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A study of faculty perceptions and engagement in interdisciplinary research within university sustainability institutes

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ABSTRACT

It has long been argued that solutions to inform better decisions on environmental challenges require research at the boundaries of scientific disciplines. Research institutes and centers at universities can be key vehicles for the convergence of scientists from multiple disciplines and the development of integrated, interdisciplinary knowledge. Through a survey of over two hundred faculty in three sustainability research institutes based in the United States, this study explored faculty perceptions of interdisciplinary research, their levels of engagement in interdisciplinary work, and how they view the role of the research institute in enabling interdisciplinary research. The investigation shows that over 95% of faculty at the institutes studied are carrying out research with colleagues outside their own discipline, with half of the faculty spending more than two-thirds of their time on interdisciplinary work. Over half of faculty members are engaging in long-distance interdisciplinary research across the natural-social sciences boundary which is seen as crucial for sustainability science. The research institutes are having a positive influence on facilitating interdisciplinarity with more than four out of five faculty indicating that the institute has enabled interdisciplinary research opportunities that would have not have been possible in their home school. The opportunity to engage in interdisciplinary research is amongst the most important reasons for faculty to join institutes. Whilst limited to three institutes, the study provides robust evidence for the powerfully beneficial role that research institutes can play as enablers on interdisciplinary research within their university.

KEYWORDS

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

INTRODUCTION

Interdisciplinary and transdisciplinary are strongly perceived as being necessary to address complex global environmental challenges, and tackle wicked sustainability problems that cross disciplinary boundaries and require different types of knowledge (Hirsch-Hadorn *et al*, 2006; Horlick-Jones and Sim 2004; Lawrence 2010; Wickson *et al.* 2006; De Grandis and Efstathiou 2016; Lang *et al*. 2012; Bammer *et al,* 2020). Interdisciplinary research and cooperation are now seen as vital elements of academic innovation (British Academy 2016). The realisation of the necessity for interdisciplinary research is not new; as far back as 1970 an Organisation for Economic Co-operation and Development conference identified interdisciplinary research as a means to respond to both changing societal and scientific challenges (Apostel *et al*, 1972). In the last two decades, there has been widespread adoption of interdisciplinarity as an institutional goal amongst universities. Most leading universities have committed to fostering interdisciplinary activity on their campuses while some institutions seek to differentiate themselves as exceptional locations for engaging in interdisciplinary research and teaching (Feller 2002; Brint 2005). A teaching and research focus on sustainability in particular seems to provide

strong opportunities for cross-university and cross disciplinary effort (Benton-Short and Merrigan 2016).

Whilst there is still no fully agreed definition of interdisciplinary research amongst the academic community, the most commonly adopted definition 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*". Interdisciplinarity is set apart from multidisciplinarity as requiring deep engagement between a number of disciplines which includes an understanding of respective terminologies and methods by the participants, and from transdisciplinarity which is commonly seen as working with stakeholders from outside the academic system (Repko *et al.* 2013). Most advocates point to problem solving as the main promise of interdisciplinary research; whether basic or applied, interdisciplinarity is supposed to solve problems that individual disciplines cannot solve alone (Klein 1996; Frodeman & Mitcham 2007).

The role of research institutes

Despite institutional goals to increase interdisciplinarity, in reality, interdisciplinary collaboration with a continuous exchange and active collaboration between different disciplines is still relatively rare and most universities are poorly configured to deliver the transformations needed to shift to more collaborative interdisciplinary structures (Palmer 2018). Weingart (1997) notes that specialisation within disciplines has increased at an exponential rate and remains a prerequisite for promotion and tenure within academic institutions. Klein (2009) identified the four main institutional obstacles to creating an interdisciplinary scientific culture in universities as organizational structure and administration; procedures and policies; resources and infrastructure; and recognition, reward, and incentives. A key challenge for universities is to adequately support and manage interdisciplinary research within academic institutions while simultaneously maintaining strong academic disciplines (LERU 2016). The goal for universities suggested by many should be to build a new layer of interdisciplinary and transdisciplinary research on top of the existing disciplines, which have proven so successful, in order to tackle the major societal challenges facing us (Dedeurwaerdere 2014).

One solution to promoting interdisciplinary research adopted by universities is to differentiate internally into a layered or matrix organization by establishing cross-cutting research centers (Biancani *et al*. 2014). This enables universities to retain traditional departments that facilitate rigorous, disciplinary academic communities whilst simultaneously having interdisciplinary research centers which provide an institutional locus to address the grand challenges of society (Stahler and Tash 1994; Jong 2008).

Bozeman and Boardman (2003) defined a research center as "*a formal organizational entity within a university that exists chiefly to serve a research mission, set apart from the departmental organization, and includes researchers from more than one department*." Research centers represent a signalling device for a university's mission and strategy and can be a significant investment in resources (Zahra *et al.* 2011). The number of interdisciplinary research centers within universities has exploded in the last two decades; large universities can have more than one hundred such centers and there are often more research centers than disciplinary departments (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). Research centers can confer multiple benefits on a university including supporting recruitment and retention, facilitating collaboration in research, securing research resources and funds, offering a sense of community, affording organizational flexibility, and focusing

on societal problems (Mallon, 2006). Research centers can also contribute a number of beneficial outcomes to affiliated faculty including increased research productivity, industry partnerships, and collaboration and networking (Corley and Gaughan 2005; Boardman and Corley 2008; Ponomariov & Boardman 2010; Gaughan and Corley 2010; Bozeman and Corley 2004, Gaughan and Ponomariov 2008; Sabharwal and Hu 2013).

The focus in this study in on sustainability research centers. There are large differences in the size and nature of university sustainability research centers varying from small centers of only 3-4 faculty members within an individual school to large state-funded research centers spanning multiple universities with hundreds of academic members. Vincent *et al* (2015, 2016) has carried out a comprehensive review, and analysis, of interdisciplinary environmental and sustainability focused US institutes and centers examining their goals, their funding sources, and how these attributes are related to their operational structures. Hoffmann and Axson (2017) have also reviewed the distinct characteristics, activities, challenges and opportunities of US sustainability institutes that spans the many disciplines of the university. This research study was interested in 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). Private philanthropic and endowment funds are key to the establishment of, and on-going financing of operations at, the institutes. 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.

