Preparing for an interdisciplinary future: A perspective from early-career researchers☆

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ABSTRACT

Increasingly, research is moving towards more interdisciplinary endeavours. Effective collaboration between people from different disciplines is necessary to maximize the potential benefits of interdisciplinarity for future research activity. This paper analyses an approach to fostering the skills required for successful cross-disciplinary collaboration from the perspective of an interdisciplinary group of early-career researchers. Our reflection on how specially designed encounters can help to shape future interdisciplinary research initiatives draws on the discussion of a four-day workshop, a post-event survey, and a review of other experiences. We conclude that interdisciplinary encounters are an effective means to support the development of future interdisciplinary researchers, with a major advantage of this approach being the opportunity for open communication. Depending on the organiser's aim, we distinguish between "cultivation" and "development" encounters. Among the multiple factors that produce successful interdisciplinary encounters, we found that selection of a theme, participants and location need to be tailored to the encounter's particular objectives. We recommend that funding bodies and other members of the research community should take note of the effectiveness of encounters to foster interdisciplinarity and generate space to develop more innovative and high-impact research that delivers solutions to the challenges facing humanity in the future.

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1. Introduction

Interdisciplinary research and collaboration can provide substantial benefits to scientists, practitioners and policy makers [1–4] and it is predicted that the future of research is increasingly interdisciplinary [5]. A growing body of research in the futures field, and elsewhere, has described the characteristics and quandaries of interdisciplinary research, including the

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issue of evaluating its quality [5–8]. A particular area of interest has been the discussion about the various logics of interdisciplinarity [1], and its benefits, risks and challenges [9–15]. While this is an interesting debate, much less work has considered the crucial question of how to build interdisciplinary capacity, particularly from the perspective of early-career researchers. Nevertheless, a recently published future model of academia stressed the need to invest in the development of future researchers [16] and this is especially the case for the particular challenges of interdisciplinary research [17]. The focus of this paper is therefore on the training and development of early-career researchers to cope with the challenges of interdisciplinarity, avoid the risks and hopefully reap the benefits of the predicted future interdisciplinary research landscape.

Although there are no widely accepted definitions of interdisciplinarity, in this paper we agree with Hicks et al. [12] who define it as the 'production of research which crosses disciplinary boundaries'. Interdisciplinarity is not new, however; academic disciplines are flexible and have frequently been combined to form new disciplines to provide better answers to emerging questions. More recent is the collaboration between distant disciplines, for example between natural and social sciences. We could call this big interdisciplinarity, as opposed to small interdisciplinarity, which implies collaboration between similar disciplines [18]. Increasingly such collaboration does not only involve academics, but also policy makers and other stakeholders may be involved in a variety of ways. For example, stakeholders can help to co-define research problems and to develop models [19], but also actively participate in data collection and scientific experiments [20]. In analogy to other authors [21,22], in this paper we specifically refer to the term 'trans-disciplinarity' only when non-scientific knowledge is incorporated or non-academic actors are involved in the research process. When this aspect is less relevant for our discussion, we follow the above-mentioned definition by Hicks et al. [12]. With Petts et al. [14], we acknowledge, however, that interdisciplinarity is not a uniform approach to research, but instead covers a continuum of approaches.

While different rationales may exist to embark on interdisciplinary endeavours [1], a common view is to consider interdisciplinarity as a means to address complex problems that cannot be dealt with from a single disciplinary perspective alone. Such problems require people from different disciplinary perspectives to work together, sharing ideas, theories and practice to reach appropriate solutions. For interdisciplinary research to be effective in addressing these problems, therefore, the conditions must be created in which appropriate interactions can be fostered between researchers, including those at an early stage in their careers. The benefits and opportunities that interdisciplinary research creates for early-career researchers are several. Exposure to interdisciplinarity can help them to understand the wider impact of their research and their "home" discipline while also contributing to wider societal questions. Interdisciplinarity may also enhance their ability to ask innovative questions with wider impact. Exposure to interdisciplinary research can also have practical career benefits, since funding is becoming increasingly available in this area to assist in solving complex (societal) issues. Thus, fostering interdisciplinary thinking and exposing young researchers to people from different disciplines (creating networks) can help their career progression by increasing their potential to secure funding.

Adopting interdisciplinarity also carries risks, and the institutional structures within which early-career researchers have to develop may restrict the options available to them. Some of these risks relate to the difficulties of obtaining lectureship positions in an area without having studied that discipline at undergraduate level and the disadvantages of not having a mainstream disciplinary expertise at the time of competing for research grants. A main obstacle towards interdisciplinary research careers is therefore the fact that academia and reward systems are still largely organized along disciplinary divides [12]. Because interdisciplinary research may compromise an individual researcher's progress within her/his discipline, this obstacle may create a risk for young researchers with less-secure academic positions [23,24]. This obstacle can become prohibitive if their peers put a high value on disciplinary research output. In addition, interdisciplinary research entails learning from other disciplines, which requires time investment [5] and thus could limit research output in the start-up phase of such research.

Embarking on interdisciplinary collaboration is not restricted to a specific career stage. However, early-career researchers may be particularly motivated to engage in interdisciplinarity through their desire to contribute to societal benefits [3,24]. Because early-career researchers are at a formative stage of their research career [5,25], however, they may need structured induction to understand and evaluate the opportunities and risks before deciding to make an enduring commitment. Recent years have seen an increasing number of initiatives to foster interdisciplinary research, including more integrative graduate education [26], interdisciplinary workshops and research funding [for example, the new European funding scheme "Horizon 2020"; 27], and interdisciplinary training programmes and workshops [5,21,26]. However, we find that among the factors that explain their sometimes limited effects [28] the perspectives from early-career researchers themselves on the topic are largely lacking.

