INTERDISCIPLINARY RESEARCH AND PROBLEM SOLVING: A GUIDE FOR STUDENTS

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Common areas of interdisciplinary study

Colleges and universities have introduced a variety of interdisciplinary studies programs during the last forty years or so. A 2006 survey of 222 colleges and universities by the Social Science Research Council indicated that the ten most commonly offered interdisciplinary majors are:

63.55%	Environmental studies and science
44.86%	Women's and gender studies
36.45%	Neuroscience and psychobiology
36.45%	American studies
33.64%	Biochemistry and molecular biology
31.78%	Asian and East Asian studies
28.04%	International relations
21.50%	African American and Africana studies
16.82%	Latin American studies
13.08%	Intercultural studies

(Repko, Buchberger, & Szostak, 2014, pp. 11-12)

The need for interdisciplinary research and problem solving

The following passage explains the need for an interdisciplinary approach to understanding and addressing environmental problems. A similar explanation could be offered for the other areas listed above.

> [T]he methods, theories, models, concepts and thought styles that are at our disposal today have mainly been developed to explain, understand and predict phenomena and processes *within* the different academic spheres (roughly divided into the humanities, social sciences, natural sciences and technology). These spheres can only to a limited extent help us understand the interaction *between* nature, humans, society and technical systems. (Öberg, 2011, p. 11)

Discipline-based research and problem solving

Discipline-based work is carried out within the academic areas that are most familiar to students: biology, history, anthropology, mathematics, and so on.

Researchers, teachers, and students are commonly organized into college or university departments; they tend to belong to discipline-based professional organizations; they tend to publish their work in discipline-based journals and book series. So a student who is majoring in biology may take a class in cell biology, which is taught by a professor who earned a PhD in cell biology from a graduate program in cell biology, who is appointed with other biologists (perhaps including other cell biologists) to the university's biology department, who presents their research and networks with colleagues at the annual meeting of the American Society for Cell Biology, and who publishes articles in peer-reviewed journals like the *Journal of Cell Biology*. We could describe similar connections for most (but not all) major areas at most colleges and universities.

The Brooks College of Interdisciplinary Studies at Grand Valley State University was created to provide a place where faculty and students can engage in forms of learning and action that cross the typical boundaries between disciplines. Besides Environmental Studies, Brooks College houses programs in Liberal Studies; Women, Gender, and Sexuality Studies; Religious Studies; LGBTQ Studies; and area studies programs including African and African American Studies, East Asian Studies, Latin American Studies, Middle East Studies, and Chinese Studies.

The familiar lines separating established disciplines can appear to students as if they mirror some intrinsic structures that forever define the spheres of human knowledge. In fact, though, the divisions among disciplines are somewhat arbitrary and fluid. On one hand, they do reflect natural similarities and connections among researchers' interests—cell biologists share core interests, problems, methods, and vocabulary with other cell biologists; they do not tend to have as much in common with, say, experts in statistics, psychology, or the history of the French Republic. On the other hand, disciplinary divisions reflect the way universities and other scholarly organizations have found it convenient to organize people and material resources like offices, laboratories, and libraries. Perhaps it makes more sense in a small college to put the lone cell biologist in a department with other biologists and even chemists; in another, a group of cell biologists may be assigned to a separate Department of Cell Biology within the medical school, perhaps on a separate campus from the Department of Biology. (In one extreme case the author is aware of, perceived differences between the faculty with "applied" and "theoretical" interests led to the establishment of two separate Departments of Psychology, in separate buildings, within the same university. We might call this a case of dysfunctional **hyperdisciplinarity**.)

Note that as researchers explore the edges of their discipline, they often discover or create connections to other disciplines. They may then find themselves engaged in interdisciplinary inquiry and collaboration. In some cases, the new approach generates new insights, questions, methods, vocabulary, and a new community of researchers emerges, all of whom rely upon these same innovations. If the new approach becomes well-established and sufficiently distinct from its various disciplinary origins, it may become a separate interdisciplinary research area. Eventually—as in the case of biochemistry—the new interdisciplinary research area may come to look a lot like a separate new *discipline*.

