The Chicken or the Egg: Does Interdisciplinary Collaboration Enhance Systems Model-Building or Does Systems Model-Building Enhance Interdisciplinary Collaborations?

Jessica L. Durfee[1], Jim I. Mills[2], Philip C. Emmi[3], and Craig B. Forster[4]
University of Utah
[1]Department of Communication
255 S. Central Campus Drive - LNCO 2400
Salt Lake City, UT 84112 USA
(801) 363-6285
jessicadurfee@yahoo.com
[2]College of Architecture + Urban Planning
[3]College of Architecture + Urban Planning
[4]Department of Geology and Geophysics

Abstract: Does interdisciplinary team collaboration enhance the knowledge generated and shared in systems model building or does model building enhance the collaboration and collegiality of interdisciplinary team members? This paper addresses the processes involved in constructing dynamic system models of "deep complexity" related to scientific and environmental issues. Typically such model-building requires the knowledge and expertise of specific disciplinary specialists. The examples used in this analysis are descriptive evidence of one team's efforts to model an urban airshed, which requires input from atmospheric chemists, biologists, engineers, meteorologists, and urban planners – just to name a few. The authors argue that addressing an emergent class of problems characterized by deep complexity requires an iterative process of interdisciplinary communication facilitated by model building. This model building, it is argued, serves as the "Rosetta Stone", which can lead interdisciplinarians to create an organic narrative to describe the system and enhance the quality of knowledge generated.

Keywords: interdisciplinary research, deep complexity, collaborative model building, system dynamics modeling.

INTRODUCTION

What comes first, the chicken or the egg? Does interdisciplinary team collaboration enhance the knowledge generated and shared in systems model building? Or does model building enhance the collaboration of interdisciplinary team members? The answer is "yes!" Interdisciplinary collaborations and mediated modeling activities simultaneously and mutually improve each other. In the spirit of the conference theme, "collegiality", this paper explores interdisciplinary collegiality and how the processes involved in constructing system models of complex scientific and environmental issues can create a symbiotic relationship between the scientists and the model-building.

Models of "deep complexity", which address issues such as biocomplexity or environmental science require the knowledge and expertise of many various disciplinary specialists. Specifically, the examples presented in this paper illustrate how modeling an urban airshed (i.e., the air quality in cities and heavily developed and populated areas) requires input from atmospheric chemists, biologists, engineers, meteorologists, and urban planners – just to name a few. This paper is based upon a descriptive study of a successful interdisciplinary team in order to illustrate the dynamics of human-model interactions. Before introducing the case study, it is important to first explain the significance of interdisciplinary research teams and systems modeling when tackling issues of "deep complexity".

Following a condensed review of the literature on interdisciplinary team research and systems modeling of complex science, the case study of an interdisciplinary team in Salt Lake City, Utah, USA will be introduced. The case study will first provide an overview of the interdisciplinary team and their goals. Second, examples of how interdisciplinary collaboration has enhanced the quality and accuracy of the systems model produced will be shared. Finally the case study includes examples of how the modeling process enhanced interdisciplinary communication and collaboration in this team.

The research question posed (Does interdisciplinary collaboration enhance model-building or does model-building enhance interdisciplinary collaboration?) leads to one answer, "yes!" both processes improve the other. However, it is impossible to differentiate which process influences and improves the other to a greater degree. Alas, one can not use an "either-or" mentality to explain the symbiotic relationship of interdisciplinary collaboration and systems model building. Systems model building improves interdisciplinary communication, because scientists of all shapes and sizes are able to contribute to a dynamic process. Building a systems model of complex environmental problems requires the insight of multiple perspectives, experiences, and disciplines. Likewise interdisciplinary collaboration improves the systems model produced. And if done correctly the process can lead to creative solutions for complex problems facing today's world.

What are Interdisciplinary Research Teams and Why are they Necessary?