This paper provides a new viewpoint on fostering future interdisciplinarity capacity from the experience of a group of early-career researchers based in Europe who participated in an interdisciplinary encounter organized by the European Science Foundation in August 2012 (see Box 1). We discuss interdisciplinary encounters, defined as short (2–7 days), targeted meetings that have the aim of fostering interdisciplinary thinking, openness, and collaboration. We analyse the elements that make encounters an effective means to foster interdisciplinarity and suggest that, to overcome obstacles towards interdisciplinary research and reap its potential benefits, incentives are needed from within academic institutions, research organizations, and funding agencies [see also 23]. Our opinions are complemented by the views of other early-career researchers through a survey, undertaken after the summit, which was designed to provide viewpoints on how the other participants understood interdisciplinarity and its relevance to their research, their assessment of the encounter organization, and how they valued the experience gained. Additionally, this paper makes recommendations on the design of encounters for capacity building and calls upon funding bodies, and other members of the research community, to invest in this type of initiative to develop researchers ready for the demands of the interdisciplinary future of academia.

Box 1. European Science Foundation's Junior Summit ''Water: Unite and Divide''.

The European Science Foundation (ESF) is an intergovernmental science body composed of 72 member organizations that together represent European research and funding bodies, along with learned societies from more than 30 European countries. Between 26 and 31 August 2012, the ESF organized an interdisciplinary summit entitled ''*Water: Unite and Divide, interdisciplinary approaches for a sustainable future*'', for early-career researchers in Stresa, on Lake Maggiore in northern Italy. The summit sought to identify challenges and opportunities posed by interdisciplinary research, and to develop mutual understanding and respect across disciplines and methodologies. The selection of water as the encounter's central theme reflected its importance in many disciplines and the major challenges it presents in the world today, which require researchers from across disciplines to collaborate in an effort to find answers and solutions. A total of 34 early-career researchers (defined as those undertaking a doctorate or those working in academia up to 10 years after PhD completion but without holding a permanent position) were selected by ESF based on motivation and career achievement. Participants were based in 14 different European countries and originated from a much wider area both within and outside Europe. The disciplinary backgrounds of participants spanned a number of fields within the humanities (15%), life, earth and environmental sciences (54%), physical and engineering sciences (19%), and social sciences (39%). The median age of the participants was 28 and their career levels ranged from PhD students to researchers, with only 25% having more than 5 years of research experience. In addition, 11 leading interdisciplinary academics from 8 countries gave their views and experience in relation to the water theme and shared their experience in interdisciplinary research.
The format of the meeting involved thematic presentations of participants' research interspersed with lectures from senior researchers. Extended discussion among participants was encouraged through social activities and scheduled breakout sessions to share ideas, discuss presentations and research, and explore common interests.
The authors of this paper formed a ''writing group'' initiated by the ESF. Members of the writing group were chosen from a larger number of applicants based on motivation and to reflect as far as possible the range of backgrounds represented at the meeting. The stated goal of the group was to write an article based on the experience in Stresa. The group was free to choose its own direction and no specific guidelines or limitations were given regarding content. In addition a ''video group'' was formed to provide an audio–visual documentation of the Stresa summit [29].

2. Interdisciplinary encounters as a means to foster interdisciplinarity

Perceived barriers to individual researchers embarking on interdisciplinary research include the relatively poor career prospects, lower esteem from colleagues, discrimination by reviewers in proposals, and disproportionate difficulty in publishing in prestigious journals [15,30]. Therefore researchers with the potential and interest to work across disciplines may need additional encouragement and resources. Providing opportunities to bring people together physically can be an important means for encouraging cross-disciplinary research [31]. In this paper, we define an event, in which people from different disciplines are brought together with the aim of learning from, and interacting with each other as an "encounter".

One common goal of encounters is to promote open communication across researchers from different fields. Open communication implies listening to, being curious of, and understanding each other's perspectives and potential contributions to joint efforts. This communicative attitude has been referred to as "appreciative inquiry" [26]. Such communication can become complex when people come from different disciplinary backgrounds and do not share in their professional practice the same language and culture [28,32]. Indeed, communication has often proven to be a stumbling block in the formation of new collaborations among disciplines, due to differences in the framing of the 'problem' that a team intends to address, for instance [14,33]. Different disciplines use different terminologies and even a single word can have multiple meanings, leading to a feeling of frustration until the ambiguity is clarified [34]. Carefully examining what is meant through feedback questions and articulation of concepts is thus essential.

In our view, for effective interdisciplinary research to take place, individual researchers should be willing and able to translate their disciplinary perspective and methods into simple concepts, and be open to learn from others. This willingness and aptitude can generate a feeling of trust and respect between researchers, which is necessary for effective collaboration [14,32]. Given the opportunities they provide for face-to-face exchange, encounters can be considered as a particularly effective means of fostering this sort of effective communication.

In this paper, we discern two main types of encounters that we refer to as "cultivation" and "development" encounters. The cultivation type is designed for those embarking on or involved in interdisciplinary projects, and it has recently received attention in the interdisciplinarity literature [5,26]. An example of a cultivation encounter is a meeting designed to (1) expose researchers who are not yet involved in interdisciplinary projects to other disciplines, (2) help participants to understand what those disciplines have to offer, and (3) explore potential ways to work with them. In addition, such an encounter may provide a platform to share experiences of the benefits or obstacles of performing research that crosses disciplinary boundaries. Development encounters, on the other hand, bring people together to generate new ideas or initiate concrete outputs, such as a joint research proposal or position paper, and are a useful means of generating new interdisciplinary projects. This second type of encounter may also involve people from outside academia, for example to jointly frame a current 'real-world' problem of industry or society (following Section 1 we may therefore define this as a transdisciplinary encounter). Given the differences between these types of encounter, we believe it is important for organizers and attendees to be clear about the aims of an encounter.

According to our categorization, the Stresa summit (Box 1) can be seen as a cultivation encounter. However, given that the meeting included two additional initiatives, a *writing group* and a *video group*, to foster further collaboration by generating output documenting the meeting, the Stresa summit contains elements of what we see as a development encounter. Notably, no guidelines or limitations were given regarding content so each group needed to formulate their own ideas based on input from researchers with different disciplinary backgrounds. This highlights that the two categories of encounters form a continuum.

