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Desiderata for Graduate Interdisciplinarity Teaching

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Abstract: The literature on interdisciplinary teaching has tended to stress undergraduate teaching. As interdisciplinary graduate teaching becomes increasingly common, we need to reflect on what graduate students need to know. This article discusses key ideas that all interdisciplinary graduate programs should communicate. In particular, we need to teach graduate students how to do interdisciplinary research. Students should also be prepared for interdisciplinary careers. Since there has been relatively little written about interdisciplinary graduate education, this article is necessarily exploratory, and intended to encourage a conversation.

Keywords: interdisciplinarity, graduate education, integration, complexity, creativity

The vast bulk of the literature about interdisciplinary teaching focuses on undergraduate teaching. Textbooks in the field are mostly aimed at undergraduates (e.g. Augsburg, 2016; Repko and Szostak, 2020; Repko, Szostak and Buchberger, 2020; perhaps Bergmann et al., 2016)—though Repko and Szostak (2020) is often used in graduate programs and Keestra, Uilhoorn, and Zandveld (2022a) is geared toward masters-level students. Yet there are now a host of interdisciplinary graduate programs at universities around the world (Vienni-Baptista & Klein, 2022). These programs naturally serve different students and have different goals than undergraduate teaching programs. Even so, we know relatively little about how to pursue graduate (especially doctoral) interdisciplinary education. As Dupin and Lyall (2024) note, "The existing literature on interdisciplinary doctoral education and how it is viewed or experienced by students is limited." The purpose of this article is to survey the various components that should characterize a high-quality graduate interdisciplinary program. Since little has been written about graduate interdisciplinary

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education, the article is exploratory. We hope to inspire further discussion of the ideas presented in what follows.[1]

We found as we wrote this paper that it often makes sense to speak directly to graduate students when describing what they need to learn and why. Yet at other times the points we make are best addressed directly to instructors and administrators. We hope that the paper as whole will be useful to both those who offer interdisciplinary graduate programming and those who receive it.

The blossoming in recent decades of graduate interdisciplinary training reflects a recognition that many important research questions require an interdisciplinary outlook (Rashid, 2021). While some university administrators may think that interdisciplinarity is best pursued after one has gained tenure in a discipline, others recognize the value of being trained from the start in interdisciplinary analysis (Lyall, 2019). In the field of interdisciplinary studies, we want then to prepare students to be able to perform quality interdisciplinary research—both while writing a thesis or dissertation and in their later careers. We also want students to understand the nature of interdisciplinarity, and of interdisciplinary research paths (Holley, 2024; Lyall et al. 2012). More generally, we want to help interdisciplinary graduate students cope with the unique challenges of their degree (Gallemí-Pérez & Chávez-Medina, 2021).

The Nature of Interdisciplinarity

Disciplinary graduate programs expose students to the nature of a particular field, and the sort of questions, theories, methods, and terminology that the field accepts. Since interdisciplinarity is still somewhat contested at the graduate level, graduate students need to have some deep understanding of what interdisciplinarity is and how interdisciplinary research is best pursued.[2]

Students need to know that, while there is some debate in the field, most scholars of interdisciplinarity see integration as a—or even the—defining characteristic of interdisciplinary research (Newell, 2007; Bergmann et al., 2012; Klein, 2012; Menken & Keestra, 2016; Repko & Szostak, 2020). Even within this majority that emphasize integration, there is debate as to whether we should limit our use of the word "integration" to the integration of disciplinary

1 A very early draft of this paper was presented in a virtual seminar to the University of Sonora in 2020, and a Spanish translation was published online at https://pics.unison.mx/doctorado/wp-content/uploads/2020/05/Reflexiones_sobre_interdisciplinariedad_en_la_ensenanza_de_posgrado.pdf We thank Dr. Emilia Castillo for inviting one of us, and the participants in the seminar for helping us clarify our ideas.

2 Szostak (2019) proposed nine defining characteristics of interdisciplinarity. Students deserve to be exposed to the debate around each of these, as well as to other literature that encourages, enables, and expands interdisciplinarity.

insights or apply it to several other elements of interdisciplinary practice such as integrating the perspectives of interdisciplinary team members (see Szostak, 2022). These simple arguments have important implications for student research: Each student should ask how they could integrate across disciplines relevant to their research topic. Students should be reassured that—though integration generally requires creativity—there are strategies that have proven quite useful in the pursuit of integration. We will discuss these below.

Graduate students should also be exposed to the debate around complexity. It is often argued that interdisciplinarity analysis is needed to address complex problems (Newell 2001; Repko & Szostak, 2020). It is not always clear what is meant by complexity. Yet this largely means that interdisciplinary research generally addresses interactions among phenomena studied in multiple disciplines.[3] Put another way, an important learning outcome for graduate programs is to appreciate that examining interactions among phenomena studied in different disciplines requires an interdisciplinary approach. This interdisciplinary approach integrates insights from different disciplines concerned with different aspects of the problem (Rashid, 2024).

The Interdisciplinary Research Process

Repko and Szostak (2020) outline an iterative ten-step process for performing interdisciplinary research. Though the book is aimed at upper-level undergraduates, it is often employed in graduate programs. Keestra, Uilhoorn, and Zandveld (2022a) are more concerned with graduate students: They employ a broadly similar process but add a step of employing research methods. That is, graduate students need to first develop an integrative theory or process as undergraduates might do, and then test this with one or (we will recommend below) more research methods.[4]

The steps in the interdisciplinary research process may seem banal at first. The first steps involve choosing a good research question and ensuring that it is suitably interdisciplinary. The next steps involve gathering relevant information. The subsequent steps involve creating common ground among insights and integrating these. Then researchers revise and test the resulting integrated insight. Finally, we persuade others of its importance. Though these steps might seem obvious, it is all too easy to forget one of them, or do it too fast, if not guided to pay attention to each.