Interdisciplinary research is becoming more necessary due to the societal and scientific complexities of problems, which are insoluble by single disciplines or experts (e.g. pollution, global warming, issues of land and water use). Complicated scientific issues, especially those related to the environment, require policy decisions and almost universally involve matters of the social, physical, and natural sciences. Such decisions need to be informed by interdisciplinary studies in order to be complete and accurate. Interdisciplinary studies are generally intersections of various theories, methodologies, and data from more than a single discipline. As complicated as it may sound, this conglomeration of epistemologies and methodologies is the only way to sincerely tackle complex scientific and environmental problems (Daily & Ehrlich, 1999; Heemskerk, Wilson, & Pavao-Zuckerman, 2003; Kostoff, 2002; Naiman, 1999).

It is important to first clarify and define concepts introduced in this section of the paper: deep complexity; interdisciplinary research and communication across specialization. "Deep complexity" refers to the physical and natural sciences, sometimes dubbed "hard" science (i.e. studies in biology, geology, physics, chemistry, and any combination of). Problems of deep complexity are defined as those issues that are embedded in social, technical and/or policy relevance, with less emphasis on discipline-related outcomes; e.g. global environmental change, natural resource management, economic globalization, etc. Importantly, these problems generally embrace extended temporal and spatial boundaries, and indeed are increasingly of global significance in space and generational significance in time. This emergent class of problems is also characterized by "fuzzy" problem boundaries, and beg interdisciplinarians to arrive at a constructed understanding of what should be included and what should be left out, which is, of course, a problem system dynamicists face with each new model building exercise.

The terms multidisciplinary and interdisciplinary are often confused or used interchangeably. In this portion of the paper we will address the differences between multidisciplinary and interdisciplinary research teams, and in the following section we will explore how communication across specialization fits into the dynamic of interdisciplinary research teams.

Research that includes multiple disciplines but each maintains their distinctiveness is multidisciplinary (Collins, 2002), while research that integrates the multiple disciplines to effectively form a new unified body of work is interdisciplinary (Kostoff, 2002). Multidisciplinary research doesn't include joint planning, management, and review of the multiple disciplines, as an interdisciplinary research initiative does. In problems of deep complexity, addressing only one or a few of the component disciplines will result in fragmented or perhaps misleading results because of neglect of discipline interdependencies – thus the importance for engaging in systems thinking and model-building. Even if all of the multiple component disciplines are addressed separately in a multidisciplinary approach, the method of integrating the multiple facets can affect the final solution. Moreover, the final multidisciplinary research product will not have the same quality as a unified research product that results from an integrated interdisciplinary study (Klein, 1990; Klein 1996). Hattery (1986) introduced a definition of interdisciplinary research which continues to be cited and used, thus this is the conceptualization that we will use in this paper: Interdisciplinary research is "an integrative research process, which takes place among researchers with different disciplinary backgrounds" (p. 13).

Part of understanding how interdisciplinary teams communicate and interact involves understanding how they negotiate understandings of content relative to different disciplinary languages and negotiate roles and expectations within the team (Biocca & Biocca, 2002; Harrington, 2002). Across the globe, scientists are suddenly being asked to transcend their disciplinary niches and work with other high-level experts in a new type of working group (with mutually constructed social identity) devoted to solving one problem (Biocca & Biocca, 2002; Rogers, 2002).

Among the major epistemological models that are being discussed as appropriate for engaging in this emerging cross-disciplinary research, two stand out and are referred to as Mode 1 and Mode 2 interdisciplinary research (The UK Economic and Social Research Council , 2004), Mode 1 interdisciplinary research "aims to further the expertise and competence of academic disciplines themselves, e.g. through developments in methodology which enable new issues to be addressed or new disciplines or sub-disciplines to be formed" (¶ 2). Mode 2 research is defined as research that addresses "issues of social, technical and/or policy relevance with less emphasis on discipline-related academic outcomes" (¶ 3). It is this second mode of interdisciplinary research that is being promoted as the solution approach for an emerging class of problems characterized by deep complexity.