3. Practical design of successful interdisciplinary encounters

To achieve their objectives, interdisciplinary encounters should be appropriately designed and delivered. We believe this is an important factor that needs to be explicitly addressed in the literature, as many descriptions and evaluations of encounters neglect to evaluate the impact of such practical design considerations on the success of the event. To provide recommendations for future encounters, we therefore offer our viewpoint on successful encounter design based on our reading of the literature, our experience from the Stresa meeting (Box 1), and a survey among early-career participants from that meeting.

The survey undertaken after the summit included twenty-six questions submitted for online completion via SurveyMonkey®. Seven open questions were used to draw out the participants' background and 19 questions addressed how the participants evaluated the encounter on a Likert scale (the survey questions are available upon request from the corresponding author. We sent the survey to 29 of the 34 early-career participants (i.e., excluding the five authors of this paper), and 26 of those returned the survey. Where relevant, in this section, we provide data and responses from the survey.

3.1. Theme of the meeting

The first element we address here is the need for a theme or topical focus. This could be an area of research or high-level broad research challenge that can be approached from different disciplinary perspectives. For example, the Stresa meeting focused on the broad theme of fresh water, bringing together researchers who study water from a variety of disciplinary perspectives.

The necessity of a theme may depend upon the aim of an encounter. For cultivation encounters, a theme allows common issues and problems to be discussed. However, if the aim of the encounter is training and development of skills, a theme is perhaps not necessary, as the challenges of interdisciplinary research cut across disciplines and research themes. For example, the Masterclass approach described by Lyall and Meagher [5] incorporated researchers from a wide variety of backgrounds who successfully shared experiences and networked without a research theme.

For development encounters, a theme provides a focus and perhaps enhances the effectiveness and speed of generating tangible outputs. However, a theme could also restrict creativity by narrowing the scope and also reducing the sense of ownership of participants. Additionally, a narrowly defined theme might attract participants predominantly from a relatively small number of disciplines, thus possibly limiting an encounter to "small" interdisciplinarity [18]. The sandpit approach, a development type of encounter advocated by EPSRC (the United Kingdom's Engineering and Physical Sciences Research Council), is centred on a particular theme, often including specialists or end-users (e.g., policy makers or industry) to assist in defining research problems [35].

In contrast, the Scottish Crucible development programme [36], which brings together 30 Scottish-based early-career researchers from very different disciplines, to provide training and promote interdisciplinary working, operates without a theme with the aim of generating as innovative and wide-ranging a number of new project ideas as possible. The Crucible scheme in Scotland initially operated on a countrywide scale (Scottish Crucible) and has also spawned a similar institutional scheme (Heriot–Watt Crucible). These schemes incorporate both cultivation and development aspects, as well as aspects of transdisciplinarity, introducing participants to policymakers and industry. The main focus, however, is the development of new projects with a particular emphasis on "big" interdisciplinarity [18]; the organizers specifically aim to bring together a highly diverse range of participants from all disciplines, and the subsequent funding for new interdisciplinary projects is awarded to the most innovative and highly interdisciplinary ideas. Therefore, it would seem that for "big" interdisciplinary development encounters a theme could actually hinder the generation of highly novel and creative new projects.

In terms of transdisciplinarity, the focus that a theme provides could be essential to ensure the participation of non-academic stakeholders, as in the sandpits. Nonetheless, the recent Scottish Government "Projects for Scotland" one-day development encounter avoided a theme and brought together Crucible alumni to discuss problems presented by stakeholders from across the whole spectrum of policy areas. The success of this approach might only work for groups with previous experience of interdisciplinarity and development encounters, as well as some degree of existing relationship; i.e., the participants having already met on past Crucible events.

One advantage of a theme for both types of encounter is the common topical interest of the group, enabling relationships to be established more quickly. Another advantage is that a theme could help meeting organizers to select participants based on their relevant background and the relevance of the meeting theme to the participant's work. For example, bringing researchers together from around Europe, a focal theme can help to establish an interdisciplinary European research network on that theme. This could also be achieved at a global level, as proofs the recently organized Food Futures networking conference organized by the International Council for Science (and others) to define future research challenges

regarding future global food sustainability [37]. However, for university or even region-wide encounters, a closer geographical proximity could generate sufficient similarity for successful learning from others' experiences (taking into account cultural institutional differences) and network building.

With regard to the Stresa encounter, the survey results showed that all but one of the respondents agreed that focussing an encounter on a particular topic was an important factor. More generally, the survey revealed that the Stresa encounter was successful both in cultivating interdisciplinary skills and attitudes and in developing collaborations leading to concrete outputs. Ninety-six percent of respondents reported being more open towards involving other disciplines in their research, with 77% indicating that the meeting had improved their cross-disciplinary communication skills. Seventy-seven percent of respondents reported having been in contact with other participants since the meeting to discuss potential collaborations. There was also a high level of interest in future development encounters, with all but one of the respondents indicating they would like to attend future events focussed on generating concrete outputs, such as a research paper or proposal.

3.2. Size of gathering

Social psychologists have long recognized that group size is an important variable in any theory of group behaviour [38]. Stewart's meta-analysis of the impact of team size on performance for groups working on complex tasks in uncertain environments reported a positive correlation between increasing team size and improved performance [39]. The explanation is that larger groups achieve higher levels of performance due to access to greater resources, including expertise. However, looking specifically at interdisciplinary research, Rhoten [40] found that this effect reached a limit for project teams of greater than 50 researchers, at which point generation of interdisciplinary knowledge was less efficient than for smaller groups. Stokols et al. [41], in their comprehensive review of the factors determining the success of interdisciplinary team science initiatives, suggest that team size must be appropriate to task requirements and goals, which could apply equally well to encounters as task performance. The appropriate group size may therefore depend upon the aim of the encounter. For example, for a cultivation encounter, a larger group (e.g., 50) may be appropriate, whereas smaller groups (e.g., 15–20) might be better suited to the generation and development of new ideas and outputs. Additionally, it is difficult to isolate the impact of group size, as group dynamics is also influenced by, and influences, many other factors. For example, depending on the time available for the encounter, different group sizes may be appropriate, allowing sufficient time for all group members to interact and possibly build sub-groups.