3 In a minority of cases, interdisciplinary research may investigate phenomena studied in one discipline but apply theories or methods from multiple disciplines.

4 Keestra, Uilhoorn and Zandveld (2022b) compare the two books. Szostak (2022) promises that the next edition of Repko and Szostak (2020) will have more material on mixed methods research and other matters of importance to graduate students.

Students need to appreciate that the process is iterative. It is no crime to revise your initial question as your research proceeds or recognize that you need more information when you are at later stages. Revising early steps is standard research practice. This is a little scholarly secret: Scholars write up research as if they proceeded from question to answer far more directly than they did. Do not feel like you are failing just because you are flailing. This is especially important at the very start. Coming up with a good research question is one of the most challenging tasks, and a student should not lose heart if this takes some time.[5]

Most importantly of all, students need to appreciate that previous researchers have identified strategies for performing each step. Students can save themselves much heartache by familiarizing themselves with these strategies. This is best done while students are performing their own research: They can then fully appreciate the value of these strategies. For example, Repko and Szostak (2020) identify a handful of criteria for a good research question: A student who evaluates their research question according to these criteria may clarify their question in valuable ways. Interdisciplinary research is hard enough without failing to benefit from the advice of those who have been there before. In addition to the textbooks listed at the start of this article, students can be encouraged to consult the "About Interdisciplinarity" set of webpages on the website of the Association for Interdisciplinary Studies (AIS— https://interdisciplinarystudies.org/) for a useful survey of best practices in research (and teaching and administration).

Disciplinary graduate students can generally follow well-understood research methodologies within their disciplines. Interdisciplinary students need to justify what they do and why, until the community of interdisciplinary researchers agrees on a set of research strategies. It can be beneficial, then, to be able to employ strategies that have been used before, and recognize when reporting your research that these strategies have proven useful to many others. Alternatively, you might develop a new strategy (or at least alter an existing one), and then you can signal the novelty of your approach by again referencing the literature on the interdisciplinary research process.

One strategy that we particularly recommend is visually mapping your research question—whether in your thesis or dissertation or for course assignments (see Davis 2022, 2024; Wallis 2019). What phenomena are implicated by your research question, and which phenomena influence which others? Reflecting on such a diagram can alert you to phenomena or relationships that had not occurred to you at first. Even if you cannot embrace each phenomenon or relationship in your research, you should appreciate the larger picture. It is very useful in a graduate seminar for students to share these maps. Other

5 Davis (2022) recommends a worksheet from Augsburg (2016) to help formulate research questions. This could be refashioned for graduate students.

students (especially if they have different disciplinary backgrounds) may be able to suggest useful additions to your map. Such an exercise might even lead to collaborative research.

Once you have a good map you can then usefully ask a further series of questions. What disciplines, if any, study each node and line on your map? What theories and methods might be employed to study each node and line? What data might proxy for each node, and how well? Which of these things has never been done (well) before?

Integration may seem the most frightening step to the novice researcher: What on earth do you do when scholars disagree about some critical element of your research question? As we will see below, integration generally requires some creativity, and this in turn requires both time and self-confidence. There are nevertheless some strategies for facilitating the task. The mapping exercise above may have a further use here: Scholars may appear to disagree because they are in fact talking about different parts of your overall research question. Indeed, a common source of disagreement is simply that scholars tend to emphasize the phenomena studied in their discipline. You can potentially integrate by showing that phenomena from multiple disciplines matter (and interact). Scholars may also disagree because they define key terms differently. You may be able to alleviate or eliminate differences by careful exercises in definition. When scholars do talk about the same well-defined process and still disagree, a useful strategy is to imagine a continuum between opposing arguments: an economist stresses rational decision-making, a sociologist stresses some sort of non-rational decision-making, and the astute interdisciplinary graduate student argues that in the particular situation being studied a mix of rational and non-rational elements will characterize decision-making.[6]

Interdisciplinary graduate students should be keenly aware of one important characteristic of interdisciplinary research—this often, though not always, takes longer to perform than disciplinary research (Ciarlante et al., 2020). This simple fact should be reflected in our expectations for graduate students (and their expectations too), and our tenure and promotion standards for faculty members. It motivates our desire as interdisciplinary teachers to communicate to students strategies for interdisciplinary research that have worked in the past so that they can avoid common mistakes.

6 Rashid (2022) notes that graduate students often need to integrate across both ethical and scientific arguments. Many of the techniques used for integrating across the latter can be applied to the former.

Mixed Methods Research

Whereas undergraduates may perform impressive research by simply integrating insights from multiple disciplines, graduate students are generally expected to apply one or more of a dozen methods employed across the scholarly enterprise (Szostak, 2004, describes the strengths and limitations of the methods). One common approach would be to use one or more methods to test a hypothesis formulated by integrating disciplinary insights.

While disciplinary scholars tend to see their discipline's methods as superior (Ciarlante et al., 2020), interdisciplinary scholars are urged to appreciate that all methods have value. Interdisciplinary graduate students may thus wish to employ more than one method in their research. Fortunately, there is a vast literature on mixed-method research, and works such as that by Hesse-Biber and Johnson (2015) usefully summarize this literature. Familiarity with this literature may well be the main thing that graduate students need to know that is not addressed at length in existing textbooks on interdisciplinarity.