A co-principal investigator in the interdisciplinary research project of our case study (whom will be formally introduced later) explained his initial experience in interdisciplinarity, similar to the Mode 1 and Mode 2 conceptions:

> *For me, the first stage of interdisciplinary work can be called "mutually defensive." It is characterized by a reliance on jargon and equations, discussions grounded in measurements and indexes, puzzlement about the possibility of progress, and mutual*

> *incomprehension. But in the second stage, which I call 'back to basics,' we learn to speak in concepts rather than measurements, we discuss what motivates certain concepts over others, and begin to draw simple analogies to well known physical realities – yes, you could call them metaphors. Finally, the end of this stage is characterized by storytelling. Once we begin to create a mutual narrative we are really engaging in interdisciplinary communication (personal communication, March 29, 2004).*

Beginning with this insight, it is no great leap to imagine an active problem solving strategy wherein interdisciplinary communication establishes a range of critical problem elements and space/time boundaries—complete with associated "reference behaviors"—and model building sharpens the vision. As the UK Economic and Social Research Council succinctly puts it:

> *Interdisciplinary research does not occur automatically by bringing together several disciplines in a research project. Extra effort is needed to promote the formation of a cohesive research team involving researchers from different disciplines, to combine, expertise from several knowledge domains and to overcome communication problems among researchers from different disciplines. Perceived problems in conducting interdisciplinary research include language and communication issues, institutional structures and procedures, and divergences in worldviews across disciplines (¶ 5).*

The emphasis above on "worldviews", which system dynamicists may recognize as synonymous with the term "mental models," is significant, and leads to an understanding of how system modeling can serve as the foundation stone upon which interdisciplinary mental models can be coalesced, problem boundaries can be sharpened, and disciplinary communications gaps bridged.

<u>Communication and Interdisciplinary Research Teams</u>

Understanding of various communication theories and research can facilitate the complicated collaborations of interdisciplinary teams, as well as provide insight on how to overcome specialization and truly engage in integrated research efforts. Likewise studies on interdisciplinarity and the communicative processes of interdisciplinary research can inform the theories and concepts developed in traditional communication scholarship. Communication scholars have expertise to offer to the conundrum facing the hard sciences, and it would be iniquitous to not contribute to the understanding of interdisciplinary team processes. Likewise understanding how interdisciplinary teams integrate can contribute to building communication theory and ultimately make applications to contemporary global experiences in interdisciplinary research. This paper explores one specific area that can enhance the current understanding of interdisciplinary communication – the use of model building as a collaborative team process, but first how do members in an interdisciplinary team communicate?

One of the co-principal investigators in this project recognized the unique nature of interdisciplinary collaborations in academia and the communication processes that challenge collegiality:

> *This group of people [acts] differently than a corporate group, a research laboratory group, a government agency group, etceteras. Academics are programmed to be experts*

> *and expound on their disciplinary knowledge. In addition they are trained to look for holes in others' arguments – at times to the detriment of team building (personal communication, March 22, 2004).*

Another major obstacle in interdisciplinary collaborative research is that it is difficult to find a common language because of discipline specialization (Bauer, 1990; Benda, et al. 2002; Glantz & Orlovsky, 1986; Sarewitz, Pielke, & Byerly, 2000; Wear, 1999). Glantz and Orlovsky (1986) recognize the example of the word "desertification" which has various different definitions in scientific disciplines such as climatology, soil science, meteorology, hydrology, geography, political science, economics, and anthropology. These differences in definition lead to miscommunication among researchers and between researchers and policy makers. Any disciplinary effort requires analyzing language, specifically definitions, terminology, and metaphors used in order to improve understanding and construct an integrated framework.

Finding a "common language" (or at least agreeing on how to communicate) is often a dialectical process (Broido, 1979; Davis, 1978; Klein, 1990). Dialectics are discourse between two or more speakers who express two or more positions or opinions. Davis (1978) suggested that dialectic is the interdisciplinary method, since interdisciplinarity is achieved when disciplinary differences are stated, clarified, and then resolved in order to produce a synthesis. Thus, dialectics can manifest in conversation, dialogue, personal e-mails and public discussions.

Communication theorist, Leslie Baxter, defined a dialectical perspective of interpersonal relationships, and this can be applied to the relationships that develop in interdisciplinary research groups. Similar to Davis and Broido's definitions, Baxter added that "a dialectic is a tension between two or more contradictory elements of a system" (1993, p. 140). Baxter (1988, 1992, 1993) has used dialectical analyses to examine the way a relational system develops and changes, how it moves in response to these tensions; and how strategic actions taken by participants in the system attempt to manage the conflict or contradictions that arise. Likewise a dialectical analysis may improve an interdisciplinary team's understanding of differences and tensions. Without a formal, meta-analysis of team communication, systems modeling efforts can simulate the processes of a dialectical analysis by forcing team members to publicly articulate their different opinions and perspectives.

