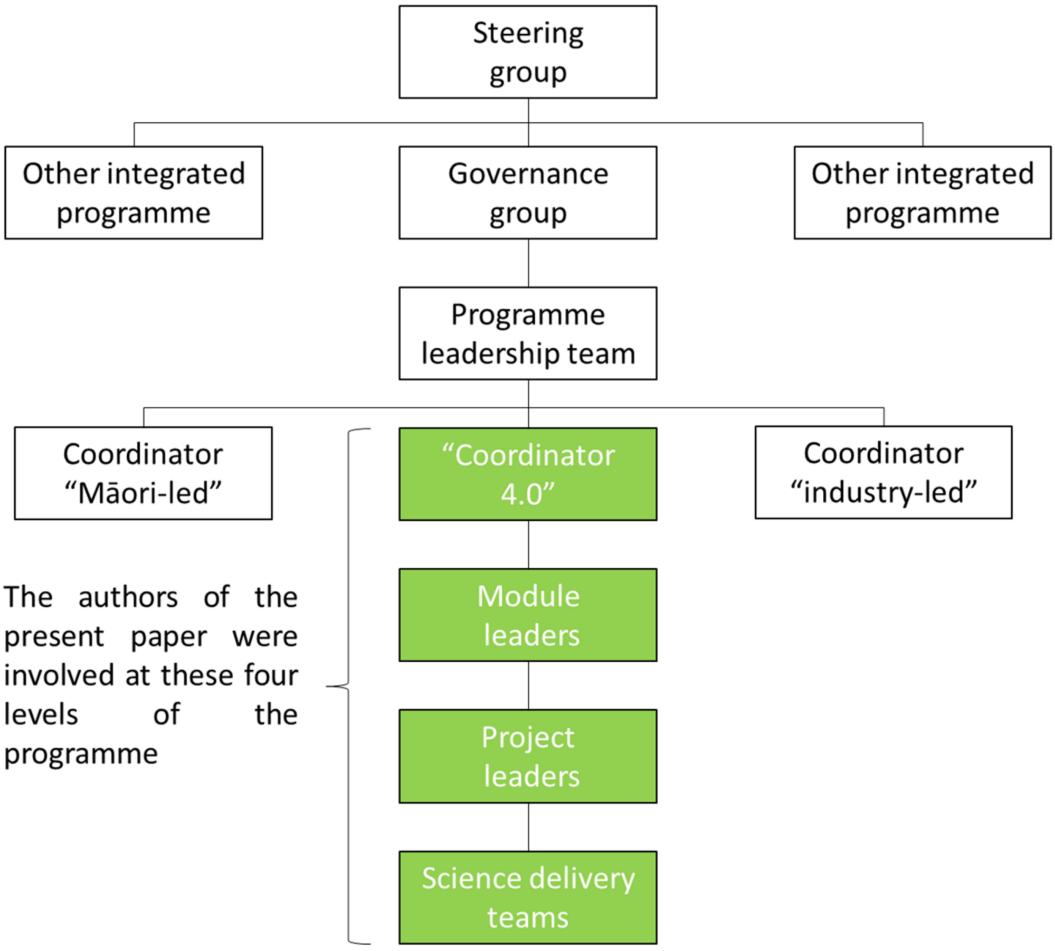

Figure 2. NZBIDA's management and governance structure.

Table 1. Managerial and governance roles within the NZBIDA programme.

Layer	Key Elements of Role
Steering group	• Approve five-year strategic plans for Integrative Initiatives and Enabling Platforms; • Approve the annual budget for Integrative Initiatives and Enabling Platforms; • Stay informed to have clear oversight of the investments; • Ensure consistency of approach across the portfolio framework; • Champion the concept of integrated and enabling approaches within and outside the organisation; • Manage risk.
Governance group	• Provide strategic viewpoint on design and delivery of the proposed plan of work; • Provide oversight and governance of the project; • Remove roadblocks to progress or refer these to the Steering Group; • Support and champion integrated approaches; • Ensure the work is well embedded within the overall AgResearch structure and integrated initiatives framework; • Ensure risk is tracked and managed effectively.
Programme leadership	• Ensure science quality; • Develop the strategic direction of NZBIDA; • Develop annual workplans, including budgets; • Monitor and report science progress to the governance group; • Identify roadblocks to progress; • Identify and champion new ways of working; • Identify opportunities to grow the programme.
Design team lead/Coordinator	• Temporarily established role to develop and implement a structured planning process, in iterations with programme leadership. The planning process was meant to: ○ Specify/clarify the desired long-term outcomes of the programme; ○ Develop a high-level research plan for realising these outcomes; ○ Identify research modules and their leaders; ○ Establish criteria and principles to guide module leaders and project leaders in developing detailed plans; ○ Facilitate communication between module leaders; ○ Ensure integration between modules.
Module leaders	• Manage and deliver their module successfully, within the required tolerances of time, cost, quality and scope; • Maintain communication between researchers within their modules; • Identify opportunities for integration of projects; • Ensure success criteria for each project are clearly defined.
Project leaders	• Manage and deliver their project successfully, within the required tolerances of time, cost, quality and scope; • Maintain communication between researchers within their project to build a team spirit.

