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Delivering on the promise: how are sustainability research institutes enabling interdisciplinary research?

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ABSTRACT

Interdisciplinary research institutes and centres have become significant elements of the university organisation, sometimes of equal or even greater influence than departments in terms of their research activity and outputs. Many of these research institutes, particularly larger institutes that include researchers from multiple departments, have made the pursuit of interdisciplinary collaboration a central goal in their research mission, and in many universities research institutes may be one of the primary vehicles by which universities deliver on their own objectives for interdisciplinarity. Despite the potential for research institutes to advance interdisciplinary research on university campuses, there are a lack of studies on how interdisciplinary research centres integrate multiple disciplines in practice, how they influence the collaborative behaviours of scientists, and how they establish collaborative communities. Within this study, thirty interviews were conducted with leadership and faculty within four sustainability research institutes in the United States exploring how research institutes support interdisciplinary research within their units. A thematic analysis on the interview data revealed eight themes on how research institutes are, and can further, enable interdisciplinary research within their organisations and universities. Some of the themes are fully implemented within the research institutes, while others are more aspirational, and signpost to where institutes can create additional capability and capacity for interdisciplinary research within their units and universities. The study will be of particular interest to research institute and university leadership who wish to cultivate a deeper culture of interdisciplinary research within their organisations.

KEYWORDS

Interdisciplinary, interdisciplinarity, sustainability, environmental, research institutes, research centers

INTRODUCTION

The advancement of inter- and transdisciplinary research within universities are seen by many academic institutions, expert groups and funding bodies as essential for solving wicked problems and grand challenges facing society [Horlick-Jones and Sim 2004; Wickson et al 2006; Lawrence 2010; Bammer et al 2020; Lang *et al*. 2012]. In particular it is widely accepted that many global sustainability and environmental challenges require research at the boundaries of scientific disciplines (Kates et al 2001; Ostrom 2009; Hirsch-Hadorn et al, 2006; De Grandis and Efstathiou 2016; Miller et al 2014*)*. In the last two decades, there has been widespread adoption of interdisciplinarity[1] as an institutional goal amongst universities (National Academy of Sciences 2005; British Academy 2016; Feller 2002; Brint 2005). Some progress in supporting interdisciplinary work in universities has been achieved; however most organisations still struggle to deliver the transformations needed to shift to more collaborative interdisciplinary structures and practices within their universities (Klein 2009; Dubrow et al 2009; LERU 2016).

Research centres and institutes

The goal in most universities has been to build a layer of interdisciplinary research on top of existing disciplinary structures (Dedeurwaerdere 2014; Aldrich et al 2014; Klein 2009). In this regard, perhaps one of the most substantial structural changes and investments to support interdisciplinarity within universities has been the widespread establishment of research units, centres and institutes (Geiger 1990; Bozeman and Boardman 2003). Research centres represent a signalling device for a university's mission and strategy, and have evolved to allow universities to increase their responsiveness to societal needs, and to attract external research funding particularly to gain the attention of private philanthropists (Stahler and Tash 1994; Jong 2008; Zahra et al 2011). Perhaps one of the most distinctive features of university research institutes is the intention to span disciplines and boundaries and foster collaboration among researchers to overcome the compartmentalisation of scientific knowledge (Bozeman and Boardman 2003; Su 2014; Boardman and Corley 2008). This department-centre matrix structure (where within the matrix the disciplines/schools might be represented by vertical lines, and centres by cross-cutting horizontal lines) enables connections to be made across disciplines allowing universities to retain traditional departments that facilitate disciplinary depth while also bringing academics together to work on problems of a common interest (Biancani et al 2014). This matrix structure enables institutes and centres to be a beneficial addition to schools and departments adding and furthering activity without competing for departmental resources.

The number of research centres within universities has swelled in the last two decades. Large universities can have more than one hundred such centres and there are often more research centres than disciplinary departments within a university (Jacobs and Frickel 2009). Between 30-40% of faculty members in science and engineering fields are members of research centers (Corley and Gaughan 2005, Boardman and Corley 2008). Sustainability and environmental centres, which are the focus of this research study, comprise approximately 8% of all United States research institutes and centres (Vincent et al 2015, 2016) and there are now few universities that do not have an environmental or sustainability focused research centre. Hoffmann and Axson (2017) have reviewed the distinct characteristics, activities, and challenges of 20 United States sustainability institutes that span many disciplines of the university finding that almost half the institutes studied focus more than 50% of their research portfolio on interdisciplinary work. It is known these interdisciplinary research centres enable universities to

[1] Whilst there is still no fully agreed definition of interdisciplinary research amongst the academic community (Wagner et al., 2011), the most commonly adopted is that offered by the National Academy of Sciences (2004) which describes interdisciplinary research as "a *mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice*".

increase research productivity, industry partnerships, and collaboration and networking (Corley and Gaughan 2005; Boardman and Corley 2008; Bozeman and Corley 2004). In addition, in an era where cross-cutting collaboration is seen as a key 21st century skill for students, centres also contribute to, and catalyse, the development of interdisciplinary teaching approaches and the establishment of interdisciplinary schools in areas such as environmental science or sustainability science (Benton-Short and Merrigan, 2016) and strengthen how universities address sustainability challenges (Hart et al, 2015).