Broido (1979) was one of the first scholars to demonstrate how the dialectical approach can be a practical methodology for overcoming disciplinary entrenchment in problem-oriented work. In his essay, Broido (1979) argued that, through a dialectical process members of an interdisciplinary team begin to see the price of reductionism and the interdisciplinary strength of integrating given disciplinary frameworks. Likewise possibilities for exporting and importing disciplinary methods and terminology become more apparent. Dialectics allow for misunderstandings, animosities, and competitions to be taken seriously and not glossed over (Broido, 1979; Klein, 1990; Klein 1996) – forcing a higher understanding through intense communication.

Thus, I'd argue that the dialectical method is imbedded in dynamic systems model building activities. Interdisciplinary team members engage in a dialectical process when deciphering the various model components that scientists may insist on including, or conversely may avoid including. Taking a dialectical perspective to interdisciplinary communication facilitates a reflexive understanding for exploring language and how it gets used in debates and discussion of complex science.

In summary, interdisciplinary research teams are typically small groups of "hard" scientists engaged in an integrative research process in order to address complex, sometimes global, scientific problems. Members of such teams struggle to overcome disciplinary differences, which manifest in their different uses of language and metaphor. Successful interdisciplinary teams engage in some type of dialectical process to better understand each other and the complex information exchanged, and that dialectical process may influence the building of a systems model – at least impact the collegiality generated in the process.

CASE STUDY: AN URBAN AIRSHED RESEARCH TEAM

The UTES Project: An Urban Airshed Research Team

For the past year I have been working with The Salt Lake Valley Airshed – Urban Trace-gas Emissions Study (henceforth the UTES project). The UTES project is funded by the National Science Foundation to study the complex factors affecting emissions of carbon dioxide, water vapor, and volatile organic compounds in the valley surrounding Salt Lake City, Utah. This research requires the interdisciplinary expertise of atmospheric scientists, social scientists, urban planners, and ecologists. Such collaborations include measuring the concentrations and emissions of the pollutant gases, tracing their origins, and evaluating the implications for effective management of the urban airshed. Project members are also engaged in developing a systems dynamics model that can be used to better understand the complexity of the urban airshed system as a whole. Eventually the team plans to introduce this model to members of the local public in an outreach initiative based on public participation and local decision-making. Hopefully the model will assist the participants in evaluating urban growth and air quality policy options.

The UTES team is lead by five principal investigators (PIs); with over 50 participating members from the University of Utah and the Salt Lake community of scientists, environmentalists, and bureaucrats. Funded participants are primarily from the University, and the "community partners" include representatives from local government, non-profit, and environmental agencies. The University partners are a mix of regular faculty and non-teaching research faculty, likewise there is a range of age and academic seniority – one person is still working towards tenure, and one person will retire in two months. There are four working groups that currently communicate via overlapping membership with each other. The four working groups are (1) Emissions Inventory, (2) Process Studies, (3) Emissions Management, and (4) Education and Outreach.

Every other week all of the members convene at a lunch seminar in which one member of the UTES research team or an outside disciplinary expert makes a formal presentation. I have attended all of the meetings and through participant observation and ethnographic fieldwork I have gleaned some insight and observations on how scientists from the most specialized fields are able to interact and progress in a complex research initiative. Communication researchers who take an ethnographic perspective focus on the speech community as the primary unit of analysis. A speech community is a "universe of discourse with a finely organized, distinctive pattern of meaning and action" (Philipsen, 1992, p. 4) Gerry Philipsen (1992) described three underlying assumptions of this type of data gathering: Speaking is structured (i.e., social rules guide the code of communication within a group). 2. Speaking is distinctive (i.e., speech communities differ among cultures and circumstances). 3. Speaking is social (i.e., communication is not just a medium for accomplishing a task, it is a part of social life and necessary for the construction of social identities). Thus, data collected under this paradigm encourages the development of a case study. A case study is an investigation of a "specific, unique, bounded system" (Stake, 1994, p. 237). Using Stake's (1994) definition, the following is a group of "collective-case studies" in which a number of cases are studied for the insights they provide to the broader category of similar cases (p. 239). Therefore snapshots of the team's experiences in interdisciplinary collaboration and model building efforts will be illustrated in the following sections.

