Disciplinary Breadth and Interdisciplinary Knowledge Production

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Lewis E. Gilbert
Columbia Earth Institute
405 Low Library / MC 4335
Columbia University
New York, NY 10027
v: 212.854.4830
f: 212.854.6309
e: gel@ldeo.columbia.edu

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Abstract: As the complexity of the challenges presented by our interactions with our planet continues to grow, we must develop new modes of knowledge production. In these modes, distinctions between multidisciplinary and interdisciplinary activities and processes have renewed importance. There are at least two distinct types of interdisciplinary activities distinguished by the disciplinary breadth they attempt to bridge. In the narrow case, reductionist processes reveal a common underlying principle or process which can serve as a Rosetta stone. In the broad case, no such common arbiter exists. Investigators must develop integrating vocabulary in the context of the full breadth of their work.

INTRODUCTION

In many fundamental ways it seems that we may have hit the percolation threshold of Earth. Far from implying that we should have another cup of coffee and another piece of pie, achieving this state of connection throughout our planet requires that we develop new ways of thinking about our relationship to Earth and about how we implement and manage our interactions with the planet (pie and coffee might help, but they alone won't do the trick).

The percolation threshold is a concept from physics. A system at that limit has interconnections which span the scale of the system and which are self-similar. The self-similarity of the interconnections implies that any subset of the largest system will also be spanned by clusters of all sizes.[1] In the sense used here, I am suggesting that human numbers and technological prowess have steadily increased to the point that we now have capabilities which rival those of natural systems and those capabilities are distributed in such a way that we now function on a continuum of scales which ranges from the global ($\sim 10^4$ km) to the most local ($\sim 10^{-2}$ km). The self-similarity and system spanning characteristics of the percolation threshold also allow information to deeply penetrate the whole system.

I have invoked the percolation metaphor to call attention to the fact that the relationship between humans and our planet has fundamentally changed. With that fundamental change come new requirements for human activities and new kinds of function of the planet as a whole. Rather than dwell on the accuracy and details of the metaphor above, the remainder of this paper is devoted to some observations and details related to how we must think about organizing ourselves to face the challenges brought on by our scale and prowess. As a concrete example of such a challenge, consider the concentration of CO_2 in the atmosphere. It is clear that fossil-fuel burning, distributed randomly over the surface of the planet, has increased the concentration of CO_2 in the atmosphere by about 1/3 since the onset of industrialization in the late 18th century. It is also well known that globally distributed oceans and forests are sinks in the global carbon

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[1] (Schroeder, 1991)

cycle. Furthermore the problem clearly has a global scale because the atmosphere is well mixed on very short time scales; thus carbon burned or removed in one place affects the concentration of the atmosphere everywhere. Finally, the complexity of the negotiations in Kyoto make it clear that small causes may have large effects (e.g., the near collapse of the entire process due to the rigidity of negotiators from a block of developing countries on a single, albeit important, point).

Necessary Knowledge

In the face of challenges such as changing atmospheres and climates, dramatic losses in biodiversity and globalization of economies, including the emergence of eastern Europe and China from decades of isolation, the US must give serious thought to the allocation of our resources (money and people in particular) toward the production of knowledge which will allow our nation to remain the global leader we have become accustomed to being. While the complexity of making such allocation decisions has been known for at least 30 years[2], the necessity of implementing structures to actually cope with that complexity has only arisen recently. It is clear in the CO_2 example above that integration of expertise from a wide range of disciplines will be necessary in order to fully understand the physical, biological and human elements of the carbon cycle and, based upon that knowledge, to devise and implement management plans for the chemical composition of the atmosphere.

Interdisciplinary endeavors of the scope we must now develop have been given very little attention up to now.[3] Thus as we move forward with development of science and related policies and budgets to address our nation's activities and role in the global context, we must take into consideration the fact that it will be necessary to carry out our research in new ways. Some of the things that must we consider in this new light include: how large research problems are articulated, how research teams are organized to address those problems, and how the results of these activities are propagated and evaluated.

