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Interdisciplinary Integration as Information Work

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Abstract: In this article, I review the ways that interdisciplinary integration is studied as a collaborative task, as knowledge synthesis modeled by various conceptual frameworks, and as a series of outcomes measurable by citation networks or real-world indicators. I argue that each of these approaches is valuable but limited in their utility as a way of understanding and evaluating integration. I suggest borrowing from the field of information studies and adopting an alternate perspective of integration as a data- and information-management practice as a means of addressing some of these limitations, and discuss the justification for and potential application of this approach.

Keywords: interdisciplinarity, information studies, information management, integration, research methods, research evaluation

1. Introduction

Interdisciplinary research tends to find itself positioned at the midpoint of a strange duality. One the one hand, the necessity of interdisciplinary approaches and solutions as means of addressing complex, multi-faceted problems such as climate change is widely discussed and accepted as a reality (Canonico et al., 2017; Feng & Kirkley, 2020; Tobi & Kampen, 2018). On the other hand, interdisciplinary research and the scholars who commit to such work can, at least in the short term (see Wang et al., 2015), experience reduced funding success and negative career impacts relative to disciplinary research and discipline-focused scholars (Bromham et al., 2016; Huang et al., 2016; Trinh et al., 2022). Reasons for the challenges faced by interdisciplinary scholars are manifold, but one major contributor is the problem of how best to evaluate the quality of interdisciplinary research (Boix Mansilla, 2006; Shapiro, 2014; Laursen et al., 2022). Here I extend this idea and suggest that the challenge is not merely the evaluation of interdisciplinary research in general, but specifically the evaluation of integration as a central practice of interdisciplinary research.

The failure to take seriously integration as a practice comprising actions undertaken during interdisciplinary research is problematic. When

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interdisciplinary scholars cannot communicate what exactly integration should or does look like in their work, challenges or shortcomings in their integration processes cannot be identified and remedied. Clearly articulated and evaluable methods are part of any rigorous research framework. If interdisciplinarity is to be treated as one such rigorous framework, rather than as a battering ram with which to attack complex problems, the processes by which knowledge from contributing disciplines are integrated must be articulated in order to be evaluated.

In this article I make the case for a pragmatic—and (I argue) scholastically promising—means of addressing this issue by adopting information science perspectives and terminology to articulate the research practices that comprise interdisciplinary integration. I review current conceptions of interdisciplinary integration and the implications thereof, then discuss how framing integration as a data and information management practice can provide tangible and easily understandable ways of demonstrating the rigor of interdisciplinary research. Limitations and future work in this area are also discussed.

2. How do We Currently Conceive of and Study Integration?

Integration Through Collaboration

The idea of the integration of knowledge, methods, and perspectives from different academic disciplines is common across most definitions of interdisciplinarity (Jantsch, 1972; Klein, 1990; National Academic of Sciences, 2005; Aboelela et al., 2007; Hoffmann et al., 2013; Siebert et al., 2020). Individual scholars can and do conduct interdisciplinary research (Manathunga et al., 2009), but several definitions of interdisciplinarity explicitly suggest that interdisciplinary research consists of collaboration between multiple scholars from differing disciplinary backgrounds (Aboelela et al., 2007; Carr et al., 2018). Integration and collaboration are two distinct concepts, but much research about interdisciplinarity focuses on how the former is enabled by the later. That is, it is not uncommon for scholars to frame interdisciplinary work as a collaborative, team communication task between multiple disciplinary experts (see Laursen & O'Rourke, 2019, for an explanation of this socio-linguistic view of integration), and to evaluate the quality of that work accordingly.

For example, Canonico et al. (2017) identify mutual understanding between collaborators as a key characteristic of successful interdisciplinary collaborations, and list organizational routines and face-to-face group meetings as important mechanisms for facilitating this success. The success of interdisciplinary research is described as requiring "continual negotiations" between collaborators who must accommodate each other's approaches (Miller et al., 2008), impacted by available personnel and their motivations

(Maglaughlin & Sonnenwald, 2005), and improved by the presence of external facilitators and collaborative visualizations of the research process (Lash-Marshall et al., 2017). None of these focus on integration itself.