Everyone loves definitions! Multidisciplinarity, interdisciplinarity, and transdisciplinarity

Repko (2008, pp. 20-21) offers the following explanations of key terms:

- **Multidisciplinarity** studies a topic from the perspective of several disciplines at one time but makes no attempt to integrate their insights. Multidisciplinary approaches tend to be dominated by the method and theory preferred by the home discipline.
- **Interdisciplinarity**. . . studies a complex problem. . . by drawing on disciplinary insights (and sometimes stakeholder views) and integrating them. By employing a research process that subsumes the methods of the relevant disciplines, interdisciplinary work does not privilege any particular disciplinary method or theory.
- **Transdisciplinarity** concerns that which is at once *between* the disciplines, *across* different disciplines, and *beyond* all disciplines. Its goal is (a) the understanding of the present world, of which one of the imperatives is the unity of knowledge, and (b) the solution of mega and complex problems by drawing on and seeking to integrate disciplinary *and stakeholder views* on the basis of some overarching theory.

There is potential for some confusion, with two different meanings of the term "transdisciplinary":

- "[One] variant of transdisciplinarity calls for 'trans-sector problem solving' where the focus of study is a mega problem or grand theme such as 'the city' or 'ecological sustainability.' Such mega and complex problems require collaboration among a hybrid mix of actors from different disciplines, professions, and sectors of society." (Repko, 2008, pp. 20-21)

  This form of transdisciplinarity is "the cooperation of academics, stakeholders, and practitioners to solve complex societal or environmental problems of common interest with the goal of resolving them by designing and implementing public policy." (Repko, et al., 2014, p. 36)

  Öberg (2011) uses the term **transacademic** to describe work that involves both academic and non-academic participants.
- Some transdisciplinary scholars, however, "reject disciplines altogether, believing that the very concept of the discipline is outdated, inappropriate, or a device to serve special interests": *e.g.*, feminist critique of disciplinary structures of knowledge as "gendered and oppressive constructions." (Repko et al., 2014, p. 36)

  This **critical interdisciplinarity** "questions disciplinary assumptions and ideological underpinnings. . . . Examples of fields that have strong critical imperatives include women's studies, developmental studies, environmental studies, and cultural studies." (Repko et al., 2014, p. 37)

  To avoid confusion, it might be preferable to use the terms "transacademic" and "critical interdisciplinarity" when discussing these two very different ideas.

Key features of interdisciplinary studies

The following summary is based on the survey of five definitions of interdisciplinarity provided by Repko, et al. (2014, pp. 24-25, 181).

1. Knowledge creation is regarded as an open-ended **process**.
2. The process is **purpose-driven**; the point of the process is to solve a **problem**.
3. Because of its orientation to a problem that is defined by certain concerns, values, and priorities, the process is **value-laden**.
4. The problem is characterized as **complex** or **"wicked,"** emerging within a complex system that often involves a mix of natural and social factors.
5. The process draws upon **multiple disciplinary perspectives**.
6. The information and techniques drawn from different perspectives are transformed to new knowledge by **integrative thinking**.

Kinds of problem that are commonly addressed by interdisciplinary and transdisciplinary studies

- Essentially contested concepts (see Gallie, 1956; Jacobs 1999; Connely, 2007)
- No technical solution problems (see Hardin, 1968)
- Wicked problems (see Rittell & Weber, 1973; Coyne, 2005)
- Social messes (see Horn, 2001)
- Mega problems (see Repko, 2008, pp. 20-21)

Interdisciplinary research: Guides to the process

Repko, et al. provided the following "road map" for interdisciplinary research (2014, p. 202):

1. Define the problem or state the research question.
2. Justify using an interdisciplinary approach.
3. Identify relevant disciplines.
4. Conduct a literature search.
5. Critically analyze the disciplinary insights into the problem and locate their sources of conflict.
6. Reflect on how the interdisciplinary process has enlarged your understanding of the problem.