In the following sections I sketch some of the 0^{th} order concepts which must guide our efforts to respond to large interdisciplinary research needs. The first section addresses the important distinction between multidisciplinary and interdisciplinary. I propose some working definitions as a foundation to organize our thinking and evaluation of how our research teams are actually working. The second section presents the idea of disciplinary breadth. The notion that some disciplines are more related than others is not new[4], but the implications for the organization of research have not been explored. I argue that there are at least two distinct kinds of interdisciplinary problems and that fostering the full range of necessary research will require that we recognize the differences between them.

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2 (Toulmin, 1964)

3 See (Klein, 1990) for a review.

4 Polanyi (1962) seems to have had the idea of disciplinary breadth within the sciences in mind, but he did not pursue it.

MULTIDISCIPLINARY VS. INTERDISCIPLINARY

One of the truisms in regard to the difficulties associated with establishing interdisciplinary groups is the necessity of developing a common vocabulary. Similarly, in discussions of interdisciplinary research itself it will be useful to be explicit in defining some terms. Most important is the distinction between multidisciplinary and interdisciplinary. Most groups can come to agreement on the following.[5]

Interdisciplinary- An activity can be said to be interdisciplinary when it produces knowledge that integrates over more than one discipline. Integration is the defining element. Interdisciplinary objects bridge two or more disciplines and result in "a new, single, intellectually coherent entity"[6] that is more than the linear sum of it parts.

Multidisciplinary - An activity is multidisciplinary when it assembles, in an additive fashion, knowledge from more than one discipline. Multidisciplinary objects combine inputs from more than one discipline, but the disciplinary elements retain their disciplinary identity and non-linearities and cross-correlations are far from dominant.

Both problems and approaches to problems can be either multi- or interdisciplinary. The case of problems is addressed in more detail below. Clearly we must strive to apply an approach which matches the character of the problem; that is while multidisciplinary approaches to broad interdisciplinary problems may yield advances they will not ever achieve the scaling necessary to fully penetrate the problem. While this is true, it is also likely that early endeavors to address large interdisciplinary challenges will of necessity, and consciously so, be multidisciplinary. Such endeavors must include as part of their charter, the goal of achieving interdisciplinary functioning.

In the following section, a brief application of these ideas is given for each of the individuals, groups and outputs of the research process.

People

Individuals can be interdisciplinary to the extent that they are familiar with and can use knowledge produced in more than one field. This usually requires that the practitioner trade off depth in a single field for breadth across the spectrum of interest. Often an interdisciplinary person will have degrees in more than a single discipline, but rarely will that person have achieved prominence in all of the fields in which they are credentialed.[7]

People are not usually thought of as being multidisciplinary. This becomes clear when the necessity of disciplines retaining their identity in a multidisciplinary object is called to mind. An individual who had knowledge of a variety of disciplines yet did not in some way integrate that knowledge would be quite an anomaly.

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5 Discussions with Michael Crow and Peter Eisenberger have helped clarify these definitions. The *Enabling Cross Disciplinary Programs* workshop at the *Organizing for Research and Development in the 21st Century* conference (24-26 April 1997, Washington, D.C.) concurred and added further clarity. Klein (1990, pages 56-73) arrives at roughly the same definitions and includes a more detailed discussion along with some case examples.

6 (Klein, 1990, p. 57)

7 There are of course exceptions which prove this rule.

Groups

The easiest group to form is a multidisciplinary one. It will be composed of a collection of people with different disciplinary backgrounds; the character of the group will reflect the disciplinary backgrounds and personalities of its members. In such a group the members bring their own expertise and interests to bear on the problem at hand but there is very little consideration of interactions or overlaps. Output from such a group usually resembles the blind men's report on elephants.