This same perspective (interdisciplinarity as a communicative, person-centric process) also underlies many published discussions on barriers to interdisciplinary research. For example, Maglaughlin & Sonnenwald (2005) pinpoint "contested collaboration," whereby collaborators from different disciplines dispute the validity of each other's contributions, as a major challenge to interdisciplinary research, while Bracken & Oughton (2006) discuss the ways in which differing metaphors and word usage between disciplines can prevent interdisciplinary collaborators from establishing shared vocabularies and (therefore) shared understanding of problems. Yet again, these are about communication and not *necessarily* integration.

It is clear that in terms of both facilitators and barriers, a large portion of research into factors affecting interdisciplinary research focuses on collaborative aspects of interdisciplinarity. Indeed, the comprehensive list of empirically demonstrated factors affecting interdisciplinary research compiled by Carr et al. (2018) appears not dissimilar from lists of general team-building and communication strategies from within the broader management literature (Gratton & Erickson, 2007; Kozlowski & Ilgen, 2006).

The literature discussed here describes interdisciplinary collaboration in great detail, but it leaves us seeking answers about the practice of integration that, presumably, is meant to result from that collaboration. Is the ability to communicate with collaborators about different disciplinary perspectives necessarily equivalent to the integration of those perspectives? If so, is there still a meaningful distinction between interdisciplinary and multidisciplinary research? We find ourselves left with a gap in understanding. If one were to build a definition of interdisciplinarity solely by engaging with this part of the published literature, they would find countless (very valuable) resources on how to assemble a cross-disciplinary team and enable effective communication and shared understanding. Both communication and shared understanding foster effective interdisciplinary collaboration, which has the objective of facilitating integration, but this literature leaves us guessing as to what that "next step"—integration—actually involves.

Integration As Conceptual Synthesis

The intuitive idea of interdisciplinary integration as a synthesis of knowledge, as the construction of a single comprehensive understanding resulting from—and expanding beyond—the cross-disciplinary collaboration process, is echoed throughout the literature (Graff, 2016; Klein, 1990; Newell, 2001; Tobi & Kampen, 2018). We can try to develop further this intuitive conception of integration-as-synthesis by making use of compelling conceptual models of

knowledge integration, albeit not developed in specifically interdisciplinary contexts.

Tobi and Kampen (2018) discuss how integration differs between convergent modules of research activity (research is completed in parallel and synthesized after the fact), sequential modules (research on earlier modules informs later modules), and embedded modules (synthesis occurs both during and after individual research modules). Also consider Boon and Van Baalen's (2019) three metaphors for the integration and linking of knowledge: the jigsaw puzzle metaphor (whereby existing knowledge fits together without changing), the conflict resolution metaphor (which focuses on resolving conflicting presuppositions between disciplines to shape each's conclusions), and the engineering design metaphor (which aims to combine disciplinary epistemic resources into a single, coherent "epistemic entity"). Sullivan (2018) describes two distinct types of integration in the context of neuroscientific research. "Small-scale integration" is analogous to combining conclusions from different laboratories after experimental results and data have been analyzed to form these individual conclusions at each lab. And "large-scale integration" is analogous to investigators forming conclusions based on analyzing the experimental results and data from multiple different laboratories together (that is, any conclusions reached are a product of both sets of data considered together).