Collaboration within research institutes

Perhaps one of the most distinctive feature that all university research institutes have in common is the intention and capability to bring together multiple disciplines and foster collaboration among researchers (Bozeman and Boardman 2003; Su 2014; Boardman and Corley 2008). Research institutes can function as intra-university "*boundary organizations*" that provide a stable organizational framework enabling collaborations across disciplines and knowledge integration (Guston 2000; Geiger 1990; O'Mahoney and Bechky 2008). Galison's (1997, p 783) concept of research institutes functioning as ''*trading zones''* for researchers interested in collaborating also provides a useful metaphor; similarly Bergmann *et. al.* (2012) indicates that the "*joint spaces*" enabled by research institutes can be an important foundation for inter- and transdisciplinary research.

Another common feature of research institutes is that they draw upon faculty in existing schools and departments for their academic membership; in most universities this membership is offered but not mandated *i.e*. faculty have a choice whether or not to participate (a choice not available within departments and schools). In this regard, institute affiliation can be seen as a "secondary membership" in addition to department or school membership. Biancani *et al* (2014) have likened research institutes to a semi-formal organization occupying a plane between the formal university and informal research teams. The voluntary nature of institute membership has important consequences for how research institutes operate; it necessitates that the institute must show some level of added value for participants to offset the costs of membership. The benefit of institute affiliation to faculty is explored in this paper.

Despite the potential for research institutes to be enablers of interdisciplinary research, the role of research institutes has largely been neglected in the discussion of interdisciplinarity (Klein 1996; Jacobs and Frickel 2009). There are few studies that have examined collaboration rates for institute members

with the exception of Gaughan and Ponomariov (2008) and Rhoten (2003); most studies of research institutes have focused on effects of institute affiliation on the productivity on research outputs (Sabharwal and Hu 2013).

Rhoten (2003) found that research institutes tended to be more multidisciplinary than interdisciplinary *i.e*. the institute demonstrates inclusion, rather than an integration, of different disciplines. Understanding the extent to which institutes and centers influence the collaborative behaviours of scientists is a key question that must be answered in the evaluation of research centers (Boardman and Corley 2008) along with the mechanisms deployed by institutes to facilitate interdisciplinary research.

There are few studies which explore whether research institutes are fulfilling their goal to be interdisciplinary entities, and no studies which have directly surveyed affiliated faculty on this question. This paper aims to fill this gap by setting out to explore the perspectives and perceptions of affiliated faculty within three sustainability research institutes based in the United States on interdisciplinary research, and on how interdisciplinary research is being facilitated and enabled by their institutes.

METHODOLOGY

This study was carried out at three 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 (Wrigley Institute) at Arizona State University, the Earth Institute at Columbia University, and the Cornell Atkinson Center for a Sustainable Future (Cornell Atkinson) at Cornell University. Interdisciplinarity is a core value of these three research institutes; all three are university institutes reaching across the campus to bring together faculty to collaborate on sustainability issues. This purpose is evident in the mission statements and goals of the institutes:

To connect scientists, scholars, humanists, engineers, technologists, policymakers, business leaders, students and communities to enhance capacity to address challenges of sustainability (Julie Ann Wrigley Global Institute of Sustainability website, 2019).

By bringing those physical scientists together with experts in economics, law, public health and policy, the institute creates collaborations that help us learn how to best address issues of global sustainability (Earth Institute website, 2019).

The practice of Cornell's Atkinson Center – to facilitate the interdisciplinary sustainability research of the colleges and co-create sustainability solutions with non-academic partners – embodies [our] institutional commitments (from the Cornell Atkinson Center for a Sustainable Future Strategic Plan, 2018-2023)

All three institutes have been established for over a decade enabling them to build significant experience and capacity in facilitating collaborative interdisciplinary research; long lead in times for capacity building has been noted to be an important factor for institutes aiming to build interdisciplinary teams (Mosey *et al.* 2012). Two of the institutes are deeply involved in teaching as well as research; the Earth Institute offers a number of undergraduate and postgraduate courses in sustainability and climate change, and the Wrigley Institute hosts a School of Sustainability.

The vast majority of faculty members within the three institutes are primarily appointed in university schools and departments and are affiliated to the Institute as a faculty scholar or fellow; some faculty within the Institute are joint appointments between the institute-school, and in some cases a number of faculty are full-time appointments to the Institute. Affiliated faculty within the institutes are generally physically located within their constituent school and department buildings *i.e*. are not in close physical proximity to each other. The number of faculty affiliates within the institutes ranged from 70 to 500. The majority of funding for research within the institutes comes from external sources along with

generous endowment grants to run operations; the philanthropic grants enabled a number of the institutes to have significant 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.

Faculty within the three institutes were invited to participate in this study by direct email. The survey was anonymous and comprised 18 questions which aimed to explore the perspectives of faculty members on interdisciplinary research[1], and on how interdisciplinary research is being enabled within the Institute. The questions were a mix of multiple choice, rankings and free text. The survey completion rates by faculty were from 25%-50% across the three Institutes. A total number of 209 faculty participated in the survey. The study and survey was reviewed and approved by the Social and Research Ethics Committee at University College Cork.

RESULTS AND DISCUSSION

Value of institute affiliation

The survey participants were asked to select the three most important benefits of being affiliated with their research institute out of a list of eight options (see Table 1). The results for the institutes are presented in Table 1 and the average across the three institutes is presented in Figure 1. The data is presented as the percentage of faculty who chose a particular option in their top three benefits. For example, 63% of faculty in Cornell Atkinson perceive "*Access to a network of university faculty with common interests in sustainability research*" as one of the top three benefits to being part of the Institute.