There are two possible configurations for a group which might be characterized as interdisciplinary. The first and easiest would be for it to be composed of interdisciplinary individuals. In this case, there is not necessarily any integration among those who make up the group and thus no guarantee that the group's output will reflect the character of the whole elephant any more completely than a multidisciplinary group.[8] On the other hand a group might be characterized as interdisciplinary if its initially alienated members had achieved a level of collaboration which allowed each member to completely represent the knowledge of each of the others. Clearly achieving this level of collaboration requires considerable investment of time and commitment and it is not common.[9]

There is a growing consensus in the scientific community that multidisciplinary groups are a better strategy for tackling complex problems than solutions which rely entirely on interdisciplinary individuals. The reasoning goes as follows: Consider a group of n individuals spanning some set of disciplines. If that group is made up of disciplinary experts, each of whom can reach a depth of 1 in their field, it will clearly be capable of greater depth in any of the represented disciplines than if that same group were made up of n individuals capable of depth $1/n$ in each of the fields. However, to get full advantage of the breadth represented by a multidisciplinary group, it may be necessary to include an interdisciplinary individual (this idea will be returned to below).

To maximize the disciplinary depth possible with a multidisciplinary group, experts in the represented disciplines need to be recruited. Disciplinary depth will reach a theoretical maximum in groups made up of the absolute leading experts; however this condition may not maximize the ability to achieve maximum breadth or integration. When considering multidisciplinary groups and their potential for knowledge creation, we cannot ignore the social dynamics of the group. The group dynamics place important constraints on the potential of the group for knowledge production and it is quite possible (likely?) that, at the extremes, there will be trade-offs between the effectiveness of the group as a whole and the disciplinary prominence of each of its members.

Knowledge

Producing new knowledge, more specifically finding solutions to problems or responses to challenges, is our overall objective. Disciplinary knowledge is the body of understanding related to a specific, historically well-defined, area of study. As in the case of elephants alluded to above, multidisciplinary knowledge is simply the linear

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[8] This conclusion may be softened somewhat as interdisciplinary people may have above average interest in integration.

[9] See for example the collaborative development scheme of (John-Steiner & Mahn, 1996) . See also Klein (1990) for several case examples.

sum[10] of two or more disciplinary bodies of knowledge relevant to a particular problem. Interdisciplinary knowledge expands multidisciplinary knowledge by exploring and developing overlaps, feedbacks and interconnections among the results of a range of traditional disciplinary explorations.

For example, a multidisciplinary textbook on greenhouse warming would include chapters on the chemistry of the atmosphere, on the physics of the atmosphere, and on the economics and politics of fossil fuel burning. In such a textbook each chapter would be freestanding and independent of each of the others. An interdisciplinary textbook on the same topic might include those same chapters but would also include discussions on the relationship between fossil fuel burning and the increase of CO_2 in the atmosphere, on the relationship between mixing in the atmosphere and fluxes of CO_2, and on the implications of development in currently industrializing nations. Furthermore it would include links from the integrating chapters to the disciplinary knowledge and would highlight important connections among the concepts in the integrating chapters as it built up a systems description.[11]

Gibbons and his colleagues have explored the notion of interdisciplinary knowledge in the context of problem driven research.[12] In their scheme, knowledge cannot be divorced from the contexts and the groups in which it is developed. They assert that a new mode of knowledge production has emerged which is distinct from the traditional disciplinary mode. The new mode is distributed among many institutions, very responsive to social needs and has distinct quality control and distribution mechanisms.

As the importance of problem-driven fundamental research[13] is further recognized the importance of developing interdisciplinary knowledge and fostering the structures that support such production will also grow. In the next section two fundamental problem types are described. Knowledge production in the first can be pursued within disciplinary structures with only slight modification. In the second, new production methods must be developed to augment our traditional

DISCIPLINARY BREADTH

It is not hard to find an investigator who has engaged in a project which they will label “interdisciplinary”; however, if you are not familiar with that person’s field or the problem being addressed you may find yourself puzzled by the label. To the participants, it is clear that they each have different trainings and come from distinct cultures; although these distinctions may not be apparent to an observer from outside the disciplines involved. To an observer sufficiently removed from the problem, the nuances of the multidisciplinary project are not always accessible. In this case the common elements of the problem dominate and disciplinary distinctions are lost. This contrast between the

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[10] Here I am using “linear” to indicate ignorance of important interconnections among the disciplinary understandings.