Other, more brief conceptual descriptions of integration reoccur throughout the interdisciplinary literature. Siebert et al. (2020) discuss "real synthesis"—implied to be something more thorough or deeper than a less "real" alternative—as the hallmark of interdisciplinarity, while other scholars suggest that integration be seen as a process of continuous interactions between disciplines (Graff, 2016) and as something with a wider meaning than mere correlation (Klein, 1990). Whether we consult detailed models or evocative descriptions, though, a concrete understanding of integration *practice* remains elusive. We could turn to Tobi and Kampen's (2018) and Boon and Van Baalen's (2019) frameworks to seek further details about how exactly their models of integration might manifest as research practice, but interestingly, both pairs of authors emphasize that the existence of these conceptual categories of integration does not mean that they are actually occurring during a given research project. How, then, can we explore integration not as an ideal but as something actually done during research?

Integration as Outcome

There are (published and underway) many interesting efforts to "see" interdisciplinary integration in action. These efforts can, broadly, be divided into those that examine real-world indicators, and those that use bibliometric methods to quantify integration.

The idea of interdisciplinarity as an approach principally for addressing real-world problems is pervasive (Woelert & Millar, 2013). For example, Newell (2001) makes the case that "the proof of successful integration is pragmatic," and Welch (2018) writes that "the value of integration . . . can be tested by applying the integrative process to solving complex problems." Painter et al. (2022) address the tendency to identify "better" interdisciplinary approaches based on the discoveries made with individual instances of the work, and Boix Mansilla (2006) reviews experts' perceptions of quality in interdisciplinary research and finds that, indeed, "indirect quality indicators"—that is, outcome-based indicators such as number of patents or number of publications—are primarily used to evaluate interdisciplinary work. Part of the dominance of this approach is likely practical: Boix Mansilla (2010) writes that interdisciplinary integration as synthesis "can only be observed through manifest communicative efforts" (p. 263) such as written explanatory papers and other final products. It is challenging to evaluate what cannot be observed. The implications of this approach on studies of integration are as follows: If we are "doing interdisciplinarity"—and therefore doing integration—in order to make some change to some real-world situation, we can observe that situation as a way to evaluate the success of our work. If the real-world observable changes in the way we wanted it to, this train of thought goes, we can conclude that interdisciplinary integration took place and was successful.

Bibliometric methods are another common tool used to evaluate whether or not integration is occurring in particular publications, areas of study, or individual researchers' careers (Laursen et al., 2022). For a selection of examples: Rakas and Hain (2019), following Porter et al. (2007), use coherence (the extent to which elements are articulated to produce meaningful collective output) and diversity (the "number, balance, and similarity" of bodies of knowledge included) as markers for the success of knowledge integration in a field of research. Bibliometric analysis of citations, publications, and networks of co-authorship and citation relationships amongst scholars are by far the most common means of assessing coherence and diversity of interdisciplinary research publications (Laursen et al., 2022; see for examples Abramo et al., 2009; Hu & Zhang, 2017; Raasch et al., 2013). Vocabulary analysis of published interdisciplinary research has also been used as a means of evaluating the extent of integration (Rakas & Hain, 2019). Bibliometric analyses that aim to empirically evaluate whether or not interdisciplinary integration has taken place share a feature in common with the real-world indicators described previously: Both approaches focus not on the research (as process) itself, but on the final products, publications, and impacts of that research.

3. Impacts of Current Approaches

Each of the above approaches to understanding and measuring interdisciplinary integration has problems or weaknesses. We have seen that cross-disciplinary collaboration is well-studied and understood, and is in itself necessary but not sufficient for interdisciplinary integration. We have also seen that conceptual models can provide us with language and frameworks for conceiving of interdisciplinary integration as a deep, continuous synthesis but do not in themselves claim that those frameworks reflect actions that are happening in "real life." Lastly, we have seen that outcome-focused approaches to evaluate whether integration is occurring address some of these deficiencies by specifically targeting integration (rather than collaboration) and situating the work very much in real research practices. However, by focusing on the final published products or real-world results of research, outcome-focused approaches can help us identify if interdisciplinary integration was completed, but they do not venture to suggest what that integration might have involved. That is to say: The outcome-focused way of exploring interdisciplinary integration means that we know a lot about what *has* happened (i.e. papers from x many disciplines are cited in this publication, therefore integration looks like y), but—somewhat counterintuitively—almost nothing about *how* it happened (i.e. what did the process of integration by which we arrived at result y actually involve or look like).