The data in Table 1 and Figure 1 shows that faculty perceive "*Access to a network of university faculty with common interests in sustainability research*" (75% faculty average) and "*Greater opportunities and support to engage in interdisciplinary research*" (67% faculty average) as the most important benefits of being affiliated with the institute. These benefits seem to be significantly more important than others. "*Support with acquiring funding for my research*" is perceived to be important at some institutes; the higher ranking for this choice might be attributable to a substantial internal seed funding programme for research projects and/or a strong research funding support office within these institutes.

The results would strongly suggest that faculty who are affiliated with a research institute place a high value on the institute member network, and the access to expertise within it, along with the opportunity to engage in interdisciplinary research with members of the network. This correlates with a previous study of research institutes in academic medicine at six universities carried out by Mallon (2006) who noted that the most important aspect of the affiliation was not a physical space or a tangible benefit like research support, but rather a spiritual notion, a sense of creativity, and of intellectual excitement; the institutes offer a sense of community of colleagues with common scholarly interests.

Table 1 The survey asked participants to select the three most important advantages and benefits of being affiliated with their research institute. See list of numbered choices below for results.

	Cornell Atkinson (n=65)	Earth Institute (n=29)	Wrigley Institute (n=111)	All Institutes (average)

[1] *Survey participants were informed that the study defined interdisciplinary research as a mode of research that integrates research from two or more academic disciplines to advance fundamental understanding or to solve problems as defined by the National Academy of Sciences (2004).*

1	Access to a network of university faculty with common interests in sustainability research	63%	86%	76%	75%
2	Support with acquiring funding for my research	68%	17%	41%	42%
3	Support with promoting my research and organising events	28%	24%	20%	24%
4	Prestige of being part of an active and leading university research institute	23%	38%	39%	33%
5	Greater opportunities and support to engage in interdisciplinary research	63%	79%	59%	67%
6	Access to a wider network of external stakeholders e.g. industry, policymakers, NGOs	32%	28%	33%	31%
7	Access to Institute facilities and space	3%	10%	17%	10%
8	Other	2%	7%	5%	4%

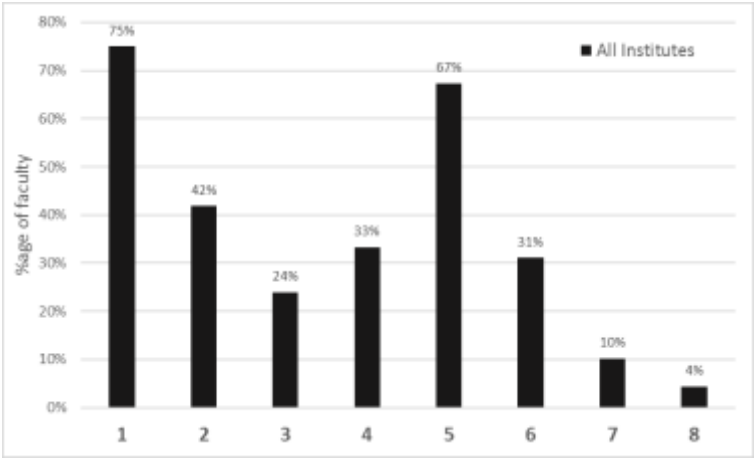

Fig 1 The three most important benefits of being affiliated with the research institute (average across 3 institutes). See Table 1 for numbered list of benefits on the x-axis.

Engagement in, and perceptions of, interdisciplinary research by affiliated faculty

Participants in the survey were asked the question "*Do you think that interdisciplinary research approaches are necessary for addressing global sustainability issues*?" and were given five options (always, usually, sometimes, rarely and never). On average, 93% of the faculty, across the three institutes, think that interdisciplinary research is either always or usually necessary to address sustainability issues; on average, 54% of faculty across the three institutes think that interdisciplinary research is always necessary (see Figure 2). These results underscore that the vast majority of faculty engaged in research within the three institutes are cognisant of the value and importance of working within interdisciplinary teams to address sustainability research questions.

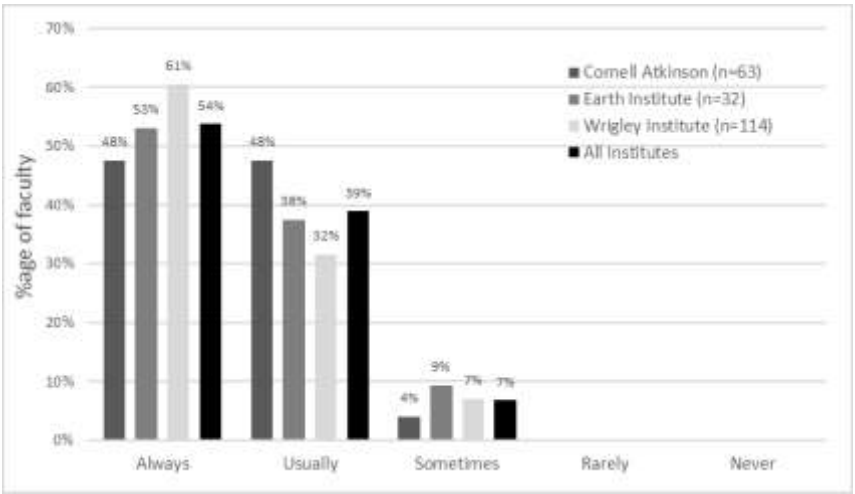

Fig 2 Faculty responses to the question "Do you think that interdisciplinary research approaches are necessary for addressing global sustainability issues?"

Survey participants were also asked to select the three most important reasons for engaging in interdisciplinary research from a list of seven options (see Table 2). There is relatively strong agreement across the three Institutes in relation to the motivations for engaging in interdisciplinary work. The most common reason selected was that it is the "*only way to address certain research*

questions" (75% average), followed by "*to cross fertilise ideas and obtain new insights or perspectives*" (67% average), and then "*intellectual curiosity*" and "*access to skills equipment and techniques not available within my discipline*" (both 55% average).