The Chicken: Interdisciplinary Influence on Model Building

As the literature and history of science has indicated, "two heads are better than one." Issues of complex science are best informed by a variety of disciplinary experts. In the case of the UTES project, modeling initiatives have involved many members of the team, but the most significant collaborations are not among the modelers themselves, but between the modelers and the scientists that are gathering measurements or creating an inventory of emissions and air quality data. Via these interactions the "measurers" gain an appreciation for the "modelers" and the "modelers" gain a deeper understanding of the data the measurement experts are collecting and synthesizing. Ultimately this dialect enhances the comprehensiveness and accuracy of the model. We will cite two examples from the UTES project that illustrate how interdisciplinary collaboration enhanced the capacity of systems models created.

Example 1: The urban heat flux debacle.

The theory surrounding urban heat fluxes is a premier example of an issue of "deep complexity" – but it is necessary to create models of air pollution dispersion, urban mixing depth and mesoscale airflow (Grimmond & Oke, 2002). After an "annual project review" meeting, meteorologist brought this to the attention to members of the Emissions Inventory working group. The discussion grew among those collecting measurements regarding the possible influence of urban heat fluxes. The issue became more complex when local geographic features were added to the discussions (the Salt Lake valley is nestled between two large mountain ranges), ultimately the engineers and atmospheric scientists, through a dialectical process, developed a deeper understanding of how urban heat fluxes might operate in the local system. The next challenge was for the scientists in the Emissions Inventory working group to explain how urban heat fluxes would fit in to the air quality model. The modelers met with the measurement scientists to discuss how to proceed with model-building, and after three long meetings – they were still stuck in "Mode 1." Finally, an undergraduate research assistant in the mechanical engineering department found an article in the Journal of Applied Meteorology and shared it with the hybrid group. The article explains urban heat fluxes and provides a model for the engineers to calibrate as well as a background story for the modelers to depict. Ultimately that article brought disciplinary experts to a common understanding of the urban heat island phenomena and facilitated the development of a more inclusive, possibly accurate systems model.

Example 2: The "TreeSim" component.

This is another example of how disciplinary expertise increased the accuracy and plausibility of model scenarios. The modeler met with the lead principal investigator for the project, a biologist, in order to construct a model of the local urban forest, and determine where this component fit into the larger air quality model. The two worked together to create a working model. After reaching a shared understanding they invited one of the community partners on the project – an urban forester. The urban forester provided substantial additional data and local reference behavior information. This extended insight enhanced the strength of the model and ultimately increased our understanding and knowledge of the local forest system

The Egg: Model Building Influence on Interdisciplinarity

Collaboration is likely to fail when scientists communicate poorly, have unrealistic expectations of one another, and internalize prejudices about alien academic fields (Heemskerk et al., 2003; Turner & Carpenter, 1999). Research has indicated that the development of conceptual models can guide and facilitate interdisciplinary communication (e.g, Heemskerk et al., 2003). As discussed earlier, communication across disciplines is challenging, but engaging in a model-building process, specifically a systems dynamics model, can enhance the dialectal process in interdisciplinary research.

Constructing a model of the urban airshed requires that disciplinary experts engage in dialectics that might have been avoided otherwise. Again, these dialectics have not only improved the system dynamics model, but they have also substantially improved the team dynamics. We will now share three brief examples of the positive influence systems model building has had on collegiality in the UTES project.

Example 1: The team first meets modeling.

After three months of informational presentations by each disciplinary expert, the team was barely beginning to see where their research and specialties intersected. Finally the P.I.s organized a meeting for all of the partners. It was at this meeting that one of the co-P.I.s first presented the idea of systems dynamics and collaborative model building. While everyone knew that the goal of the project was to ultimately create a systems model of the local airshed, many members didn't understand how that process was going to evolve, in fact, nearly everyone was spending their energy and resources determining the breadth and depth of technical atmospheric measurements. But at this meeting, a few members began to recognize the importance of integrating data and knowledge – and this lead to increased conversations and information exchanges. Even the lead PI, who was skeptical of modeling capabilities from the onset was now visualizing extensive interconnections and articulating them with other team members. These conversations did not stop at 5:00 PM when the meeting adjourned – they continued for months, and still continue today, as these researchers use the model as a place to exchange expertise. "Building the model" is not necessarily the focus of the project, but it keeps the project focused.