3.4. Frustrations and Challenges

The task given to the design team was to develop a highly integrated programme. Expectations for the programme were high. Furthermore, in the first phase of NZBIDA, the company had already struggled in putting together an integrated programme, as indicated in the practice note by Percy [23]

> *"Despite our best intentions, the integration between the whole programme did not work as well as anticipated. The outputs from the first phase were always going to be a number of use-cases/proof of concepts, with some being more integrated to others and the overall programme outcome and vision. The concept of outcome-driven research, and what this means in practice, was not always fully appreciated and endorsed by team members".*

Most of the problems encountered within the first phase of the programme were experienced from the beginning of the second phase. Despite that, the design and planning

process progressed reasonably smoothly up to the point when the high-level plan was signed off. Subsequently, the design team yielded control to the broader team of researchers participating in the programme. Notwithstanding the effort put in the task clarification and high-level planning, the subsequent process did not proceed as intended. The brief was mostly ignored, frustration grew among many team members, and relations were strained. Integration of purpose was problematic, with researchers having different ideas about what direction of the programme should be. Epistemic integration felt forced and not reflecting the needs of the various projects. Furthermore, decision making was slow, indicating that there were problems with the functional integration of the programme.

As is mentioned in Section 1, it is not unusual to encounter these kinds of problems within integrated programmes. For example, Aslin and Blackstock [24] offered a long list of barriers to integrated research, many of which share similarities to the ones we encountered. We can infer that these types of problems, rather than being due to failure of individuals, are symptoms of underlying systemic problems. On one hand, these systemic issues originate in the unique characteristics of integrated research programmes, and on the other hand are due to the lack of competent management and governance systems that are well-aligned with these characteristics.

4. Lessons from Governance Theory, Management Studies and Organisational Economics

In the present section, we explain how we turned to a variety of approaches from governance theory, management studies and organisational economics to help us address the challenges discussed in the previous sections.

4.1. How to Organise Collaboration When Integration of Purpose Is Hard—Lessons from Corporate and Cooperative Governance Theory

For various reasons, integration of purpose proved difficult to realise within NZBIDA. For a start, the programme mission was broad and ambiguous, which led to different stakeholders within the programme having very different ideas about what the programme was trying to achieve. Related to this, it proved difficult to find a right balance between democratic decision making and hierarchical decision making, with programme management sometimes relying on the former and sometimes on the later. This led to confusion about responsibilities and accountabilities, including about the extent to which researchers on lower levels could shape or steer the overall direction of the programme.

Furthermore, many of the researchers participating in the programme had different, sometimes conflicting, interests, which meant that it could be a slow and cumbersome process for the group of researchers to agree upon things. For example, researchers were competing with each other for internal funding, which means it was difficult to get them to reach a consensus about goals and means. Additionally, for some researchers the programme was their main source of funding, while for other researchers, it was just one of many programmes. This led to frictions, both large and small, about the effort researchers put into the programme.

All these reasons appear to result from the same underlying cause: the lack of a competently designed governance structure, which makes it hard to realise effective and efficient collective action within the programme. In some ways, a research programme shares similarities with a start-up company: its organisational structure, governance, ethics and norms all need to be developed. However, unlike a start-up, a programme is often integrated into an existing organisation such as NZBIDA and does not start completely from scratch. While the existing structure and policies can offer guidance, they can also be a hindrance and lead to messy and ambiguous situations. For example, within NZBIDA, the programme hierarchy did not match the organisational hierarchy. As a result, situations arose where project managers could be leading and evaluating their own line managers within the context of the programme. The upshot is that, even though NZBIDA is embedded within an organisation, it still needs is own structure and norms that are only partially determined by the broader organisational context.

To help design a more competent governance structure for NZBIDA, we are using both corporate and cooperative governance theory as guidance. The former offers insight into what governance mechanisms are required to support and control programme management and limiting agency costs resulting from conflicts of interest and under-performance at the managerial level. The latter offers insight into how to deal with heterogenous groups of workers and what types of mechanisms can be put in place to limit the democratic costs involved in instances when collective decision making is required. Of course, a programme is neither a corporation (investor-owned firm) nor a cooperative and we, therefore, do not intend to blindly follow the theories, but rather adapt them to the programme context.

4.1.1. Dealing with Agency Costs

Agency costs are the expenses incurred by a principal (e.g., an individual, programme or organisation) when delegating decision-making authority to a representative or agent (e.g., [25–29]). Examples of such costs include the fees associated with hiring a stockbroker to manage an investment portfolio or the expenses incurred by shareholders when they employ a manager to oversee a company. Agency costs may include both direct costs, such as the agent's fees or salaries, as well as opportunity costs, such as when the agent takes a suboptimal action because their interest are not aligned with that of the principal.