[11] Imagine a cross between a well developed hypertext document and Billy Pilgrim’s story in Vonnegut's *Slaughterhouse Five*.

[12] (Gibbons et al., 1994)

[13] (Stokes, 1997)

participant's label and the observer's impression begins to illuminate the idea of disciplinary breadth.

An example will help to clarify this contrast. In an effort to understand the variation in ice sheet flow and deformation in Antarctica, a geophysist and a glaciologist formed a team and brought their combined skills to bear. The geophysist was trained in marine geology and geophysics (MGG) and is an expert in collecting and interpreting underway geophysical data. She used these skills to outfit an airplane to collect data on the internal structure of Antarctic ice sheets and information about the interface between the ice and underlying rock. The glaciologist was trained as such and brought an expertise on the internal deformation and flow of glaciers. For all intents and purposes, the peer groups in which each of these people were trained do not intersect. They each brought a successful funding history from the NSF to the project; however, that funding came from distinct programs within the NSF. They had difficulty gaining funding and defending their science due to classical sniping across fields by reviewers. This project has all the characteristics of an interdisciplinary collaboration, yet when I *first* learned about it, I had difficulty understanding why it carried such a label. To me it seemed that they were studying glaciers using geophysics and that the problem was a clever use of MGG expertise. I had missed the glaciological nuance of the ice sheet problem and with that dropped the entire problem into the single discipline of geophysics.

While perhaps naive, the anecdote above hints at one of the principle classes of problems that will frame the notion of disciplinary breadth. A clearer example is the following: At a recent workshop,[14] a Department of Energy participant, whose field is chemical physics, noted that as a research scientist she had been working on interdisciplinary problems for 3 decades and that her organization has a long history of supporting such work. As we delved deeper into the details of these statements we learned that the range of problems she was referring to had a common foundation in the physics of molecules. Thus as research teams composed of people with physics, chemistry, and engineering backgrounds delved deeper into the problems around which the team had formed, they discovered a common underlying principle. In fact this is also the case in the ice sheet example above; as the problem was explored, its focus became flow along boundaries which is a physical problem common to both geophysics and glaciology.

A generalization of the interdisciplinary nature of the chemical physics and ice sheet flow problems is illustrated in Figure 1a. In that figure, an interdisciplinary challenge is identified and a team forms around it.[15] Each member of the team brings their unique disciplinary perspective to the problem, but there exists at least one underlying principle which they all hold in common. This common principle will be revealed if the investigation proceeds "far enough" in a reductionist mode.

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14 *Enabling Cross Disciplinary Programs* at the *Organizing for Research and Development in the 21st Century* conference (24-26 April 1997, Washington, D.C.).

15 The temporal relationship between the formation of the team and the identification of the challenge is an important one. In the multidisciplinary case it is clear that the problem can be enunciated prior to the formation of the team. This is probably also true of many interdisciplinary cases. It is not clear that *all* interdisciplinary problems can even be formulated in the absence of an interdisciplinary team.