The literature on mixed methods recognizes two broad types of research. In the first, different methods are applied to different elements of a research question. In the mapping exercise recommended above, you might have found that some relationships can be studied using statistical analysis while other relationships are best appreciated through interviews.

In the second type of research, multiple methods are applied to the same relationship. This may occur sequentially, as when interviews are employed to ascertain the reasons for particular statistical regularities or irregularities. Alternatively, multiple methods may be applied simultaneously. Here we explicitly appreciate that all methods are biased and attempt to "triangulate" across the results obtained from different methods in order to gain a less biased appreciation of the relationship in question. Researchers attempting to triangulate should be particularly familiar with the strengths and limitations of different methods (Szostak, 2004).

There is considerable overlap between the literature on mixed methods and on interdisciplinarity (Szostak, 2016). The key to both is an appreciation that no method or discipline is perfect. Both grapple with the fact that disciplines tend to reify their methods and may thus disdain scholars who borrow from multiple disciplines. Yet both literatures emphasize that it is eminently feasible to do so. The mixed-methods literature argues that a scholar can readily develop expertise in multiple methods. And just as the interdisciplinary literature warns scholars to appreciate the power of "disciplinary perspective" (see below), the literature on mixed methods warns us to recognize that methods are embedded within broader "methodologies." This broader context often includes tacit understandings of how to perform research in a particular discipline. These methodologies guide how questions are chosen, which data is employed, how it is interpreted, and so on. The graduate student can only

pick up the relevant tacit knowledge by both reading widely in a discipline and interacting with scholars or students from that discipline.

With a few exceptions, there is no evidence that interdisciplinary strategies such as those described above have been widely adopted by interdisciplinary graduate programs (Rashid, 2024). Thus, all interdisciplinary graduate programs should familiarize their students with:

> The fact that all methods have strengths and limitations (and thus biases), and should know the particular strengths and weaknesses of any method they apply.
>
> The different types of mixed methods research and what the literature has to say about how best to combine methods.
>
> The fact that all methods are embedded within methodologies that are mostly tacit: Students should be careful of inadvertently offending disciplinary expectations.

Creativity and Interdisciplinarity

Creativity is generally defined as producing some idea that is both novel and useful. Novelty, it is widely appreciated, comes from drawing a new connection among existing ideas. Since the interdisciplinary researcher seeks to draw connections and (hopefully) produce something useful (that is, that some audience will appreciate), then interdisciplinary research is an inherently creative act (see Darbellay, 2024). However, the interdisciplinary researcher should not be apprehensive that creativity is essential to their task for three reasons (Szostak 2017a):

> We all have creative potential (and indeed are all creative in our daily lives)
>
> We can learn to be more creative (Darbellay, 2024, has advice on how)
>
> Interdisciplinary education itself enhances creativity, for it exposes us to a broad range of ideas that we might integrate across, and guides us to see issues from multiple perspectives

It should be no surprise that the interdisciplinary research process, as described above, bears a strong similarity to the creative process as outlined by many authors. In both cases, we must start with a question or problem. We then need to gather relevant information. There is then an act of inspiration in which we make novel connections. We then carefully revise and test our inspiration. Last but far from least, we persuade others of the value of our inspiration.

There are three key points we would make about creativity here. First, you should recognize that the act of inspiration occurs subconsciously. There is also generally a role for subconscious thought processes in acts of persuasion. Interdisciplinary research thus necessarily combines conscious and subconscious processes. Importantly, the subconscious needs some time to operate. We all have experiences in life where we are walking in a park or taking a bath, and suddenly the solution to some problem in our life comes to us. The lesson here for graduate students is that if they spend every waking minute worrying about their research, they are unlikely to come up with great ideas. You need to relax and think about other things—or ideally about nothing at all. (There are conjectures that music, aromas, and other stimuli are conducive to inspiration; feel free to see what works best for you.) Yet there is no use in relaxing until you have done much work and are very familiar with your research question and what others have said about it. Inspiration, it is often noted, can only come to the prepared mind. One of our favorite techniques is mind-mapping (Buzan, 2010), in which you place all relevant ideas on a piece of paper and draw lines among those that seem to be related. This is similar to the mapping exercise above but can include theoretical, empirical, and methodological ideas. You consciously study this for a while, and then relax. This sort of exercise often encourages us to draw connections subconsciously that we were not able to do consciously.

Second, there is a tradeoff throughout the research process between creativity and feasibility. If you read in epistemologically distant disciplines—physics and literature, say—you may find it hard to draw connections, but any connections you do draw are likely to be quite novel. Likewise, the broader your research question, the more likely you are to both stumble and be really creative. And, sadly, the broader your approach, the easier it is for other scholars to spot weaknesses in it. The student should make a conscious decision about how creative they want to risk being.

Third, creativity smartly shared is better than creativity not shared. The histories of both art and science are littered with innovations that were ignored for decades or centuries. It may well be that the key to being a successful creator is not so much having great ideas as being able to convince others of the value of these great ideas. Scholars and students should not shrug and say, "I had a great idea. It was ignored." We have a responsibility to market our ideas. Moreover, persuasion in academia involves more than just producing compelling evidence—though hopefully this is important. A telling metaphor or anecdote or picture may be more important in getting your ideas across. This brings creativity back in: These metaphors or anecdotes or pictures will likely not be immediately apparent and thus have to be created.