From the literature, and our own experiences, between 20 and 35 participants appears to be a common number of participants for encounters aimed at early-career researchers (e.g., Stresa, sandpits, Crucible, Food Futures, all discussed in Section 3.1). This number is in most cases complemented by five to 15 more experienced researchers, although these are not necessarily all present for the full duration of the meeting, but may serve as keynote speakers or mentors. Although, based on our discussion, this number can be considered good for networking and idea generation, practical reasons (e.g., costs, available funding, accommodation space) are most likely another key reason for selecting this number. The choice of number of participants is often not justified in the literature studies of these encounters.

The Stresa survey indicated that 92% agreed that the number of participants was right for this encounter. From comments during the meeting we also learned that many Stresa participants considered the number of people taking part in the meeting to be appropriate, i.e., small enough to feel intimate, and providing sufficient opportunity to interact with everyone given the length of the encounter (see also Section 3.7).

3.3. Background of participants

The background of encounter participants is another important factor. Significant diversity in background, culture and discipline might require a longer time for the group to develop relationships. Stokols et al. [41] report that, although teams in which members share similar demographic and educational characteristics are more socially cohesive, there is no evidence that homogeneous teams perform better than heterogeneous ones. For encounters, the advantage of very heterogeneous groups is the incorporation of sufficient diversity to enable optimal interdisciplinary interaction. This is particularly important for development encounters, where the aim is to generate new interdisciplinary research ideas. However, as heterogeneous teams are likely to take longer to build relationships, time should be devoted to developing relationships and trust within the encounter [32]. Additionally, incorporating some homogeneity—e.g., inviting participants from a certain university or country, those at a similar career stage or those interested in a particular research theme—might assist with relationship building.

As mentioned in Section 3.1, the Crucible schemes aim to maximize the diversity of participants to ensure "big" interdisciplinarity and highly novel ideas. This is also a key feature of the sandpit-type encounters. In an article about the sandpit psychology, the organizational psychologist Bharat Maldé recognized that gender and cultural diversity were crucial to the success of a sandpit [42]. Both these types of encounters are more focused on development and therefore the degree of openness and interest of participants in interdisciplinary working were selection criteria in the application process. In cultivation encounters, the experience with interdisciplinary research may be less critical, but in the cases known to us, a willingness of the participants to engage in interdisciplinarity should exist or at least should appear from, for example, the applicant's motivation letter.

A final aspect relating to the background of participants is whether persons outside academia are invited to participate in the encounters, i.e., making these more transdisciplinary events. In cultivation encounters, the role of, for example, policy-makers

and industry could be to raise awareness of real-world problems and the need for solutions that cross disciplinary boundaries. However, societal stakeholders themselves (such as policy makers) are more likely to be motivated to attend development encounters, e.g., sandpits, where joint tangible outcomes can be generated that also delivers benefit to them. One further example of such an encounter is the Maths in Industry workshops (http://mathsinindustry.com/), where industrial end-users present a problem on the first day of a five-day residential workshop before returning on day 5 to hear the progress made towards a solution. The advantage of this approach is the limited time requirement for end-users, thus increasing the likelihood and ability of industry to engage with this type of transdisciplinary developmental encounter. We note, however, that the notion of end-users and the more limited involvement may not reflect the fully integrative nature of transdisciplinarity as some studies define it. Hence, organizers of encounters should not only consider *whether* persons from outside academia should be involved, but also carefully think about *how* they should be involved.

In the Stresa encounter, the size was large enough to incorporate significant diversity in background, culture and discipline, bringing together many different perspectives. The survey indicated that all respondents thought the disciplinary diversity of participants was sufficiently broad. Nobody commented on the absence of potential end-users or stakeholders. However, as the Stresa encounter had more of a cultivation focus, this lack of transdisciplinarity was perhaps less of a problem than it might be in other types of development encounters.

3.4. Career stage of participants

A relevant question is at what stage of their career should scholars and researchers attend interdisciplinary encounters. While other literature has considered interdisciplinary exposure and experiences at different career stages [23,24,43,44], we found that little published work has focused on encounters as a mechanism to foster interdisciplinary research at different career stages.

Encounters allow for the exchange of research outputs, plans, and visions. PhD students benefit from interdisciplinary encounters through training in cross-disciplinary communication, and a broadening of their perspectives beyond the often narrow and highly specialized doctorate. Several authors argue that such broadening should, although most often does not, already start at the undergraduate level [17,45,46]. An additional advantage for PhD students of broadening their perspectives, besides better placing their work in context, is that this can inform decisions about future career directions at a stage where it is comparatively easy to change field. Cultivation encounters may thus provide substantial benefit to PhD students, and can constitute an essential element in the training of future researchers [31].

Post-doctoral early-career researchers face pressure to bring in funding and publish academic papers in order to secure permanent positions. As for PhD students, cultivation encounters offer the opportunity to place their work in a larger perspective and define future collaborations and lines of research. Additionally, the networking opportunities offered by such encounters are a useful way for early-career researchers to build confidence in both their own research and in developing working relationships across disciplinary borders.

However, at the post-doctoral stage, cultivation encounters could be complemented by development encounters focused on generating new output, especially projects that lead to long-standing collaboration between researchers from different disciplines. This would help early-career researchers to secure funding and develop wider networks. Crucible participation, for instance, is restricted to early-career researchers and several participants consider that the experience was key to the success of their research careers and critical in securing future funding (personal communication). Sandpit organizers, on the other hand, encourage participation from researchers at all career stages, but note that the attitudes and approach of early-career researchers make them particularly successful participants [42].

Senior researchers may also benefit from interdisciplinary encounters. One example might be new motivation and interest sparked by the possibility of exploring new fields, or new application areas for their research approaches. Like early-career researchers, senior academics are likely to be interested in funding opportunities to cement relationships and deliver interdisciplinary work. Consequently, development encounters with this type of incentive might work well. Finally, encounters at this level allow for leading academics to discuss the future research agenda, feeding recommendations into funding bodies and policy makers.