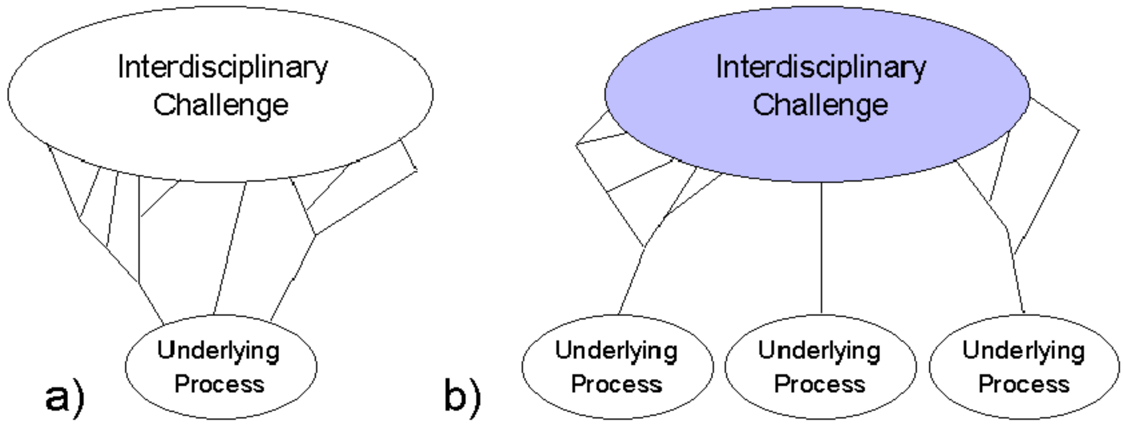

Figure 1: Two fundamental classes of interdisciplinary problems.

The underlying principle provides the rosetta stone for the development of a common vocabulary. Alternatively that principle can be thought of as *providing* the common language for the group. In that language, similar concepts with differing names can be translated and concepts unique to a particular discipline can be explained.

Figure 1b illustrates a very different situation. As in the 1a case, a challenge is identified and a team is formed; however in this case there is no underlying principle common to the entire team. While reductionist progress may reveal common foundations among some of the members, no amount of reduction will join the whole team.

In this case an *a priori* common language does not exist. Translations and explanations must be constructed by the team itself within the context of the unifying challenge and with little recourse to external arbitration.[16] It is in this context that an interdisciplinary individual in a largely multidisciplinary group can be important. While that individual may not have the disciplinary depth of any of the other members of the group, that person will be able to translate between the other experts and can serve as a catalyst for the development of the vocabulary and communication skills necessary for the group to move from the production of multidisciplinary output to interdisciplinary knowledge.

An example of the situation in Figure 1b is the problem of ecological valuation. In its simplest form this problem requires the attention of an ecologist and an economist. These two disciplines are rooted in very different realms with little or no “real”[17] overlap. Ecology and economics may share some mathematics, and that can be a useful tool in developing collaboration, but the *things* they study are fundamentally different. In the context of ecological valuation, ecology is focused on natural ecosystems and their functioning. Economics, as currently formulated, is focused on the functioning of human capital and monetary systems. In reductionist modes, ecology focuses ever closer on

[16] It is this need to develop a common language from scratch which casts doubt on the possibility of formulating all interdisciplinary challenges prior to the formation of a team.

[17] Here I am assuming the existence of “reality” which is independent of the observer or her context.

biomes while economics focuses ever closer on sectors and firms.[18] This is in contrast with the disciplines of chemical physics (chemistry and physics) which each focus ever closer on the workings of (for simplicity) solid state matter.

Integration in ecological valuation at the level of the challenge is clear in Costanza et. al.'s[19] recent effort to calculate the value of global ecosystem services and natural capital. That paper brought together global syntheses of land use and cover change, biome distributions and functions and cost / benefit analysis. The authors also note the potential importance of work on ethics, but did not include such considerations in their calculation. The work of the integration presented was all in translating and registering at the highest level of each of the elements. The results of their efforts are summarized in a table which gives value per unit area in a matrix of services and biomes. While interconnection among services and biomes is considered, it is considered only to avoid double counting; that is, it is considered only to be sure that it can be removed from the calculation! The paper as a whole is a linear sum of perspectives from several disciplines and represents a multidisciplinary addition to our understanding of ecosystem value.

The multidisciplinary nature of the Costanza example brings us back to some of the detail in Figure 1. While the integrating challenges have been labeled Interdisciplinary in that figure, multidisciplinary efforts are subject to the same taxonomy that has been outlined so far. Any challenge may have a particular mapping into the conceptual frame of Figure 1; the knowledge produced by efforts to address that challenge may be multi- or interdisciplinary depending upon the skill of the team addressing it. It is the extent to which the researchers are able to identify and harness interconnections among their own perspectives which determines the extent to which the team's output will capitalize on any non-linear potential inherent in the challenge.