Numerous problems can result from this focus on the "what" rather than the "how" of integration. Evaluating interdisciplinary integration based on citations in final publications can be misleading. See for example Pinheiro et al. (2022), who find that greater self-citation by male researchers can decrease their work's apparent interdisciplinarity using bibliometric approaches, or Wang and Schneider (2020), who demonstrate the inconsistency across bibliometric measures designed to capture aspects of interdisciplinarity (e.g. disciplinary diversity) and question the validity of those measures as ways to "see" interdisciplinarity in action. Reliance on non-robust measures of interdisciplinarity and integration can pose problems for research evaluation, science policymaking, and the research funding decisions dependent on both (Wang & Schneider, 2020).

As well, if we evaluate interdisciplinary integration based on "real world" problem-solving outcomes rather than bibliometric indicators, we can become subject to outcome bias, whereby positive outcomes can cause evaluators to overlook the possibility of randomness, luck, or invalid methodological choices (Fanelli, 2012; Brownback & Kuhn, 2019), and flawed decision making processes can become codified within organizations because they by chance resulted in success in the past (Kausel et al., 2019; March, 1991; Peecher & Piercey, 2008). The impact of outcome bias becomes even more pronounced in the context of interdisciplinary research, where the complex systems that are

generally the subjects of interdisciplinary efforts make it even less feasible to assume a linear relationship between research processes and outcomes (Newell, 2001). An interdisciplinary research project may be evaluated as successful if it results in social change or addresses a problem, but the process by which knowledge from contributing disciplines were integrated may not reach the standards of rigorous research, even if individual disciplinary components do.

By focusing evaluation of interdisciplinary research on outcomes or final publications without trying to directly explore practices of integration and how they shape researchers' conclusions, we fail to directly explore the research—and therefore the merits of interdisciplinarity as epistemological framework and toolkit—at all. Without an understanding of what exactly interdisciplinary integration should or does look like in practice, interdisciplinary researchers can face difficulty communicating about their methods and approaches, and it becomes challenging to identify and address methodological problems with interdisciplinary approaches, which likely contributes to lasting conceptions of interdisciplinary research as less rigorous than disciplinary research. These perceptions, in turn, adversely impact the funding success of interdisciplinary research proposals (Bromham et al., 2016; Huang et al., 2016; Shapiro, 2014) and the career trajectories of interdisciplinary researchers (Boix Mansilla, 2006; Li & Chen, 2022; Manathunga et al., 2009; Trinh et al., 2022).

Recent initiatives on the parts of funding agencies are beginning to explore how to address problems with current ways of conceiving and evaluating interdisciplinary integration (Government of Canada, 2022; National Academies 2021). I propose another possible solution: adopting data- and information-management perspectives to articulate and evaluate the practices of interdisciplinary integration, rather than mere collaboration, idealized concepts of integration, or integrative outcomes and final products.

4. Terminology

It is worth pausing here to clarify the terminology to be used through the remainder of this article. To be clear: "Data" and "information" are distinct elements. "Data" are commonly defined as the products of observation in the forms of symbols representing properties of objects, events, or an environment (Ackoff, 1989; Rowley, 2007). I follow D'Ignazio and Klein (2020) in adding that data are not only numerical but are non-neutral in origin and can also take the forms of "words or stories, colors or sounds" or any other type of observation that has been "systematically collected, organised and analysed" as part of qualitative as well as quantitative research. "Information" is inferred from data by adding structure or context and takes the forms of descriptions and answers to questions (Ackoff, 1989; Rowley, 2007). For example, for a project investigating climate change over time, data might be a

collection of hourly temperature measurements, while information might be a plot showing the trend in temperature over the time period of interest. For our purposes, the distinction need not be strict: Both data and information serve as the "raw materials" of interdisciplinary research at different stages of the research process. Our interest in the present article lies with the "stuff" or objects (e.g. .XLSX files, tables in databases, paper notes, .DOCX files, records in citation management software) containing those raw materials (Floridi, 2002). Accordingly, in the sections that follow, I reference "data holdings" and "information assets" for specific objects as needed, though most statements apply generally to the objects of research regardless of whether their contents are data or information.