Collaboration in research institutes

The function of centres and institutes to afford greater interdisciplinary collaboration has been variously described in the literature as joint spaces, trading zones, boundary organisations, networks of practice, semi-formal organisations, and hybrid organisations. Bergmann *et al.* (2012) discusses the need for joint spaces within universities to facilitate coordination and integration of research between disciplines as an important foundation for inter- and transdisciplinary research. Galison (1997) and Gorman (2010) describe trading zones as places in which different scientific cultures with their own languages develop the equivalents of pidgin in which experts learn to use the language of another research to communicate with that community. O'Mahoney and Bechky (2008) examined how boundary organisations such as research centers help to bridge disciplinary divides and create *''a mechanism that reinforces convergent interests while allowing divergent ones to persist''*. Biancani *et al* (2014) have likened research institutes to a semi-formal organization occupying a plane between the formal university and informal research teams; membership of the semi-formal organisation is voluntary and researchers and groups can flexibly come together for short or long periods and dissolve when no longer needed.

The decision whether or not to collaborate remains very much within the control of the individual (Bozeman and Corley 2004); as research institutes cannot oblige researchers to engage in interdisciplinary work they can only exert soft influence by creating a conducive and welcoming environment where collaboration flourishes; a sanctuary where interdisciplinary work is favoured and valued. The traditional genesis of interdisciplinary collaboration, and maybe most forms of collaboration, within universities has been through informal networks which have been slowly established over time i.e. an "invisible college" (Price and Beaver, 1966). In this sense, research institutes exist to make the invisible visible and to replace the informal nature of collaboration with a more structured approach.

Institutes can also be considered a collaborative community or perhaps a set of interweaving collaborative communities (Siedlok *et al* 2015). Collaborative communities rely on trust and the quality of relationships among its members to initiate, share, and integrate knowledge (Adler & Heckscher 2006); this remains in contrast to hierarchical communities within traditional university administration and schools which rely on authority rather than trust as the coordinating mechanism. Whilst research institutes have the potential to create these collaborative settings for interdisciplinary research within universities, research by Rhoten (2004) indicates that that the reality of knowledge integration in interdisciplinary centres can be far from ideal arguing that the broad research themes adopted by larger centres are too unspecific and lack discrete targets of work to catalyse collaboration between the disciplines.

Despite the potential for research institutes to advance interdisciplinary research on university campuses, the role of research institutes has largely been neglected in the discussion of interdisciplinarity (Klein 1996; Jacobs and Frickel 2009; Gulbrandson 2011). There are a lack of studies on how interdisciplinary research centres integrate multiple disciplines in practice, influence the collaborative behaviours of scientists, and establish collaborative communities (Boardman and Corley 2008; Avila Robinson and Sengoku 2014; Lyall and Fletcher 2013). The question remains as to how

research centres create the conditions which are known to be necessary for effective interdisciplinary research such as sustained and intense communication, talented leadership, appropriate reward and incentive mechanisms, adequate time, seed funding for initial exploration, and willingness to support risky research (National Academy of Sciences 2005). There is an inherent tension for large research institutes, which can have hundreds of affiliated scientists, in creating multiple groups of collaborative groups of scientists. If the trend is towards large-scale interdisciplinary research cooperation, research centres will continue to be at the core of this and it is imperative that we develop a deeper and more nuanced understanding of how research centres are, and can do enable interdisciplinary research. This paper aims to fill this gap by setting out to explore how research institutes are enabling interdisciplinary research within their institutes and universities through a series of interviews with institute leadership and faculty.

The research study focused on large scale sustainability centers located within a single university that include faculty from across the sciences, engineering, business, law, social sciences, health, and humanities. These research centers are created by universities and generally sustained by a combination of university resources and individual investigator grants, foundations, and industry funds (Bozeman and Boardman 2013). Although the terms "research centers" and "research institutes" can be inter-changeable, the term "research institutes" is used hereafter within this paper as it is usually taken to mean large research entities within the university system.

METHODOLOGY

This study was carried out at four sustainability research institutes in the United States from February 2019 to July 2019. The institutes which participated in the study were the Julie Ann Wrigley Global Institute of Sustainability (GIOS) at Arizona State University, the Nicholas Institute for Environmental Policy Solutions at Duke University, the Earth Institute at Columbia University, and the Cornell Atkinson Center for a Sustainable Future at Cornell University. Interdisciplinarity is a core goal of these four research institutes; a key reason for the establishment of the institutes was to reach across the campus to bring together faculty across many disciplines to collaborate on sustainability issues. All four institutes have been established for over a decade enabling them to build significant experience and capacity in facilitating collaborative interdisciplinary research.

The majority of faculty members within the institutes are primarily appointed in university schools and departments and are affiliated to the Institute as a faculty scholar or fellow with the exception of the Nicholas Institute which has mostly core full-time staff appointments, combined with affiliated faculty in the schools within the university. Affiliated faculty within the institutes were largely physically located within their constituent school and department buildings *i.e*. are not in close physical proximity to each other. Funding for research within the institutes generally comes from external sources. A number of the institutes were established with endowment grants, and philanthropy remains a vital source of funding to run operations along seed funding programmes to support internal collaborative research. The institute directors report at the level of Vice-Provost or President demonstrating the intention of the institute to reach across the university.

Semi-structured interviews with a set of open-ended questions was carried out by the author with 6-9 staff and faculty members at each institute. A total of 30 interviews were carried out. All interviews were conducted face-to-face except one which was conducted over skype. Interviewees were asked to describe their interdisciplinary research activities and associated challenges and benefits; the role research institutes have a role to play in facilitating interdisciplinary research; whether membership of the institute enabled greater opportunities to collaborate with researchers outside their own discipline; how collaborative communities are facilitated within the Institute; and additional actions that institutions could take to support interdisciplinary research. Interview lengths ranged from 45 minutes

to 70 minutes with an average of 60 minutes. All interviews were audio-recorded and transcribed for analysis.