Klein (1990) offered a more detailed outline of the interdisciplinary inquiry process:

> Interdisciplinarity is neither a subject matter nor a body of content. It is a process for achieving an integrative synthesis, a process that usually begins with a problem,

question, topic, or issue. Individuals must work to overcome problems created by differences in disciplinary language and world view. Although there is no absolute linear progression, there are a number of different steps in the process:

1. a. *defining* the problem [question, topic, issue];
   b. *determining* all knowledge needs, including appropriate disciplinary representatives and consultants, as well as relevant models, traditions, and literatures;
   c. *developing* an integrative framework and appropriate questions to be investigated;
2. a. *specifying* particular studies to be undertaken;
   b. *engaging* in "role negotiation" (in teamwork);
   c. *gathering* all current knowledge and *searching* for new information;
   d. *resolving* disciplinary conflicts by working toward a common vocabulary (and focusing on reciprocal learning in teamwork);
   e. *building and maintaining* communication through integrative techniques;
3. a. *collating* all contributions and *evaluating* their adequacy, relevancy, and adaptability;
   b. *integrating* the individual pieces to determine a pattern of mutual relatedness and relevancy;
   c. *confirming or disconfirming* the proposed solution [answer]; and
   d. *deciding* about future management or disposition of the task/project/patient/curriculum.

Related problem solving methods

- **Systems thinking** (Meadows, 2008; Aronson, 1996-98): Systems thinking may be contrasted with the "analytical thinking" that characterizes traditional disciplinary approaches to inquiry. Systems thinking "focuses on how the thing being studied interacts with the other constituents of the system—a set of elements that interact to produce behavior—of which it is a part. This means that instead of isolating smaller and smaller parts of the system being studied, systems thinking works by expanding its view to take into account larger and larger numbers of interactions as an issue is being studied. This results in sometimes strikingly different conclusions than those generated by traditional forms of analysis." (Aronson, 1996-98, p. 1)

- **Design thinking** (Brown & Wyatt, 2010; Morris & Warman, 2015): Design thinking is an approach to problem solving that originated in industrial product

> design, but which has been adapted into a more general process that may be applied in a variety of complex situations. It emphasizes beginning with a deep understanding of the needs of the people whom the solution is intended to help, moving on to a creative phase of developing ideas about how to address the problem, and then a process of experimental prototyping and testing of the most promising solutions before settling on a final approach.

Interdisciplinary learning as a special case of integrative learning

> Integrative learning comes in many varieties: connecting skills and knowledge from multiple sources and experiences; applying theory to practice in various settings; utilizing diverse and even contradictory points of view; and, understanding issues and positions contextually. Significant knowledge within individual disciplines serves as the foundation, but integrative learning goes beyond academic boundaries. Indeed, integrative experiences often occur as learners address real world problems, unscripted and sufficiently broad to require multiple areas of knowledge and multiple modes of inquiry, offering multiple solutions and benefitting from multiple perspectives. (Association of American Colleges and Universities, "Statement on Integrative Learning," 2004, quoted in DeZure, 2010, p. 373)

DeZure noted that not everyone agrees about the extent to which interdisciplinary students need to master bodies of disciplinary knowledge:

> there are faculty who challenge the centrality of disciplinary knowledge inherent in these definitions, preferring interdisciplinary approaches to teaching and learning that reduce the hegemonic influence of the disciplines in higher education, focusing instead on general skills in critical and analytical thinking and integrative problem solving. (DeZure, 2010, 373)

This view aligns with the "critical interdisciplinarity" described by Repko, et al. (2014, pp. 36-37). Such an approach to interdisciplinary education would focus mainly on developing the kinds of knowledge, skills, values, and habits that facilitate the integration of knowledge. Students with this preparation would be distinctively equipped to work as facilitators on a team of disciplinary experts. Their own expertise would be in coordinating knowledge and fostering communication within the group's joint research and problem solving efforts.