These results on motivations for engaging in interdisciplinary research broadly correspond with literature on rationale for research collaboration. Academic faculty have varied reasons for participating in interdisciplinary research; Katz and Martin (1997) and Beaver (2001) list up to eighteen reasons for why academics engage in collaborative research but do not rank them. Haylor (2012) proposes that collaboration among scientists contribute to seven main benefits for the researcher including: (1) sharing of knowledge, skills and techniques (2) tacit knowledge transfer (3) learning the social skills needed to work as a part of a team (4), source of creativity (5) intellectual companionship/networking (6) greater scientific visibility, and (7) pooling equipment. In a series of interviews examining collaboration in science systems across a number of different countries, Thorsteinsdottir (2000) found that the main reason collaboration takes place is that scientists wish to access expertise and complementary skills which allow them to tackle more complex problems. In an open questionnaire on motives for collaboration, Melin (2000) also found that access to special competences and equipment to be amongst the important motives for collaboration although noted that social reasons such as long-time friendships can be as important as cognitive and technical reasons with social reasons (including previous collaboration or mentorship) being responsible for 32 per cent of collaborative choices.

Table 2 The survey asked participants to select the three most important reasons for engaging in interdisciplinary research. See list of numbered choices below for results.

		Cornell Atkinson (n=61)	Earth Institute (n=30)	Wrigley Institute (n=114)	All Institute (average)
1	Access to skills, equipment and techniques not available within my discipline	64%	51%	51%	55%
2	Intellectual curiosity	52%	53%	59%	55%
3	To increase my chances of getting funding	18%	19%	28%	21%
4	To cross-fertilise ideas and obtain new insights or perspectives	67%	70%	63%	67%
5	To plug into a wider network of contacts	10%	15%	26%	17%
6	Only way to address certain research questions	79%	79%	66%	75%
7	Other (please specify)	10%	13%	6%	10%

Faculty were asked the question "*How frequently do you engage in interdisciplinary research i.e. work with colleagues outside your own discipline*?" and were given four choices: 0-10% of the time, 11-30% of the time, 31-60% of the time, and 61-100% of the time (see Figure 3). The results across the three institutes share similar trends. On average, over three quarters of faculty (76%) claim to spend more than one-third (31-100%) of their research time on interdisciplinary work. Almost 50% of faculty claim to spend more than two-thirds of their time working with colleagues outside their own discipline (at Wrigley Institute this rises to 65%).

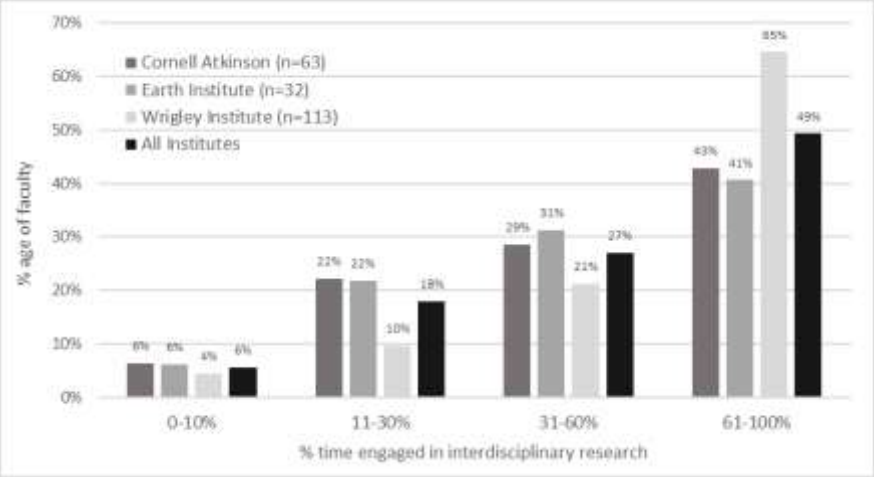

Fig 3 percentage of the time Institute faculty engage in interdisciplinary research

Overall these results are surprising in terms of the proportion of faculty giving significant amount of time to interdisciplinary research. Notwithstanding the substantial body of literature on interdisciplinarity, there are limited studies which quantify the amount of time researchers spend engaged in interdisciplinary research. Rhoten (2004) found that faculty within interdisciplinary research centers allocate a substantial of amount time to interdisciplinary research reporting that they spend about 50% of their total work time on center-related interdisciplinary activities. This high level of interdisciplinary work may be a feature of interdisciplinary centers, and the researchers within them, as in contrast Lee and Bozeman (2005) indicated that faculty typically spend only about 11% of their time working with other disciplines in the same institution (the remainder was spent working members of their own departments [50%], working alone [15%] or with outside collaborators [25%]).

Interdisciplinary distance

In the study, faculty were asked to state their home school, academic discipline, the broad area that their research was situated in, and what other disciplines they collaborated with. This gave an indication of the type of interdisciplinary collaborations that each faculty member was engaged in, if any. In order to analyse and understand the nature of interdisciplinary collaboration within the institutes, disciplines were categorised into the "super-disciplines" of (i) natural and applied sciences which emphasise empirical knowledge development and (ii) social sciences and humanities which use qualitative techniques to study aspects of human society. This broad classification is consistent with the Biglan classification scheme (Biglan 1973) which is the most cited organizational system of academic disciplines where the highest categorisation level of academic disciplines is "hard" (natural and applied sciences) and "soft" (social sciences and humanities); it also follows the delineation of the main academic cultures identified as natural science and social science/humanities (Snow 1959).[2] Based on the concept of two super-disciplines, three classifications were developed to understand the spanning of interdisciplinary distance within the research institutes under study.