Example 2: The spaghetti bowl.

After six months of discussion among the team members, one of the modelers created an introductory model map to explain the initial interconnections that they team had identified. This diagram was presented to all of the team partners and external review board. When first introduced, you heard members gasp, "Oh my!" Look at that 'spaghetti bowl!'" After a few quiet moments, members around the room began to interject places where they say their discipline could contribute – specifically the meteorologists and GIS (geographic information system) specialist. While these two experts were immediately verbose, many others made follow-up comments in the next meeting. Thus, the presentation of the model generated a conversation in which the focus was recognizing the interconnections of each other's work.

Example 3: Joe's eureka moment.

While we've avoided using names throughout this analysis, this particular example has come to be known to the modeling team as "Joe's eureka moment" thus it is impossible to continue protecting Joe's anonymity. Joe is a mechanical engineer, and a co-PI on the UTES project, he was also involved in the "urban heat flux debacle." In fact his eureka moment was born in the fourth meeting of the modelers and measurers, after the article from the "Journal of Applied Meteorology" was shared. One of the other co-PIs shared his interpretation:

> *You should have seen Joe! He nearly jumped out of his seat! We started with that LUMPS paper [the article from the Journal of Applied Meteorology], it has a nice, simple model dealing with vegetation, heat fluxes, and urban development. We started with pictures from two points of view, Phil and I started seeing a STELLA model, and Joe's crew was envisioning the LUMPS model. Then we discussed the differences between the two models and that is when Joe had his eureka moment. He was finally primed to understand what a STELLA model could explain, and how his model would inform the STELLA model. Joe actually suggested putting together a simple model! I felt like he finally had an appreciation for what we do (personal communication, March 18, 2004).*

This interaction among isolated disciplinary experts would have never happened if it weren't necessary to discuss the deep complexity of the urban heat flux phenomenon and how it impacts air quality. Thus the model provided a forum for the researchers to find an appreciation for each other, and ultimately a deeper sense of respect and collegiality. Which in turn, improves the interdisciplinary collaboration and quality of knowledge generated from the team's efforts to model the dynamic system of the local airshed.

DISCUSSION

The examples from the UTES project are merely snapshots of experiences in an interdisciplinary team commissioned to develop a systems model for an issue of deep complexity. Around the world scientists are being asked to collaborate and integrate their expertise in order to better understand the global magnitude of complex, scientific issues. These collaborations are not piecemeal efforts to enhance our understanding of the world, but complicated, deliberated dialectal interactions. Experts trained in one mode of thinking – one paradigm of thought – one worldview are now being challenged to see other mental models that they didn't even know existed. Both challenges can be overwhelming, first to tackle issues of deep complexity, and second to work with other "alien" scientists at the boundary of one's own discipline. However, the process and the outcome may be enhanced by engaging in systems model building.

Again, building the model is not necessarily the focus of the project, but it keeps the project focused. Likewise improving communication across disciplines is not the goal of the project, but it can become a valuable commodity for improving our understanding of the very complex world we inhabit. In conclusion, it is not a question of which comes first, the chicken or the egg, it is recognition that both exist simultaneously and mutually influence each other to create a dynamic foundation for collegiality and enhanced problem solving.

Acknowledgments. This research is funded by the National Science Foundation Biocomplexity in the Environment Program, award number ATM 02157658. The authors would like to thank the anonymous reviewer for his/her insight as well as Dr. Marouf Hasian for his feedback. We'd would also like to recognize the members of the UTES team, especially the co-principal investigators: Diane Pataki, Joe Klewicki, Tarla Rai Peterson, Craig Forster, and Philip Emmi.

REFERENCES

Bauer, H.H. (1990). Barriers against interdisciplinarity: Implications for studies of science, technology, and society (STS). Science, Technology, & Human Values, 15(1), 105-119.