Interdisciplinarity as a distinctive realm of inquiry: Strengths and limitations

The interdisciplinary expert working with a team of specialists is in a position to recognize both the strengths and the limitations of the project at hand, of team members' knowledge, and of their process of inquiry. Öberg observed that

> One of the key elements of a holistic approach is that no matter how much information you gather, it will never be possible to fully understand or predict the behaviour of a complex system. Various disciplines have developed different ways to demarcate, describe and understand the whole or a piece of the whole. The process by which you formulate the aim of a study, alone or in collaboration with others, helps you to define your choices and thus set the boundaries of your study. In order to study something it is necessary to choose to study some but not all issues, to pick one out of many potential perspectives, to use one or a few out of a number of possible methods—which inevitably means that other issues will not be studied, and other perspectives and methods will not be used. The knowledge gained through the study will be one picture out of several possible ones. Even when you take a holistic approach, a study will *always* only render one description among many of the whole or a piece of the whole. (Öberg, 2011, p. 84)

Öberg noted that, without the specialist's deep disciplinary expertise, the interdisciplinary inquirer must develop levels of disciplinary literacy, familiarity, and competence that are sufficient to carry out rigorous work, or to evaluate the work of others.

> All procedures demand craftsmanship, and if you are the one collecting the information, you must master the basic techniques. If someone is collecting the information for you, you must know enough about the technique to be able to figure out if the one collecting the information for you has done a reliable job or not. (p. 86)

Finally, Öberg cautioned against the temptation—or the expectation of others—that the interdisciplinary inquirer ought to try to master every discipline relevant for a project:

> To become "sufficiently" knowledgeable in a discipline is in itself immensely time consuming, since disciplines have fuzzy borders; it can always be debated if you know enough to count as an expert. You risk finding yourself reading to become "sufficiently" knowledgeable in each of the identified disciplines. And you will always find yourself insufficiently knowledgeable. No matter what, you will *always* encounter people who will argue that you do not know enough in discipline X. (p. 30)

There is thorough "mastery" of the knowledge, techniques, traditions, and culture of a relevant discipline—and then there is knowing enough to draw on the mastery of disciplinary specialists and make progress toward solving the problem at hand. The latter is very often what is needed. Many of the problems that arise in in transacademic work are not conceptually difficult to address, but require creative, practical implementation of well-established knowledge and techniques. Many academic experts are trained to conduct "pure research" that presses against the very boundaries of established knowledge. As Robert Frodeman observed, though, "when academics go out into the world they quickly find that most people have quite specific and limited needs for additional knowledge" (2014, p. 62).

What we know, how we know it, and how we know that we know it

Mansilla (2010, p. 295) proposed a distinctive epistemology, an account of what knowledge is, for interdisciplinary studies:

> A *pragmatic constructionist* epistemology rooted in the work of philosophers Nelson Goodman and Catherine Elgin meets the criteria [for an adequate account of interdisciplinary knowledge]. As *constructionist,* the epistemological framework proposed posits that the purpose of inquiry (and learning) is the advancement of understanding. Inquiry is not the accumulation of propositional knowledge in search for certifiable truths. Rather, inquiry seeks a broad, deep, and revisable understanding of its subject matter. Taking a *pragmatist* stance, the proposed epistemology puts a premium on the purpose of knowledge construction. It judges the worth of an emerging insight by its effectiveness in advancing the desired understanding.
>
> Ultimately, understanding involves the construction of what Elgin defines as a *system of thought in reflective equilibrium.* Elgin argues that a system of thought is in reflective equilibrium when its components are reasonable in light of one another and the account they comprise is reasonable in light of our antecedent convictions about the subject at hand. Such a system, she notes, affords no guarantees. It is rationally acceptable not because it is certainly true but because it is reasonable in the epistemic circumstances. Building and validating understanding involve a series of delicate adjustments by which new insights are weighed against one another and against antecedent commitments about the subject matter. A conclusion is deemed acceptable not through a linear source of argumentation but through a host of sources of evidence (much of which may not precisely 'match up', but paints a telling picture) which include findings, statements, and observations, as well as useful analogies, telling metaphors, and powerful exemplifications. The acceptability of a knowledge system is to be measured against the purposes of inquiry that guide its production. Justification is also provisional. In Elgin's view, considered judgment recognizes the unfortunate propensity for error of the human mind and adapts to it by demanding corrigibility. This epistemology demands that we be prepared to criticize, revise, reinterpret, and abandon intellectual commitments when more reasonable ones are conceived.