The Relationship between Disciplines and Interdisciplinarity

Graduate students in any interdisciplinary program need to appreciate that interdisciplinarity is still widely misunderstood within the academy. Many disciplinary scholars mistakenly fear interdisciplinarity because they confuse it with anti-disciplinarity (see Jacobs, 2013, for example). Graduate students should appreciate the advantages of the sort of specialized research that occurs within disciplines. A group of scholars that shares an understanding of a set of theories and methods and terminology can converse very easily. They do not have to explain the theory or method they are employing or describe the phenomena they are investigating but can move quickly to describe small tweaks they may have made to preceding research. Yet this advantage of specialized research comes with a cost: These communities naturally ignore the theories and methods used by others and the phenomena studied by others. This disregard creates the opening for interdisciplinary scholars who can build upon the insights of disciplines to create a more comprehensive understanding, and then let disciplinary scholars know what they are missing by ignoring alternative theories, methods, and phenomena.[7]

There is thus ideally a symbiotic relationship between disciplines and interdisciplinarity. Each can benefit from the other. We may well urge disciplines to be more flexible but should not wish to erase specialized research from the face of the earth. We can patiently and humbly explain the implications of our research to disciplinary scholars while appreciating their hesitance to embrace new theories or methods or phenomena. Graduate students who are aware that some disciplinary scholars have misplaced fears about interdisciplinarity can write and present their research in a way that calms those fears. In doing so, they not only advance their own careers but the acceptance of interdisciplinarity within the academy.

Interdisciplinary students at any level need to be able to define both disciplines and interdisciplinarity. We would argue that disciplines have a handful of essential elements:

> A set of phenomena that are usually investigated, and thus a set of typical research questions
>
> Favored theories (which evolve slowly through time)
>
> Favored methods
>
> Epistemological attitudes regarding how and how much we can know about the world

7 Rashid (2022) makes an interesting observation that the interdisciplinary research process often guides him and his graduate students to suggest hypotheses for disciplinary research that would not have occurred to a researcher embedded in that discipline.

> An institutional structure of departments, disciplinary associations, and journals, that reward those who ask the right questions with the right theories and methods, and punish those who do not.

Note that these elements cohere. Disciplines choose methods that are well-suited to investigating their theories and investigate phenomena to which these methods are well-suited. If a discipline has chosen quantitative methods, it will theorize about phenomena that can be quantified and ignore phenomena that cannot. Quantitatively-oriented disciplines tend to believe epistemologically that a great deal of objective understanding is possible, while qualitatively-oriented disciplines tend to think that there will always be scope for different interpretations. The institutional structure of the discipline will then encourage and reward a coherent "disciplinary perspective," or way of looking at the world, that combines its theoretical, methodological, epistemological, and other preferences.

Much of this "disciplinary perspective" may be subconscious. Disciplinary perspective provides a critical barrier to cross-disciplinary communication (the other main barrier is differences in definition, discussed briefly above). Disciplinary scholars may tend to underappreciate any idea emanating from a different perspective. This will often reflect differences in theory, method, research question, and epistemology. The best antidote to this communication barrier is open-minded conversation. One useful technique is to employ a questionnaire on methodological and epistemological issues, and then invite a discussion about why people gave different answers. Such conversations yield greater understanding and a softening of extreme attitudes (O'Rourke at al. 2013).[8]

Interdisciplinary research, then, can be understood as asking a research question that crosses disciplinary boundaries. This will most often involve engaging with phenomena that are studied by different disciplines. It will often involve utilizing theories or methods from different disciplines. It will certainly involve integrating insights from different disciplines. This, in turn, will require evaluating these insights in the context of disciplinary perspective. It will likely require reflecting on epistemology and developing an interdisciplinary epistemological outlook (see our discussion of philosophy of science below). Less obviously, it will involve either meeting the expectations of some interdisciplinary community of scholars or struggling to meet some set of disciplinary expectations.

As noted above, one common characteristic of interdisciplinary research is "complexity." That is, interdisciplinary scholars and students engage in research questions that involve interactions among many phenomena. Whereas disciplinary scholars often (though far from always) study systems

8 O'Rourke et al. (2024) provide much useful advice on how to employ such questionnaires in both undergraduate and graduate classrooms.

of stability among the phenomena they study, interdisciplinarians often study unstable systems. Indeed, the systems of stability studied within disciplines are usually shocked by phenomena studied by other disciplines (Szostak, 2017b). Disciplinary scholars may be well aware of these potentially destabilizing effects but may nevertheless find interdisciplinary discussion of these disturbing. Moreover, interdisciplinary understandings are often "messier" than disciplinary understandings. Though the interdisciplinary researcher can sometimes produce a tidy answer, they may well find that they favor quite different explanations of different causal relationships within their complex problem. The interdisciplinary graduate student should recognize that complexity creates another set of challenges in persuasion.

Depth versus Breadth of Interdisciplinary Knowledge

Graduate students need to do original research. They need to establish that they have both mastered a relevant literature and moved beyond it. Moreover, they need to move beyond in a manner that is recognized as appropriate by some academic community.

It is often recommended that interdisciplinary graduate students pursue a "T-shaped" expertise (van der Zwaan, 2017, p. 156), where a depth of knowledge in one discipline is coupled to breadth of knowledge across other disciplines. They can then ideally establish a reputation both within that discipline and within the community of interdisciplinary researchers. They will likely pursue a research question that resonates within that discipline, and utilize theories and methods from that discipline. They can innovate by showing how either the phenomena studied in other disciplines, or theories and methods (or perhaps terminology) employed in other disciplines, can shed light on that research question. This is the safest form of interdisciplinarity for it has a strong family resemblance to disciplinary research. The student should nevertheless be aware that many disciplinary scholars will be suspicious of any borrowings from other disciplines. For example, economists have until recently downplayed the cultural influences upon economic decision-making—though this is changing. Faced with a paper applying sociological theory and employing interviews or surveys (rather than the mathematical modeling and statistical analysis favored in economics), many economists might remain thoroughly unconvinced, even if most of the paper employed economic theory and methods. An interdisciplinary scholar might view the same paper as only one, limited perspective on the problem because it relies on one discipline more than others.

