AVANT, Vol. XIII, No. 1
ISSN: 2082-6710 avant.edu.pl/en
DOI: 10.26913/ava202206

# Three Problems of Interdisciplinarity

**Yvan I. Russell**
Middlesex University London
*yvanrussell@gmail.com*

Received 16 March 2022; accepted 17 June 2022; published 9 August 2022.

**Abstract**

Interdisciplinarity is widely promulgated as beneficial to science and society. However, there are three quite serious problems which can limit the success of any interdisciplinary research collaboration. The first problem is expertise (it takes years of effort to cultivate a deep knowledge of even one discipline). The second problem is comprehensi-bility (experts in different disciplines do not reliably understand each other). The third problem is service (in a given interdisciplinary endeavour, it often occurs that one discipline benefits and the other discipline does not benefit). This essay is an elaboration of these three problems. Parallels are drawn between translation between languages and translation between disciplines.

**Keywords**: interdisciplinary; collaboration; research; expertise; academia

## 1. Introduction

Imagine reading a sentence where the first half was written in English—*und die andere Hälfte wäre auf Deutsch geschrieben* ("and the other half was written in German"). Who can understand the full sentence? A monolingual English or monolingual German (with no translator) will understand only half. I begin this essay with a simile: "mixing disciplines is like mixing languages". Think of immigrants whose native language is different from the main language of their new home (Grimstad et al., 2014). A two-language sentence needs both speaker and audience to understand both languages. Grimstad et al. (2014) made a linguistic study of Norwegian-Americans, highlighting numerous examples of mixed-language communication (MLC). One example is the phrase "field-a" which means "the field" (English word "field" + Norwegian suffix "-a"). In that community, English words were being inserted into a Norwegian grammatical structure (Grimstad et al., 2014). In the word "field-a", Norwegian is dominant because the underlying grammatical structure is Norwegian. English is just adding a word. One could flip it around and make English dominant. Imagine the phrase "I love *Norge*" ("I love Norway"). Here, the Norwegian word ("Norge") is being inserted into an English grammatical structure ("I love [word]"). How thoroughly can you mix two languages together? Let us think back to our opening sentence ("Imagine reading a sentence…"). It was half-English and half-German. One can argue that English and German were not really mixed at all. The English part had no German and the German part had no English. Instead, a point of contact was found in the middle of the sentence where both halves could attach. To an English-German bilingual, the sentence was meaningful despite the awkwardness.

I also provided the example of Norwegian-American MLC, where a Norwegian grammatical structure incorporated some English words (Grimstad et al., 2014). Here, the word "field" inside "field-a" is not English anymore. It is now a loanword (originally English, now Norwegian). English loanwords do not alter the underlying grammatical structure of Norwegian. Linguists have a name for the type of language-change found in Norwegian-American MLC. It is called "late-insertion exoskeletal theory" (Grimstad et al., 2014). Norwegian provides the exoskeleton and English words are inserted therein. Let us take this "late-insertion exoskeletal theory" idea and apply it to *interdisciplinary research* (IDR). One discipline provides the exoskeleton and the other discipline provides the "insertion." Here, the mixing between disciplines is minimal. Mixing more thoroughly is tricky. Just as there are very real barriers between languages, there are very real barriers between disciplines. In this essay, I use language as an extended metaphor to highlight three problems of interdisciplinarity. Throughout, I refer to the speakers of language (not to academic linguists) and compare language speakers to the practitioners of science.

Interdisciplinarity is widely promulgated as a positive goal in academia (see Brown, 2020; Frodeman, 2014; Grüne-Yanoff, 2016; Huutoniemi et al., 2010; Jacobs & Frickel, 2009; Khilji, 2014; MacLeod, 2018; Porter & Rafols, 2009). In one of the earliest papers on the subject, Darden and Maull (1977) described the purpose of interdisciplinarity: "To answer questions which, although they arise within a field, cannot be answered using the concepts and techniques of that field alone" (Darden & Maull 1977, p. 59). Their statement is still broadly valid today. What arises out of interdisciplinarity needs to be "a value-added contribution" (Khilji, 2014, p. 5). Science is full of interdisciplinary success stories. For example, Hazen (2012), in describing one of his research projects, wrote: "we employed an electron microprobe… a machine familiar to mineralogists but rarely used by paleontologists" (p. 244). Even taken out of context, the above quote clearly demonstrates how successful interdisciplinarity is often just one discipline lending its tools to another (here the word "tools" could refer to many different things, whether an actual physical device, an analytical technique, or a set of concepts, cf. Huutoniemi et al., 2010; Klein, 2017; MacLeod, 2018; Schmidt, 2008). However, my goal in this essay is to dwell upon three barriers to success in interdisciplinary collaborations. The first is the problem of *expertise*. Scientific expertise, like language fluency, takes years to cultivate. The second problem is *comprehensibility*. Due to interdisciplinary differences, miscommunication is inevitable. The third problem is *service*. Which discipline is being served? When an IDR project is implemented (especially a funded project where collaborators are duty-bound to work together), the goal of the research project is to ultimately produce a benefit (e.g. peer-reviewed publications). My contention is one discipline usually benefits over the other.

What is interdisciplinarity? That is a deep question, which has been explored by numerous authors (e.g., Andersen, 2016; Aram, 2004; Cooke et al., 2020; Frodeman, 2014; Grüne-Yanoff, 2016; Huutoniemi et al., 2010; Jacobs & Frickel, 2009; Klein, 2008, 2017; Khilji, 2014; MacLeod, 2018; Mäki, 2016; Schmidt, 2008; Sugimoto & Weingart, 2015). Table 1 is my non-systematic sampling of definitions of "interdisciplinary" from the literature. As shown in table 1, the definitions are brain-meltingly heterogeneous. One can see that some papers provide an easily quotable definition (e.g., Mäki, 2016). Other papers provide a quantitative measure (e.g., Yegros-Yegros et al., 2015). Still others took a typological approach (e.g., Huutoniemi et al., 2010; Klein, 2017), providing a catalogue of myriad existing definitions. Furthermore, there are useful related terms (cross-disciplinary, monodisciplinary, multidisciplinary, transdisciplinary, etc.) which I will not discuss here (but see Huutoniemi et al., 2010; Klein, 2017; Pan & Katrenko, 2015, etc.). Despite the heterogeneity shown in Table 1, there are a number of common themes apparent in Table 1. This set of themes can be ring-fenced arguably well by the workmanlike definition provided by Pan and Katrenko (2015). They defined IDR as "research [that] integrates separate disciplinary data, methods, tools, concepts, and theories in order to create a holistic view or common understanding of a complex problem" (p. 11).