- Within discipline *e.g.* a zoologist with a plant scientist
- Short distance (within super-discipline) *e.g*. an engineer with a biologist
- Long distance (between super-disciplines) *e.g*. an ecologist with a social scientist

To illustrate the use of this classification, some examples of responses from the survey and their subsequent classifications are provided in the Appendix in Table A1. The survey data for the three interdisciplinary distance classifications are shown in Figure 4 (percentage faculty in each category). The results show that across the three institutes, at some stage, an average of 95% of the faculty are

[2] Of course there can still be much cross-over between these super disciplines e.g. social scientists may often use methods resembling those of the natural sciences as tools for understanding society, and economists can use both quantitative and qualitative methods.

engaged in collaboration with faculty outside their own discipline (short or long distance). An average of 40% of faculty engage in short distance interdisciplinary research, and an average of 55% engage in long-distance interdisciplinary research.

Within the literature on interdisciplinary research there has not been substantial attention given to interdisciplinary distance (Uzzi *et al*. 2013); most investigations simply assess whether discipline spanning has occurred without considering the relationship between the spanned entities. Leahey *et al.* (2017) suggests that spanning two closely related disciplines is hardly different from not spanning at all.[3] Lélé & Norgaard (2005) argue that the barriers of working together in interdisciplinary research are the least among different natural scientific discipline; the natural and social sciences are reputedly the most difficult boundaries to cross academically (Poole 1994).

The results in this study indicate that there is substantial long-distance interdisciplinary collaboration across the natural sciences and social sciences/humanities boundaries. This is very encouraging as stronger interactions between natural and social sciences are perceived as being particularly critical for sustainability science and to understand the role of the human dimension in generating global change (Strang 2009). Lariviére *et al.* (2015) also found that long-distance interdisciplinarity leads to higher scientific impact.

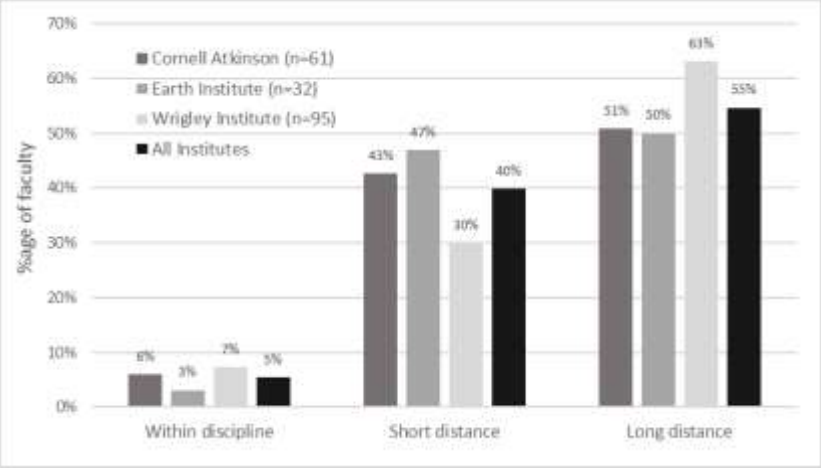

Fig 4 Interdisciplinary distance classifications for survey responses from faculty at the three institutes

Effects of institute affiliation on interdisciplinary research behaviour amongst faculty

Institute faculty were surveyed on whether they considered that facilitating interdisciplinary research should be a core part of the mission and activities of their institute and were provided with two choices (Yes and No). The results are shown in Table 3. Even though the vast majority of the affiliated faculty of the institutes are located in schools and departments arranged along disciplinary lines, over 99% of surveyed faculty indicated that interdisciplinary research should be a core part of the mission and activities of their institute. This underlines that affiliated faculty perceive that research institutes are a

[3] Whilst there is no clear definition of disciplines, in order of transcending different methods, tools and epistemologies, it is clear that a collaboration between a chemical engineer and mechanical engineer might be easier than a collaboration between a chemical engineer and a biologist, which again might be easier than between a chemical engineer and a sociologist.

potential key enabler for interdisciplinary research within their university systems, and that they believe that institute should actively pursue this goal within their activities.

Institute faculty were asked the question "*Has affiliation with the Institute enabled greater opportunities to collaborate with researchers outside your own discipline (than would have been possible in your home department/school)*?" Survey participants were asked to select Yes or No (see Table 3). On average across the three institutes, 84% of faculty responded "Yes" to the question whether institute affiliation had enabled greater opportunities to participate in interdisciplinary research than would have been possible in their home school and department. This indicates that Institute affiliation is having a very positive effect on the level of interdisciplinary collaboration carried by affiliated faculty. Although many university-based research institutes and centers were established to improve interdisciplinary collaboration among faculty members there are relatively few empirical studies which have explored whether centers have been successful in this objective. In a study of six interdisciplinary environmental research centers, Rhoten (2004) found that 83% of center members indicated that their relationships with other center members had positively influenced their own research agendas. Gaughan and Ponomariov (2008) found increased co-authorship as a result of affiliation with a multidisciplinary research center. Boardman and Corley (2008) found that center affiliated faculty are 88% less likely to work alone when compared with faculty members that are not affiliated with a research center. Recent analysis by Zuo and Zhao (2018) suggests that collaborations within multidisciplinary research institutes are more interdisciplinary, but that just creating an academic institution with a diverse faculty body is not sufficient to foster more interdisciplinary collaborations; coordination, management, and incentives are necessary to fully exploit the potential for interdisciplinary exchange and collaboration.

The faculty affiliated with the research institutes were asked if they would like to participate more frequently in interdisciplinary research efforts, approaches and teams within the Institute than they are doing now (see Table 3). The intention of the question was to discern whether there was an appetite for increased interdisciplinary interaction within the Institute (or whether faculty were at capacity for interdisciplinary research work). On average across all three Institutes 80% of the faculty indicated that they would like to participate in more interdisciplinary research indicating that there remains a significant potential for institutes to increase interdisciplinary research interactions amongst faculty.