Overall, it would appear that cultivation encounters are more suited to early-career stages, with development encounters best for more senior researchers. However, regardless of career stage, a researcher's previous exposure to interdisciplinarity might impact upon the choice of appropriate encounter [41]. Those new to interdisciplinarity, at all levels of academia, would benefit from cultivation of ideas, concepts and skills related to interdisciplinarity, and exposure to other disciplines. This is in agreement with Lyall and Meagher [5], who found that researchers at all career stages benefited from reflecting on the process of undertaking interdisciplinary work. It is also consistent with the selection criteria of the more development-focused encounters (e.g., Crucible and sandpits), where the attitude towards, and experience of, interdisciplinarity is considered critical to successful participation.

Another question regarding career stage and encounters is whether participants should all be of a similar career stage or not. Encounters at a similar career stage allow participants to share their common experiences. For example, PhD students could discuss supervision and their experiences in obtaining supervision from various supervisors with different disciplines. Likewise, early-career researchers may discuss the challenges of obtaining a permanent position, publication requirements, and barriers related to cross-disciplinary collaboration. Nonetheless, mixed encounters could enrich this interaction, allowing participants to learn from more senior attendees, which is particularly valued by early-career researchers [47].

A further advantage of mixed encounters is the establishment of contacts that might help PhD students to obtain their first postdoctoral position, early-career researchers to build networks, and senior researchers to identify qualified and motivated candidates to join their research team. With regard to sandpits, the choice of a mixed encounter is justified by an attempt to maximize diversity to "boost the richness of thinking around a topic" [42].

One disadvantage of mixed-career stage encounters is that differences in the existing skills and interests of researchers at different career stages could present a challenge in designing and delivering an encounter suitable for all attendees. For example, experienced interdisciplinary senior academics might not benefit greatly from a cultivation encounter that is highly focussed on training and skills development and, equally, a PhD student might find a development encounter aimed at generating research proposals unsuitable. This illustrates the importance of clearly communicating the aims of the encounter to potential participants to ensure they select appropriate encounters to attend.

The survey results indicate that 85% of respondents were opposed to the idea of restricting participation to those from one career stage. One explanation for this finding could be that participants at the Stresa meeting commented that a valuable aspect of the summit was the opportunity to interact with senior academics. The survey results show that a major benefit of encounters is the chance to learn from more experienced colleagues, and that this opportunity is particularly valued by early-career researchers.

3.5. Location of meeting

Bringing people together in one physical location is an important part of an encounter [31]. One reason for this is that face-to-face contact has been shown to be essential in establishing trust between people [32,48]. The role of the environment in which the encounter takes place is important in establishing effective interdisciplinary interaction. Levels of interdisciplinary collaboration have been positively linked to the team members' rating of their physical environment [41,49]. Research has identified several important environmental factors, namely the provision of quiet, comfortable meeting places containing adequate materials to support discussions, and in which privacy and accessibility can be controlled [41]. These studies have mainly focused on interdisciplinary projects rather than encounters, though the above requirement for meeting spaces could equally well apply to development encounters, allowing for people to break out into small groups to discuss potential ideas.

Place attachment is the affective bond that people establish with specific areas, where they prefer to remain and where they feel comfortable and safe [50]. Changing location and stepping out of this "comfort zone" has been linked with enhanced creativity [51], an essential element for defining new interdisciplinary research. In itself, interdisciplinarity can often be considered a step outside of the comfort zone of one's discipline through engagement with new disciplines. Discussions with some of the Stresa delegates during the meeting confirmed that they found that attending an encounter in an unfamiliar and inspiring location promoted relationship building and creativity. The role of place in inspiring communication and creativity was also identified from the survey, with 92% of respondents agreeing this was an important element of the encounter. The same opinion was heard among participants of the Food Futures networking conference (personal communication). Additionally, we believe that a neutral environment where nobody has a strong place attachment stimulates the building of new relationships between people.

3.6. Programme structure

An important element of programme design is that of the programme structure in terms of activities. There is little work in the literature to support an evaluation of this element, though studies by Lyall et al. [25], Lyall and Meagher [5] and Graybill et al. [26] do analyse some of these elements. In the masterclass approach adopted by Lyall and Meagher [5], the activities were focused on informal group discussions based around readings or fictional scenarios, aimed at sharing experiences. The PhD training programme reported by Graybill et al. [26] involves both cultivation elements, comprising seminars, coursework and facilitated workshops, and a development aspect in which small groups work on a joint paper. The Stresa event incorporated a mixture of lectures with open discussion sessions, short presentations from all participants, breakout discussion groups, and output-related activities such as the writing and video groups.

Appreciative inquiry (see Section 2) was identified by Graybill et al. [26] as a critical personal attitude required for successful interdisciplinary engagement. This attitude can be practiced with dialogue-based approaches; while this can be as simple as a conversation between researchers from different disciplines, when aiming at synthesizing viewpoints and understanding within larger groups, more structured approaches and facilitation become important [52]. One option for this could be the use of a model-based approach, where participants use a model (or product or vision) to stimulate interaction and arrive at shared understanding [52]. This last approach may be particularly useful for development encounters, including those of the transdisciplinary type that involve societal stakeholders, to arrive at a common problem understanding. In our view, cultivation encounters should have substantial time in the programme to train and foster the attitude of appreciative inquiry amongst participants by explaining its notion, using simple one-to-one dialogues, and exploring more structured synthesis approaches.

Besides fostering appreciative inquiry, literature suggests that attention to the process of collaboration and communication is a critical part of developing interdisciplinary skills. Critical reflection on this process can be achieved

in a variety of ways, such as facilitated workshops [26], group discussions around scenarios [5], or sharing experiences through lectures and informal chats (as in Stresa). For instance, the short (10-min) presentations by the early-career researchers at Stresa provided a good way to expose participants to a wide variety of different disciplines while simultaneously offering them practical experience in improving their ability to communicate with a highly diverse audience. Which elements to incorporate in the programme largely depends on the specific aims of the encounter. In cultivation encounters, lectures and seminars from senior academics can expose participants to other disciplines, thus creating conditions to understand and respect what they can offer. Seminars that were particularly valued in Stresa were those where senior academics shared personal experiences, both positive and negative, on interdisciplinary collaboration. More in-depth appreciation of the presenter's discipline and her/his experiences was obtained during the significant time (30–45 min) allocated after each lecture for discussion, which was positively evaluated by all Stresa participants. A focus on practicing with and sharing experiences on collaboration processes thus seems a relevant element of cultivation encounters; development encounters should equally take time to consider how the collaboration process develops over the course of the encounter (and after), and not merely focus on the concrete output in the form of papers or proposals.