The skills of the liberally educated interdisciplinary expert

Much interdisciplinary research and problem solving is conducted in a collaborative team with other academic experts or professionals. In such a setting, the biggest challenge is to make each member's distinctive knowledge and insights available to the whole team in a constructive and useful way, while preventing their disciplinary commitments from becoming barriers to progress. The goal is to promote **integrative learning** about the problem at hand, rather than generating a clash of fragmented and dissonant points of view on it. The team must see itself as engaged in an ongoing process of integrative learning, the purpose of which is to find a solution to the problem.

Many kinds of barrier to this process may arise. The group might arbitrarily overemphasize one disciplinary perspective or one member's contribution at the expense of others. Differences in members' assumptions or their commitment to different, and even incompatible, fundamental principles may lead to deep confusions or conflicts that are hard to unravel. A single strong-willed, persuasive, or charismatic member may dominate and distort the course of inquiry. Multiple strong-willed members may set up an unproductive rivalry for control. Particular team members may come to feel excluded or alienated because their perspective does not seem to receive proper consideration. Most people who have worked on group projects will be familiar with these and other ways that interdisciplinary work can fall apart—and there is little that is more frustrating than seeing an important project fail due to these kinds of conflict.

The AACU statement cited previously gives us an account of integrative learning: "connecting skills and knowledge from multiple sources and experiences; applying theory to practice in various settings; utilizing diverse and even contradictory points of view; and, understanding issues and positions contextually."

We now turn to two more practical questions:

- How exactly does integrative learning happen?
- How does the interdisciplinary expert help facilitate the process of integrative learning?

DeZure indicated that there are some distinctive interdisciplinary skills, aside from whatever specialized skills one might possess in connection with their particular disciplinary expertise. These "general skills in critical and analytical thinking and integrative problem solving" are, for the most part, the practical skills of philosophical thinking. They in turn draw upon the kind of broad knowledge and habits of thinking that are characteristic of liberal education (as contrasted with technical or professional training). Among the skills and knowledge that the liberally educated interdisciplinary expert brings to the process, and which are especially important to the "how" of interdisciplinary learning, are the following:

Integrative skills

1. Define or redefine the project's core purpose(s)
2. Facilitate communication across areas of expertise by translating and clarifying jargon and technical terms
3. Identify the embedded or guiding values of the various participants
4. Provide a store of relevant general and broad knowledge, including historical and cross-cultural perspectives

Critical skills

5. Introduce specific methods and strategies for integrative learning, *e.g.*, systems thinking, design thinking, or idea mapping
6. Identify and challenge unacknowledged assumptions in epistemology, metaphysics, and values

7. Offer critiques of both quantitative and qualitative methodologies
8. Display and critique the logical structure of arguments
9. Point out cognitive biases, logical fallacies, and mistakes in the use of statistics
10. Present critical and constructive counterexamples

Creative skills

11. Identify similarities across disparate fields, such as common patterns in processes and logical similarities among problems
12. Propose thought experiments, such as reversing a key assumption
13. Identify instances of "positive deviance" in a complex situation, where people or processes are already successfully solving a problem by acting outside the norm
14. Introduce precedents from history, philosophy, or literature and other arts
15. Imagine unorthodox alternatives

Given this list of skills we can begin to envision what the interdisciplinary expert would actually do to facilitate inquiry on a team. In principle, any member of a team might well do the exact same thing as the interdisciplinary facilitator—and in fact, one would expect others to begin do so as they become more familiar with the inquiry process and the kind of communication that is needed. The interdisciplinary facilitator is the one who is comfortable and familiar with this process from the beginning, and who can teach it to the others—mainly by modeling it in their meetings. It may be helpful to consider some concrete illustrations of how the skills listed above can be applied:

1. A university-wide task force sets out to design a new library to accommodate a book collection, and a student and faculty population, that have outgrown the old building. In exploring how people now actually use libraries, though, the facilitator helps the group understand that the actual purpose of their project is not to design a bigger "library"—conceived as a quiet, climate-controlled building to house books—but rather to design a common space where people can go, individually or in groups, to acquire and generate knowledge with easy access to stored records of all kinds. What is needed is not a bigger book warehouse, but a comfortable "learning and information commons" that happens to include a large collection of books (most of which do not need to be on display, as long as they are well-catalogued and easily retrievable).