Much of the corporate governance literature focuses on minimising opportunity costs. These costs can be reduced through two main mechanisms: (1) implementing incentive structures that align the interests of the principal and agent, and (2) implementing monitoring mechanisms to track agent behaviour and performance. For example, in an investor-owned firm, share packages can be included in managerial remuneration to help ensure managers act in the best interest of shareholders, if these packages are appropriately structured. External monitoring, as well as internal monitoring, can also be used to limit opportunity costs. In investor-owned firms, external monitoring is typically conducted through capital markets and accountants, while internal monitoring is usually carried out by the board of directors. The board has a clearly defined mandate and associated responsibility for defining ethical and professional standards, conducting audits and so on.

In contrast to IOFs, research programmes usually do not have the option to implement elaborate incentive packages. Additionally, external monitoring of researcher managers and programme leaders by funding agencies is typically not as continuous or thorough as in capital markets. As a result, internal monitoring mechanisms and associated professional and ethical standards become a crucial method for reducing agency costs in research programmes. However, unlike IOFs, such monitoring does not have to primarily occur in a top–down manner. Research programmes have the potential advantage of bottom–up monitoring, which can be facilitated by the workers. Similar to cooperatives, the "workers" in a research programme have a greater incentive to monitor managerial performance than workers tend to have in an IOF. In the case of cooperatives, this is because the workers themselves have a vested financial interest in the success of the organisation, similar to the shareholders in IOFs but unlike most workers in IOFs. For researchers, this is because they tend to have a more active interest in the capital and resources that the programme puts at their disposal than the average worker within an IOF. Without such resources, they will not be able to conduct their studies and experiments and further their academic careers.

The NZBIDA programme can take several measures to reduce agency costs. Firstly, by ensuring responsibility for control and oversight does not become diluted, for example, by reducing the number of hierarchical layers within the programme. Fewer layers will enable more competent top–down monitoring and should also facilitate bottom–up monitoring by researchers on the ground floor, as decision making becomes more transparent. Secondly, and related to the previous point, the programme or their external stakeholders could take further steps to support and leverage bottom–up monitoring. For instance, the programme could invite researchers from the ground floor to attend meetings of the programme leadership on a rotating basis. This would help provide assurance to the researchers

working on the ground floor that the program's formal procedures are being implemented effectively and that decisions are being made in the best interest of the program.

4.1.2. Dealing with Democratic Costs

Democratic costs refer to the expenses incurred in undertaking, managing and governing collective decision-making processes [30]. These costs include: (1), the costs of providing incentives to workers or members to participate in voting, committees, etc.; (2), the disruptions caused by conflicts of interests between the various constituents and groups that make up the organisation; and (3), the costs associated with managing and dealing with such conflicts [31]. Similar to agency costs, democratic costs can be direct, such as time spent on meetings [32], or opportunity costs, such as delayed or suboptimal decisions [33,34]. Collective decision-making processes are part-and-parcel of integrated research programmes, where the needs and goals of a disparate set of stakeholders have to be accommodated and managed, often with limited hierarchical authority.

Cooperatives rely heavily on collective decision-making processes and often have members with diverse interests. As a result, they have traditionally faced challenges in managing democratic costs. To help address this issue, the literature on cooperative governance has extensively explored ways to manage collective decision-making processes. It therefore provides valuable insights into how democratic costs can be limited. For example, Pozzobon [30,34] suggest several mechanisms for reducing problems and costs associated with collective decision-making processes:

- To prevent gridlock and ensure timely decision-making, it is important to implement effective and clear voting procedures;
- Given the high costs associated with mobilising groups and encouraging participation, it is advisable to limit collective decision-making processes to critical issues;
- Instead of encouraging mass participation, mobilisation efforts should focus on under-represented groups, such as certain science disciplines that are not well-represented in the decision-making process;
- Ensure proper representation of different groups of workers/members at the board level;
- Related to the previous point, it is important to strike a balance between the size of executive and control boards. They should not be too large (which can lead to stalling of the decision-making process) or too small (which can result in certain groups being under-represented).

To reduce democratic costs within the NZBIDA programme, the following actions are recommended. Firstly, clear voting procedures should be implemented at each level of the programme to prevent gridlocks and resolve disputes efficiently. Secondly, the role of researchers in the decision-making process should be clarified. Specifically, it would be beneficial to clearly distinguish between issues where researchers on the ground floor have a vote and those where they have only an advisory role. This can prevent confusion and dissatisfaction among researchers, facilitating smoother consensus building.

4.2. When and How to Stimulate Epistemic Integration across the Programme—Lessons from Thompson's Work on Interdependencies

A frustration that some researchers within the NZBIDA programme encountered was the feeling that the need to pursue epistemic integration across parts was forced upon them, without sufficient insight into where it was potentially useful and where it was a distraction. Rather, researchers were asked to attempt to find as many linkages between projects as they could by programme management; or at least so it felt. This was a consequence of how the programme was functionally structured and organised, with some of the modules involving a lot of parts and trying to encourage researchers to explore the potential for epistemic integration across all the parts. However, as the modules were set up along broad thematic lines rather than based on the potential of parts to deliver integrated results, this led to frictions.