An alternative approach is to recommend a depth of understanding of interdisciplinarity itself, combined with a breadth of knowledge across a set of disciplines relevant to a particular research question. The student's

innovation here may involve mastery of the interdisciplinary research process, and especially the ability to integrate insights from multiple disciplines. It will likely also involve some mastery of mixed methods analysis: The student will be expected to provide some evidence for the theoretical integration that they have achieved. That is, the student, having posited some theoretical synthesis, will need to combine methods from different disciplines in investigating this.

In doing so, they can be guided by an appreciation that disciplines tend to choose methods that are biased in favor of their theories (Szostak, 2004). Mathematical modelling is well-suited to the common assumption of rational choice in economics (for then we need not examine thought processes in detail but merely know the individual's goals and choices), whereas interviews and surveys are much more likely to uncover non-rational influences upon decision-making. Though it is crucial that interdisciplinary scholars test theories from discipline A with methods from discipline B, they should appreciate that scholars from discipline A will likely then be suspicious of their findings. One underappreciated advantage of mixed methods research is that different disciplines tend to identify with particular methods. The interdisciplinary researcher can thus usefully triangulate across diverse methods—though the risk is that disciplinarians will disdain the nefarious influence of unfamiliar methods in such a study.

In deciding between these two approaches to interdisciplinarity—depth in a discipline versus depth in interdisciplinarity—the student might wish to reflect on where they hope to land a job. Though the world and academy are slowly shifting toward interdisciplinarity, many interdisciplinary scholars will find themselves looking for jobs in disciplines, or being interviewed by an employer with a disciplinary background. Lyall (2019) explores the challenges that interdisciplinary graduate students face (at least in the United Kingdom) in an academic job environment that often favors disciplines. She notes in particular that interdisciplinary scholars spend a lot of time explaining their research—and often the essence of interdisciplinarity itself—to disciplinary colleagues. Interdisciplinary scholars may seem to be "jack of all trades, master of none," but "the unique strength of interdisciplinarians is not their knowledge of several disciplines but their more tacit, integrative skills and panoptic perspectives" (p. 66). Yet tenure and promotion decisions are often made with respect to disciplinary standards (p. 99). It may then be safer to pursue T-type interdisciplinarity.

Students should also be guided to think about where they might publish their research. The trick that both disciplinary and interdisciplinary scholars need to learn is that scholarship is a conversation. You may think your ideas are brilliant, but you must in the first paragraph(s) of a paper or book convince others that your ideas are useful to understanding questions of interest to them. You need, that is, to enter an existing conversation and add to it. Ask yourself what conversation you are entering. An interdisciplinary scholar

may find that they are entering multiple conversations. One potential advantage of interdisciplinarity is that you may be able to publish your findings in different places by fitting them into different conversations. Yet you need to understand a conversation fairly well to enter it. You need not only to know what questions scholars ask but what the key disagreements are and what theories and methods have been applied. Note that in persuading others to pay attention to your ideas you may have to reframe your research question(s) in order to fit their conversation—unless you had originally formulated your research question(s) with that conversation in mind. More practically, what journals does this conversation occur in, and how open to ideas from multiple disciplines do they seem to be?

Team research

It is important to appreciate that individuals can perform interdisciplinary research. Still, it can be advantageous to combine researchers with expertise in different theories, methods, and disciplines. The advantage is obvious: No individual researcher needs to master all of the theories or methods employed in the research project. Yet students considering collaborative research—whether in graduate school or later in their careers—should be made aware of a set of challenges:

> Team members still need to know enough about the research undertaken by other team members to be able to combine their research usefully.
>
> Team members will have to grapple with the differences in perspective and terminology that plague cross-disciplinary communication. (They can usefully employ the strategies for addressing these that we discussed above.)
>
> It is not enough to gather a set of people with the necessary expertise. They also have to work together, and thus need to have personalities that fit together. One arrogant person can destroy a team that dislikes arrogance.
>
> Team members need to be able to depend on each other. It can be useful to have each member perform some small task early on to establish dependability.
>
> We have stressed that interdisciplinarity is a creative process. Team meetings must strike a balance: There must be scope for innovation (brainstorming) but enough structure that each team member feels that the project is moving forward.
>
> It can be useful to agree early on about whose name appears on publications (or grant proposals or patents) and in what order. Many teams get sunk through battles over such things.

> Large teams need a leader who can guide but respect the ideas of all. It is now widely appreciated—at least among scholars of interdisciplinarity—that somebody on the team (ideally the leader) should be an expert in interdisciplinarity itself. Lyall (2019, p. 67) appreciates that those with interdisciplinary graduate training "should be regarded as catalysts, bridge builders and integrators who are good at bringing people together and making links." She argues (p. 95) that interdisciplinary education fosters leadership, communication, and negotiation skills.
>
> All teams need some way of keeping track of what everyone is doing, and working collaboratively on research articles.

Happily, there is a ton of advice on team research out there. See the websites of Science of Team Science (https://www.inscits.org/) and Transdisciplinarity-Net (https://transdisciplinarity.ch/en) and also Hall et al. (2018). Corbacho and Fiore (2024) describe how to teach teamwork skills to students. Students should appreciate that the skills required to be a successful team researcher are different from those required to be a successful individual researcher.