**Table 1: Sample of fourteen papers from the interdisciplinarity literature**

| *Paper* | *Summary* | *Definition of interdisciplinarity* |
|---|---|---|
| Darden and Maull (1977) | Discussion of "interfield theories," with historical examples (e.g. how cytology helped genetics by locating the gene). | Shared problems between fields, where one field fills gaps left open by another field. |
| Fuller (1991) | Discussion of how disciplinary boun-daries emerge, in part due to how each discipline writes about its own history. | Bounded disciplines result from need to form institutions; no specific definition of interdisciplinarity. |

| | | |
|---|---|---|
| Aram (2004) | Attempt to define interdisciplinarity by interviewing faculty directors. Identified four types of interdisciplinary scholar. | Core dimensions are "knowledge" and "action" —what we learn and how it is practiced/applied. |
| Klein (2008) | Proposed a framework of 7 principles for evaluating IDR, on the assumption that disciplines vary widely in multiple ways. | "…generative processes of harvesting, capitalizing, and leveraging multiple kinds of expertise" (p. S116). |
| Schmidt (2008) | Detailed philosophical examination of the various definitions of interdisciplinarity. Provides new classification schemes. | "…an integration instrument in order to relate various patchworks of disciplinary knowledge" (p. 56). |
| Jacobs and Frickel (2009) | Sociological review of interdisciplinarity as a policy, assessing the feasibility of IDR in current organisational structures. | Solves what disciplines cannot solve alone, despite epistemic and administrative barriers. |
| Porter and Rafols (2009) | Study of the disciplinary diversity of published papers in six fields, based on a network analysis of citations made, etc. | "…should be based on the content of the research outcome"; (p. 722); "…multidimensional…" (p. 729). |
| Huutoniemi et al. (2010) | Developed a set of indicators for the categorisation of interdisciplinarity, to analyse the content of IDR proposals. | "…interaction among different bodies of knowledge or research practice" (p. 81). |
| Kahn (2011) | Critique of academic culture where IDR is encouraged, but institutional and cultural barriers cause difficulties for researchers. | Used biological classification (e.g. species, genus, etc.) as a metaphor for distance between disciplines. |
| Yegros-Yegros et al. (2015) | Study of citation impact of IDR research, finding that greater interdisciplinarity does not lead to being cited more often. | Operationalised as the disciplinary diversity of papers in the reference lists of papers. |
| Andersen (2016) | Analysis of the dynamics of scientific collaborations which allow IDR, focusing on the cognitive resources of scientists. | Disciplines are domains of shared expertise; IDR is interlocking expertise between collaborators. |
| Grüne-Yanoff (2016) | Argued that IDR successful even when it does not change the nature of disciplines involved (historical examples provided). | "… is a regulative ideal" (p. 343); "…describes non-actual states… worthy to be realized" (p. 344). |

| | | |
|---|---|---|
| Mäki (2016) | Provided a long list of talking points as an organisational framework for developing a "philosophy of interdisciplinarity." | "…whatever relevant relationship between two or more scientific disciplines or their parts" (p. 329). |
| MacLeod (2018) | Argued that failures of interdisciplinarity are attributable to collaborators not truly understanding each other ("opacity"). | Emphasised domain specificity of disciplinary expertise; IDR needs to overcome cognitive barriers. |

I am not an expert in interdisciplinarity, nor am I a professional philosopher. However, I am a cognitive scientist with a highly interdisciplinary research profile (Gana et al., 2022; Phelps et al., 2018; Phelps & Russell, 2015; Robertson & Russell, 2016; Russell et al. 2008, 2016, 2020; Russell, 2011; Russell & Gobet, 2012, 2013; Russell & Phelps, 2013, etc.). I am not trying to compete with the philosophers of interdisciplinarity (e.g. the deep and thorough analysis of MacLeod, 2018, amongst many others). I have not written about interdisciplinarity before — but I have lived it. "Lived experience" is a legitimate source of information in research, as seen in studies such as that conducted by Bullock and Bunce (2020) where they did research on the UK prison system by speaking to prisoners themselves (rather than speaking to academic criminologists). Research on "lived experience" has even been used for the study of interdisciplinarity, where non-philosophy academics have been interviewed for their views (e.g. Aram, 2004; Cooke et al., 2020; Leigh & Brown, 2021). Thus, here, I humbly offer my own perspective (written by someone who loves interdisciplinarity, but who has found himself in some difficult, even acrimonious, situations that arose out of misunderstandings between disciplines).

## 2. The problem of expertise

As an academic, I have developed expertise in my chosen disciplines. Although I don't have a precise definition in my head of the word "discipline" (cf. Sugimoto & Weingart, 2015), I feel that a given academic discipline matches the description of a "community" (cf. Bessant, 2018; MacLeod, 2018). Newly-published papers within a disciplinary community are passed around, debated, challenged, emulated, cited, and remembered. Disciplines have their own conferences, their own journals, their own cultures (and the list goes on). The disciplines outside my community are like foreign countries. Interdisciplinarity can be thought as a "focus outward, away from a group of peers" (Frodeman, 2014 p. 36). What happens when I travel outside my discipline? For example, I am not a food scientist, but I might choose to read Tharanathan et al. (2006), a food science paper about the *mango fruit*. Let me quote some interesting facts about mangoes:

> The mango tree is erect, 30 to 70 ft (10–40 m) high, an arborescent, evergreen with symmetrical, round and broad canopy, or more upright with a relatively slender crown. Its color varies between green through yellow to red. The tree is long-lived and mature specimens can survive for more than one hundred years. (Tharanathan et al. 2006, p. 98)

The above is a pleasant read, but—as a non-expert in that discipline—I could never have written a food science paper myself. When reading the paper, I learned numerous interesting facts ("who knew that mango trees were so tall?"). I evaluated the whole paper only through the filter of my non-expert eye. I cannot claim to have expertly understood the more technical paragraphs (such as Tharanathan et al. 2006, pp. 109-113). Although the paper was written in English, the whole paper is only partly comprehensible to me. I am happy to agree with the authors when they called the mango the "King of Fruits" (Tharanathan et al. 2006, pp. 95, 96)—but I am far less confident in evaluating their paper in most other respects. I could never have peer-reviewed their manuscript (obviously, the journal would never have invited me). Beyond that, if I were interested in becoming a food scientist, qualified to peer-review that paper, then I would need to *re-educate*, undergoing (at bare minimum) many years of postgraduate study (Feldon, 2015). In terms of evaluation, I can only make some general inferences. For example, I know that the paper likely underwent a rigorous peer review. I can look up the impact factor of the journal, how many citations that paper has, and the CVs of the authors. Yet, I know virtually nothing about the history of food science, the ongoing debates in that discipline, the major schools of thought, the names of the most famous food scientists, etc. Nor do I have the expertise to accurately distinguish between appropriate and inappropriate methodology in food science. All of that knowledge would take *years to absorb*.

