Learning to synthesize:
A cognitive-epistemological foundation
for interdisciplinary learning

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> With the Vietnam Veterans memorial, I needed to ask myself the question 'what is the purpose for a war memorial at the close of the twentieth century?' …Perhaps it was the empathic idea about war that led me to cut open the earth, an initial violence that heals in time but leaves a memory—like a scar.
>
> Maya Lin, Boundaries 2000

> Water resource are critically influenced by human activity, including agriculture and land use …changes in population, food consumption, economic policy... In order to assess the relationship between climate change and freshwater, it is necessary to consider how freshwater has been and will by affected by changes in these non-climatic drivers.
>
> IPCC Climate Synthesis Report 2007

Overview[1]

The tension is clear. Excerpts like the ones above shed light on forms of interdisciplinary reasoning that are increasingly in demand at the dawn of the 21st century and yet, psychological studies of interdisciplinary learning and cognition to date have been surprisingly sparse and non-paradigmatic. Missing, in my view, is a generative epistemological foundation for the study of interdisciplinary cognition. One that can embrace a broad range of interdisciplinary intellectual agendas, while attending to the disciplinary foundations on which such insights are build and the intellectual processes required to integrate them in a coherent whole. Consider the two excerpts above. In the first, artist Maya Lin describes the Vietnam Veterans Memorial as a scar. Her metaphor frames the Vietnam War experience in terms of a country divided by the war and in need of healing. In Lin's work, detailed analysis of military records gives room to names chronologically engraved on reflective granite, where living selves and lost others meet and reconcile — where art and history intertwine to illuminate past and present human experience. Resulting from a scientific collaboration of unprecedented scope, the second vignette highlights factors affecting freshwater availability in times of climate change. In the report produced by the Intergovernmental Panel on Climate Change, biological, chemical and physical laws are used to determine the quality and quantity of available water resources. Superimposed on this natural phenomenon, is an analysis of the human drivers that intensify natural water cycles: population growth, climate variation, and economic development.

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How do memorials and complex explanations function as interdisciplinary learning achievements? How do individuals come to integrate disciplinary traditions and what cognitive demands does interdisciplinary learning impose? A striking array of metaphors have been deployed to describe the nature of interdisciplinary intellectual activity — from working at "crossroads" and in "trading zones" to engaging "boundary objects" and "bridges" (Klein, 2005). Metaphors have served us well as evocative approximations to interdisciplinary cognition. However, they have proven less productive in their ability to structure strong research agendas or to design empirically-grounded programs on interdisciplinary learning and its assessment. This chapter seeks to move beyond evocative language to examine the phenomenon of interdisciplinary learning in epistemological and cognitive terms.

Interdisciplinary learning is a process by which individuals and groups integrate insights and modes of thinking from two or more disciplines or established fields, to advance their fundamental or practical understanding of a subject that stands beyond the scope of a single discipline (Boix Mansilla 2006; Gardner 2008; National Academies 2005). Interdisciplinary learners *integrate* information, data, techniques, tools, perspectives, concepts, and/or theories from two or mores disciplines to craft products, explain phenomena, or solve problems, in ways that would have been unlikely through single disciplinary means. Conceived as a cognitive phenomenon, understanding interdisciplinary learning demands an empirical examination of the mental processes involved, such as analogical reasoning, conceptual blending and complex causal reasoning. However, because key to interdisciplinary learning is the integration of knowledge forms that respond to distinct epistemologies (preferred units of analysis, methods, validation criteria), a psychological study of interdisciplinary learning requires a strong epistemological foundation. It requires an articulation of the nature of disciplinary knowledge and the methods and criteria by which such knowledge is produced and deemed acceptable. It also requires an epistemological theory that enables us to make sense of –and validate- the insights that emerge at multiple interdisciplinary crossroads.

In this chapter, an epistemological foundation for interdisciplinary learning is proposed. I argue that a *pragmatic constructionist* view of interdisciplinary learning can account for the variety of enterprises considered "interdisciplinary." Such a view can illuminate the process of considered judgment and critique involved in advancing an understanding that integrates multiple specialties effectively with a purpose in mind. Interdisciplinary learning, it is argued, involves a series of delicate adjustments by which new insights are weighted against one another and against antecedent commitments about the subject matter under study. To advance the case for a *pragmatic constructionist* theory, I first review available literature on interdisciplinary learning, considering their strength and limitations. I show how epistemological assumptions frame (and limit) our understanding of interdisciplinarity by revisiting two classic approaches-- logical positivism and E. O. Wilson's *Consilience.* I then introduce pragmatic constructionist framework for interdisciplinary learning and test it against the two learning examples described above: creating historical monuments and explaining water availability. The chapter concludes with recommended future avenues for research and instruction in which interdisciplinary learning is considered as a cognitive phenomenon with deep epistemological roots.