5. Addressing the Problem: Integration as Information Work

We can adopt a data- and information-centric perspective from which to explore interdisciplinary integration. From this perspective, we conceive of integration as a set of data and information management practices, and we take as our objects of focus the research data holdings and information assets being generated and analyzed during interdisciplinary research. Consider, for example, a hypothetical interdisciplinary research project that aims to identify artefacts being found during an archaeological dig. During the course of this work, written "art history" descriptions of artefacts may be recorded by hand in field notebooks, while "biochemical" metrics of soil acidity and bioindicator presence in the location where the artefacts were unearthed are recorded in Excel spreadsheets. Both of these forms of information will (presumably) be integrated by researchers to reach informed, interdisciplinary conclusions about the age and provenance of the found artefacts. The notebooks and spreadsheets, our information objects, contain the information (or representations of the information) being integrated. If we adopt an information studies perspective, we claim that by studying these information objects and the ways in which they are changed, shared, and analyzed during the integration process, we can learn more about what that process involved. This focus on the "stuff" of interdisciplinary research helps us mitigate the challenges presented by current ways of conceiving of integration—namely, by providing the "real life" picture of interdisciplinary integration activities that we cannot get from theoretical conceptual models while avoiding the bias that comes with the typical after-the-fact approach.

The benefit of this proposed information-centric approach is that, by virtue of its focus on information holdings and infrastructures, it frames interdisciplinary integration as a demonstrable and concrete research practice, a process that can be explicitly planned for in research proposals and evaluated by the reviewers of said proposals. Of course, I unequivocally do not seek to

advocate for data- and information-management practices as the sole lens through which to evaluate interdisciplinary integration; rather, I suggest that this approach can offer another means of demonstrating the rigor and activities of interdisciplinary research in such a way that reviewers and funding agencies can evaluate the research practices themselves, rather than the associated outcomes or final publications.

The remainder of this section is dedicated to exploring first the precedent for an information science approach as a means of studying interdisciplinary integration, then to suggesting how the proposed approach might be used to create a functional tool for interdisciplinary researchers. Limitations of the approach are also addressed.

An Information Approach to Studying Integration

The proposed information-centric perspective draws on the practice turn, a shift across several academic contexts to decenter mind and textual content while refocusing scholarly discussion on "things, practical knowledge, and routine" (Reckwitz, 2002; Schatzki et al., 2001). For our purpose of better understanding and articulating the practice of integration as performed during interdisciplinary research work, the adoption of a practice-focused approach is supported by the contention that, per Kendig (2018),

> All scientific work, including pure theorizing, consists of actions . . . . This refocusing of science on scientific practices highlights the activities that are revealed when we look at the processes and doings of science by scientists and scientific communities . . . rather than exclusively on the products of science. (p. 3)

To be clear, what is proposed here is the examination of integration practices on a within- and during- project level, rather than attempting to observe them once they have already been done (for example, by analyzing the citations of published papers). I suggest that a useful way of doing this is by narrowing our focus on data and information, and the accompanying structures. For us, Kendig's "science" refers to interdisciplinary research, and the processes, doings, and things on which we can focus our attention are the data holdings of specific interdisciplinary research projects and the ways in which they are stored, shared, or transformed during integration. By focusing on information assets and infrastructure of projects in progress rather than more generally on collaboration strategies or resulting research publications and outcomes, we can gain insight and clearly communicate about the "how" of interdisciplinary integration as it is occurring in practice. Since raw research data can serve as artefacts of research in progress, studying these data and the ways that researchers interact with them can be helpful to research about interdisciplinarity by serving as a means by which we can explore integration.