2. The economist on a team insists that a solution should "maximize utility" and that the group must be conscious of the "opportunity costs" involved in various proposals. The facilitator notices embarrassed silence from several people in the room—they all learned these fundamental concepts, at some point, but have forgotten their exact meaning. "I'm not sure everyone is familiar with exactly how you're using those terms in this context. Could you give us an example to clarify it for everyone?"

3. An engineer, a mathematician, a visual artist, and a historian walk into a meeting with very different assumptions about what we can know and how we can know it. As O'Rourke and Crowley put it, people may have widely differing views concerning "what we are like that we may know the world (i.e., the *Epistemology* category) and what the world is like that we may know it (i.e., the *Metaphysics* category)" (2013, p. 1943). The mathematician may tend to rely on formal reasoning about abstract, universal cases and be most comfortable when a solution can be logically proven to be true. The engineer may look first to established, familiar solutions—or, in a different style of thinking, to the newest available technology—and will accept one as right when it is tested and shown to work more or less as expected. The historian might prefer to amass a large body of documented evidence for any proposed answer, and, knowing that every inquiry will overlook some evidence and that all evidence is open to differing interpretations, may be very reluctant to accept any solution as decisive or final. The artist may tend to look at the margins of the problem rather than the well-defined core, seeking its peculiar and interesting anomalies; they may look for connections and resemblances to seemingly unrelated problems for a new understanding. Moreover, the artist may tend to think and to communicate in images and visual patterns rather than in sentences or equations. The facilitator does not reconcile these different attitudes, assumptions, and styles of thinking about knowledge, but can help participants bring them to light so they can learn how to use them and explicitly consider which are appropriate to the problem at hand. O'Rourke and Crowley have developed a formal workshop procedure called the Toolbox to help in accomplishing this, but the process can be largely achieved through a discussion of fundamental questions such as "To what extent is past experience actually relevant to this question?" or "What kind of certainty can we really expect in this situation?"

4. Just as there are frameworks like the Toolbox for exploring fundamental assumptions about knowledge, there are well-developed frameworks and instruments for promoting integrative and creative thinking about problems. Design thinking, for example, lays out a process of inquiry that begins with empathetic observation of needs and cycles through definition of purpose, ideation, prototyping, and testing of a proposed solution. Systems thinking might challenge the analytic search for explanations by drilling down into details about a large number of specific cases (*e.g.*, Are there any common features in the lives of the 30 people who committed violent crimes in this neighborhood last year?), and instead pull back to look at an array of different general data for patterns that correlate with the overall trend (*e.g.*, Can we overlay demographics, income, education, employment, housing, and even the weather for the neighborhood, and compare it to data from other times and places?).

These four examples should provide a sense of the kinds of practical things a liberally educated interdisciplinary facilitator is particularly well-equipped to do on a team. A great deal of it comes down to conscious and reflective use of good thinking. Some,

however, require formal training (*e.g.*, logic and statistics) or familiarity with particular methods, theories, or tools for thinking.

All of these skills facilitate **integrative learning**. "Integrative learning" is itself a technical term which should be clarified. "To integrate" things just means to combine them so they become parts of a larger whole—think of the way we integrate water, flour, eggs, and sugar into cake batter. Consider what is going on in our four examples: they show specific ways in which different kinds of knowledge and different methods of inquiry can actually combine to become parts of an interdisciplinary group's integrative learning process.

In questioning the group's basic assumption about what a library is, the facilitator allows everyone to realize several important things. Members of the team realize that they *had* a basic unstated assumption, and that the past experiences that gave rise to that assumption might not be altogether relevant to the experience of 21st century users. They come to see that basic concepts like "library" can and do change over time in response to new technology and new user expectations. Finally, they learn that there are in fact experts in library design and use who have made suggestions about what is essential to the function of a library. In this case, what is essential is information and learning—but with the realization that information now means more than just a collection of printed books, and learning means more than just reading them.