Table 3 Data from three survey questions on faculty perceptions on interdisciplinary research within the three institutes

	Do you think that facilitating interdisciplinary research should be a core part of the mission of Institute"?		*Has Institute affiliation enabled greater opportunities to collaborate with researchers outside your discipline?"*		*Would you like to participate more frequently in interdisciplinary research efforts within the Institute*	
	Yes	No	Yes	No	Yes	No
Cornell Atkinson (n=63)	100%	0%	87%	13%	78%	22%
Earth Institute (n=31)	100%	0%	90%	10%	91%	9%
Wrigley Institute (n=112)	98%	2%	75%	25%	70%	30%
All Institutes (average)	99%	1%	84%	16%	80%	20%

Supports for interdisciplinary research within institutes

The study explored the role of the research institute in faculty's efforts to carry out interdisciplinary research. Faculty were asked the question "*How important is support from the Institute to your efforts to conduct interdisciplinary research*" and provided with five choices (not important, rarely important, sometimes important, usually important, and always important). The results show that there is strong alignment across the three institutes on how faculty perceive support within their institutes for carrying out interdisciplinary work (see Figure 5). Overall, 84% of faculty think that support from the institute is

either sometimes, usually or always important to their interdisciplinary research efforts. The highest response was for "Sometimes Important" (42% average), followed by "Usually Important" (26% average), and "Always Important" (17% average). This would indicate that faculty consider their research institute to play a valuable supporting role in facilitating interdisciplinarity in their research efforts, but are likely not to be reliant on the institute to instigate and enable this interdisciplinary work.

Faculty were asked whether the institute was a supportive organization in which to do interdisciplinary research through the question "*How would you rank the general supportiveness for interdisciplinary research at your Institute*". Overall, across the three institutes, 87% of faculty perceive that their institute is either supportive, very supportive, or extremely supportive of interdisciplinary research (see Figure 6). The highest faculty response was for extremely supportive (33% average), followed by very supportive (30% average), and generally supportive (23% average) signifying that the three institutes under study have had some success in developing and delivering robust support structures for interdisciplinary research within their organizations.

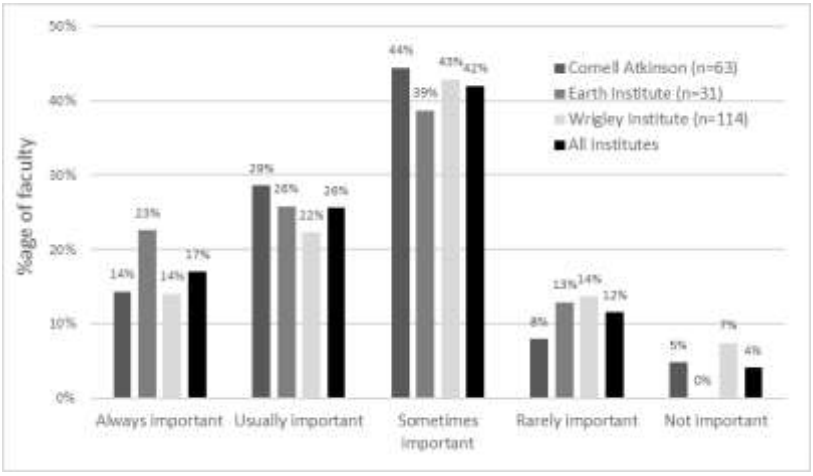

Fig 5 Data from survey question "How important is support from the Institute to your efforts to conduct interdisciplinary research?"

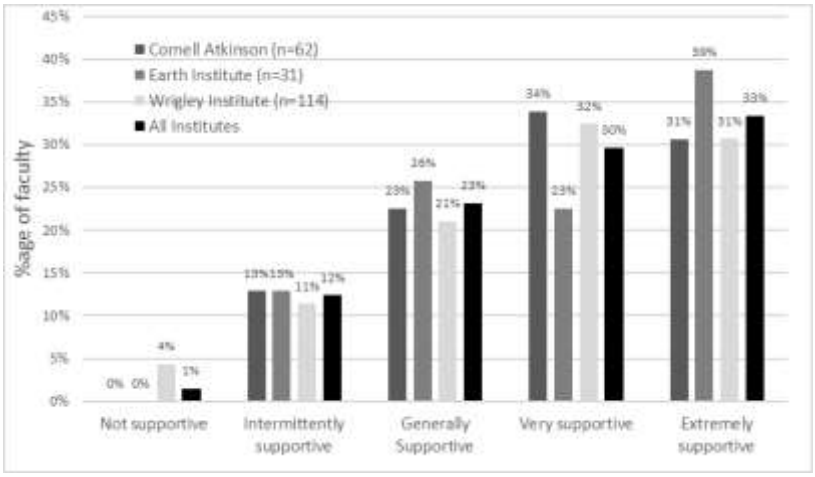

Fig 6 Data from survey question "How would you rank the general supportiveness for interdisciplinary research at your Institute?"

Faculty were also asked to select the three most important institutional supports that are, or could be, provided by the institute to enhance interdisciplinary research from a preset list (see Table 4 for list and results). Institute faculty perceive that the most important support that the institute can offer is "*Providing seed funding for interdisciplinary research projects*" (81% faculty across the three institutes). This underpins the perceived importance of financial incentives to stimulate the development of interdisciplinarity reflecting similar findings by Seaton and Thiele (2017). The second most important support was "*Fostering an open and visibly collaborative environment" (*67% across the three Institutes), followed by "*More workshops and opportunities to work on shared sustainability problems*" (45%) and "*Joint appointments and tenure with academic departments*" (39%). The results broadly correspond to a survey done at university level by National Academy of Sciences (2004) which found that the top three actions to take to facilitate interdisciplinary research were to nurture a collaborative environment, to provide seed money for interdisciplinary projects and provide incentives including hiring and tenure policies that reward involvement in interdisciplinary research. However, supports such as "*Recognition and reward for interdisciplinary research efforts*" and "*Interdisciplinary research training programmes*", which are frequently listed as key institutional barriers to interdisciplinarity (Klein 2009) were not perceived as being important supports which institutes are offering, or could, offer. A possible reason for this is that faculty consider that these are not issues which institutes can influence, or take substantial action on.

Table 4 Survey participants were asked to select the three most important supports for interdisciplinary research that are, or could be, provided by the institute. See list of numbered choices below and results.