For me, reading Tharanathan et al. (2006) was like "going on holiday" in a foreign-to-me discipline. Compare this to "going on holiday" for real. Much as I enjoyed visiting Paris for a weekend, I will never be French. When reading a guidebook about Paris, I learned numerous interesting facts ("who knew that the Eiffel Tower was so tall?"). I evaluated the whole city only through the filter of my non-expert eye (I am mostly distracted by beautiful architecture, nice cafés, museums, etc.). I cannot claim to expertly understand the city. Even though I have access to English-language guidebooks, the whole city is only partly comprehensible to me. I am happy to agree with the authors of a guidebook when they wrote that "Paris is a seductive destination at any time of year" (Tracanelli, 2016, p. 17)—but I am far less confident in evaluating the city in most other respects. I could never have been employed by a major publisher to write a travel book on Paris. I lack deep knowledge of Parisian history, politics, and culture; nor do I have the expertise to determine the veracity of most statements about Parisian history, politics, and culture. All of that knowledge would take *years to absorb*.

Adopting the principles of intellectual humility (e.g. Tanesini, 2018), I need to remember that my expertise is *bounded*. Outside that boundary, there are vast territories in which I am not expert. Reading the literature outside the boundaries might be somewhat recreational and even pleasurable, but there is a certain usefulness in discovering fascina-ting linkages between different worlds of knowledge and then being able to incorporate these new links into one's published output (I have done it myself, e.g. in Russell & Gobet, 2013, where I cited from a wide range of disciplines). An author may (justifiably or not) decide to venture into a discipline in which they are not expert. That author might spend multiple hours reading papers in that discipline and then incorporate that knowledge into a manuscript. That author might even manage to summarise the information accurately. However, it is not the same time investment as that of real expertise. That is why an expert's expertise can sometimes be surprisingly narrow. An expert chess player, for example, is good at chess, but research shows that expertise does not automatically transfer to non-chess domains (e.g. Sala & Gobet, 2017). There is a considerable time investment required to cultivate expertise in any domain (Ericsson, 2006; Gobet & Chassy, 2009; Gobet, 2016), the classic example being the many years of effort required to become a chess grandmaster (Campitelli & Gobet, 2008). Revisiting our language analogy, we can think about how learning a language (particularly a second language) requires considerable time investment in order to attain fluency (Jackson & Kaplan, 1999). As a parallel, we can also think about how putting in years of persistent effort is also necessary to become an expert *scientific* researcher within a given discipline (Andersen, 2016; Feldon, 2016). Shallow expertise may sometimes be acceptable—such as in the context of introductory-level teaching (Newell, 2007)—but here I specifically refer to expertise as it enables IDR success. The "mango / Paris" parallels drawn above may seem a bit whimsical, but it was intended as an illustrative walk-through to reinforce a serious message about IDR. If I had a serious desire to write a legitimate paper on food science in the very near future, then I'm perhaps delusional to imagine that I can do it wholly on my own. Instead, it would be much wiser to find a collaborator who is an actual food scientist. Then, the challenge is not to equal the expertise level of that collaborator, but to at least learn *just enough* to be able to work with that person (cf. Andersen, 2016)—analogous to knowing *just enough* German to converse with someone who knows *just enough* English.

## 3. The problem of comprehensibility

> Scientific disagreement is all too often a product of talking past each other or a failure to recognise where the language used in related disciplines diverges. (Brown, 2020, p. 6)

Just as two people who speak dissimilar languages can fail to understand each other, academic experts in dissimilar disciplines can fail to understand each other (cf. MacLeod, 2018, pp. 707-711). In the case of language, incomprehension can range from the obvious to the hidden. It is obvious when somebody asks "how do you say…?" However, it is possible for misunderstandings to stay indefinitely cloaked. For example, an English speaker learning German could mistakenly use the word "also" (pronounced "alzo") intending the English meaning (which means "in addition to")—not realising that in German, the word has a different meaning (it means "therefore)". If uncorrected, the misguided English speaker may continue to wrongly use the word "also," transmitting a different message from that which was intended. This would be a misunderstanding due to cross-language "polysemy" (where there are multiple meanings assignable to the same word). Cross-*disciplinary* polysemy can occur, too. For example, Bunch (2014) reviewed a misunderstanding surrounding the word "perimortem". One can deduce the meaning of "perimortem" etymologically:

> This amalgam of Greek (peri) and Latin (mortem) root words translates to "all around, about, near, enclosing, surrounding" [peri] and "death" [mortem]. (Bunch, 2014, p. 1041)

The layperson meaning inferred in the quote above (e.g. "during the death process") is employed relatively rarely (Bunch, 2014). In science, there are narrower technical meanings. In forensic anthropology, "perimortem" has been used in the analysis of skeletal remains. It refers to evidence of bone trauma that is presumed to have occurred during the death process (e.g. a bone fracture in a long-dead skeleton is perimortem if the injury is judged *not* to have occurred before death or after death). But in medicine, the word is used *not* in the context of death—but in *birth*. A perimortem birth occurs when a baby is born "at or during the time of death of the mother" (Bunch, 2014, p. 1042, italics removed). That is a radically different meaning from that in forensic anthropology. Hence, we have polysemy between disciplines, where "perimortem" is a homonym. The homonym sets the stage for the misunderstandings to occur. What if a forensic anthropologist and medical scientist collaborate? Will they preclude a semantic misunderstanding by sitting down and discussing the semantics of the word "perimortem"? It seems unlikely (unless there is an incident that forces that conversation to occur).

Beyond a single word, we can think of broader misunderstandings—such as polysemy surrounding a whole *concept*. Think of the many ways, for example, that the concept of "culture" is defined and operationalised across different disciplines (Cobley, 2008). In each discipline, a given word or concept has its own semantic baggage. It may have connotations, implications, and ramifications that are not obvious to a novice. In the *other* discipline, that very same word or concept might have *different* connotations, implications, and ramifications (also not obvious to a novice). Thus, the word (e.g. "perimortem") or concept (e.g. "culture") is a homonym. To avoid cases of cloaked misunderstanding, the ideal IDR scientist should be expert in *both* discipline X and discipline Y. Furthermore, that double-discipline-expert should be a proficient "discipline-translator"—someone who can function as an intermediary. It is also important to think about the everyday *hiddenness* of expertise. Look at the face of any given expert. That person has a world of knowledge hidden away inside the brain. Even if that expert is delivering a lecture, the students in the lecture hall witness only a tiny slice of that expert's expertise at any given moment. Such hiddenness makes it far too easy to underestimate the expertise of an observed person—and far too easy to underestimate how many years of effort was required to attain that expertise. In other words, we look at an expert and form an impression—but in reality there are large gaps in our knowledge about that expert's expertise. We fill in the gaps with our own assumptions.