Interdisciplinary learning

Empirical studies of interdisciplinary learning today unfold without a generative epistemology or convergent lines of research that would render knowledge accumulation possible. Interdisciplinary learning has been linked to critical thinking skills; more sophisticated conceptions of knowledge, learning and inquiry and hightened learner motivation and engagement (Huber & Hutchings 2004; King, & Baxter Magolda, 1999; Hursh, et al 1988; Minnis & John-Steiner 2005). Occasionally, authors have advanced conceptual models of interdisciplinary learning mechanisms rooted in specific learning theories. Models vary in the degree to which they are empirically or conceptually based and the dimensions of interdisciplinary learning they seek to explain. For example, the Conceptual Blending theory, advanced by Gilles Fauconnier and Mark Turner, captures a key human cognitive computation: the capacity to combine two existing concepts to produce a new unit of meaning. Blended concepts such as "problem-solving" or "hand-writing" are pervasive in every day language and contribute to our capacity to make efficient sense of the world around us. Matthew Miller showed how compound concepts –for example, *empirical bioethics*--and concepts of expanded meaning –such as *innovation* in evolution, cell development, technology and organizations--enabled individuals to integrate disparate bodies of information. His study illuminates micro-representations of interdisciplinary integrations; it does not address the process by which integrated concepts are constructed.

Researchers following a Neo-Piagetian tradition put a premium on the construction and revision of knowledge structures of increasing levels of complexity and abstraction. Understanding the connection between two concepts must be preceded by a lower level understanding of each concept in isolation. Further, understanding the connections between sets of related concepts builds on a prior low level understanding of each participating set. Higher order concepts such as "systems" or "systems of systems" organize lower order ones rendering such abstractions a desirable mark of learning success. Applied to interdisciplinary contexts, a neo-Piagetian approach suggests that at first, learners construct abstractions in one relevant discipline. They then acquire knowledge in two or more disciplines but do not draw connections among them. Third, they integrate knowledge from two disciplines around a central and more abstract theme. Eventually, Lana Ivanitskaya and her colleagues suggests, learners build an overarching knowledge structure of still further complexity and abstraction that can be applied to new interdisciplinary themes.

Emphasizing the social dimension of learning and cognitive development, researchers such as Svetlana Nikitina and Rebecca Burns characterize progressive appropriation of disciplinary discourses and modes of thinking among individuals trained in different fields. These authors take the social mediation of learning as their point of departure. Their proposed learning progressions begin with an individual's sensitivity toward foreign concepts and terms from a colleague in another discipline, followed by a growing capacity to define such constructs and eventually utilize them productively in interdisciplinary contexts as part of an established personal repertoire. Similarly emphasizing communicative dimensions of interdisciplinary learning, others examine collaborative learning in the construction of a common ground—a shared definition of a problem or approach on the part of a two or more individuals (Bromme 1999).

The emerging research on interdisciplinary learning has benefited from multiple approaches to studying human cognition and their corresponding assumptions about the nature of knowledge. Perspectives are also limited. For example, an emphasis on integrative concepts must be complemented with a sense of how concepts are learned. A neo-Piagetian commitment to complexity and abstraction as markers of learning sophistication must be complemented with an account of learning in which other cognitive goals are pursued such as effectiveness or innovation. Models differ in their assumptions about the nature of knowledge and the process by which it is acquired. In fact, to be informative, a comprehensive framework for the study of interdisciplinary learning begins with greater clarity about the nature of what is being learned. What constitutes interdisciplinary knowledge or understanding? Can we discern key dimensions of this elusive epistemological phenomenon to inform a theory of interdisciplinary learning?

The problem of reductionism

"Interdisciplinary learning" encompasses diverse cognitive endeavors: from aesthetic interpretations of past events, to comprehensive explanations of water availability. It engages concepts and modes of thinking in a broad range of specialties. An epistemological foundation for interdisciplinary learning must account for such variety, while illuminating the processes of learning involved. Generally speaking, epistemological theories seek to illuminate the nature, scope, and utility of knowledge. They differ, however, in the way they characterize the landscape of human knowledge and insight, the relative significance they attribute to particular knowledge forms, and the standards and criteria by which knowledge is deemed acceptable (Elgin, 1997). As a result, epistemological frameworks also differ in their utility to shed light on interdisciplinary knowledge integration.