		Cornell Atkinson (n=58)	Earth Institute (n=29)	Wrigley Institute (n=106)	All Institute (average)
1	Fostering an open and visibly collaborative environment	68%	74%	58%	67%
2	Providing seed funding for interdisciplinary research projects	90%	81%	71%	81%
3	Joint appointments and tenure with academic departments	34%	43%	39%	39%
4	More workshops and opportunities to work on shared sustainability problems	50%	47%	38%	45%
5	Co-location space for researchers from different disciplines	12%	15%	30%	19%
6	Recognition and reward for interdisciplinary research efforts	22%	32%	36%	30%
7	Interdisciplinary research training programmes	24%	8%	28%	20%

In addition to selecting from a preset list of supports that the institute could offer to enhance interdisciplinary research, the survey participants were asked the open question "*if you could recommend one action that the Institute could take to best facilitate interdisciplinary research, what action would that be*?". This open (free text) question enabled the capture of a more diverse range of viewpoints and is included here for that reason. The question responses were gathered and clustered into a number of broad categories as shown in Table 5. Whilst there was a good deal of variance between institutes in response to this question, seed funding and networking/convening initiatives again emerge as the most important means of facilitating interdisciplinary research in research institutes, followed by education and training, research proposal writing and facilitation, tenure and promotion, and deeper integration of humanities and social sciences. Some further detail on the responses are provided below.

Networking and convening initiatives: The responses on networking and convening encompass many suggestions around events for bringing affiliated faculty together. Suggestions include mini conferences and seminars, theme based brain-storm sessions, speed-networking events, lightning talks, TEDx like conference, week-long cross-disciplinary retreats and workshops, and problem-oriented working groups. The goal of these events can be just for faculty to get to know each other, but they can also have a tangible outcome such as writing a research proposal together or the production of a white paper. A number of suggestions focused on the importance of informal events such as parties, coffee mornings, meet-and-greets, and other social gatherings to build up trust and relationships between

faculty. There were also suggestions that institutes could focus on providing more information on the expertise and subject areas of affiliated researchers such as websites and databases. Rather than having what some called "*ineffective get-together events",* some faculty expressed a preference for the Institute to act as a match-maker or "*marriage broker*" trying to connect people whose research overlaps, identify researchers who would benefit from working with each other, and enable them to build their interdisciplinary "dream team" from the ground up.

Seed funding: The provision of seed grant funding programmes for interdisciplinary work was a very common response from survey participants particularly in the Earth Institute (65% of responses focused on seed funding). Participants expressed a concern that it is more difficult to find external funding for interdisciplinary work and that interdisciplinary research should be preferentially funded from internal sources. The three Institutes studied in this research already had comprehensive seed funding programmes in place and a significant part of the work of the institute was directed towards evaluating research proposals and dispersing seed funds. Most survey participants simply asked for increased amounts of seed funding, although some requested that current seed funding programmes be changed or reformed e.g. "*to transform research questions into longer-term projects*" or to "*directly fund interdisciplinary PhD programmes*". A number of participants expressed concern that some of the projects that received funding under current seed funding programmes were superficial or "*name-only*" interdisciplinary projects, so it may be important for institutes to carry out post-project evaluation of the interdisciplinary outcomes of funded projects.

Education and training: There were a variety of responses from Cornell Atkinson and Wrigley Institute around education and training as important actions that could be taken by the Institute. This included the provision of interdisciplinary courses and programmes for undergraduates and postgraduates which would provide an opportunity for faculty from across campus to work together, and potentially support future research collaborations. A number of the responses suggested the establishment of courses and workshops to help "*disciplinary-trained people to understand the changes that they would need to go through if they really wanted to conduct interdisciplinary research*" and to "*teach best practices for interdisciplinary research"*. These programmes would be aimed at both faculty, postdoctoral, and postgraduate students.

Supportive institute leadership: A vital element for interdisciplinary and transdisciplinary research within the institutes are enabling and supportive leadership, management and administration staff. Leadership and management play a key role in facilitating interdisciplinary collaboration including a regular convening of faculty from different departments through seminars, brown bags lunches, and funding calls; matchmaking; screening of research ideas and proposals to include additional disciplines; and using their experience to advise and guide new collaborations. Survey participants asked institutes to provide "*grant writers to help write large interdisciplinary proposals*" and a "*grant concierge*" to connect and "*bring teams together to pursue advertised interdisciplinary research proposals*" and enable "*brainstorming responses*". A related role which a number participants asked for was that of a facilitator "*to help teams work well across disciplines*" and provide skilled support on how to fully integrate disciplines. The need for facilitation supports for interdisciplinary work has been highlighted in a number of studies (Zuo and Zhao 2018; Lyall and Fletcher 2013) which have pointed out that having diverse faculty body and simply aggregating disciplines is not sufficient to foster more cohesive research collaborations; interdisciplinary research needs coordination and management to span disciplinary boundaries. It is vital that universities continue to invest in the staff and the leadership who can perform these functions.

Tenure and promotion: A number of affiliated faculty indicated that an important activity for the institutes to promote interdisciplinarity was action on tenure and promotion asking Institute leadership

to "*work with departments to modify promotion criteria*", "*raise profile and value of such research*", and "*figure out how to ensure that people are rewarded*" for interdisciplinary research in their home departments and to "*institutionalize and reward team science and interdisciplinary work*". Klein and Falk-Krzesinski (2017) and Dubrow *et al* (2009) provide a systematic and informed approach for how to recognize interdisciplinary and collaborative work in the promotion and tenure process.

A deeper integration of humanities and social sciences: A number of survey respondents in Cornell Atkinson and the Wrigley Institute indicated that a key action on promoting interdisciplinary research is to "*be more open to humanities collaborations*", "*more fully recognize the importance of the humanities in defining questions and generating sustainability research*" and avoid interdisciplinary engagement social sciences and humanities in an "*add-on manner*".