I have described misunderstanding over a single word ("perimortem") to hint at misunderstandings on much larger issues. Every discipline has its own multifaceted culture. All of those facets are subject to misapprehension. Collaborators across disciplines may not realise how much they differ in their preferred types of methodology and analysis, venues of publication, theoretical goals, etc. (MacLeod, 2018). As Newell (2007) said, "every discipline makes a number of assumptions, many of them tacit" (p. 256). Experts from different disciplines might converse with each other in literally the same language (e.g. English)—but may be "speaking a different language" when communicating on a scientific level.

## 4. The Problem of Service

As mentioned earlier, Grimstad et al. (2014) referred to the model of "late-insertion exoskeletal theory" to describe how Norwegian immigrants in America incorporate English words into their Norwegian grammar. Who benefits from this "insertion"? If one regards a loanword (such as "field") as an *asset*, then the benefit goes to Norwegian (or, to be precise, to Norwegian-American MLC). The English language gains nothing and loses nothing. The billions of English speakers in the world carry on speaking English, oblivious to the very existence of Norwegian-American MLC. How does this "loanword" story apply to interdisciplinarity? Thinking again of "late-insertion exoskeletal theory" (Grimstad et al., 2014), the "exoskeleton" is the academic discipline and the "insertion" is the bit from another discipline. That cross-disciplinary insertion might be small (e.g. a loanword or "loan-concept") or something more substantial (such as a methodological technique). To explore the problem of "service," this section will review eight published academic papers. The first four papers are from various disciplines in which I am not expert (Fraknoi, 2007; Murray, 2015; Wade et al., 2019; Hamet & Tremblay, 2017). I chose them simply because they are interesting. The final four papers on the list were chosen simply because they are mine (Phelps et al., 2018; Russell et al. 2008, 2016; Russell, 2011). For all eight papers, I arrive at a decision about which discipline benefits. The first paper is a musical example.

Fraknoi (2007) combined music, astronomy, and education in a paper that summarises the use of astronomically-themed music to help educate school-age children and teenagers about astronomy. He lists the various approaches that teachers take to incorporate music into their astronomy classes. His appendices provide an extensive list of songs with educational content (as well as identifying to which theme in astronomy the song relates to—for example, the song “Cygnus X-1” by Rush is about the scientific discovery of a black hole). In terms of which discipline benefits, the Fraknoi (2007) paper will mostly help school teachers who teach astronomy. Therefore, education is the beneficiary of this study. The only possible benefit to the field of astronomy is indirect (e.g. if astronomy lessons inspire a student to pursue a career in astronomy).

In our second example, Murray (2015) reviewed the study of rock art and its relation to astronomy. There are many examples of ancient/prehistoric painting, seen in caves and elsewhere, depicting images of the night sky. Although it is difficult to determine even an approximate date on prehistoric rock art, it is undeniably some indicator of “the very beginnings of celestial observation” (Murray, 2015, p. 240). The study of astronomical rock art is clearly a benefit to archaeology (which attempts to understand peoples of the past)—but it does not seem to benefit the modern science of astronomy at all. Hand painted star maps lack the precision needed for an astronomer to use them as an actual star map (even if some constellations are recognisable).

In our third example, Wade et al. (2019) combined medicine and Egyptology, providing a case study of the medical imaging of an Egyptian mummy aged 2,500-2,700 years old. It was not the report of a newly-discovered mummy. It was a re-analysis of mummified remains that had been analyzed ten years prior in an earlier publication. Wade et al. (2019) reported on how the assessment has changed due to advancements in the field (for example, in the previous analysis, the mummy was judged to have died at 25-35 years old; in the new analysis, 35-55 years old). The authors emphasised the interdisciplinarity of their study. An Egyptologist can enlist the help of a medical pathologist to diagnose a mummy’s cause of death—but the average medical pathologist (with no Egyptological expertise) should not be presumed expert in assessing a mummified corpse (where the internal organs are highly distorted and shrunken). It is easy to see the benefit Wade et al. (2019) had to Egyptology (we have learned something new about mummification) but it is difficult to see the benefit of this paper to the general discipline of medicine (which aims to treat living humans).

Fourth, I look at Hamet and Tremblay (2017) in their review of artificial intelligence (AI) in medicine. They highlight numerous examples where AI can perform tasks which are difficult for humans to perform. Four examples are: (1) computation of DNA variants to identify risk factors for disease; (2) extracting relevant patterns from medical records during diagnosis (e.g. family histories or predispositions to disease); (3) the invention of psychotherapeutic “avatars” (with “emotional intelligence”) to help manage pain and emotional disturbances in children; (4) nanorobots that help to guide drugs inserted into the body to reach their intended destination within the body. Clearly, these engineering feats are beneficial to more than one field. With every new innovation, there is an advance *both* in medicine and computer engineering.

The above four papers illustrate an asymmetry of “service” in IDR. In three of four papers (Fraknoi, 2007; Murray, 2015; Wade et al., 2019), it seems that only one discipline benefits from the research. The fourth paper (Hamet & Tremblay, 2017) is the only one whose benefits appear to flow towards more than one discipline. The following four papers are my own. First, Russell et al. (2008) was a combination of comparative psychology (human-animal comparisons) and behavioural economics—where the methodology in a comparative psychology study was inspired by results in behavioural economics on humans. The discipline-benefit of the Russell et al. (2008) paper was wholly to comparative psychology (not to human behavioural economics). Second, Russell (2011) was a combination of archaeology and cognitive psychology. The research questions of the study came from “cognitive archaeology” (which analyses prehistoric material to study of how the mind evolved). However, the paradigm was inspired by classic cognitive psychology paradigms. Here, the discipline-benefit was wholly to cognitive archaeology (not to cognitive psychology). Third, Russell et al. (2016) was a combination of cognitive psychology and cultural anthropology (in the sub-discipline called the “cognitive science of religion)”. This paper adopted a classic experimental paradigm from cognitive psychology (the “Tower of Hanoi” game, or TOH), and then using the results of the study to make inferences about religion. Here, the discipline-benefit was mainly to the cognitive science of religion (only of minor interest to cognitive psychology). Fourthly, Phelps et al. (2018) was a combination of computer science and primatology (an observational study of chimpanzee social behaviour). As authors, we were a mix of primatology and computer science. The latter introduced analytical techniques foreign to primatology, creating a highly atypical type of analysis. Here, the discipline-benefit was wholly to primatology (not to computer science). To summarise, my four papers were all interdisciplinary but highly asymmetrical in which disciplines were serviced.