Successful encounters do not simply take place when physically putting motivated and qualified participants together. The same is true for interdisciplinary research programmes; they require inspiring leadership and pro-active management [31]. In analogy, encounters require facilitation by one, or several, persons that strongly identify with the encounter's aim, communicate this in an inspirational way, and effectively work with the participants towards achieving that aim. Particularly for cultivation encounters, this requires building in frequent reflection moments by the facilitator, during which the programme elements of the encounter are put in perspective of the aim. Also for certain development encounters, for instance in the case of the sandpits, the role of facilitators is considered essential to maintain focus and maximize creativity [53]. However, the Maths in Industry workshop events are often more informal; perhaps here the precise definition of the problem by end-users at the start of the meeting facilitates this type of approach. Based on our experiences, we strongly support the notion that a good facilitator is essential to deliver a successful encounter.

Informal, unstructured time is an important part of an encounter, with 92% of respondents agreeing that this time within the Stresa encounter was a useful means of exchanging ideas and building relationships. In particular, participants felt that the interactions over coffee and dinner promoted more confidential discussions between all participants and facilitated communication with senior academics. As described in Section 2, developing trust is an important element in cross-disciplinary communication; both the length of the meeting and the social time promoted the development of trust between participants.

From the above discussion, we conclude that specific attention to appreciative inquiry, reflection on the process of collaboration, effective facilitation, and inclusion of informal, unstructured time for relationship building is key to deliver successful encounters.

3.7. Length of the encounter

The final element we consider is the length of an encounter. Important factors that impact upon the appropriate length are the type of encounter, the specific aims and, crucially, the number and background of people attending, which links to the time required for relationship and network building. Longer time will evidently be required to deliver the concrete outputs sought in development encounters. We see the development encounter as a way to bring people together to stimulate ideas which will be further developed after the encounter.

In general, Stresa participants reported satisfaction with a four-day encounter, though there was some interest in a longer event. One of those in favour of a four-day encounter justified this opinion as a balance of enabling sufficient time for relationship building while recognizing the effort and energy required from delegates. This encounter was longer than the masterclasses described by Lyall and Meagher [5] or the training encounters described by Graybill et al. [26]. However, the PhD programme reported by Graybill et al. [26] was a series of encounters throughout the duration of a PhD. Stresa participants were opposed to a series of shorter encounters. Such a series is perhaps more suitable for the type of training Graybill et al. [26] describe, applicable to people normally working in close proximity. This could be within the same institution (Graybill, Heriot–Watt Crucible) or within a relatively small geographical area (Scottish Crucible). An advantage of a series of shorter encounters is the opportunity to continue building relationships between events and the potentially increased diversity of participants, as those who work part-time or with external commitments might find it easier to commit to a series of shorter sessions than to a whole week away.

Other encounters are of a similar length to Stresa, including the sandpits and Maths in Industry workshops, and the international Food Futures networking conference. In the UK, in response to the 2002 *Roberts Review* [54], academic institutions conduct research skills development trainings (three-day residential 'encounters') in which participants develop career-oriented transferable skills for research [55].

We find that, based on these experiences, no golden rule exists for encounter length, but that approximately three to five days is standard for encounters that bring together people from a larger geographical area. Financial considerations of the funder and possibilities for leaving day-to-day activities for all participants likely play an important role in defining the length. If organizers need to adhere to a pre-defined length, we recommend that the encounter aims, as well as other elements of the practical design discussed in Section 3, are properly tuned with this length.

4. Conclusions

This paper started from the premise that a tendency exists for research and research funding to increasingly cross disciplinary borders. Part of the rationale for this trend is the societal demand on science to come up with better and more relevant answers to face present-day problems [4]. While not entering the debate regarding the reasons for researchers to embark on interdisciplinary endeavours in depth, we noted that other rationales exist [1]. What is relevant here is that the research landscape is changing, and can be expected to change further towards more interdisciplinary focus in the future. Given the challenges involved in interdisciplinary research, we identified the need to support and prepare early-career researchers for this gradual transformation of the playing field of science. We focussed on one particular way to achieve this, i.e., through bringing people from different disciplines together for a limited number of days in what we define here as an 'encounter', organized with the aim of learning from, and interacting with each other.

Although there are other ways to foster interdisciplinarity, in our view interdisciplinary encounters are particularly effective in helping researchers to build a research network, exposing them to new perspectives and ideas, and providing them with practical experience of cross-disciplinary communication. In addition, time away from day-to-day, often more disciplinary, work activities helps to provide a space to reflect on personal research directions. This view is shared by an increasing number of institutional, national, and international institutions and agencies, judging from the increasing number of such encounters that have been organized over the last decade.

A major advantage of interdisciplinary encounters is the opportunity they provide for open communication. Effective interaction and collaboration between disciplines relies on openness and communication between individuals [34]. To successfully embark on interdisciplinarity, individuals should have a curious and inquiring mind, and be willing to incorporate perspectives from other disciplines. We do not suggest that interdisciplinarity be restricted to a select group of skilled communicators, but rather highlight the importance of creating space for exchange and development of communication skills through mechanisms such as encounters.