Philosophy of Science

Every graduate student should know a bit of philosophy of science. However, this is especially important for interdisciplinary graduate students. Students within particular disciplines may be able to have successful careers while naively believing that their method(s) is flawless, and that their discipline is slowly but surely progressing toward incontrovertible truth (or not, depending on the discipline). Since interdisciplinary research tends to be messy (with many interacting variables) and uses multiple theories and methods, it is crucial for interdisciplinary graduate students to know that contemporary philosophers of science agree that proof and disproof are impossible, no method is perfect, and there are always alternative explanations of any research result. Though some philosophers are nihilistic (that is, they treat scholarship as a game), others argue that the best we can do is slowly amass argument and evidence until a consensus is achieved (provisionally) within some academic community. Most such philosophers further argue that we can be most confident in a result that is supported by research employing more than one method (and perhaps theory). This understanding of philosophy may provide limited solace when some referee complains that you have not proved your line of argument. Yet it should guide you to appreciate that no argument is perfect. It is also the case that almost no argument is totally misguided: You should always seek a kernel of truth within any widely held line of argument. The interdisciplinary task of integration may seem bizarre to those who mistakenly think that ideas must be totally right or totally wrong, but makes enormous sense once we accept that most ideas are imperfect.

A few other lessons from the philosophy of science deserve mention (Szostak, 2007):

> Language is inherently ambiguous, but there are strategies for reducing ambiguity.
>
> Scholars are biased in many ways (consciously or subconsciously), but there are strategies for both individually and collectively reducing bias.[9]
>
> The phenomena that we study interact in myriad ways. There are no "closed systems" of phenomena such that none of them interact with phenomena outside the system. We are always, then, analyzing some part of a hugely complex set of interactions. We should never lose sight of the possibility that some phenomenon outside our research program exerts an important influence on the phenomena we study.
>
> There are empirical regularities in the world, but these must often be contextualized since all phenomena are causally related to phenomena outside the research study (A has effect Y on B but only in the absence of C, for example).
>
> There is an external reality, though humans are limited in their ability to accurately or precisely perceive this.

The Value of an Interdisciplinary Research Seminar

To this point, we have stressed a variety of definitions, strategies, and understandings that can usefully be communicated to graduate students. Nevertheless, we have had cause along the way to refer to tacit understandings that are harder to identify and thus teach. Lyall (2019) wonders if these tacit understandings might be more important than the formal understandings we have focused on above. These understandings are best communicated in graduate seminars in which graduate students discuss their research. These seminars can serve a wide variety of purposes:

- As noted above, students can give useful advice to each other. This will especially be the case if the students in the seminar have different disciplinary (and sociocultural) backgrounds. This sort of advice can be facilitated by formal exercises in which students try to flesh out (for example) a visual map of each other's research question. Students can then adjust their choices about which disciplines to draw upon, and how and why.

9 Schmidt (2021) makes a compelling philosophical argument for blending the instrumental interdisciplinarity that this article focuses on with critical interdisciplinarity, which examines power imbalances and collective biases in the academy. Some graduate programs will likely want to explore critical interdisciplinarity in detail.

- Such seminars can help students in clarifying methodology. The sort of questionnaire employed by O'Rourke et al. (2013) might be employed to aid students in appreciating each other's approach to research (see O'Rourke et al., 2024). Oberg (2013) suggests a slightly different set of questions, regarding the student's purpose, reflexivity, and so on that are also designed to guide the student to clarify their research question and methodology. Lyall et al. (2011) also propose a set of questions.
- This advice can also be practical: how to choose a supervisory committee and address particular program requirements (and especially the nature of a dissertation proposal), get published, and obtain grants.[10] It can also address the myriad little challenges one faces in doing a large-scale research project for the first time. Such seminars might usefully also reflect on the risks and benefits of an interdisciplinary career, and how students might best prepare themselves for the job market (Lyall 2019).
- Conversations in such a seminar can strengthen understandings of different disciplinary perspectives.
- Students may decide to collaborate and can then learn about the challenges of and strategies for successful team research. Lyall et al. (2011) report that students in such seminars often discover connections between their research interests that were not immediately important.
- Such seminars can and should encourage metacognition—reflection on how we think, and thus the biases we may have. There are again particular exercises that might facilitate this goal. Brooks et al. (2019) recommend three strategies for encouraging metacognition: tests that expose implicit biases, critical reflection on group-performed research, and critical reflection on one's identity and approach.
- More generally, such seminars can encourage attitudes conducive to interdisciplinary research such as open-mindedness, respect, collaboration, and intellectual flexibility. Stokols (2013) discusses how to encourage such attitudes, as does Augsburg (2014).

In sum, while there is much that we can teach graduate students, there is much that students can only learn while doing research. Since interdisciplinary researchers face a common set of challenges, it is beneficial for students to gather and share their challenges and triumphs. In doing so, these seminars also serve to communicate that interdisciplinary research is challenging but also feasible and rewarding. Students noodling away in isolation can become anxious; it is healthy to appreciate that other students are grappling with similar problems.

10 Collett (2021) discusses a variety of challenges that interdisciplinary graduate students face, including conflicting supervisory styles and expectations about the purpose of a doctorate, increased administration, and pressure to publish in multiple fields.

Students need to be exposed to examples of both good and bad interdisciplinary research. The sort of seminar discussed here, focused on student research, allows the students much scope for identifying strengths and weaknesses in each other's approach. Yet students need also to be exposed to both exemplary and questionable examples of published interdisciplinary research. They should evaluate papers and books in light of their understanding of the interdisciplinary research process. Did authors employ appropriate strategies, and did they employ them well?

Some Thoughts on Administration and Teaching

Interdisciplinary graduate students, especially if they aspire to work in academia, deserve to know something about the role and status of interdisciplinarity within the wider academy. They are, after all, affected in myriad ways by these institutional considerations as they pursue their studies. We are purposefully brief here.