The interviewees were drawn from institute leadership and affiliated faculty; approximately 25% of interviews were with institute leadership/management and the remainder were with faculty and staff. The selection of the interviewees was based on suggestions/recommendations by institute leadership and faculty (snowballing) along with faculty which had a clear interest in interdisciplinary research evident through publications. Interviewees were invited to participate by email and provided with an overview of the study and its objectives beforehand. All invited interviewees accepted.

A multiple–case studies approach was used which allowed the researcher to explore the research question under study through the use of a replication strategy *i.e.* seeking patterns of similar results across four institutes to produce substantial support for the development of themes (Yin, 1994; Eisenhardt, 1989).

Thematic analysis was chosen as the research method for the study. Thematic analysis is an approach for the extraction of meanings and concepts from data and includes examining, and recording patterns or themes (Boyatzis, 1998). It is widely recognised as a useful method for examining the perspectives of different research participants by highlighting similarities and differences, generating unanticipated insights and providing a rich and detailed account of data (King, 2004). The outcome of the thematic analysis is typically a set of themes that highlight important points regarding the research data and shows a pattern or meaning related to data sets.

The interview transcript data was analysed by thematic analysis following Braun and Clark's six step framework (Braun and Clark 2006; Maguire and Delahunt 2017). The thematic analysis in this study was a top-down analysis driven by the specific research question "*how do, and can, research institutes facilitate interdisciplinary research within their units and universities*". The thematic analysis was inductive and data-driven *i.e*. the interview data was collected and the themes emerged from the analysis of thematic patterns in the data. The inductive analysis enabled the coding the data without trying to fit it into a preconceived ideas. The analysis in the study takes place at a semantic level *i.e*. only the explicit meanings of the data were interpreted (Braun and Clarke 2006). The thematic analysis was carried out manually. Whilst this approach was lengthy it enabled the research to become very familiar with the data and reflect on content to clarify meanings. The 200 pages of interview data were read several times and all comments and statements which related to, and which captured something interesting about, the research question were identified and highlighted. The statement texts were transferred into an excel spreadsheet, and preliminary codes were developed for each statement. These codes referred to pertinent parts of the data that related to the research question and may contribute to a theme. The preliminary codes were then re-examined for recurrence, and reworked to develop sets of common codes. From these codes, 12 themes were initially developed; these themes were overall patterns in the codes that were important and interesting by addressing the research question. The themes not necessarily the most numerous patterns but also those revealed a significant aspect in answering the research question. Common elements between themes were captured and the 12 themes were eventually collapsed to eight overall themes addressing the research question (see Table A1 in Appendix for example of thematic analysis approach for interview text).

The study and survey was reviewed and approved by the Social and Research Ethics Committee at University College Cork. To protect confidentiality the interviewees and institutes are not directly named in the survey results. The four institutes have been anonymised as A, B, C and D and each interviewee has been given a unique identifier based on their institute and whether they were faculty (F) or leadership (L) e.g. AF1 is a member of faculty at Institute A, and BL1 is a member of institute leadership at Institute B.

RESULTS AND DISCUSSION

A thematic analysis of the interview data generated eight themes which addressed the research question of this study *"how do, and can, research institutes facilitate interdisciplinary research within their units and universities"*. The themes are summarised in Figure 1. The themes are closed interlinked. Some of the themes (e.g. community of scholars, funder of interdisciplinary research, valued network) are fully developed and implemented within the research institutes, while other themes (such as advocate for interdisciplinary scholarship and skilled facilitator) are more aspirational, and point to where institutes can create additional capability and capacity for interdisciplinary research within their units. Each theme is discussed in detail below.

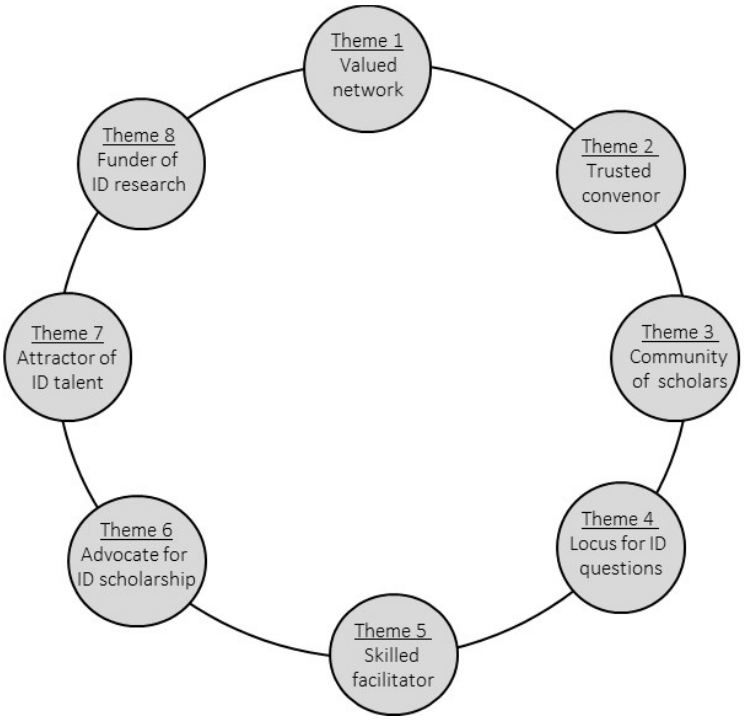

Figure 1 Eight themes or modes by which research institutes enable interdisciplinary (ID) research within their organisations and universities.