Another detail of Figure 1 is the difference between shading of the challenge in 1a and the challenge in 1b. Figure 2 helps to illustrate the meaning of this difference. Figure 2 is a conceptual map into which academic pursuits can be classified. Disciplines such as physical oceanography and geochemistry map into the physical processes region; disciplines such as medicine and biology map into the biological processes region; and disciplines such as economics and engineering map into the human processes region. Some questions, such as anthropogenic forcing of atmospheric chemistry, require knowledge from two of these regions and those questions map into the intersections of two of the lobes. Finally, questions such as those related to the impacts of fossil fuel burning require perspectives from all three of the lobes and those questions map into the center of the diagram.

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[18] It may be that conceptual models which highlight analogies between sectors and biomes can be constructed, but these analogies should not be confused with real overlap. This point and caution should not be taken to minimize the importance of such analogy building. Quite the contrary, analogy building is in fact the activity which leads to the establishment of a common language at the challenge level (Figure 1b).

[19] (Costanza et al., 1997)

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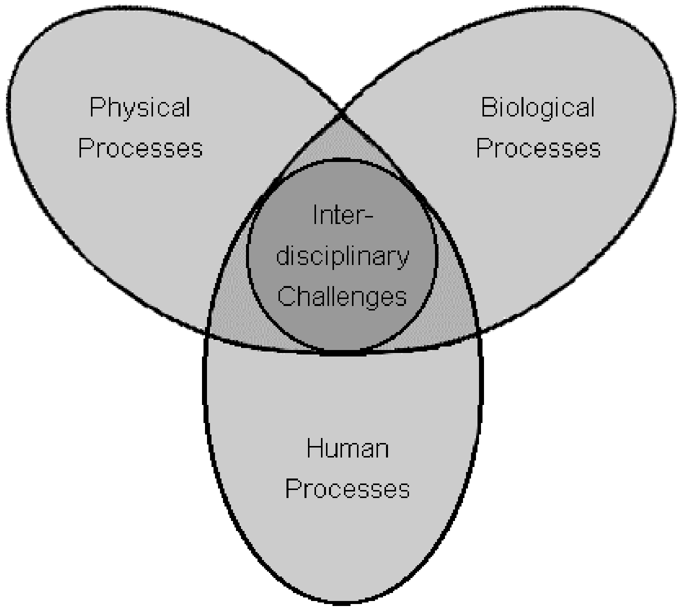

Figure 2: A conceptual disciplinary map.

The shading in Figure 1a indicates that challenges in that situation are at the same level as the outer regions of the lobes in Figure 2 while the challenges in Figure 1b map into the center of the disciplinary map. In addition to disciplinary problems, within the outer regions of any of the lobes in Figure 2, there are challenges which are interdisciplinary but which have a common foundation. These are problems which are analogous to the chemical physics and ice sheet examples above. Challenges which map into the central region of Figure 2 are inherently multi- and interdisciplinary and have roots which map into two or more of the outer lobes. As such the disciplinary roots of those problems do not overlap. While the translation necessary for interdisciplinary knowledge to be produced can be accomplished through coordinated reductionism in the outer lobes, this is not the case in the center of the diagram. In the center of the diagram, multidisciplinary knowledge can be produced through the combination of disciplinary reductionism. Interdisciplinary knowledge production in that region requires the construction of and agreement on vocabulary and technique in a more holistic context.

The distinction between these two fundamentally different types of problems formalizes the notion of disciplinary breadth. Challenges which are rooted in several principles which have little or no overlap have greater disciplinary breadth than those which are rooted in a common foundation.