For example, in the pursuit of epistemic integration, researchers were being asked to participate in frequent meetings within their modules, where they were also getting updates about projects that were unrelated to their own part of the programme. Partially as a result, several researchers avoided attending these meetings, thereby also losing the opportunity to link to parts of the programme that were indeed related to their own work. In hindsight, it would have been better to support module leaders in taking a more focused approach to epistemic integration, that is, organising functional integration better. To help organise functional integration, we are turning towards Thompson's [35] foundational work on dependencies (see [36,37] for other recent applications of his work).

In an integrated research program, dependencies arise when the programme cannot be broken down into sub-tasks or projects that can be independently completed by different researchers or groups. Rather, it requires some degree of cross-part coordination. Thompson [35] identifies three main types of dependencies:

- A pooled dependency arises when various projects rely on a shared resource, such as a laboratory or equipment, but the projects can function relatively independently from each other with little cross-project collaboration amongst researchers. Coordination challenges in such situations include determining how to distribute access to the shared resource among the various projects and how to properly maintain the resource;
- A sequential dependency occurs when one project's outputs, such as data generated through an experiment, becomes an input for another project. To effectively manage this type of dependency, the supplying project must have a basic understanding of the type of data the client project requires and what is expected in terms of data integrity and validity. While the supplying project needs to have a working knowledge of the concepts and methods used by the client, they do not need to be fluent in the client's "language" as adaptations are relatively infrequent compared to projects with reciprocal dependencies;
- A reciprocal interdependency occurs when there are bi- or multilateral dependencies between projects, meaning that project A not only receives inputs from project B, but project B also requires inputs from project A. This type of interdependency can arise when researchers from multiple projects collaborate on developing different components of a model, for example. In such cases, frequent adaptation to each other's demands is crucial, and researchers must be able to effectively communicate and understand each other, which can be challenging when different disciplines are involved.

The level of frequency and complexity of coordination mechanisms needed to manage these dependencies varies [38,39]. Pooled dependencies may only require basic planning, such as scheduling and dividing lab time among researchers, although additional coordination mechanisms may be necessary if compliance with shared resource rules is an issue. Sequential dependencies typically require additional coordination mechanisms, such as output standardisation to manage dependencies. However, output standardisation may not always be feasible, for example, because it is hard to establish at the outset of a long-running project what type of results are going to be realised over the project's lifetime. In such cases, projects may have to rely on process standardisation instead. Managing reciprocal interdependencies depends on the number of involved projects. When there are only two projects, lateral linkages between them should be developed and strengthened, such as having some researchers actively involved in both projects. However, when reciprocal interdependencies exist between more than two projects, it becomes infeasible to rely on lateral linkages. In such scenarios, a hierarchical structure, where several previously independent projects are combined under the management of a single module, may be a more efficient way to manage the interdependencies.

To be able to apply Thompson's work to the NZBIDA programme, it is important to first identify the types of dependencies that exist or may arise between the various projects within the program. To facilitate this, we have created a brief questionnaire for the project leaders to complete regarding the types of dependencies they anticipate with the other

projects in the program. Secondly, informed by the outcome of the questionnaire, projects should be grouped into modules based on the types of dependencies between them, rather than solely based on the subject matter being studied (e.g., consumer, greenhouse gas emissions). It is beneficial to group sequentially or reciprocally dependent projects together, as these types of projects require more frequent communication. Thirdly, coordination problems and mechanisms should be aligned to minimise coordination costs and limit the number of required meetings for programme participants. For instance, projects with only pooled dependencies may not require "science" meetings and can instead limit their collaboration to reaching a consensus on how administrative tasks such as scheduling or budgeting should be organised. This approach can help alleviate meeting overload and any sense of forced integration and collaboration among researchers.

4.3. When to (Not) Functionally Integrate Projects within a Programme—Lessons for Determining Programme Hierarchy and Boundaries from Transaction Cost Economics

Another problem within NZBIDA was a slow decision-making process, partially due to too many management layers within the programme and partially due to ill-defined decision-making processes within the layers. Regarding the former, it appeared that the management layers were not communicating well, in part because most layers seemed to have both too much information and too little information. They had too much information, in the sense that each layer had a lot of projects to cover. They also had too little information, in the sense that many of the upper layers appeared to have little insight into what was actually happening within the projects. To give an example of the latter, there were no clear procedures in place for resolving disagreements within the design team. This led to a slow and cumbersome decision-making process with lots of frustrations and disputes about how to design the programme.

To help ensure that the programme will have a functional structure that supports effective decision making going forward, we have turned towards transaction cost economic (TCE) for guidance. TCE is helping us to re-assess: (1), programme administration and bureaucracy (by providing insight into the comparative (dis)advantages of centralisation versus localised decision making); (2), programme scope or boundaries (by helping us to develop efficiency criteria for determining what projects to include in the programme and which ones to spin-off); and (3), module boundaries (by providing insight into how to determine what projects should be functionally organised together, and which ones should be kept separate from one another).