Theme 1: Institutes as a large and valued network of faculty interested in sustainability research

Building and sustaining networks is a key characteristic of boundary spanning organisations (Williams 2002; Carmen-Lemos 2018). Membership of an interdisciplinary research centre can be seen as another social network for faculty within the university (Aboelela 2007; Mallon 2006), but one that is built deliberately rather than informally and accidentally. Within the interdisciplinary network, faculty must be able to find each other easily, know who has the relevant expertise, and be able to connect in a manner where there is a high likelihood of successful collaboration. A common viewpoint was that the institute serves as an enabling network and the connective tissue across the university linking environmental and sustainability research scholars. Most research institutes have relatively low barriers to entry; one institute director pointed at the value of "*taking a big tent approach*" that reaches across the university to create a large institute as the "*larger the network, the greater the people value it*". The starting point for this network might simply be a frequently updated and well curated institute website with a searchable database of faculty from different disciplines.

It is through the Institute that I have gotten to know many members of other faculty and other disciplines. Without that it would have been very difficult [BF5]

I didn't have an institute like this before and it was really hard to find people to collaborate with [DF4]
Having this rich intellectual tapestry from which I could draw collaborators for proposals was just phenomenal [BF3]

I was just on the website today searching through to try to find some people to recommend to some colleagues about potential grant collaborators [AF3]

Interdisciplinary collaboration can have significant costs and barriers (Brown et al 2015; Klein 2009; National Academy of Sciences 2005); a very common theme across interviewed faculty was that the institute can make a real impact on reducing the transaction costs of collaboration across disciplines.

I would like to think that as we build this culture of staff/faculty collaboration that we will lower the time and effort and distraction required for faculty [AL1]

If there were no institute it would be harder to interact and collaborate with people in other departments and other schools [BF2]

Institutes can "load the dice" in favour of successful collaborations. A key aspect of the Institute network that makes it valuable to potential collaborators is that it is a filtered, self-selected network and that the people within that network generally have a high appetite for interdisciplinary collaboration. Institute leadership and management can also act as matchmakers for reliable collaborators to identify which people to bring together and may recommendations or vouch for a faculty member's credibility as a collegial scholar.

It's a clearinghouse of other faculty who want to engage in interdisciplinary research. And so it is a place to go and find the other people who want to play [AF4]

There is a sort of a filter. The filter is that these are people who are interested in working with others beyond their own discipline, but also others who have a bit of a track record [BF4]

Understanding whether they would be a good collaborator for when you are going outside that domain of familiarity. I don't want to go out there if I have an inkling that they are not trustworthy [AF3]

I am always thinking…that's interesting, you should talk to so and so. That is always in the back of my mind. There is always someone who is doing something that is somehow related [BL1]

Theme 2: Institutes as trusted convenors and honest brokers

One of the overarching themes in how research institutes can facilitate interdisciplinary research is that of convening *i.e.* frequently bringing together researchers who would not otherwise meet in different formats to become acquainted, discuss shared interests, negotiate values, and build consensus. These processes are critical for inter- and transdisciplinary research (Pohl 2005; Carew and Wickson 2010; Lippe vom Brocke 2016). A strong theme across the interviews was that the institute can act as a trusted convenor or honest broker for bringing faculty from different disciplines together. Faculty may be hesitant to engage with interdisciplinary work if it is initiated by a particular academic school, or likely to be dominated by a particular discipline. In this regard institutes can act as an "*impartial central operator*" [CF2] to "*avoid giving one unit more importance* [DF6]". If the Institute has its own building, this impartial common ground for convening can be physical as well as intellectual.

We can provide a convening space, that is a really important function. It's often considered to be a neutral non-threatening environment [DL2]

We are an academic Switzerland. We are a place where the disciplines and faculties can work together [CL1]

One institute director called this convening "*organised serendipity* [BL2]" where you create structures for repeat engagement of faculty.

We help assemble the right people, we help the organisers think about who the right people are, we send out the invitations [AL2]

It sounds trivial but all I had to do was show up and there were people in the same room. They make it easy for you to show up but also make it easy not to show up if you don't want to [CF4]

The modes and methods for convening within institutes were the subject of a great deal of discussion within interviews; institutes utilise many different formats including seminars, brown-bags, annual receptions, barbeques, brainstorming sessions, monthly book clubs, retreats, thematic working groups, and funding call rapid response teams. Rhoten (2004) found that researchers with the freedom to enter and exit collaborative teams report more progress with interdisciplinary work. However Blomqvist et al (2016) warns that there is a risk that research centres can become arenas for ambiguous interactions, futile compromises and unproductive meetings. The interviews reveal that institute leadership dedicate a lot of thought to designing ways to bring faculty together in a manner that is engaging and intellectually stimulating, and around topics where different disciplines could contribute and potentially garner research funding and generate projects. Institutes are striving to continually innovate, experiment and renew the formats for convening as there appears to be a life span for collaborations, working groups and teams, and formats become fatigued after a period of time.

There is no single right way of convening. It's such a craft industry. It's not like there is a formula to apply in every instance [CL1]

I think it is natural for collaborative communities to ebb and flow. I have an attention span that spans about 5 years at a time [CF4]

We worked on some things together and that was really effective for a while and then there was a sense that we were done with it [CF1]

Whilst many faculty professed to enjoying the intellectual excitement of interdisciplinary discussions and events (see Theme 3), they are likely to want see something tangible emerging from convening events rather quickly or they are apt to lose interest. This is typically a research proposal for internal or external funding resulting in a collaborative project. The central importance of the research project as the basis for collaboration was emphasised in many of the interviews as it generates a tangible basis for interdisciplinary collaboration over a period of years.