Table 5 Broad categories of responses of institute faculty om one action that the Institute could take to best facilitate interdisciplinary research (given as a percentage of faculty who responded).

	Cornell Atkinson (n=45)	Earth Institute (n=20)	Wrigley Institute (n=79)
Networking and convening initiatives	24%	15%	20%
Seed funding	29%	65%	18%
Education and training	11%	0%	16%
Research proposal writing and facilitation	11%	0%	11%
Tenure and promotion	2%	5%	10%
Deeper integration of humanities and social sciences	13%	0%	8%
Keep up the good work	4%	0%	4%
Increasing interdisciplinary research visibility	0%	10%	4%
Other	4%	5%	9%

CONCLUSION

This study underscores that research institutes and centers are key to a university's goals to deliver interdisciplinary research focused on societal problems. The investigation indicates that a very large proportion of faculty are engaging in interdisciplinary research, and are spending significant amounts of their research time working in interdisciplinary teams. Over 95% of affiliated faculty indicate that they are doing research with faculty outside their own discipline, and 50% of faculty are spending more than two-thirds of their time working with colleagues outside their own discipline. The survey results also suggest that a significant amount of faculty are engaging in long-distance interdisciplinary research with an average of 55% of the affiliated faculty indicating that they work across the natural-social sciences boundary which is seen as crucial for the sustainable management of ecosystems and resources, and for the design of more effective policies and interventions.

The study shows the vast majority of faculty perceive interdisciplinarity to be essential and necessary to properly address sustainability research questions and challenges. There was strong agreement across the three Institutes on the main motivations for engaging in interdisciplinary work *i.e*. the only way to address certain research questions, to cross fertilise ideas, and obtain new insights or perspectives.

The research institutes within the study are having a very positive influence on enabling interdisciplinary research within their universities and amongst their affiliated faculty, with almost all faculty agreeing that interdisciplinary research should be a core part of the mission and activities of the Institute. More than four out five faculty consider that the institutes had enabled greater opportunities to participate in interdisciplinary research than would have been possible in their home school and department and

would like to participate more frequently in interdisciplinary research efforts, approaches and teams within the Institute than they are doing now.

Whilst faculty can have a variety of motivations for participating in research centers and institutes, the study shows that access to interdisciplinary expertise within the institute, and the opportunity to engage in interdisciplinary research with members of that network are amongst the most important reasons. The level of faculty interest in interdisciplinary collaborative research is very encouraging for research institutes who are working to promote these type of collaborations. The vast majority of faculty across the three institutes perceive that support from the institute is either sometimes, usually or always important to their interdisciplinary research efforts and consider their research institute to play a valuable and supportive role in facilitating their research efforts.

A key question is how interdisciplinary collaborations can best be supported and enabled by the Institute. This study indicates that faculty perceive the important supports that the Institute can offer are to provide seed funding for interdisciplinary research projects, and to foster an open and visibly collaborative environment. It is very advantageous for an institute to be in a position to offer internal funding to seed interdisciplinary collaboration and faculty clearly see this as a clear benefit of being part of the Institute. Interdisciplinary research takes extra time and groundwork; seedcorn funding provides a necessary catalyst for bottom–up interdisciplinary projects to get off the ground. However it may be important that the Institute has clear pre- and post- evaluation methods for assessing the interdisciplinary nature of the funded projects to ensure that they are integrative and advance fundamental understanding beyond the scope of a single discipline; this could be done by using a framework proposed by Klein (2008).

The results suggest that there is a significant opportunity for research institutes to be innovative and creative about how can they bring faculty together to work collaboratively through networking and convening, education and training in interdisciplinary tools and techniques (for both students and faculty), mentoring and facilitation, and a deeper integration of social sciences and humanities. How this is done may vary from institute to institute, but as a starting point, faculty need to know who is in the institute and what their expertise is. The institute needs to provide multiple and varied opportunities for them to get together frequently to discuss shared research problems and to work together to provide outcome-oriented answers to research questions from the position of multiple disciplines. Forging synergies across disciplines is difficult and is a long-term endeavour and rarely happens spontaneously; effective interdisciplinary research has to be planned and continuously revisited. The exciting challenge for institute directors and management is to continue to provide location-specific responses to enable interdisciplinary research teams and projects that faculty perceive as being intellectually worthwhile, will have impactful outcomes, and will support their academic progression. Institutions may need to develop and mentor faculty to have the capability to develop teams of interdisciplinary researchers who can nurture interdisciplinary research capacity.

This study will be of particular interest to research institute leadership along with university management and administration responsible for overseeing research institutes, and tasked with increasing levels of interdisciplinary research within their universities. It provides evidence that research institutes are fulfilling their mission within universities to bring interdisciplinary teams together to work on relevant research questions. However the study is limited to three large US sustainability research institutes, and it may not be representative of smaller environmental research centers, units and clusters that engage in interdisciplinary research within the university system.

Future research could be focused on gaining a greater understanding through detailed qualitative research on how interdisciplinary teams are formed within institutes, whether the teams are

multidisciplinary or interdisciplinary, how they formulate shared research questions and overcome epistemological barriers, and ultimately whether the resulting research outputs have greater impact on the problems they are addressing than research from a single disciplinary perspective.

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Appendix

Table 6 Example of six responses from the survey and categorisation into (i) within discipline (ii) short distance and (iii) long distance classifications.

	Survey Responses			Categorisation
	Home discipline	*Area of research*	*Other disciplines collaborated with*	*Interdisciplinary distance*
1	Life sciences and ecology	Ecosystem ecology	Life sciences and ecology	Within
2	Engineering	Alternative fuels for combustion engines	Fluid mechanics, reacting flows, heat transfer	Within
3	Biological and Environmental Engineering	Sustainable energy and synthetic biology	Physics, microbiology	Short
4	Environmental Science	Groundwater microbiology	Public health and engineering	Short
5	Economics	Public Economics and Development Economics	Philosophy, Sociology, Physics	Long
6	Law School	Environmental law	Engineering, geology, economics, public policy	Long