Above, we can see that 87.5% (7/8$^{th}$) of the papers were asymmetrical. Obviously, this is a tiny and biased sample, but I conjecture that this approximate result should apply more generally. My impression of IDR is that, in a given piece of research, one discipline takes all the benefit and the other discipline simply provides an "insertion". Is this a problem? Some might regard the asymmetry of service as a *normal* feature of IDR (not something to worry about). Asymmetry might even be desirable (e.g. when discipline X lends it tools to discipline Y to solve a specific problem that only exists in discipline Y). However, there might also be some danger to the careers of some collaborators involved in an IDR project. Asymmetry of service can lead to sub-optimal career outcomes for those scientists who participate in a research project but whose discipline-benefit from that project is low. This can deprive a collaborator of an opportunity to publish a paper valued in their discipline.

## 5. How to succeed?

> Interdisciplinarity sometimes seems synonymous with the idea that researchers will somehow learn to work in more fluid open-ended problem-solving environments without adhering to disciplinary problem-solving recipes and norms. (MacLeod, 2018, p. 714)

As the above author described, these idealistic goals can fail to be reached due to incompatibilities between disciplines (cf. Andersen, 2016; Freeth & Vilsmaier, 2019). World-class expertise in one discipline does not necessarily transfer to another discipline. Successful collaborations rely on more than bringing together intelligent people (Andersen, 2016; Freeth & Vilsmaier, 2019; MacLeod, 2018). One should consider differences in *discipline-culture* too (see Newell 2007, pp. 255-257). The predominant worldview within a discipline can differ markedly from that of another. Hazen (2012) provided an example in the field of research that investigates the origin of life on Earth:

> In origins-of-life research (and probably in most other disciples as well), scientists gravitate to models that highlight their personal scientific specialty. Organic chemist Stanley Miller and his cohorts saw life's origins as essentially a problem in organic chemistry. Geochemists, by contrast, have tended to focus on more intricate origins scenarios involving such variables as temperature and pressure and chemically complex rocks. Experts in membrane-forming lipid molecules promote the "lipid world," while molecular biologists who study DNA and RNA view the "RNA world" as the model to beat. Specialists who study viruses, or metabolism, or clays, or the deep biosphere have their idiosyncratic prejudices as well. We all do it; we all focus on what we know best, and we see the world through that lens. (Hazen 2012, p. 138)

In the best case, a diversity of those lenses, working together, might yield a solution to a particular problem. Open and effective communication is crucial to success (Freeth & Vilsmaier, 2019).

One approach to learning about how to communicate interdisciplinarily is to study examples of how communication has failed in past IDR collaborations

(Keestra, 2017). For example, MacLeod (2018), as an outside observer to a real-life IDR project, described one such failure: the story of what went wrong within a large interdisciplinary project. One of them was a research collaboration between a group of economists and ecologists. A conclusion of his study was that there were severe barriers between the disciplines. One thing he observed was that the economists were more *theory-driven* (interested in creating theoretical models) whereas the ecologists were more *data-driven* (interested in looking for causal relationships in the data and less interested in ascertaining whether the data fit theoretical models). In other words, the economists wanted to achieve *one* set of goals and the ecologists wanted to achieve a *different* set of goals. The two sets of goals were incompatible (we might consider such a difference of goals as a "cultural difference" between the disciplines). In the research project, problems ensued which could not simply be overcome by each side learning the technical details of the other group's discipline. I was not a member of the project that MacLeod (2018) studied. However, his narrative brought back some powerful memories for me. It reminded me of the large IDR project in which I was a postdoctoral research fellow years ago (I've deliberately chosen not to name names). In that project, there was a great deal of personal acrimony between some of the senior figures in the project. Years later, upon reflection, I realized that the conflicts stemmed from a deep incompatibility inherent in the way that the intellectual goals of members from one discipline were considerably different from the intellectual goals of members from another discipline. In that situation, people in that project were seemingly highly unlikely to acknowledge that cultural differences were the root cause of the discord. Instead, the other side was just "wrong". However, the very earliest meetings in that ill-fated project were brimming with conviviality, significant mutual admiration between esteemed experts, and enthusiastic discussion around a grand, overarching, mission statement. In a project such as this, a broad research aim is easily proclaimed (e.g. a group of enthusiastic geologists might herald: "let's solve the riddle of life's origin!") but the collaborations are trickier in the actual process (Keestra, 2017; Freeth & Vilsmaier, 2019; MacLeod, 2018). Admittedly, competition is a normal feature of academia (Carson et al., 2013), but the problem that I am highlighting is the unnecessary fracturing of a team. Macleod (2018) described such dysfunction this way: "Lack of understanding of each other's methods leads to fragile trust relationships that can break down when requests cannot be understood or interpreted as productive or warran-ted" (p. 707).

Who benefited from the collaboration studied by MacLeod (2018)? My conjecture (based on parallel experiences in my own career) is that one of the groups emerged as *dominant* (able to control the agenda — perhaps by pushing project resources towards their own ends). Let me outlay the general problem in simple bullet points:

1. Groups A and B form an interdisciplinary collaboration.

2. Group A is from discipline X
3. Group B is from discipline Y
4. The career goals of A are to benefit X
5. The career goals of B are to benefit Y

Such conditions encourage conditions that appear to be a zero-sum game, where most of the benefit flows to *either* discipline X *or* discipline Y (but not both). Will things be any better if the interdisciplinary team can find a "third way"? Let us imagine a third way where A and B can work together and facilitate the creation of "Ж" (pronounced "zhe")—a melding of discipline X and discipline Y (i.e. transdisciplinary). Who will benefit? In a perfect world, Ж becomes a new discipline, generating Ж-publications that benefit X, Y, and Ж. In reality, this melding will likely not happen—for two reasons.