The fundamental question posed by TCE (transaction cost economics) scholars to those who advocate for integrated research programmes would be: If integration consistently enhances research outcomes, why not integrate all research projects into a single program? TCE scholars would contend that transaction costs prevent integration from always improving research outcomes.

"Transaction costs" include the resources expended by actors in the organisation and management of economic and other types of social activities [40–42]. In the context of an integrated research programme, these costs encompass the resources required to: identify appropriate projects and skilled researchers; coordinate workflows; establish collaborative norms and practices, such as by incentivising researchers to timely share information; ensure individual projects are aligned with the overall programme; settle disagreements among participants; monitor and evaluate progress; and so on. Transaction costs also include agency costs and democratic costs, which were discussed in Section 4.1 from different theoretical angles.

From a TCE perspective, the costs of organising and coordinating research programmes increase substantially with their growing size and complexity (or at least, absent a proper modularisation of tasks and workflows). Firstly, it becomes more difficult for the managers of the programme to keep track of what is going within the programme. In particular, it becomes harder to timely and accurately assess changes in lower levels of the programme and thus to take effective action when a project is underperforming or being mismanaged

(see [43]). Secondly, it becomes more difficult to establish a performance-oriented culture within the programme, as incentive intensity becomes diminished (see [43]). There are several reasons for this. For example, researchers may become less invested in the programme, as their stake in the programme outcome—including both their ability to take credit for any success, as well the likelihood that they will be held responsible for any failure—tends to decrease when the number of projects or researchers involved in the programme increases. In addition, as the programme boundaries expand, researchers deal less with outside stakeholders and more with each other. This can further diminish incentive intensity for a couple of reasons. For example, fewer researchers have to justify their work directly to funding agencies, which reduces external pressure. Further, as researchers are expected to collaborate with each other within the program, they become somewhat locked into dealing with each other. As a result of such expectations, a project manager may be more patient with underperforming researchers from a supplying project compared to a scenario where the two projects would not have been part of the same programme. This can lead to a culture of complacency and forgiveness for underperformance [43].

Because of such challenges, programme leaders should always question what the benefits are from integrating or maintaining a research project within a programme. To minimise potential problems and costs, only project opportunities that meet specific criteria should be included. Specifically, based on TCE, we suggest that projects should only be integrated when their outputs are aligned with programme mission and goals and at least one of the following conditions is met:

(a) The desired outputs of the project are ill-defined at the outset and will need to be revised over the course of the programme, for example, because of new research findings or because of changes in the larger environment in which the projects or programme are embedded;
(b) In addition to the outputs of the project team, their processes, methods and ways of working are also valuable to the other programme participants, and need to be closely monitored by these participants to be understood;
(c) Related to the previous point, regular interactions between members of the focal project and members from other projects within the programme are critical to the success of the project, the other project(s) within the programme or both;
(d) The programme provides the project with access to unique resources and capabilities (such as intellectual property, laboratory access, rare specialist workers) that are essential for the project's success and cannot be easily acquired elsewhere.

It is important to note that a project's relevance to a programme mission does not automatically warrant its inclusion in the programme. If none of the conditions mentioned above (a to d) apply, it may be more advantageous for the project to seek funding from another source to avoid excessive interference from programme management. Additionally, removing or excluding such a project from the programme could also benefit the programme by reducing the administrative workload on its managers.

Programme managers and other stakeholders can apply conditions 'a' to 'd' not only to individual projects but also to help organise projects into modules. Designing the programme in a modular way based on these criteria can limit unnecessary transaction costs. A TCE-inspired modularisation encourages researchers to collaborate with projects that have synergies and reduces their exposure to projects where synergies are lacking, ultimately reducing information overload and administrative costs. This approach is complimentary to the modularisation approach suggested in Section 4.2.

To apply lessons from the TCE framework to NZBIDA, one could include questions in the earlier mentioned questionnaire that give programme management insight into the extent to which criteria 'a' to 'd' apply to the various projects. Based on these answers, we may recommend that the boundaries of some modules are redrawn, or that certain components of the programme should be spun-off from the programme as they do not meet these criteria. For example, some of the other workstreams outside the main modules

of the programme could be spun-off from NZBIDA as none of these conditions appear to apply.

Furthermore, to enable quicker and better-informed decision making by programme management we propose to reduce the number of hierarchical layers. This should reduce the need for intervention by programme management, as those making the decisions are closer and better aware of the "realities on the ground". Integration of purpose would also increase, as a smaller group of people has to converge and agree upon which direction the project should be headed. We expect that improved governance oversight will be realised for the same reasons.

Additionally, as is discussed in Section 4.1, we recommend to also put in place mechanisms for quickly reaching decisions within the now reduced number of programme layers.

Finally, project leaders could also be empowered to make more decisions themselves. For example, as is also discussed in the previous section, we propose that decisions about epistemic and functional integration between projects are no longer made on a global level, but locally by the project leaders (who are best informed about what types of cross-project linkages are most likely to lead to meaningful outcomes). Empowering local decision makers could further reduce the information burden on programme management.