In asking the economist to explain their somewhat technical terms, the facilitator accomplishes several important things at once. First, these crucial economic concepts are made immediately available for the whole group to use. Beyond this, though, the facilitator is alerting everyone to the problem with using unfamiliar disciplinary terms (or jargon), while gently revealing that everyone will at some point feel a little stupid because they don't know what's being said. They show that this is nothing to be embarrassed about, and model how to overcome the problem in communication. After one or two requests for experts to explain their terminology to the group, everyone will be aware of the need to minimize the use of jargon, and to help others understand it when it is introduced.

In the example of the engineer, mathematician, and historian, the facilitator displays their differing disciplinary assumptions about how we know the world, and what is worth knowing about the world. These assumptions give rise to various methods and standards of inquiry. As Aristotle said, different levels of certainty are appropriate to different kinds of subject matter (*Nicomachean Ethics*, I.3.). A mathematician is right to insist on absolutely certain logical proof of a theorem, while a historian is right to accept what is at best only a very likely explanation of an event. In the context of trying to solve a particular problem, there may be a place for multiple standards of certainty, and different ways of establishing knowledge. As in the case of clarifying jargon, making these different standards and ways of knowing explicit can avoid miscommunication; beyond this, the different approaches are then available for everyone in the group to use as appropriate.

When a facilitator brings in established frameworks and instruments for approaching a problem, everyone involved finds themselves thinking according to an unfamiliar method. Nobody's disciplinary expertise is privileged, but it is all potentially relevant. Everyone will need to adapt their accustomed ways of thinking, and their familiar standards of certainty, to the new framework. In doing so they will all have to reflect on their

own methods and assumptions. They will need to explicitly consider how well those approaches fit the present situation. If they do seem to have something to contribute, they will need to consider the best way to communicate that connection to the others in the group. The external problem-solving framework thus serves as a neutral playing field for all the disciplines involved in the project.

The virtues of integrative learning

Recall that integrative learning involves "connecting skills and knowledge from multiple sources and experiences; applying theory to practice in various settings; utilizing diverse and even contradictory points of view; and, understanding issues and positions contextually." We can now see some of the ways that this occurs. Individual members of the team become explicitly aware of their own assumptions, beliefs, and commitments about knowledge and the world, and they begin to see the relative strengths and limitations of their own approach. At the same time, they become familiar with the assumptions, beliefs, and commitments of other kinds of experts. As a result of this encounter, the group members are able to combine these diverse ways of knowing into a process of interdisciplinary inquiry that is shared by the whole group, and which is oriented to the specific problem at hand. Recall Mansilla's (2010) observation that "The acceptability of a knowledge system is to be measured against the purposes of inquiry that guide its production." Another group, approaching another problem, would combine their diverse perspectives to create a different process for inquiry.

In this exploration of how the interdisciplinary thinker facilitates integrative learning within a group, we have focused on the skills involved. As Robert Frodeman noted, however, successful interdisciplinary work involves something beyond a mere collection of skills:

> Skill at interdisciplinary work thus becomes a matter of character rather than methodology. Interdisciplinary work requires the development of a peculiar set of virtues—or perhaps better said, the development of a set of virtues to a particularly heightened degree. These include the openness to new perspectives, a willingness to admit the inadequacies of one's own point of view, to be wrong and to play the fool, and generosity in interpreting the position and motives of others. Rhetorical skill thus plays as much of a role as logic, as we adjust our diction as well as our standards to the exigencies of the moment. (2014, p. 48)

The interdisciplinary thinker has distinctive intellectual virtues—habits and predispositions in thinking that help facilitate the inquiry. A broad liberal education is especially effective at helping students cultivate these virtues, and this is one of the factors that make liberal education especially important in an age of extreme technical and disciplinary specialization. As Frodeman observed, "We live in a deeply, irretrievably technological age; in what might be seen as an irony but which naturally follows, philosophy and the humanities have never been so necessary to our personal and public lives" (2014, p. 6).