The first reason is that it's exceedingly difficult. For all collaborators—group-A-experts and group-B-experts—transfiguring into Ж-experts is hard work. Becoming a Ж-expert would entail a partial *unlearning* of one's own discipline (Keestra, 2017). Group-A-experts would need to disown parts of their A-expertise and assimilate parts of B-expertise. Group-B-experts would need to disown parts of their B-expertise and assimilate parts of A-expertise. Unfortunately, the time frames of funded research projects are often far too short to allow for such thoroughgoing re-education. Within this constraint, A-experts can, at best, reach the level of *B*-novice. B-experts can, at best, reach the level of *A-novice*. Novice is better than beginner, but it falls short of expert. It is unrealistic to expect that an established scientist can pupate into another kind of scientist within a too-short time frame (cf. MacLeod, 2018, pp. 703-705). If we think of a time-constrained funded project with an A-group and a B-group, operating with finite resources, the path of least resistance is for opposing camps to *compete* with each other—creating an asymmetry of service (one discipline wins and the other loses). The second reason for Ж-failure is that, even if Ж were successfully attained, it might be an unloved offspring. Looking back at our language analogy, we can say that a worst-case scenario of accomplishing Ж would be like awkwardly mixing two languages together (as in our first sentence of this essay, "Imagine reading a sentence…"). Alternately, a *best*-case scenario of accomplishing Ж would be akin to producing an artificial new language (such as Esperanto). In best and worst cases, the audience for the work is limited (receptive communities are small or even tiny). Accordingly, recent research has shown that, in terms of scientific impact (number of citations in the literature), the more heterodox (highly interdisciplinary) a paper is, the less scientific impact it has (Pan & Katrenko, 2015; Yegros-Yegros et al., 2015). As Frodeman (2014) wrote: "Part of the definition of a discipline is that there is an agreed upon means for evaluating work" (p. 39) (cf. MacLeod, 2018, pp. 711-714) A heterodox paper may be too outside the comfort zone of "agreed upon means."

Some philosophers (e.g. Grüne-Yanoff, 2016) have made the point that interdisciplinary success does not require that a new discipline needs to emerge at all. Given the difficulties of Ж, this is a compelling argument. Staying in one's own silo has at least the benefit of the stability of that silo. The alternative — too much heterodoxy — has its own particular dangers. Imagine if two scientists work together, but know little of each other's disciplines. The expert user of electron microprobes, for example, has a different set of cognitive resources than the collaborator from another discipline (cf. Andersen, 2016). That scientist has the expertise to use the machine and interpret its output. What if that scientist makes a serious blunder in his analysis? His non-expert collaborator may not catch the error. It should not be presumed safe just because experts are sitting together in the same room (Keestra, 2017). The collaborators (even if highly expert in their own domains) might, at worst, be simply "going on holiday" in each other's disciplines. Freeth and Vilsmaier (2019) proposed a system of managing IDR collaborations through a recognition of *researcher positionality*. This is an acknowledgement that a given collaborator in a project has a unique set of skills, opinions, and competencies, and should be managed accordingly. Imagine my following scenario with an imaginary "expertise scale":

1. Scientists A, B, and C form an interdisciplinary collaboration.
2. There is an expertise scale where 1.0 is maximum expertise and 0.0 is no expertise at all.
3. Scientist A has 0.9 expertise in discipline X (and minimal expertise in discipline Y).
4. Scientist B has 0.9 expertise in discipline Y (and minimal expertise in discipline X).
5. Scientist C has 0.4 expertise in discipline X and 0.4 expertise in discipline Y.
6. Scientist C (the interdisciplinary "translator") has enough expertise to facilitate comprehension between scientists A and B.

As shown, scientist C lacks high expertise. Yet, scientist C is more expert than A in discipline Y and more expert than B in discipline X. To be useful, scientist C should at least reach some adequate extent of usefulness. Scientist C could be the linchpin, occupying a position of *betweenness*. "Betweenness" is a measure taken from social network analysis (Freeman, 1977): it is a quantification of the extent to which an individual in a social network occupies the sole intermediary position between two unrelated social clusters (e.g., a maximum betweenness score would indicate than an individual is the sole communicative link between two groups). Applying the concept of betweenness to IDR, it is the extent to which scientist C can function in an intermediary role between scientists A and B. Like a language interpreter, scientist C can use that betweenness to help build a foundation of three-way comprehension.

It is possible, of course, that scientist C is not needed. This would be true in the presence of a *polymath*. The history of science is replete with tales of polymaths (Augier & March, 2002; Pettit, 2015; Schmidgen, 2018; Terjesen & Politis, 2015). True polymaths likely owe their success to: (1) high intelligence which sped their mastery of new domains, and (2) a huge time investment in pursuing that mastery (cf. Sala & Gobet, 2017). Imagine if scientist A has 0.9 expertise in *both* discipline X and Y. In the language analogy, a polymath is like someone fully fluent in two languages. However, we should also acknowledge a *disanalogy* between scientific expertise and a speaker's language ability. Languages are characterised by quite a high degree of intra-language uniformity. A common word, for example, has a semantic meaning known by all or most speakers of a given language. In science, in contrast, "scientists usually subspecialize, and members of a profession will therefore share some core parts of a set of cognitive resources while other parts will be shared by only a few" (Andersen, 2016, p. 3; cf. MacLeod, 2018, pp. 707-711). This implies that the cross-disciplinary barrier is higher than the language-speaker's barrier. Two astronomers, for example, may have studied undergraduate-level astronomy—but later, in graduate school, one specialised in planetary rings and the other specialised in black holes. Can these two scientists now converse about planetary rings and black holes? They can, but as expert-to-*novice*, not expert-to-expert. Beyond the issue of expertise, however, we should bear in mind that—although the presence of a polymath may solve the expertise problem—it does not solve the comprehensibility problem. Every expert has bias. The problem of comprehensibility is still there.

My paper is obviously not the first to identify problems and possible solutions in IDR (previous examples: Freeth & Vilsmaier, 2019; Keestra, 2017; Khilji, 2014; Leigh & Brown, 2021; MacLeod, 2018; Newell, 2007, etc.). I merely offer my own perspective. Certainly, the analogy between language fluency and scientific expertise has its limits (and might even be considered philosophically flippant) — but, no analogy is perfect. As a heuristic tool, my analogy has value in that it forcefully pushes the collaborator into a box with hard walls. Collaborators are like language learners. Discipline barriers are as flummoxing as language barriers. That's a message that the public can understand. In this paper, I have sketched the idea of a "discipline translator," but this might justifiably be labelled a tepid solution. When reading detailed investigations of failed IDR projects, such as that in MacLeod (2018), it seems abundantly clear that, across the fissure between the A-group and B-group, there likely needs to be more than just an agreeable "discipline translator" willing to gingerly jump back and forth over the gap. Instead, particularly in a large project, there needs to be an extensive and well-funded infrastructure specifically designed to engineer compatibilities between that A-group and that B-group (Khilji, 2014). In pursuing interdisciplinarity, all of the collaborating scientists should be fully aware that expertise is domain specific, that disciplines (and their goals) are culture-specific, that the likelihood of misunderstanding is extremely high, and that not every discipline benefits equally in a given research endeavour. Successful IDR should be laboriously hard-working in "translating" between disciplines, fully committed to shared comprehension, and respectful of the slow-growth nature of expertise.