This focus on research data (and their storage, sharing, and analysis) as objects of study situates the proposed approach in an information science context. Information science as a field primarily concerns itself with the study of the "gathering, organizing, storing, retrieving, and dissemination of information" (Bates, 1999). The narrow focus proposed here is only one potential information science approach—elsewhere in the field, scholars explore implicit knowledge structures and question the assumptions that underpin 'information' as a concept (Patin et al., 2021; Jimenez et al., 2022). We keep such rich context in mind, but here make use of a specific area of information research: that which will allow us to explore data and information objects as traces or artefacts of a specific information practice (in our case, integration) (Wildemuth, 2017; Hartel, 2020).

Virkus and Garoufallou (2020) give a thorough overview of recent, data-focused information science publications that explore data "from the perspective of research or practice" as I propose here, and the overlap of data research and information research is noted by Hou et al. (2018) and Wang (2018). A practice approach has also been explicitly applied before to information studies research (Hartel, 2006; Savolainen, 2008). Per Cox (2012), practice-focused information research considers what constitutes information in a given practice and the "concrete mechanisms" through which that information is found, used, created, and shared. This is the approach I suggest here, applied to interdisciplinary integration.

An Information Approach to Evaluating Integration

The practice-focused, information-centric approach to integration suggested here opens up new methods for exploring "real world" interdisciplinary integration as a subject of study in itself, but also offers potential as a means of evaluating interdisciplinary work while reducing susceptibility to outcome bias. I propose a framework with which we can break down the information management practices happening during interdisciplinary integration. This framework is not proposed as a replacement or correction to the conceptual frameworks for integration proposed by Tobi and Kampen (2018) and Boon and Van Baalen (2019) and discussed previously. Instead, these functional categories of information integration activities are intended to serve as a valuable heuristic for understanding the activities and actions that might comprise interdisciplinary integration on a data and information level. They include administrative integration, methods integration, and content integration.

Administrative integration refers to the integration activities in which disciplinary data and information assets are linked by administrative metadata, file names, folders, or shared variables. Administrative integration is concerned with data objects and involves things like storing all of our observational notes in a shared repository, establishing common vocabularies among

project collaborators, or otherwise ensuring that our data are stored in a way that will allow us to compare them between disciplines, not just within disciplines. Administrative integration activities provide the scaffolding (in the form of shared variables or units of measurement) that can help scholars integrate the data generated from different disciplinary approaches, but that scaffolding does not in itself integrate the data on that scale.

Methods integration refers to a type of interdisciplinary integration where data and information management methods established or commonly used by one discipline are used to work with information assets in another. We can see evidence of methods integration when we think about what was done to collect, process, and analyze data—for example, an ecological research project making use of virtual modeling approaches from the computer science discipline to analyze data, or a library studies project using ethnographic field notetaking methods common to anthropological research to generate its dataset.

Content integration is an information-focused way of referring to integration as it differentiates interdisciplinary research from single discipline and multidisciplinary research (see "Integration as Conceptual Synthesis" section above). Content integration is concerned with the actual informational content stored within or represented by our data objects. In content integration, information from one disciplinary context either shape the information we can extract from another disciplinary context or are combined with information from that second discipline to generate new knowledge that is a product of both. An understanding of the practices of content integration can come from the knowledge and information management literature, specifically from foundational work by Choo (1996, 2001) on sense-making and knowledge creation—put simply, content integration is the synthesizing work we do with the information stored in our integrated datasets or collected by our integrated methods.

Generally, we might expect to see more than one of these forms of information integration occurring within a single interdisciplinary project. For example, it may be challenging for researchers to integrate content (e.g. develop an interdisciplinary model of climate impacts that includes both ecological and economic impacts) without having administrative integration practices in place to facilitate the exchange of information between contributing disciplines (e.g. producing a database containing both ecological and economic data for the particular space or time of interest). This is not to say that every interdisciplinary project will necessarily include all three types of information integration. It is easy to imagine a research endeavor that sets out to do interdisciplinary work, establishing shared terminology and data storage (administrative integration), but where team members largely analyze and write about only the data most relevant to their own home discipline (no or minimal content integration).