T-people, gadflies, and flywheels

The interdisciplinarian is sometimes characterized as the "T-shaped person": they have "vertical" depth of expertise in their own discipline that is comparable to anyone else, but their ability to communicate and use these integrative, critical, and creative skills allows them to connect "horizontally" with people from other disciplines—the top of the T (Brown & Wyatt, 2010, p. 34). In academic settings it is usually safe to assume that everyone has, or is working toward, a formal degree in some discipline. Anyone with expert interdisciplinary skills whom we encounter in an academic setting will therefore usually be this kind of T-shaped person. The ultimate model of the T-shaped interdisciplinary inquirer would be the scholar who has deep expertise (the equivalent of advanced degrees and many years of study) in multiple disciplines. Aristotle, Da Vinci, and the eminent religious studies scholar Huston Smith come to mind as examples. These are excellent models of interdisciplinary thinkers and anyone would welcome a chance to work with someone like them. The world produces very few such polymaths and geniuses, though, and in my experience they do not tend to be appointed to our local committees and task forces. Brown and Wyatt set a more realistic expectation, that "every member of the team needs to possess a depth of skill that allows him or her to make tangible contributions to the outcome" (2010, p. 34). This makes sense where people are expected to provide some specific disciplinary expertise: the lone chemist needs to be a good chemist, the policy expert needs to be an actual expert on policy, and so on.

Transacademic projects often involve people who are not experts in any disciplinary field, however. Concerned citizens, volunteers at a non-profit organizations, and lower-level employees of a business or city government nonetheless may have much to contribute to the project. At a minimum—and quite importantly—they have expertise in their own concerns, their own perceptions of the situation, and on what the problem means within their own social and work circles. In some situations, this expertise may be far more important than any academic or professional expertise. The crucial thing about the T-shaped person is not that they possess some disciplinary expertise—it is that they are able to reach out and connect with others, and bring them into the inquiry. In short, it would be a mistake to assume that *every* member of an interdisciplinary team needs to have deep vertical expertise, as Brown and Wyatt suggest.

In environmental discussions it is sometimes assumed that one must possess scientific expertise in order to contribute anything. This assumption shaped the earliest interdisciplinary programs in ecology and environmental sciences. When it became apparent that increasingly detailed scientific knowledge alone was not having much effect on people's treatment of the environment, training in public policy and environmental law was added. This combination gave rise to interdisciplinary programs in natural resource management and environmental studies. Subsequently—with the recognition that there is more involved in humans' relations to our environments than is conveyed in science, policy, and law—there has been a movement toward broader "third generation" programs in environmental and sustainability studies. Such programs include education in environmental arts and humanities, so that students are familiar with the social, cultural, and historical contexts in which people interact with one another and with the world. They regard art, history, economics, biology, and geology as disciplinary and cultural

lenses through which people understand their world. They are able to move from one lens to another, drawing upon each to better understand and motivate people's behavior. Programs built on this model are broadly interdisciplinary. Many are examples of "critical interdisciplinarity," in that they see entrenched disciplinary separations as a limited way of thinking that has in some cases actually helped create the environmental problems we now face. The interdisciplinary environmentalist may thus sometimes be most effective when acting as a critic of certain kinds of disciplinary expertise.

Such a person is not working as a T-shaped person, but rather as facilitator and critic of the process of inquiry. This may mean taking on the role of a Socratic gadfly who exposes, provokes, and challenges the basic assumptions people bring to the process. It may also mean (at the same time) serving as the coordinator of the group's dialogue, facilitating the transfer of information and ideas among the whole group—in the same way that a flywheel in a machine serves to regulate the energy and direction of the whole system, thus affecting all the separate parts and helping them work together more efficiently.

As interdisciplinary projects become more common, we can expect a growing professional role for facilitators working as such "flywheel people." Frodeman noted that "trends strongly point toward the creation of a new discipline of interdisciplinarity, with specialists whose expertise lies in the analysis of how to communicate with and integrate across the disciplines, and between the disciplines and society." (2014, p. 40). Their main expertise would be in interdisciplinary research and problem solving itself. One can envision them working as consultants for organizations full of disciplinary experts, much in the same way that designers, marketing experts, and business strategists currently do. There is a place for both the T-shaped interdisciplinary expert and for the flywheel.

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