**Acknowledgements:** I would like to thank the editor and two anonymous reviewers for their comments.

**References**

Andersen. H. (2016). Collaboration, interdisciplinarity, and the epistemology of contemporary science. *Studies in History and Philosophy of Science*, *56*, 1-10. https://doi.org/ 10.1016/j.shpsa.2015.10.006

Aram, J. D. (2004). Concepts of interdisciplinarity: configurations of knowledge and action. *Human Relations*, *57*, 379-412. https://doi.org/10.1177/0018726704043893

Augier, M., & March, J. G. (2002). A model scholar: Herbert A. Simon (1916-2001). *Journal of Economic Behavior & Organization*, *49*, 1-17. https://doi.org/10.1111/0033-3352.00043

Bessant, K. C. (2018). *The relational fabric of community.* New York: Palgrave Macmillan.

Brown, R. L. (2020). Why philosophers and scientists should work together. *The Biologist*, *67*, 6-7.

Bullock, K., & Bunce, A. (2020) 'The prison don't talk to you about getting out of prison': on why prisons in England and Wales fail to rehabilitate prisoners. *Criminology & Criminal Justice*, *20*, 111-127. https://doi.org/10.1177/14773708211012624

Bunch, A. W. (2014). National Academy of Sciences "standardization": on what terms? *Journal of Forensic Sciences*, *59*, 1041-1045. https://doi.org/10.1111/1556-4029.12496

Campitelli, G., & Gobet, F. (2008). The role of practice in chess: A longitudinal study. *Learning and Individual Differences*, *18*, 446-458. https://doi.org/10.1016/j.lindif.2007.11.006

Carson, L., Bartneck, C., & Vogas, K. (2013). Overcompetitiveness in academia: a literature review. *Disruptive Science and Technology*, *1*, 183-190. https://doi.org/ 10.1089/DST.2013.0013

Cobley, p. (2008). Culture: definitions and concepts. In W. Donsbach (Ed.), *The international encyclopedia of communication* (pp. 1-7). London: Wiley. https://doi.org/ 10.1002/9781405186407.wbiecc071

Cooke, S. J., Nguyen, V. M., Anastakis, D., Scott, S. D., Turetsky, M. D., Amirfazli, A. et al. (2020). Diverse perspectives on interdisciplinarity from members of the College of the Royal Society of Canada. *Facets*, *5*, 138-165. https://doi.org/10.1139/facets-2019-0044

Darden, L., & Maull, N. (1977). Interfield theories. *Philosophy of Science*, *44*, 43-64. https://doi.org/10.1086/288723

Ericsson, K. A. (2006). The influence of experience and deliberate practice on the development of superior expert performance. In K. A. Ericsson, N. Charness, P. J. Feltovich, & R. R. Hoffman (Eds.), *The Cambridge handbook of expertise and expert performance* (pp. 683-703). Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO978051181 6796.038

Feldon, D. F. (2016). The development of expertise in scientific research. In R. Scott & S. Fosslyn (Eds.), *Emerging trends in the social and behavioral Sciences* (pp. 1-14). London: Wiley.

Fraknoi, A. (2007). The music of the spheres in education: using astronomically inspired music. *Astronomy Education Review*, *5*, 139-153. https://doi.org/10.3847/AER2006009

Freeman, L. C. (1977). A set of measures of centrality based on betweenness. *Sociometry*, *40*, 35-41. https://doi.org/10.2307/3033543

Freeth, R., & Vilsmaier, U. (2019). Researching collaborative interdisciplinary teams: practices and principles for navigating researcher positionality. *Science & Technology Studies*, *33*, 57-72. https://doi.org/10.23987/sts.73060

Frodeman, R. (2014). *Sustainable knowledge*. Basingstoke: Palgrave.

Fuller, S. (1991). Disciplinary boundaries and the rhetoric of the social sciences. *Poetics Today*, 12, 301-325. https://doi.org/10.2307/1772855

Gana, F. L., Saadee, F., & Russell, Y. I. (2022). Gender differences in childhood anxiety in relation to school performance. *North American Journal of Psychology*, *24*, 291-296.

Gobet, F. (2016). *Understanding expertise: a multidisciplinary approach*. London: Palgrave.

Gobet, F., & Chassy, P. (2009). Expertise and intuition: a tale of three theories. *Minds and Machines*, *19,* 151-180. https://doi.org/10.1007/s11023-008-9131-5

Grimstad, M. B., Lohndal, T., & , Åfarli, T. A. (2014). Language mixing and exoskeletal theory: a case study of word-internal mixing in American Norwegian. *Nordlyd*, *41*, 213-237. https://doi.org/10.7557/12.3413

Grüne-Yanoff, T. (2016). Interdisciplinary success without integration. *European Journal for Philosophy of Science*, *6*, 343-360. https://doi.org/10.1007/s13194-016-0139-z

Hamet, P., & Tremblay, J. (2017). Artificial intelligence in medicine. *Metabolism*, *69*, S36-S40. https://doi.org/10.1016/j.metabol.2017.01.011

Hazen, R. H. (2012). *The story of Earth: the first 4.5 billion years, from stardust to living planet*. New York: Penguin.

Huutoniemi, K., Klein, J. T., Bruun, H., & Hukkinen, J. (2010). Analyzing interdisciplinarity: typology and indicators. *Research Policy*, *39*, 79-88. https://doi.org/10.1016/j.respol.2009.09.011

Jackson, F. H., & Kaplan, M. A. (2001). Lessons learned from fifty years of practice in government language teaching. In J. E. Alatis, & A. Tan (Eds.), *Georgetown University round table on languages and linguistics 1999*: *language in our time* (pp. 71-87). Washington: Georgetown University Press.

Jacobs, J. A., & Frickel, S. (2009). Interdisciplinarity: a critical assessment. *Annual Review of Sociology*, *35*, 43-65. https://doi.org/10.1146/annurev-soc-070308-115954

Kahn, J. (2011). The two (institutional) cultures: a consideration of structural barriers in interdisciplinarity. *Perspectives in Biology and Medicine*, *54*, 399-408. https://doi.org/10.1353/pbm.2011.0028

Keestra, M. (2017). Metacognition and reflection by interdisciplinary experts: insights from cognitive science and philosophy. *Issues in Interdisciplinary Studies*, *35*, 121-169.