But the rubber hits the road with the research project and engaging in an enduring fashion. Projects are what makes the world go around [CL3]

If there is nothing on the pavement hard for people to collaborate over, they sort of lose interest. The project is everything, it dissolves boundaries [DL1]

The importance of physical proximity and having a shared physical space in the institute was raised in many interviews reflecting findings in literature e.g. Katz [1993] found that co-authorship decreased exponentially with distance; Cummings and Kiesler (2005) showed that long physical distance lowered the productivity of interdisciplinary projects. The value of unprompted and non-directed interaction with colleagues over a coffee was frequently highlighted in interviews. Some of the institutes in this study had a building with co-located researchers from different disciplines but even within these institutes it was not possible to have all institute faculty co-located. Physical co-location of affiliated

faculty represents a conundrum for research institutes as it may be equally futile to rigidly co-locate faculty when what is needed are fluctuating project teams.

The water cooler meetings are so helpful but our physical location prevents that from happening [BL1]

One thing we don't have to our detriment is common physical space. We are very spread out. There isn't that spontaneous coffee interaction that is really, really important [CF2]

Theme 3: Institutes as a supportive community of scholars for interdisciplinary research

Institutes can provide a "secondary home" for faculty in addition to their primary home school or department. Rogers (2012) suggests that research centres can provide a place for intellectual interdisciplinary companionship. Mallon (2006) observed that the most important aspect of the centre may not be a tangible benefit like physical space or research support, but rather a spiritual notion, a sense of creativity and of intellectual excitement; likewise Blomqvist (2016) emphasises that belonging to a research centre involves both the mind and the heart. The role of the institute as welcoming space for interdisciplinary work was frequently referred to by interviewees. Many faculty pointed to the enjoyment and intellectual stimulation which they obtain from engagement with other disciplines within the institute. As membership of most institutes is voluntary and by self-selection, the capacity to be able to engage in interdisciplinary research within the institute can be a key value-added of membership.

My time at the institute has been some of the best time I have had in academia. I have learned so much by hanging out economists and it has changed my view of how I approach my work [AF2]

It is good to have an umbrella organisation. There is an identity community function that is valuable. [BF1]

So it has been for me an incredible intellectual driver. To have my own perspectives and thought processes broadened by interaction with people viewing it from an entirely different perspective, that to me as an academic has been incredible, and it has been a privilege and it was certainly something I was missing at my previous university [BF3]

Institutes frequently have a mission, goals, and culture which are distinct and different to schools such as an exclusive focus on one particular area of research, and placing a high value on inter- and transdisciplinary methods and broader societal impact [Hart et al 2016]. University faculty can strongly identify with the vision and values of institutes perhaps even more strongly than that of their own school or department.

When I learned about the institute, I thought that this is what I cared about. That was my research identity. And I think that a lot of faculty feel that too [AF1]

I always thought the people in the institute were my people, my tribe, this is a group of people who come from various disciplines that all have this commitment to sustainability and make this world a better place [AF3]

To me the institute provided a much richer intellectual environment than I would ever find in this department [BF3]

Pfirman and Begg (2012) highlight that interdisciplinary scholars must often "go out on a limb" and live without the comfort of expertise and of community. The institute's support of interdisciplinary research provides an environment where interdisciplinary and transdisciplinary research approaches are respected, promoted and legitimised and where interdisciplinary scholars can find peer support for their work.

What we try to do is to create a culture of mutual respect of different ways of understanding and knowing. [DL2]

I have a sense that the culture here is much more about domains of knowledge; you are in a room talking to people because you have all similar questions and concerns, not defending territory about what methods and theories you are drawing from [DF4]

Theme 4: Institutes as a locus for big interdisciplinary ideas and questions

One of the strengths of interdisciplinary research approaches are when they are applied to address and solve specific sustainability issues or questions [Hart et al, 2016]. These real-word problems and questions can be considered to be boundary objects for faculty to converge around and used by scholars from different disciplines to catalyse interdisciplinary synthesis without losing their own identity [Guston 2001; Pennington *et al* 2016]. The research institute can be a locus for the generation of boundary objects, research ideas, and questions which require interdisciplinary expertise and which are large enough in scope to necessitate contributions from a range of disciplines. The focus on generating research questions and "*providing interesting problems for people to work on [BL2]"* was a strong feature of interviews with faculty.

I find the best of the interdisciplinary work is driven by the question, the question lies at the heart of it. It's that question that will attract the scholars from the multiple disciplines because they see a piece of themselves and a piece of what they are really interested in that question [DF1]

I don't define my work by the discipline; I define it by a community of questions. I like to be in an environment where it is the questions that are dominating. I think makes it a much more inclusive community [DF4]

I think Institutes should foster good ideas, we are on this intellectual endeavour. Our currency should be good ideas [DF3]

Institutes can play a crucial role in bringing applied research questions to the table. The leadership and staff within the institutes studied have extensive external networks, comprised of policymakers, industry, communities, and environmental NGOs, enabling the institute to be a conduit for bringing problems and questions from external stakeholders to their research community. Many faculty emphasised that they engage in interdisciplinary research because it is best means "*to answer the questions of the partners that we are working with [CF1]"*. The institute leadership can act as a translator and mediator for sustainability problems held by external stakeholders, or presented by faculty, by helping to refine them into interesting intellectual interdisciplinary research questions that faculty can engage with. The institute can also support faculty in developing the ideas and/or act as a filter for the ideas, using their domain-specific and institutional knowledge to advise on what has been tried before, and new directions that can be taken. This can be particularly important for faculty who are bringing disciplinary expertise to the table to answer a sustainability research question, but may not have a familiarity with state-of-the-art knowledge in the broad sustainability field.

The university has a mission to be at the service of society and the institute is designed to do exactly that. To ask what are the complex challenges out there. In doing so we connected faculty and students to these real world problems [CF1]

We provide that iterative bridge helps refine research questions and can create an improvement in the relevancy of the work in the target audience [CL1]

We can provide our own contacts. You can come to us with ideas and we can provide traffic control and serve as a means of making sure that we are not repeating what has been done [DL1]

Institute leadership can also take what might be a rather disciplinary question or idea from a faculty member and enlarge it into a wider set of interdisciplinary questions involving more disciplines enabling larger interdisciplinary projects than would be possible for an individual on their own in school or department.