The modern research university was designed around disciplines. While interdisciplinarity is now widely advocated, there is often still a power imbalance between disciplines and interdisciplinarity. Interdisciplinary scholars must strive to ensure the continued viability of their programs, and to gain appropriate resources and institutional visibility (Augsburg & Henry 2009; Litre & Burstyn, 2024). Graduate students looking toward academic jobs should be aware that hiring committees at many institutions may want to see an ability to teach and research within a disciplinary setting. This is changing as more undergraduate (and graduate) teaching programs are created and gain enough institutional stability to employ full-time interdisciplinary scholars, but is still a problem (more in some parts of the world than others; Vienni-Baptista & Klein, 2022).

Though the ideal institutional structure for encouraging interdisciplinarity is not obvious, there is much accumulated knowledge about what works and what does not in program administration.[11] Ideally, administrative structures encourage disciplinary scholars to appreciate the benefits of interdisciplinarity. Most importantly, career progress decisions regarding interdisciplinary scholars need to be based on interdisciplinary criteria: Interdisciplinary scholars too often suffer by being judged by disciplinary standards. (This is why

11 Cross-appointments, interdisciplinary departments, and flexible department structures (in which scholars from multiple disciplines share a department) all have advantages and disadvantages. The most important single factor may be a senior administrator with responsibility for and understanding of interdisciplinarity, and some budgetary influence. Funding formulas have sometimes proven useful: Interdisciplinary programs that attract students then gain guaranteed funding (Tanner, 2022). Lindvig (2023) compares the "loud voices" of administrators talking about interdisciplinarity with the "soft voices" of those actually doing it.

the AIS has a document providing advice on promotion and tenure guidelines on its website.)

Likewise, best practice strategies for interdisciplinary teaching have been identified. Students pursuing a teaching career should be familiar with these. Szostak (2024) provides advice on a wide range of issues and an entry point to the wider literature. The "About Interdisciplinarity" set of webpages on the AIS website, as mentioned above, also provides advice on both teaching and program administration.

Interdisciplinarity is lauded for potentially providing insights into pressing public policy challenges. Interdisciplinarity might thus enhance the reputation of the entire scholarly enterprise. Interdisciplinary research can transcend the biases and disagreements that characterize scholarship.[12] Dupin and Lyall (2024) discuss how policy concerns often motivate the creation of graduate interdisciplinary programs, and how such programs might better prepare graduate students for policy work.

Possible Graduate Interdisciplinary Courses

How might a program be structured to include all this material? A core course about the interdisciplinary research process is likely essential (Rashid, 2021). Students should be expected to complete a research project for the course (individually or in groups). The strategies for performing interdisciplinary research are only fully appreciated when students apply them. Discussion of creativity should figure prominently in the course. Such a course should also include lots of material on mixed methods analysis. Alternatively, a second course might focus on mixed methods analysis. In either case, students should be taught that all methods have strengths and weaknesses and shown the multiple ways in which different methods can usefully be combined. This material is also best learned while students are applying it to a research project.

We have mentioned above the importance of a graduate seminar in which students discuss their research. Such a course might be structured so that much of the information described in this article, but not included in the courses above, is conveyed in the first couple of weeks. This material can be used to encourage discussions among students about why they were drawn

12 This point was recognized by the British Academy (2016, p. 81): "Even if the research findings originate in distinct disciplines, their full value to policymakers will be revealed only after they have been combined into a coherent, IDR package." Notably, this finding reflected extensive surveys with both researchers and policy-makers. Gabriele Bammer of Australian National University has been advocating linkages between integrative research and policy-making for decades. She (and Peter Deane) founded Integration and Implementation Sciences (https://i2s.anu.edu.au/), a network and website that advocates for and provides advice on the interconnected acts of integration and policy implementation.

to an interdisciplinary program and what they hope to achieve in the program and beyond.

Beyond this essential material, there is scope for considerable diversity in graduate programs. Pursuit of T-shaped interdisciplinarity will require in-depth exploration of a discipline. Most programs will have a thematic focus and will thus need courses that introduce students to the literature on that theme. Note, though, that there are common interdisciplinary challenges and strategies that transcend themes. Courses on the interdisciplinary research process, mixed methods analysis, and research seminars can usefully be taken by students from interdisciplinary programs with a different thematic focus.

The NUS Graduate School for Integrative Sciences & Engineering

It is useful at this point to describe one graduate program that incorporates the ideas above.[13] In 2003, the National University of Singapore (NUS) established the NUS Graduate School for Integrative Sciences and Engineering (NGS) with a mission to enable PhD students to pursue interdisciplinary research across the domains of science, engineering, computing, and/or medicine. Realizing that solving real-world, complex problems required integrative research approaches, the university launched the direct-entry "NGS PhD scholarship" to push students to venture into fields different from their own and conduct research that transcends traditional disciplinary boundaries.

NGS had 2 main objectives:

- to drive research uniting two or more fields
- to develop integrative thinking and a scholarly ethic through its core curriculum

NGS students were able to choose supervisors from two or more different fields thanks to NGS's close ties with other Faculties and Schools in NUS and with the research institutes of Singapore's Agency for Science, Technology and Research (A*STAR). NGS students also benefitted from NUS's web of synergistic, complementary partnerships with leading research institutes in the United States, United Kingdom, Continental Europe, Japan, China, South Korea, and Australia. These connections meant that NGS students could pursue world-class research at home and abroad.