Khilji, S. (2014). Human aspects of interdisciplinary research. *South Asian Journal of Global Business Research*, *3*, 2-10. https://doi.org/10.1108/SAJGBR-12-2013-0090

Klein, J. T. (2008). Evaluation of interdisciplinary and transdisciplinary research: a literature review. *American Journal of Preventive Medicine*, *35*, S116-S123. https://doi.org/ 10.1016/j.amepre.2008.05.010

Klein, J. T. (2017). Typologies of interdisciplinarity: the boundary work of definition. In R. Frodeman (Ed.), *The Oxford handbook of interdisciplinarity* (2nd ed.) (pp. 21-34). Oxford: Oxford University Press.

Leigh, J. & Brown, N. (2021). Researcher experiences in practice-based interdisciplinary research. *Research Evaluation*, *4*, 421-430. https://doi.org/10.1093/reseval/rvab018

MacLeod, M. (2018). What makes interdisciplinarity difficult? Some consequences of domain specificity in interdisciplinary practice. *Synthese*, *195*, 697-720. https://doi.org/10.1007/s11229-016-1236-4

Mäki, U. (2016). Philosophy of interdisciplinarity. What? Why? How? *European Journal for Philosophy of Science*, *6*, 327-342. https://doi.org/10.1007/s13194-016-0162-0

Murray, W. B. (2015). Astronomy and rock art studies. In C. L. N. Ruggles (Ed.), *Handbook of archaeoastronomy and ethnoastronomy* (pp. 239-249). London: Springer. https://doi.org/ 10.1007/978-1-4614-6141-8_10

Newell, W. H. (2007). Decision-making in interdisciplinary studies. In G. Morçöl (Ed.), *Handbook of decision making* (pp. 245-264). New York: Marcel Dekker.

Pan, L., & Katrenko, S. (2015). *A Review of the UK's interdisciplinary research using a citation-based Approach*. London: Elsevier.

Pettit, C. (2015). One-man multidisciplinarian. *Nature*, *525*, 319-320. https://doi.org/ 10.1038/525319a

Phelps, S., Ng, W. L., Musolesi, M., & Russell, Y. I. (2018). Precise time-matching in chimpanzee allogrooming does not occur after a short delay. *PLoS One*, *13*, e0201810. https://doi.org/10.1371/journal.pone.0201810

Phelps, S., & Russell, Y. I. (2015). Economic drivers of biological complexity. *Adaptive Behavior*, *23*, 315-326. https://doi.org/10.1177/1059712315593607

Porter, A. L., & Rafols, I. (2009). Is science becoming more interdisciplinary? Measuring and mapping six research fields over time. *Scientometrics*, *81*, 719-745. https://doi.org/10.1007/s11192-008-2197-2

Robertson, L. P., & Russell, Y. I. (2016). Age and gender differences in smiling and laughter: the power asymmetry hypothesis retested. *Human Ethology Bulletin*, *31*, 5-14. https://doi.org/10.22330/heb/311/005014

Russell, Y. I. (2011). Prehistoric stone tools, chess expertise, and cognitive evolution: an experiment about recognizing features in flint debitage. *Journal of Evolutionary Psychology, 9*, 249-269. https://doi.org/10.1556/jep.9.2011.3.3

Russell, Y. I., Call, J., & Dunbar, R. I. M. (2008). Image scoring in great apes. *Behavioural Processes*, *78*, 108-111. https://doi.org/10.1016/j.beproc.2007.10.009

Russell, Y. I., & Gobet, F. (2012). Sinuosity and the affect grid: a Method for adjusting repeated mood scores. *Perceptual and Motor Skills*, *114*, 125-136. https://doi.org/10.2466/ 03.28.PMS.114.1.125-136

Russell, Y. I., & Gobet, F. (2013). What is counterintuitive? Religious cognition and natural expectation. *Review of Philosophy and Psychology*, *4*, 715-749. https://doi.org/ 10.1007/s13164-013-0160-5

Russell, Y. I., Gobet, F. & Whitehouse H. (2016). Mood, expertise, analogy, and ritual: an experiment using the five-disk Tower of Hanoi. *Religion, Brain, & Behavior*, *6*, 67-87. https://doi.org/10.1080/2153599X.2014.921861

Russell, Y. I., Stoilova, Y., & Dosoftei, A.-A. (2020). Cooperation through image scoring: a replication. *Games*, *11*, 58. https://doi.org/10.3390/g11040058

Sala, G., & Gobet, F. (2017). Does far transfer exist? Negative evidence from chess, music, and working memory training. *Current Directions in Psychological Science*, *26*, 515-520. https://doi.org/10.1177/0963721417712760

Schmidgen, H. (2018). The last polymath. *Nature*, *561*, 175. https://doi.org/10.1038/d41586-018-06613-9

Schmidt, J. C. (2008). Towards a philosophy of interdisciplinarity: an attempt to provide a classification and clarification. *Poiesis & Praxis*, *5*, 53-69. https://doi.org/10.1007/ s10202-007-0037-8

Sugimoto, C. R., & Weingart, S. (2015). The kaleidoscope of interdisciplinarity. *Journal of Documentation*, *71*, 775-794. https://doi.org/10.1108/JD-06-2014-0082

Tanesini, A. (2018). Intellectual humility as attitude. *Philosophy and Phenomenological Research*, *96*, 399-420. https://doi.org/10.1111/phpr.12326

Terjesen, S., & Politis, D. (2015). In praise of multidisciplinary scholarship and the polymath. *Academy of Management Learning & Education*, *14*, 151-157. https://doi.org/ 10.5465/amle.2015.0089

Tharanathan, R. M., Yashoda, H. M., & Prabha, T. N. (2006). Mango (*Mangifera indica L.*), “the king of fruits” — an overview. *Food Reviews International*, *22*, 95-123. https://doi.org/ 10.1080/87559120600574493

Tracanelli, C. (Ed.). (2016). *Insight guides city guide Paris* (16th ed.). London: Doring Kin-dersley.

Wade, A. D., Beckett, R., Conlogue, G., Garvin, G., Saleem, S., Natale, G., Caramella, D., & Nelson, A. (2019). Diagnosis by consensus: a case study in the importance of interdisciplinary interpretation of mummified remains. *International Journal of Paleopathology*, *24,* 144-153. https://doi.org/10.1016/j.ijpp.2018.10.007

Yegros-Yegros, A., Rafols, I., & d’Este, P. (2015) Does interdisciplinarity research lead to higher citation impact? The different effect of proximal and distal interdisciplinarity. *PLoS One*, *10*, e0135095. https://doi.org/10.1371/journal.pone.0135095