We can help them reach out to disciplines when they are sparking an idea and haven't it fully thought through and generate the ideas collectively so that a discipline is not an add on [BL1]

The crafting of the question is crucial so that people really feel like they have a stake in the answer [DF4]

Theme 5: Institutes as skilled facilitators for interdisciplinary research

One of the barriers to interdisciplinary research is that there is a significant up-front cost for faculty; interdisciplinary research takes more time, effort and commitment from faculty to overcome epistemological differences, understand dissimilar methodologies, and build research questions of common interest [Brown *et al* 2015; Katz and Martin 1997]. The interviews showed this to be a common experience of interdisciplinary research amongst institute faculty members.

We had a two year project where at least a year and a half was spent just trying to understand each other. [AL2]

It took years to really understand the other pieces. I didn't need to understand the gory details but just enough to understand the language. It took a while to figure out what the goal was [BF2]

It is clear from the interviews that many faculty struggle with the process of doing interdisciplinary research; it takes a lot longer than it should particularly for faculty who have not worked in this way previously. There is a large body of literature available on how to successfully engage in interdisciplinary research, but even faculty doing deeply interdisciplinary work seemed largely unaware of these best practice guidelines. The interviews indicate that institutes could potentially play a vital role in acting as a skilled facilitator for interdisciplinary projects bringing its theoretical knowledge and practical experience to bear on interdisciplinary projects particularly in the early stages as faculty work out where they might contribute, how they can co-create research questions of mutual interest, and how they can bring different methods to bear on the research question. As research projects come and go, institutes can continually learn from them and build institutional memory and long-term capacity in doing and facilitating interdisciplinary research at the coal-face. Few other entities within the university have this capability.

A huge part of the institute's work has been opening up the black box of what happens between ecology and economics and making that transparent and clear. We had lots of workshops where we had ecologists and economists to sit down and figure what they did and how to connect one to the other [CF1]

Getting people to work together effectively is something that we could do better. Because honestly they don't know how to talk to each other unless you have someone facilitating it [CL3]

I think for an interdisciplinary project, leadership is up there with funding as being critical. Being able to see the different pieces and facilitate the process of a common understanding of what is the goal and how to get there [BF2]

I think a lot of interdisciplinary research happens by instinct. We might want to formalise that a bit. I think it is a seat of the pants approach we have been taking and it could be done better [BF4]

Von Wehrden *et al* (2019) and Brundiers *et al* (2013) emphasise the crucial importance of the role of the facilitator and boundary manager for inter- and transdisciplinary research. The facilitator will know which specific skills and individuals are needed and what resources can be called upon, help create trust, guide and mediate discussion, and support the team in finding common ground on which to build. The British Academy (2016) recognise that managers of interdisciplinary units can be critical to bringing together teams and call for their role and skills to be valued and supported. Two of the four of institutes in this study had embedded research funding offices which faculty felt play a vital role in enabling interdisciplinary research teams and projects.

The research team here is fantastic. These are people who really know how to put together a research proposal, and pull together teams, and facilitate the administration of complex interdisciplinary grants [DF3]

There is a difference between a proposal team within the university and one that is in-house; they really know the scientists, they know the themes, they know what we are after [DL1]

Having one person who is able to bridge, who is able to point out when we are talking past each other has been very helpful (CF2)

Interdisciplinary research requires additional skillsets and competences and may require training and development for students and faculty (British Academy 2016). Again institutes can play a role in providing training courses, mentoring, and guidance for faculty and research teams interested in doing interdisciplinary research. Whilst some of the institutes studied did provide training for postgraduate and postdoctoral researchers this was not a common feature, and this training was mostly not available to, or taken up by faculty.

If we want interdisciplinary research we have to train people to do that function, and we have to select for people who are willing to work with people who do that function [CL3]

The most important action for institutes is training for faculty around strengthening interdisciplinary work. We need to strengthen the ability for faculty to truly do interdisciplinary work and that is going to require some training and tools for faculty [AF1]

Theme 6: Institutes as a voice and advocate for interdisciplinary scholarship within the university

A theme which emerged from interviews was that research institutes can be an advocate for interdisciplinary values and scholarship within their universities. The institute can legitimately speak on behalf of a large cohort of faculty who are engaged in interdisciplinary research, and be a powerful champion for collaboration between disciplines. Institute directors have a voice at the senior leadership table within the university and are in a position to ensure that interdisciplinary scholarship is defended and recognised. The institute voice can be even more compelling when a number of university research institutes work together to develop new structures and systems to support interdisciplinary research. Institute projects that cross disciplines can serve as exemplars of successful interdisciplinary research; faculty who are deeply engaged in interdisciplinary research within the institute can take this positive experience back to their schools and be a champion for interdisciplinary research within their units. In this sense, research institutes can be the agents of change in their university as proposed by Rogers (2012), acting to transform the culture and work patterns of the organisation in line with an interdisciplinary research strategy. Mallon (2006) suggests that university leaders might capitalise on these aspects of research centres by rewarding leaders who embrace a collaborative point of view.

Institutes can play an important role in protecting their members. Institute directors should be capable of articulating an argument for why the environment they provide, in the terms of a place where interdisciplinary scholarship can be done, is important to have. I mean that would be a major thing [DF1]

The institute has made sustainability and interdisciplinarity credible within the university. The way that the institute works has been a model in incentivising and promoting interdisciplinary work and real world engaged work which is being copied by multiple units across campus [AF2]

A key way that institutes support interdisciplinary work is a top down assurance that what you do matters; you don't want to be fighting against that, it is an undertow that is debilitating [DF3]

Many faculty interviewed expressed the view that institutes have the potential to influence tenure and promotion criteria within universities which are long recognised barriers for interdisciplinary research [Klein, 2009]. Within one institute in this study, which incorporates a school, the institute had separate tenure and promotion criteria for disciplinary and interdisciplinary research and faculty could select which set of criteria they wished to be evaluated under.