We can turn this framework of integration activities into a useful tool. When evaluating proposed research or applications, funding agencies and publishers require a description of planned methods and a management plan for research data (Finkel et al., 2020). I suggest here that, in addition to a detailed description of methodology and data management practices for the proposed research, interdisciplinary researchers should include a statement or plan for how exactly their interdisciplinary research project proposes to integrate disciplinary data and information.

Drawing on the three functional categories of integration described above, a sample guide of questions to consider when designing an integration plan is developed as part of the present work (see Appendix). The guide draws inspiration from the sample Data Management Plan created by University of Toronto Libraries (2022) and from the templates for datasheets created by Gebru et al. (2020). It includes questions such as,

- Have all contributors agreed on common terminology to use in project datasets and information assets? (Administrative integration)
- Who will be carrying out data collection and analysis activities? Do they work with all data, or only a subset of it? (Methods integration)
- Will data from multiple disciplinary components interact and influence each other early in the research process (data collection and analysis) or will they first make contact when you are writing a final publication? (Content integration)

The guide is designed with flexibility in mind and aims to support thinking about integration as an information and data management process without excluding qualitative research projects or research projects with non-tabular data and information holdings. The intentionally high-level question guide developed here could serve as an interdisciplinarity-specific means of laying the groundwork for the data management plans required for many research funding applications, but is not solely a pragmatic compromise. Exploration of the data and information management practices of interdisciplinary integration can also be valuable for interdisciplinary researchers as a tool for self-assessment and critical reflection on their research practices (Reich, 2017; Seidel & Fixson, 2013).

Limitations and Considerations

The data-and-information-centric approach to integration that I propose here is not without its limitations. Keller et al. (2017) thoroughly summarize the ways in which differing disciplinary contexts have different best practices for "good" data, and a "one size fits all" approach to the evaluation of interdisciplinary information management would unavoidably seek to judge at least part of each interdisciplinary research project by non-relevant criteria. Even

on a more conceptual level, Carp et al.'s (2001) arguments of interdisciplinarity as a tool against institutional control are again worth considering. Miller et al. (2008) suggest that to provide a "specific action agenda or rigid outline for successful interdisciplinary research" would be contrary to the ideal that "a reorganization of multiple, potentially equally valid ways of knowing requires a negotiation governed by the specifics of the question and the composition of the research team" (p. 13). A guide for planning and evaluating information integration would seem to work against this goal.

In response to these limitations, I would emphasize again that this article by no means sets out to argue for a single, information-centric orthodoxy as the only tool with which to evaluate whether all interdisciplinary research is being done "the right way," or indeed that information and data objects, to the extent that these concepts attempt to codify knowledge and make it tangible, can capture every nuance of interdisciplinary integration. Collaborative, conceptual, and bibliometric means of exploring integration are, as demonstrated by the decades of rigorous research cited previously, vitally important parts of understanding interdisciplinarity, and outcomes are valuable parts of how to evaluate the success of interdisciplinary research work. Rather, I make the assertion that they are just that: parts of interdisciplinary research, rather than the whole. Absolutely, information management is not the only lens through which we should study and evaluate interdisciplinary integration, but it *is* an as yet underused tool to assist interdisciplinary researchers in demonstrating the rigor of our work and in reflecting on our own research practices.

Nor do I attempt, in offering an information-centric question guide for describing integration practices, to argue that scholars' answers to the proposed questions should be converging on any particular tendency or that a particular practice of integration is necessarily better than any other. The multiplicity of ways of knowing and integrating captured under the umbrella of interdisciplinarity are interdisciplinarity's strength, and while I find it plausible that a comparison of information integration practices across multiple projects could reveal useful commonalities or shared challenges, the goal here is not to prescribe what information integration *should* look like. I only suggest that, whatever forms of integration are adopted by a given research endeavour, the robustness of that research and completeness of its eventual evaluation can only be improved by the researchers taking the time to consider and describe their integration as thoroughly as they do their other research practices.