SOME IMPLICATIONS

The scheme developed here is not meant to be an operational model, it is only meant to illustrate one aspect of the complexity of developing teams to produce interdisciplinary knowledge. The element of this model that is most important is the fact that not all multi- and interdisciplinary challenges are the same; thus the logistics of addressing them will vary depending upon the particular challenge. Infrastructure, in the form of funding mechanisms, communication networks, publications, etc., which is highly adapted for one class of problem, is not necessarily going to serve well for other classes. As the disciplinary breadth of a challenge grows, the need to integrate at the level of the challenge becomes greater. In particular, the need to explicitly and consciously develop a common vocabulary becomes ever more important. In addition to vocabulary, challenges with great disciplinary breadth have the need to develop common methodologies. At the very least, as in the ecological valuation example,[20] there is a need to modify existing disciplinary techniques to suit new multi- or interdisciplinary challenges.

In addressing challenges which have large disciplinary breadth (e.g. climate change) the contrast between multidisciplinary and interdisciplinary becomes particularly important. We must not be content with multidisciplinary solutions to our largest challenges. In the context of such challenges, multidisciplinary work fails to address the fundamental lack of overlap at the foundational level. As long as disciplinary identity is maintained, we are left with compilations that do not include interconnections among the disciplines. Such outcomes can provide important first steps toward the identification and understanding of those interconnections, but we must be sure that we take the time and invest the resources to fully explore them.

It is important that reductionist practice fails to produce integration in problems with significant disciplinary breadth. This fact has been recognized implicitly as our research organizations have come to recognize the importance and difficulty of interdisciplinary research. With the idea of disciplinary breadth outlined here and illustrated in Figures 1 and 2, it is clear that, while reductionist practice will continue to be important, we need to expand our research practices to include a range of integrating practices and infrastructures. Reductionist practice is the foundation of disciplinary progress and provides at least the physical and biological sciences with their current standards for rigor. We must bring analogous standards of rigor to the integrating practices we must now develop. Furthermore we should avoid thinking of reduction and integration as competing or exclusive activities. The challenge presented by the spectrum of disciplinary breadth is to use all of our available tools appropriately and to their fullest potential.

By definition, the production of interdisciplinary knowledge blurs boundaries among the people and ideas involved in the work. This blurring threatens the status quo and as such it is a stress on our research communities and institutions. Among other things, this reflects the great progress we have made in understanding our world and the fact that we have reached a point where we must address the complexity of our relationship to our planet. It may be that a great deal of this complexity is only apparent and is a result of the historical artifacts of our current disciplinary disposition.[21] As we explore interdisciplinary frontiers and build the capacity to address challenges with ever greater disciplinary breadth, the stress of our current transition will subside. If we are successful, our students' students will find interdisciplinary challenges of great breadth to be natural formulations and they will produce, as a matter of course, knowledge of significant breadth which is both rigorous and integrated.

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[20] (Costanza, et al., 1997)

[21] Note that disciplinary breadth is defined in the context of a particular portfolio of disciplines. As we progress we may find our current disciplines to be anachronistic and that a different portfolio is more useful.

References

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V. O., Paruelo, J., Raskin, R. G., Sutton, P., & van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature*, *387*, 253-260.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P., & Trow, M. (1994). *The new production of knowledge: the dynamics of science and research in contemporary societies*. Thousand Oaks: SAGE Publications.

John-Steiner, V., & Mahn, H. (1996). Sociocultural approaches to learning and development: a Vygotskian framework. *Ed. Psych.*, *41*(4), 191-206.

Klein, J. T. (1990). *Interdisciplinarity: history, theory, and practice* (1 ed.). Detroit: Wayne State University Press.

Polanyi, M. (1962). The republic of science: its political and economic theory. *Minerva*, *1*(1), 54-73.

Schroeder, M. (1991). *Fractals, chaos, power laws: minutes from an infinite paradise*. New York: W.H. Freeman and Company.

Stokes, D. E. (1997). *Pasteur's quadrant: basic science and technological innovation*. Washington, D.C.: Brookings Institution Press.

Toulmin, S. (1964). The complexity of scientific choice: a stocktaking. *Minerva*, *2*(3), 343-359.