The institute can be a leader for change in promotion and tenure criteria; finding a way to formalise criteria for interdisciplinarity or be a champion for cases that go up for interdisciplinary research. Finding a way to facilitate that and to give that importance, I think the institute does that [DF6]

A key action that institutes could take to facilitate interdisciplinary research is to work with the deans to make sure that their researchers are not hindered by doing interdisciplinary research. [BL1]

Institutes should get together and push universities to expand what they see as criteria for success in academia. I think that the leaders of the three big institutes need to speak as one voice and start pushing upper administration about recognising interdisciplinarity in tenure and promotion [BF3]

Theme 7: Institutes help attract and retain interdisciplinary research talent

An unanticipated theme within the interviews was that research institutes can attract academic talent who are explicitly interested in interdisciplinary research to the institute and the university. The presence of an interdisciplinary institute can be a key reason why new faculty wish to join, or remain, at the university thereby further increasing the university's interdisciplinary research capacity. A strong interdisciplinary ethos within a university, delivered on the ground by institutes, can be a competitive advantage in the search for academic talent creating a virtuous circle.

So the university was bold enough to create a structure where the goal of the structure is to create collaboration across disciplines; I thought it was new and exciting and I wanted to be on a campus that valued that [BF3]

The institute keeps the faculty interested and retained at the university by giving them the opportunity to explore their intellectual curiosity beyond their discipline. Some people have told me anecdotally that they would probably not be here still if they hadn't had the opportunity to work more broadly beyond their department [AL1]

You create a culture that people are attracted to; the people who come here and are recruited here know that this university has this culture and that's how they like to work. There is a self-fulfilling nature to it [CL1]

Institutes can also influence and advocate for interdisciplinary scholarship in faculty recruitment. Joint faculty linked to, or recruited in partnership with institutes, are a common mechanism for universities to promote interdisciplinary teaching and research. There were some cases within institutes studied, where the recruitment of a new member of faculty was based on a particular theme or problem and did not specify a particular discipline at the outset.

When schools are recruiting faculty, they will ask us to input to see if the appointment will fit with the community of scholars which we have developed and so that is helpful in the recruitment [BL1]

They might not be joint hires from the get-go but we were hiring around a theme or a problem and it is open across disciplines or schools [CL3]

We said we wanted a scholar to help us think about human well being. And it was wide-open. We didn't specify disciplines [DL2]

Theme 8: Institutes provide seed funding for interdisciplinary research

One of the most tangible mechanisms for institutes to support interdisciplinary research within universities is to provide a dedicated funding stream for it [National Academy of Sciences 2005]. The British Academy (2016) asks for university seedcorn funding for interdisciplinary research to be protected as it takes extra time and groundwork. All of the institutes studied had internal research funding streams in which interdisciplinarity was a key evaluation criteria; this was a significant means of bringing faculty together within the institute. Seed funds are perceived by faculty to be one of the most important actions and incentives that an institute can take to enable interdisciplinary research [Bolger 2020].

The institute can have resources that allow individuals to come together to work on a problem that might not be fundable through traditional routes [DF1]

I think that money on the table being conditional on interdisciplinary research is important; it being labelled as requiring this kind of interaction. I don't think it will happen often otherwise [BF4]

We provide seed funding for interdisciplinary working. We see it as our job to fund research that sits between departments and schools [BL2]

Money gets people talking. It is much easier if you can give out money {AF4]

Whilst internal funding programmes within institutes are viewed very positively by most faculty, some interviewed faculty sounded as note of caution that these funding programmes don't always guarantee high quality interdisciplinary work, and highlighted the risk that faculty "game" the incentives to produce superficial interdisciplinary interactions. Work by Freeman e*t al* (2014) suggests that collaborations based on ideas and relationships rather than on funding lead to more highly cited papers.

Sometimes when you put a lot of resources on the table people become quite territorial [BF3]

So in the long run it is not just about seed money but it is about structural incentives to get people to do more interdisciplinary research if they realise that. [BF1]

It may be important for institutes to critically evaluate the short and long-term outcomes from internal seed funding programmes to establish whether they are achieving the intended interdisciplinary and collaborative goals (Sá 2008). Whilst co-authored papers with authors from different were the most straightforward metric, there was a recognition that this needed to be supplemented by qualitative approaches.

There is a part of me that thinks that this isn't something that you can measure easily. It's something that one would want to see activities documented that define why you couldn't have done that on your own, and why you needed that interdisciplinary working group [BL2]

Did we change the way people think about the problem by using this interdisciplinarity? That to me is the fundamental thing [AF4]

CONCLUSION

The data from this study revealed eight themes for how research institutes enable interdisciplinary research within their organisation and universities. The interviews underscore how research institutes occupy an ideal organisational position within the university to be vehicles for progressing an interdisciplinary research agenda having the in-depth knowledge of faculty expertise, research interests, and the research area to be most useful in terms connecting, convening, networking and community building. The study shows interviewed faculty to be very favourable and positive about the culture and supports developed within the institutes for interdisciplinary work. The interview themes

and areas where institutes could further develop and embed interdisciplinarity within their units are elaborated on below.