In this paper, we have provided a critical evaluation of interdisciplinary encounters, taking the ESF summit in Stresa as a main example. Our focus was particularly on the practical organization of such encounters, an aspect that is not much highlighted in existing literature. In particular, we recommend effective facilitation, inclusion of informal, social time and inviting participants from a range of backgrounds and career stages. Other factors depend more upon the aims of the encounter and we believe that it is critical that the aims of the encounter are clearly defined, communicated to potential participants, and reflected in the participant selection criteria. We hope and believe that our discussion may guide organizers of current and future interdisciplinary encounters, by critically contemplating their choices regarding the objectives and the programme design of the encounter. In this way, our intention is to contribute to making future encounters more effective, thus better enabling researchers to work across disciplines and improving future interdisciplinary collaboration.

A main distinction that we make is between cultivation and development encounters. Cultivation encounters aim at creating awareness of what interdisciplinarity can offer and the challenges involved, whereas development encounters bring people together to generate new ideas or initiate concrete outputs. While encounters could combine elements of both, it is useful for organizers to carefully consider the aims of the encounter in the light of this distinction.

Funding bodies and other members of the research community that have not yet done so, should take note of the effectiveness of encounters to foster interdisciplinarity and generate space to develop more innovative and high-impact research that delivers solutions to the challenges facing humanity in the future. To achieve this, research funding schemes promoting interdisciplinary research in thematic areas are fundamental. To generate highly novel and innovative proposals, and encourage participation from early-career researchers, we suggest that such schemes consider an approach involving pre-proposal encounters that bring together researchers from different disciplines to explore potential project ideas. The recent call for community building projects on food security and land use change published by the Belmont Forum as well as the EPSRC sandpits serve as examples. This approach will be especially valuable for early-career researchers with a less well-established network of contacts, particularly from outside their disciplinary specialism. Based on the positive response of participants in the Stresa encounter and the opportunities for collaboration it generated, we believe that careful consideration should be given to ensuring adequate funding for such initiatives in the future to support early-career researchers to successfully contribute to the future interdisciplinary research landscape.

Acknowledgements

References

[1] A. Barry, G. Born, G. Weszkalnys, Logics of interdisciplinarity, Economy and Society 37 (2008) 20–49.

[2] B. Bozeman, P.C. Boardman, Managing the New Multipurpose, Multidiscipline University Research Centers: Institutional Innovation in the Academic Community, IBM Center for the Business of Government, Arlington, VA, 2003p. 55.

[3] R. Frodeman, Introduction, in: R. Frodeman, J.T. Klein, C. Mitcham (Eds.), The Oxford Handbook of Interdisciplinarity, Oxford University Press, New York, 2010, pp. xxix–xxxix.

[4] H. Nowotny, P. Scott, M. Gibbons, 'Mode 2' revisited: the new production of knowledge – introduction, Minerva 41 (2003) 179–194.

[5] C. Lyall, L.R. Meagher, A Masterclass in interdisciplinarity: research into practice in training the next generation of interdisciplinary researchers, Futures 44 (2012) 608–617.

[6] A.L. Carew, F. Wickson, The TD wheel: a heuristic to shape, support and evaluate transdisciplinary research, Futures 42 (2010) 1146–1155.

[7] J. Robinson, Being undisciplined: transgressions and intersections in academia and beyond, Futures 40 (2008) 70–86.

[8] F. Wickson, A.L. Carew, A.W. Russell, Transdisciplinary research: characteristics, quandaries and quality, Futures 38 (2006) 1046–1059.

[9] G.D. Brewer, The challenges of interdisciplinarity, Policy Sciences 32 (1999) 327–337.

[10] B.C.K. Choi, A.W.P. Pak, Multidisciplinarity, interdisciplinarity and transdisciplinarity in health research, services, education and policy: 1. Definitions, objectives, and evidence of effectiveness, Clinical and Investigative Medicine 29 (2006) 351–364.

[11] L.K. Hessels, H. van Lente, Re-thinking new knowledge production: a literature review and a research agenda, Research Policy 37 (2008) 740–760.

[12] C.C. Hicks, C. Fitzsimmons, N.V.C. Polunin, Interdisciplinarity in the environmental sciences: barriers and frontiers, Environmental Conservation 37 (2010) 464–477.

[13] L. Lau, M.W. Pasquini, Meeting grounds: perceiving and defining interdisciplinarity across the arts, social sciences and sciences, Interdisciplinary Science Reviews 29 (2004) 49–64.

[14] J. Petts, S. Owens, H. Bulkeley, Crossing boundaries: interdisciplinarity in the context of urban environments, Geoforum 39 (2008) 593–601.

[15] I. Rafols, L. Leydesdorff, A. O'Hare, P. Nightingale, A. Stirling, How journal rankings can suppress interdisciplinary research: a comparison between innovation studies and business & management, Research Policy 41 (2012) 1262–1282.

[16] E. Blass, A. Jasman, S. Shelley, Postgraduate research students: you are the future of the academy, Futures 44 (2012) 166–173.

[17] H. Newing, Interdisciplinary training in environmental conservation: definitions, progress and future directions, Environmental Conservation 37 (2010) 410–418.

[18] F. Morillo, M. Bordons, I. Gomez, Interdisciplinarity in science: a tentative typology of disciplines and research areas, Journal of the American Society for Information Science and Technology 54 (2003) 1237–1249.

[19] A. Voinov, F. Bousquet, Modelling with stakeholders, Environmental Modelling & Software 25 (2010) 1268–1281.

[20] R. Bonney, C.B. Cooper, J. Dickinson, S. Kelling, T. Phillips, K.V. Rosenberg, J. Shirk, Citizen science: a developing tool for expanding science knowledge and scientific literacy, Bioscience 59 (2009) 977–984.

[21] P. Holm, M.E. Goodsite, S. Cloetingh, M. Agnoletti, B. Moldan, D.J. Lang, R. Leemans, J.O. Moeller, M. Pardo Buendía, W. Pohl, R.W. Scholz, A. Sors, B. Vanheusden, K. Yusoff, R. Zondervan, Collaboration between the natural, social and human sciences in global change research, Environmental Science and Policy 28 (2013) 25–35.

[22] T. Jahn, M. Bergmann, F. Keil, Transdisciplinarity between mainstreaming and marginalization, Ecological Economics 79 (2012) 1–10.

[23] P. Blackmore, C.B. Kandiko, Interdisciplinarity within an academic career, Research in Post-Compulsory Education 16 (2011) 123–134.