6. Concluding Thoughts and Looking Forward

This article reviews the ways that interdisciplinary integration is understood as a collaborative task, as knowledge synthesis modeled by various conceptual frameworks, and as a series of outcomes measurable by citation networks or

real-world (e.g. policy) outcomes. Each of these approaches to integration is valuable but limited, and subsequent difficulty in understanding and evaluating integration as hallmark of interdisciplinarity contributes to career challenges faced by interdisciplinary scholars. An information studies approach, by reframing integration as a data and information management practice, provides a relatively easy-to-digest way of understanding and demonstrating the activities of interdisciplinary work.

It is my primary intention for the approach proposed in this article to serve as a jumping-off point for further research and exploration in this area. In terms of future directions, the next steps are to further articulate the proposed framework and then to conduct case studies and observational work. This work could take the form of analyzing interdisciplinary integration through an information studies lens to explore whether this lens is truly a helpful way of understanding integration practices, and to try applying the question guide (see Appendix) to explore whether conceiving of integration as information practice is of practical use to interdisciplinary researchers.

The many scholars and thinkers advocating the incredible value of interdisciplinarity as a tool for understanding a complex world are not making baseless claims: Decades of evidence support the claim that interdisciplinary research is an effective way of solving problems and finding innovative solutions (Klein, 1990; Aldrich, 2014; Jung et al., 2021). I have endeavoured to make the case in this article that more than just a blunt force tool for solving problems (as it often seems to be discussed), interdisciplinarity is a rigorous research framework, and that using an information management approach to more clearly understand and articulate the integration practices that comprise that framework is one way to advance the latter perspective.

Biographical Note

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Appendix
Sample Integration Plan Guide For Interdisciplinary Research

What is an integration plan? Integration of data and information from different disciplines is an important part of interdisciplinary research. An integration plan is a tool for treating integration of your data as part of your methodological approach that should be justified and considered in advance.

Why should I use an integration plan? Developing an integration plan while planning your research project can ensure that from the beginning of your work, you can manage data and information from different disciplinary components so that they will be easy to meaningfully integrate when it comes time for analysis.

The following table is a sample guide consisting of questions that should be answered collaboratively by researchers while planning and proposing an interdisciplinary research project. *If any of the three types of integration are not being used, your integration plan should explain why.*

Table 1: Integration plan sample guide

Type of Integration	Integration Plan Questions
Administrative Integration	Who is contributing to this project and what are their disciplinary affiliations? Will contributors be able to access data or information from outside of their disciplinary area of expertise? Have all contributors agreed on common terminology to use in project datasets and information assets? Can all contributors understand what information and data are stored in a given file? Will data or information collected by different disciplinary contributors be stored separately or in a shared repository? If separately, how will it be combined? If in a shared repository: • How will the structure of your repository facilitate integration of data and information from different disciplines? • When in the research process will data and information be entered into/removed from the shared repository?
Methods Integration	Are your proposed data collection or analysis methods associated with one particular discipline? How will you adapt these methods for your interdisciplinary research? Is there precedent in published literature for using these data collection or analysis methods for interdisciplinary research? Who will be carrying out data collection and analysis activities? Do they work with all data, or only a subset of it?
Content Integration	What research questions are you attempting to answer and why is an interdisciplinary approach being used? How will data or information collected in one disciplinary context influence data or information from or for another disciplinary context? How will integration of interdisciplinary data inform results? Will project contributors interact with data or information from outside of their disciplinary area of expertise? Will information from multiple disciplinary components interact and influence each other early in the research process (data collection and analysis) or will they first make contact when you are writing a final publication?