Baxter, L. A. (1988). A dialectical perspective on communication strategies in relationship development. In. S. Duck (Ed.), Handbook of Personal Relationships (pp. 257-273). New York: Wiley.

Baxter, L.A. (1992). Interpersonal communication as dialogue: A response to the social approaches forum. Communication Theory, 2, 330.

Baxter, L.A. (1993). The social side of personal relationships: A dialectical perspective. In S. Duck (Ed.), Social Context and Relationships: Understanding Relationship Processes (vol. 3, pp. 139-169). Newbury Park, CA: Sage.

Benda, L. E., Poff, N. L., Tague, C., Palmer, M. A., Pizzuto, J., Cooper, S., Stanley, E., & Moglen, G. (2002). How to avoid train wrecks when using science in environmental problem solving. BioScience, 52(12), 1127-1136.

Biocca, Z. & Biocca, F. (2002). Building bridges across fields, universities, and countries: successful funding communication research through interdisciplinary collaboration. Journal of Applied Communication Research, 30(4), 350-357.

Broido, J. (1979). Interdisciplinarity: reflections on methodology. In J. Kockelmans (Ed.), Interdisciplinarity and Higher Education. (pp. 244-304). University Park, PA: Pennsylvania State Univ. Press.

Collins, J.R. (2002). May you live in interesting times: Using multidisciplinary and interdisciplinary programs to cope with change in the life sciences. BioScience, 52, 75-83

Daily, G.C., & Ehrlich, P.R. (1999). Managing earth's ecosystems: An interdisciplinary challenge. Ecosystems, 2, 277-280.

Davis, W. (1978). The act of interpretation: a critique of literary reason. Chicago: University of Chicago Press.

Glantz, M. & Orlovsky, N., (1986). Desertification: anatomy of a complex environmental process. In K. Dahlberg & J. Bennett (Eds.), Natural Resources and People: Conceptual Issues in Interdisciplinary Research. (pp. 213-229). Boulder: Westview Press.

Grimmond, C.S.B., & Oke, T.R. (2002). Turbulent heat fluxes in urban areas: Observations and a local-scale urban meteorological parameterization scheme (LUMPS). Journal of Applied Meteorology, 41, 792-810.

Hattery, L. H. (1986). Interdisciplinary research management. In D.E. Chubin, A.L. Porter, F. A. Rossini, & T. Connolly (Eds.), Interdisciplinary Analysis and Research. (pp. 13-28). Mt. Airy, MD: Lomond Publications, Inc.

Harrington, N.G. (2002). Funded research in communication: A chairperson's perspective. Journal of Applied Communication Research, 30(4), 393-401.

Heemskerk, M., Wilson, K., & Pavao-Zuckerman, M. (2003). Conceptual models as tools for communication across disciplines. Conservation Ecology, 7(3): 8. [online] URL: http://wwww.consecol.org/vol7/iss3/art8

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

Klein, J.T. (1996). Crossing Boundaries: knowledge, disciplinarities, and interdisciplinarities. Charlottesville: University of Virginia Press.

Kostoff, R. N. (2002). Overcoming specialization. BioScience, 52(10), 937-941.

Naiman, R.J. (1999). A perspective on interdisciplinary science. Ecosystems, 2, 292-295.

Philipsen, G. (1992). Speaking culturally: Explorations in social communication. Albany: State University of New York Press.

Rogers, E.M. (2002). Funding international communication research. Journal of Applied Communication Research, 30(4), 341-349.

Sarewitz, D., Pielke, R.A., & Byerly, R. Eds. (2000). Prediction: Science, Decision-making, and the Future of Nature. Washington D.C.: Island Press.

Stake, R.E. (1994). Case studies. In N.K. Denzin & Y.S. Lincoln (Eds.), Handbook of Qualitative Research (pp. 236-247). Thousand Oaks, CA: Sage.

Turner, M.G., & Carpenter, S.R. (1999). Tips and traps in interdisciplinary research. Ecosystems, 2, 275-276.

United Kingdon Economic and Social Research Council (2004), http://www.esrc.ac.uk.

Wear, D.N. (1999). Challenges to interdisciplinary discourse. Ecosystems, 2, 299-301.

Back to the Top