4.4. Key Lessons

Table 2 provides an overview of key lessons drawn from the three literature streams mentioned above. Programme managers and researchers can adapt and apply these insights to the management and governance of their own integrated programmes. The critical issue is to ensure that governance structures and coordination mechanisms are aligned with the unique characteristics of integrated programs. Doing so can help ensure that researchers collaborate in a more engaging and productive manner, managerial oversight is improved, project and programme managers can be more easily held accountable for their performance and overhead costs associated with programme administration are reduced.

Table 2. Summary of key lessons from Section 4.

Challenge	Key Lessons
How to create a competent programme governance structure	An integrated research programme is a temporary, hybrid-organisational form that shares traits and problems with cooperatives, as well as with start-ups and investor-owned firms more generally. To reduce agency costs and democratic costs, a competent governance structure should consider the distinctive features of integrated research programmes, as well as their similarities with other organisational forms. When such costs are high, cooperation within the programme is difficult and time-consuming, which will undermine efforts to realise integration of purpose and epistemic integration (none of which is guaranteed).
How to minimise agency problems	Similar to cooperatives, "workers/researchers" in a research programme have strong incentives and abilities to monitor managerial performance. To reduce agency problems, research programmes can leverage these abilities and support bottom-up monitoring. This can help to offset the structural problems associated with top-down monitoring by the internal and external institutions in which research programmes are usually embedded (the researchers are the experts).
How to manage democraticprocesses	Increased participation by researchers in programme decision-making can support integration of purpose. However, it can also derail it by slowing down the decision-making process and by increasing the frequency and ramifications of gridlocks. The following steps may help to avoid such scenarios: • Limit collective decision making to important issues, given the substantial costs associated with mobilising researchers and encouraging their involvement; • Focus mobilisation efforts on under-represented groups (e.g., researchers from science disciplines that are not adequately represented at the programme management level) rather than aiming for mass participation; • Establish effective and clear voting procedure that help to avoid or resolve stalemates in a legitimate manner.

Table 2. *Cont.*

Challenge	Key Lessons
How to manage project dependencies	The type of dependencies that arise amongst the various projects within a programme influences both the degree of epistemic integration that is required across projects, as well as the type of functional support structures and methods that are suitable for realising efficient and effective cross-project coordination: • For pooled dependencies amongst projects, there is a limited need for realising a shared understanding of concepts, theories and methodologies amongst the different projects. Little epistemic integration is necessary and basic planning suffices to manage cross-project linkages; • Sequential dependencies need to be managed either through output standardisation (when desired outputs can be clearly defined at the start of the projects) or through process standardisation (when outputs cannot be easily defined). Epistemic integration starts to become important as the "supplying" project needs to understand what type of data the "dependent" project needs, what types of methods for generating data are acceptable, etc.; • In case of reciprocal interdependencies, projects need to frequently adapt to each other, and researchers will need to be able to quickly understand each other when such adjustments need to be made. Epistemic integration is thus critical. To support such integration, the involved project leaders need to stimulate and cultivate strong linkages between researchers from the respective projects. When reciprocal interdependencies exist between more than two projects, combining these projects under the management of a single module can be beneficial.
How to limit the administrative costs of integrated programmes	As programmes increase in size and complexity, the costs of administrating and running them are likely to increase dramatically (at least without proper modularisation). This is for two main reasons: • It becomes more challenging to assess changes in lower levels accurately and promptly, making it harder to intervene successfully. This can manifest itself in over-reach by programme management in some parts of the programme (e.g., unnecessary micro-management of certain projects) and "under-reach" in other parts (e.g., lack of timely intervention in the mismanagement of a critical project with global implications); • As the number of projects or researchers involved in the programme increases, the stake each individual researcher has in the programme's success becomes smaller, which leads to a decrease in incentive intensity; • To avoid programmes from becoming excessively large and complicated, programme managers should regularly assess the benefits of including or retaining a research project within the programme vis-à-vis simply using a project's outputs and keeping it at arms-length from the programme. To limit unhelpful intervention by programme management and to maintain or increase incentive intensity in programmes that are already large and complex, tasks and workflows need to be properly modularized (for example, based on transaction cost economising principles).
How to select and structure underlying projects	In order for a project's inclusion within a programme to be of mutual benefit to both the programme and the project, the latter's outputs must align with the programme mission, and at least one of the following conditions should be met: • The desired outputs of the project are ill-defined at the outset of the programme and will need to be refined and clarified over the course of the programme; • Not only the outputs of the project are important to the programme mission and success, but also its methods and ways of working; • Regular interactions between the project and other members within the programme are critical to the success of the project, the larger programme or both; • The programme provides the project with access to a unique resources or capabilities that are critical for the project's success; • These criteria for selecting projects can also be used for selecting clusters of related projects and organising them into modules.