[24] D. Rhoten, A. Parker, Risks and rewards of an interdisciplinary research path, Science 306 (2004) 2046.

[25] C. Lyall, A. Bruce, W. Marsden, L. Meagher, Identifying Key Success Factors in the Quest for Interdisciplinarity Knowledge, University of Edinburgh, Edinburgh, UK, 2011p. 49.

[26] J.K. Graybill, S. Dooling, V. Shandas, J. Withey, A. Greve, G.L. Simon, A rough guide to interdisciplinarity: graduate student perspectives, Bioscience 56 (2006) 757–763.

[27] European Commission, Proposal for a Council Decision on Establishing the Specific Programme Implementing Horizon 2020 – The Framework Programme for Research and Innovation (2014–2020), Brussels, Belgium, (2011), p. 128.

[28] A. Bruce, C. Lyall, J. Tait, R. Williams, Interdisciplinary integration in Europe: the case of the fifth framework programme, Futures 36 (2004) 457–470.

[29] European Science Foundation, ESF Junior Summit Water: Unite and Divide, 2013 (accessed 16.08.13) www.esf.org/water.

[30] C. Lyall, I. Fletcher, Experiments in interdisciplinary capacity-building: the successes and challenges of large-scale interdisciplinary investments, Science and Public Policy 40 (2013) 1–7.

[31] C. Lyall, A. Bruce, W. Marsden, L. Meagher, The role of funding agencies in creating interdisciplinary knowledge, Science and Public Policy 40 (2013) 62–71.

[32] L.J. Bracken, E.A. Oughton, 'What do you mean?' The importance of language in developing interdisciplinary research, Transactions of the Institute of British Geographers 31 (2006) 371–382.

[33] M.B. Mayhew, X. Guo, S.B. Haase, A.J. Hartemink, Close encounters of the collaborative kind, Computer 45 (2012) 24–30.

[34] M. Marzano, D.N. Carss, S. Bell, Working to make interdisciplinarity work: investing in communication and interpersonal relationships, Journal of Agricultural Economics 57 (2006) 185–197.

[35] J. Giles, Sandpit initiative digs deep to bring disciplines together, Nature 427 (2004) 187.

[36] Scottish Crucible, 2013 (accessed 16.08.13) http://www.hw.ac.uk/scottishcrucible/.

[37] M.G. Rivera-Ferre, L. Pereira, T. Karpouzoglou, K.A. Nicholas, S. Onzere, W. Waterlander, F. Mahomoodally, A. Vrieling, F.D. Babalola, C.C. Ummenhofer, S. Kusch, A. Dogra, A. de Conti, S. Baldermann, C. Evoh, A vision for trans-disciplinarity in Future Earth: perspectives from young scientists, Journal of Agriculture, Food Systems, and Community Development (2013) (in press).

[38] E.J. Thomas, C.F. Fink, Effects of group-size, Psychological Bulletin 60 (1963) 371–384.

[39] G.L. Stewart, A meta-analytic review of relationships between team design features and team performance, Journal of Management 32 (2006) 29–55.

[40] D. Rhoten, A Multi-Method Analysis of the Social and Technical Conditions for Interdisciplinary Collaboration, The Hybrid Vigor Institute, San Francisco, CA, 2003p. 56.

[41] D. Stokols, S. Misra, R.P. Moser, K.L. Hall, B.K. Taylor, The ecology of team science – understanding contextual influences on transdisciplinary collaboration, American Journal of Preventive Medicine 35 (2008) S96–S115.

[42] B. Maldé, Sandpit psychology, 2013 (accessed 15.08.13) http://www.epsrc.ac.uk/funding/routes/network/ideas/Pages/SandpitPsychology.aspx.

[43] V. Castán Broto, M. Gislason, M.-H. Ehlers, Practising interdisciplinarity in the interplay between disciplines: experiences of established researchers, Environmental Science & Policy 12 (2009) 922–933.

[44] S.G. Clark, M.M. Steen-Adams, S. Pfirman, R.L. Wallace, Professional development of interdisciplinary environmental scholars, Journal of Environmental Studies and Sciences 1 (2011) 99–113.

[45] J.L. Innes, Multidisciplinarity, interdisciplinarity and training in forestry and forest research, Forestry Chronicle 81 (2005) 324–329.

[46] K.C. Ewel, Natural resource management: the need for interdisciplinary collaboration, Ecosystems 4 (2001) 716–722.

[47] K.A. Stamatakis, W.E. Norton, S.W. Stirman, C. Melvin, R.C. Brownson, Developing the next generation of dissemination and implementation researchers: insights from initial trainees, Implementation Science 8 (2013).

[48] G.M. Olson, J.S. Olson, Distance matters, Human–Computer Interaction 15 (2000) 139–178.

[49] D. Vinokur-Kaplan, Treatment teams that work (and those that don't): an application of Hackman's group effectiveness model to interdisciplinary teams in psychiatric hospitals, Journal of Applied Behavioral Science 31 (1995) 303–327.

[50] B. Hernandez, M.C. Hidalgo, M.E. Salazar-Laplace, S. Hess, Place attachment and place identity in natives and non-natives, Journal of Environmental Psychology 27 (2007) 310–319.

[51] G. Drake, 'This place gives me space': place and creativity in the creative industries, Geoforum 34 (2003) 511–524.

[52] G. Bammer, Disciplining Interdisciplinarity: Integration and Implementation Sciences for Researching Complex Real-World Problems, ANU E Press, Canberra, Australia, 2013.

[53] EPSRC, More about sandpits, 2013 (accessed 16.08.13) http://www.epsrc.ac.uk/funding/routes/network/ideas/Pages/moresandpits.aspx.

[54] G. Roberts, SET for Success: The Supply of People with Science, Technology, Engineering and Mathematics Skills, Royal Society of Chemistry, London, 2002

[55] E. Alpay, E. Walsh, A skills perception inventory for evaluating postgraduate transferable skills development, Assessment & Evaluation in Higher Education 33 (2008) 581–598.