It is clear from the interviews that the organisation of interdisciplinary research within institutes cannot not be left to chance; institutes need to have a clear strategy and actions for how to deliver on their interdisciplinary goals. Emphasis should be placed on building internal capacity to institutionalise interdisciplinary research. The interviews indicate that institutes could greatly benefit from more collective learning across their interdisciplinary research projects. A careful examination of successful interdisciplinary projects, and the processes underpinning them, to internalise this knowledge within the organisation would facilitate capacity building. The focus should be on the process as much as the research and outcomes. Institutes could consider developing specific local frameworks for interdisciplinary research, a kind of methodological toolbox that harvests the lessons from institute faculty engaged in this work combined with project case studies.

Closely connected with this collective learning would be to put in place a simple evaluation process of interdisciplinary research projects within the institute. The process should focus on the quality and nature of the interdisciplinary research examining the emergent whole in how disciplines are combined, whether the project answered the research question it set out to address and whether the outcomes are distinctly different from those that would be achieved by a single discipline.

A sustained set of strategies are needed by the institute to repeatedly generate genuinely collaborative teams; these strategies need to be adapted to local circumstances and allowed to naturally evolve over time to meet the needs of faculty. The interviews would suggest that institutes must engage in a continuous process of creative destruction and reinvention, making sure to "sunset" events and teams that have served their purpose and create new ones.

Craft skills are needed for interdisciplinary working; there is no reason to assume that faculty have these skills. The interviews showed that many faculty face a steep learning curves when engaging in interdisciplinary work. Institutes should ensure that faculty have the opportunity to develop the best-practice skillsets through training and workshops. Institutes could also consider investing in development of skilled facilitators amongst its staff and faculty for building collaborative cross-disciplinary projects. The interviews in this study indicate that this facilitation role might sit comfortably with the roles of a research funding support office in an institute given that this role has already strong elements of consortium building, a clear focus on call topics, and will produce projects to work on. Institutes could also consider selecting faculty who are deeply involved in interdisciplinary work to be part of an advisory team to identify local barriers, propose relevant local actions, and mentor students and faculty.

Within their universities, there is an opportunity for research institute directors to act in unison to influence university policies on tenure and promotion to include criteria which recognise interdisciplinary research and create a critical mass for change and new norms for how research work is evaluated. Much interdisciplinary research can go under the radar at universities; institutes can shine a light on this work creating a portfolio of interdisciplinary work and be beacons for best practice.

It is acknowledged that interdisciplinarity is not the only goal of research institutes, that interdisciplinarity may not be needed to answers all sustainability research questions, and that interdisciplinarity may not be the end but the means by which to generate better answers and more usable knowledge to research questions. A key task for institute leadership is to discern when interdisciplinary research is required and to focus their efforts on those scholars who do wish to engage in interdisciplinary work. Aligning the institute's interdisciplinary research agenda with the strategic mission of the university, and with the research goals of faculty is crucial. Interdisciplinary research

institutes will ultimately falter if their work is seen as unconnected and irrelevant to the research goals of faculty.

A limitation of the study is that it is confined to four large US sustainability research institutes which have a cross-university research remit; the study may not be representative of smaller environmental research centers, units, and clusters that engage in interdisciplinary research within the university system. In addition, within the four institutes investigated, the interviewees for the study tended to be those leadership and faculty staff who are committed to promoting and engaging in inter-disciplinary research; the study may not be representative of faculty who are less engaged in inter-disciplinary work within the institute.

This study provides a deeper understanding of how interdisciplinary research is being enabled at research institutes and offers signposts for how research institutes can further embed interdisciplinarity within their units. The study will be of particular interest to research institute and university leadership who wish to cultivate a deeper culture of interdisciplinary research within their organisations. It is suggested that further research on interdisciplinarity within research institutes could focus on gaining a better understanding of the complex social and intellectual processes behind interdisciplinary research projects within the institutes which will enhance the prospects for the creation and management of successful programmes and projects.

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Appendix

Table A1 Example of thematic analysis approach for interview text

Research question: how do, and can, research institutes facilitate interdisciplinary research within their units and universities?			
Interview text	First Coding	Second coding	Theme
"I can think of two major categories of benefits for affiliation and engagement. We are an academic Switzerland. We are a place where the disciplines and faculties can work together. We have infrastructure on the basics of grant management, project management, to sort of helping to have the space for a convening of ideas from colleagues, and schools from different disciplines. The University is very proud of its interdisciplinary culture. We have Schools and Masters that have interdisciplinary themes running through them. We harvest on the wonderful culture that has been built here already but there is still needs to be dedicated resources to facilitate, convene and enable interdisciplinary work for areas of interest to the. It lowers the transaction costs for those faculty to engage in interdisciplinary collaborations. The second thing is that iterative bridge which helps refine research questions and can create an improvement in the relevancy of the work in the target audience. The intellectual capital is not only being delivered but it is being refined in the process of conversation with external audiences. "	an academic Switzerland; a place where the disciplines and faculties can work together	Institute as a neutral convenor	Theme 2: Institutes as trusted convenors and honest brokers
	Space for a convening of ideas from faculty from schools from different disciplines	Institute as a convenor	Theme 2: Institutes as trusted convenors and honest brokers
	needs to be dedicated resources to facilitate, convene and enable interdisciplinary work…	Institute lowers the transaction costs for interdisciplinary research	Theme 1: Institutes as a large and valued network of faculty interested in sustainability research
	lowers the transaction costs for those faculty to engage in interdisciplinary collaborations.	Institute lowers the transaction costs for interdisciplinary research	Theme 1: Institutes as a large and valued network of faculty interested in sustainability research
	that iterative bridge helps refine research questions and can create an improvement in the relevancy of the work in the target audience	Institute helps define and refine research questions	Theme 4: Institutes as a locus for big interdisciplinary ideas and questions

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