5. Discussion: Towards a Framework for Designing, Managing and Governing Integrated Research Programmes

Drawing from lessons learned about how to support the various forms of integration from both theory and practice, we propose a tentative high-level framework for designing, managing and governing integrated research programmes (please see Figure 3).

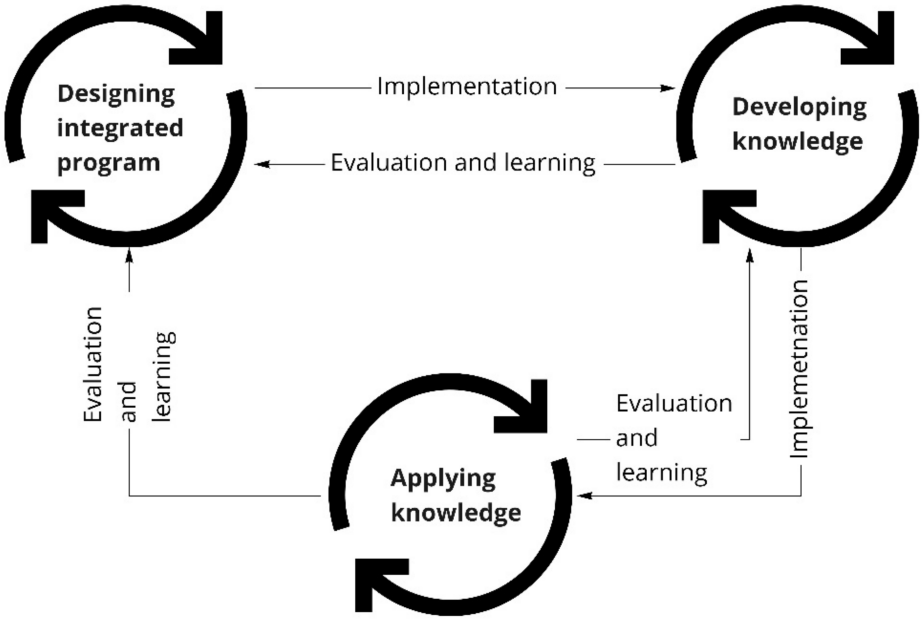

Figure 3. A high-level framework for designing, managing and governing integrated research programmes.

The framework consists of three iterative loops that are interconnected, forming a larger loop of continuous evaluation and learning:

- The design loop, in which a shared purpose is established, the required degree of epistemic integration is determined, and a functional support system to efficiently separate and integrate workstreams is designed and implemented;
- The knowledge development loop, in which researchers and other stakeholders collaborate to create new knowledge along the workstreams differentiated in the design loop; and
- The knowledge application loop, in which this newly created knowledge is applied to the problem or subject matter in question.

During each of the loops, programme management and researchers should obtain new information and learnings about the suitability of their approach and adjust where necessary. For example, in the knowledge development loop, participants should assess whether the created workstreams effectively support knowledge development and facilitate the desired level of epistemic integration. In the knowledge application loop, participants should evaluate how well the developed knowledge addresses or illuminates the problem the programme seeks to investigate or solve. Based on this evaluation, programme management may need to adjust the program's design, such as revising objectives or narrowing the programme focus. These changes can affect the level of epistemic and functional integration required to achieve the programme objectives. Subsequently, changes in epistemic and functional integration can impact the type of knowledge the programme produces, and so on.

For the purposes of this paper, the design loop, which integrates the three forms of integration, is most relevant. This loop comprises four phases (see Figure 4), which the participants will likely need to complete multiple times throughout the programme to achieve successful outcomes.

In the first phase of the design loop, the participants in the programme will have to realise some degree of integration of purpose. That is, they need to develop some common understanding of what the aim or vision of the programme is. In the first iteration of this loop, the participants should attempt to agree only upon a tentative, high-level aim as the programme participants may still be unfamiliar with each other's modes of thinking and speaking (epistemic integration is weak or absent), while appropriate decision-making

structures may be missing (the functional support system still needs to be created or is in its early stages). Therefore, it is best to avoid delving into the specifics of the subject matter, which is more likely to result in disputes and high democratic and agency costs, particularly when a common language for facilitating mutual understanding is missing and mechanisms for resolving disputes are not yet in place. Once some degree of epistemic and functional integration is established within the program, the participants will have the support structures in place to develop a more clearly defined vision.

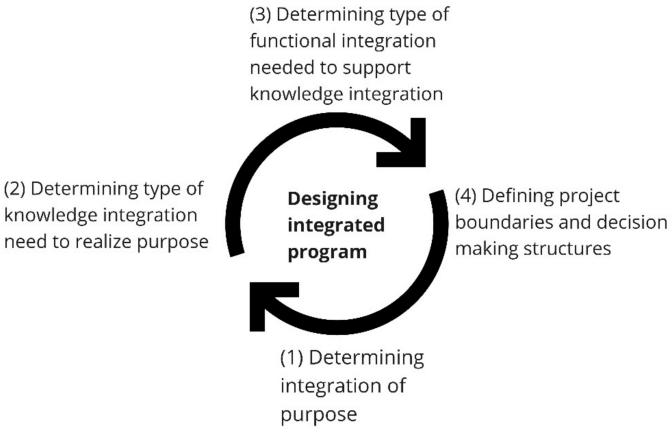

Figure 4. The design loop in-depth.