NGS's core curriculum, which comprised the three mandatory courses described below, provided training in areas not covered by traditional PhD

13 Other significant interdisciplinary doctoral programs (Rashid, 2024) include: the Swedish National Graduate School for Competitive Science on Ageing and Health (SWEAH), Duke University's Bass Connections, Sorbonne University's Interdisciplinary Doctoral Programs

curricula (course descriptions are reproduced verbatim from the respective source pages):

> *Academic Professional Skills and Techniques.* The goal of this module is to introduce students to NGS and to equip them with the academic know-how to succeed in this programme. Among other things, students will practice their academic writing and presentation skills. They will engage in in-depth research discussions and learn how to conduct a scientific dialogue. There will be intense scientific discussion on topics within and across discipline with instructors and peers in the form of small group journal clubs. (https://nusmods.com/courses/GS5002/academic-professional-skills-and-techniques)
>
> *Research Ethics and Scientific Integrity.* The module covers issues that graduate students in science and engineering shall face at some point during their PhD candidature and in their subsequent academic careers. Through lectures, discussions and presentations, students shall ponder on and analyze ethical issues and dilemmas associated with data archival, mentoring, authorship, credit sharing and conflicts of interest. They shall rationalize internationally sanctioned rules and regulations in dealing with ethically sensitive research subjects. They shall be taught sensible and appropriate approaches in dealing with incidents of scientific misconduct, and how ethical integrity should and could be maintained in spite of research intensity and competition. (https://nusmods.com/courses/GS6001/research-ethics-and-scientific-integrity)
>
> *Interface Science and Engineering.* The module consists of a series of lectures and discussions/presentations that would provide students with an interdisciplinary exposure and knowledge foundation for selected research areas/themes that are of prime importance to humankind, and where interdisciplinary science and engineering are frequently practiced. Some of these areas are traditional strategic areas which NUS has great research strength in, and others are emerging areas of intense interest. Each theme is taught and coordinated by two instructors, who will contribute to different, yet complementary, perspectives of the theme. The areas/themes may include "infectious agents and global pandemics", "Omics", "Renewable Energy", "Human-Computer Interactions" and "Environmental problems/climate change". (https://nusmods.com/courses?q=gs6883a)

These courses were taught by faculty members from different departments so that students would develop an interdisciplinary mindset, cultivate a range of professional skills (both "hard" and "soft"), and possess a keen sense of academic honour and integrity.

The NGS PhD programme is now known as the Integrative Sciences and Engineering Programme (ISEP) under the NUS Graduate School (NUSGS).

The NUS Graduate School

The NUS Graduate School (NUSGS) was established in 2020 to provide leadership in graduate education at NUS and to strengthen the University's culture of curiosity-driven and innovation-oriented learning and research for PhD students across all faculties (and not just one programme). NUSGS oversees all of the University's graduate research programs, coordinates outreach efforts, and fosters greater collaborations across disciplines.

NUSGS requires all PhD students to take the two courses described below which, similar to the NGS courses, provide training in areas not covered by traditional PhD curricula (course descriptions reproduced verbatim from the respective source pages):

> *Academic Communication for Graduate Researchers*. Designed for all PhD students of the NUS Graduate School (NUSGS), this course facilitates further development of students' academic literacies in critical reading, writing and oral presentation. For critical reading, students will be guided to deconstruct and evaluate arguments—competences which students will then deploy by writing a proposal. In writing the proposal, students will need to demonstrate the ability to use suitable academic conventions. This proposal will subsequently be delivered as an oral presentation to a cross-disciplinary audience. This course utilizes a blended learning approach, where students' learning experiences will comprise in-class and online synchronous and asynchronous lessons and activities. (https://nusmods.com/courses/NG5001/academic-communication-for-graduate-researchers)
>
> *Research Ethics for Graduate Researchers*. This course, compulsory for all PhD students in NUS, introduces the learner to ethical issues in research. It provides an in-depth analysis of core topics, namely data management, publication practices, authorship criteria and responsibilities, research integrity, misconduct, questionable research practices, and conflicts of interest. Learners will be allowed to choose two elective topics based on their research needs. A case-study approach will serve as the basis for an in-depth analysis. Each topic emphasizes the importance of promoting ethical conduct in research. A blended learning 2.0 pedagogical approach involving synchronous and asynchronous learning activities will be adopted. (https://nusmods.com/courses/NG5002/research-ethics-for-graduate-researchers [Forthcoming])

Another key aspect of PhD education under NUSGS's charge is the "Three Minute Thesis" (3MT), an annual competition that celebrates the research of PhD students. The 3MT is an opportunity for students to refine their academic presentation skills by succinctly explaining their research in language

appropriate to a non-specialist audience; and to encourage socialization that fosters interdisciplinary collaborations by drawing students out of their disciplinary "silos."

Since 2021, NUSGS has been running training workshops to prepare NUS PhD students for local and overseas 3MT competitions. In 2023, a PhD student from NUS's Integrative Sciences & Engineering Programme won first prize in the Universitas 21 (U21) 3MT competition (https://universitas21.com/news-and-events/news/u21-three-minute-thesis-r-global-competition-2023-winners-announced). This was the first time that an NUS PhD student won first prize for 3MT at the international level.

Concluding Remarks

This article has outlined a list of concepts, strategies, and practices that we should strive to teach graduate students. The list is not short, but it is certainly feasible. One question that merits further inquiry is whether existing textbooks and resources are sufficient for the proper guidance of graduate students. Such a question is only answerable if we first agree on what it is that graduate students need to learn. A related question involves the training of graduate supervisors. Dupin and Lyall (2024) worry that supervisors are often unaware of what a good interdisciplinary thesis should look like. We hope that this paper sets the stage for answering these questions.

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