In the second phase of the design loop, the participants need to assess the degree of epistemic integration required to achieve the programme aim. This involves determining the extent to which different forms of knowledge need to be combined or fused. Initially, the purpose of epistemic integration may be simply to facilitate understanding among participants from different disciplines. As the programme progresses and its aim becomes better defined, the degree of epistemic integration required should depend on the extent to which the aim can be broken down into separate problems. This includes identifying the overall problem the programme is trying to solve, the science and non-science disciplines involved in addressing the problem and the extent to which the problem can be divided into separate sub-problems or tasks that can be independently addressed by these disciplines without interaction effects.

In the third and fourth phases of the design loop, the participants will have to design the functional structure needed to support the programme workstreams and overall administration. This will involve: (a) identifying the types of interdependencies that exist between the different workstreams (e.g., pooled, sequential, normative); (b) determining, largely based on these dependencies, which workstreams should be functionally combined or integrated (e.g., in modules) and which ones should be kept separate. The underlying objective is to facilitate more engaging and productive collaboration among researchers. This is achieved, amongst others, by enabling closer collaboration between researchers from related workstreams, while protecting them from information and meeting overload from unrelated workstreams; (c) organising programme management and governance in a transaction cost-efficient manner. This includes setting up and implementing an administrative structure that enables timely, informed and competent decision-making across the various levels and workstreams of the programme. This structure should be designed to mitigate agency problems, minimise issues related to collective decision-making processes and lower the administrative burden and costs associated with managing and governing the programme (please see Table 2 in Section 4.4).

An iteration of the design loop can be regarded as successful when it yields the programme management team new or more refined insights into:

(1) What the purpose of the programme is, and of its components, and how widely are these shared amongst the participating researchers;

(2) What types of disciplines need to work closely together to be able to contribute to realise this purpose, and which disciplines can contribute more by operating in a relatively independent manner; and
(3) How workflows and administrative support structures should be organised to enable efficient and effective collaboration by researchers, programme managers and other stakeholders across the programme.

New or refined insights in these areas will put the programme management team in a good position to advance knowledge development and application.

6. Conclusions

Funding agencies are placing greater emphasis on supporting research programmes that tackle complex sustainability challenges through integrated approaches. Integration is encouraged in the hope of achieving benefits such as synergies, efficiency gains and increased collaboration between researchers. However, in many cases, these benefits are not realised, in part because the relationships between different forms of integration are insufficiently recognised and poorly managed.

To help address that, in the present paper, we have discussed three forms of integration—normative (purpose), epistemic and functional—and explored the relationships between them. Drawing on our own practical experience in designing an integrated programme, as well as the literature on governance, management studies and organisational economics, we have presented a high-level framework that can help researchers and stakeholders take a more holistic, calculative and iterative approach to co-designing, managing and governing integrated research programmes.

A more holistic approach to integration involves considering how much and what type of integration is necessary within the programme alongside the three intertwined dimensions of the concept (purpose, epistemic and functional). A more calculative approach involves explicitly considering and accounting for the additional incentive and coordination costs associated with realising integration. It also involves setting up an administrative structure that minimises the overhead costs of managing and governing the programme and maximises the amount of funding directly used for research purposes. A more iterative approach to integration involves: (a), supporting a gradual roll-out of integration across the programme, as integration is often difficult to realise at the start of a programme; (b), factoring in that the degree and type of integration the programme requires may change over time due to the ambiguity and uncertainty associated with complex, ill-defined problems.

A more holistic, calculative and iterative approach to designing, managing and governing integrated research programmes can help researchers, programme managers, funding agencies and other stakeholders better understand the conditions under which different forms of integration are likely to be beneficial and when integration should be avoided. This, in turn, can help them realise the advantages of integrative research programmes while avoiding pitfalls. Without such an approach, attempts at integrative research are likely to go in circles, disintegrate into independent pieces of work or incur unnecessarily high administrative costs. As a result, the numerous complex problems and sustainability challenges the world faces, are likely to remain unsolved.

Further work could enrich the programme management guidelines we have developed in Section 4 of this paper, by drawing upon a broader range of organisational and strategic management approaches, such as the resource- and capabilities-based view of organisations or real-options theory. In addition, managers and researchers that are in the process of setting up new science programmes could use the framework we have developed in Section 4 as a reference. Through utilising the framework, they can evaluate its strengths and weaknesses and report their findings to aid in refining the framework. Finally, it is important to conduct additional case studies in this area to gain a more comprehensive understanding of the range of administrative systems and processes used to manage and govern integrated programmes, as well as to explore stakeholder satisfaction with these

systems. Such studies could offer further insights into the types of support systems and processes that integrated programmes require.

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