The search for an integrated theory of knowledge has galvanized thinkers in a number of intellectual traditions (Gould, 2003). Scholars have sought to distill underlying patterns across apparently disconnected disciplinary facts or claims. While efforts to make reasonable connections across knowledge spheres are laudable, their results have all to often prioritized a single preferred mode of explanation typically stemming from logic and mathematics or, more recently, from biology. In what follows, two such reductions are considered: Logical Positivism as exemplified in the classic work of A. J. Ayer and *Consilience* as introduced by E.O. Wilson, in 1998.

Logical Positivism dominated English speaking philosophy since its origins in the School of Vienna of the early 1920s. It regarded logic and mathematics as sources of analytical truths and the natural and social sciences as the only way to reveal verifiable truths about the world. It placed a premium in propositional knowledge, restricting the universe of meaningful claims to those that can be, in principle, verified or falsified by experience or logical proof (Ayer 1946; Popper, 1965). Yet, as Ayer's emotive theory of ethics suggests, propositions pertaining to the moral or aesthetic realm remain outside of the logical positivist worldview. They cannot be empirically or logically confirmed or disconfirmed. Similarly non propositional knowledge embodied in images or movements cannot be considered properly meaningful. Logical positivism in its strictest form sought to guarantee that if a claim satisfies its validation criteria it is highly credible. However, it does so at a cost. It restricts the kinds of knowledge it seeks to understand to science and logic, excluding important human cognitive achievements in the realms of art and normative moral reasoning (Goodman, 1976; 1978).

When applied to knowledge representation in interdisciplinary learning, logical positivism emphasizes the acquisition of propositional knowledge in the disciplines and the development of deductive and inductive reasoning skills. Yet confronted with Maya Lin's Vietnam War Veterans Memorial it falls short. It remains unable to make sense of Lin's aesthetic experience and is silent about her visually nuanced interpretation of the past. Too complex and uncertain to be encoded in a system of irrefutable premises and logic, too semantically dense for modeling and verification, the monument falls outside the purview of the positivist mind and explanatory framework.

Edward O Wilson's theory of *Consilience* stands out as a rather recent effort to bridge C. P. Snow's two cultures of sciences and humanities (Snow, 1998; Wilson, 1998). Consilience admits, at least in principle, a diversity of intellectual endeavors. It seeks, in practice, to bring specialists together to "agree on a common body of abstract principles and evidentiary proof" (p .10). Wilson characterizes it as "a new 21^{st} century enlightened unity of knowledge" (p.14). Consilience, he proposes, can unite the humanities and the sciences legitimately. It grants the humanities the right to articulate human and cultural constructs to be studied —consciousness, beauty, altruism, cooperation—and entrusts the biological sciences with the power to explain them.

Yet, to understand Maya Lin's aesthetic and evocative achievement, Consilience sidesteps history, art and architecture to look at the human biology of visual perception. Lin's aesthetic use of notations on reflective granite or her symbolic violation of the natural landscape is overlooked by Consilience; as is the way in which multiple interpretations of the monument give new meaning to the experience of war. Rather, an unwavering aspiration to scientific truths leads Consilience to seek a biological explanation of our aesthetic mind. Aesthetics as a form of knowing in its own right is "black boxed" and evolutionary hypotheses about our universally wired preference for slightly symmetrical visual patterns and open prairie landscapes prevail. Consilience is useful for framing interdisciplinary endeavors when learners seek to explain the biological foundations of human life. It is limited, however, when learners seek other goals, such as understanding the emotional cost of war, or exploring how to use the arts to heal and reconcile. A more pluralistic epistemological theory is in order—one that embraces the multiple knowledge forms on their own terms and at the same time discerns between more and less trustworthy insights.

A pragmatic constructionist epistemology

Interdisciplinary pursuits are diverse: the learning demands of designing a historical monument contrast substantively with those of explaining climate change. Substantive cognitive transfer across tasks can rarely be expected. What constitutes a productive epistemological framework for interdisciplinary learning? Arguably, four criteria are required: First, an epistemological framework must be *pluralist* in its capacity to account for multiple forms of disciplinary understanding on their own terms and embrace various intellectual agendas. Second, it must be *relevant* to the phenomenon of interdisciplinary learning illuminating the processes of interdisciplinary integration. Third, the theory must *explain* how knowledge advances from less to more accomplished instantiations; shedding light on the essential dynamics of learning. Finally,it must offer some form of *knowledge quality assurance*—an epistemic mechanism that diminishes the likelihood of error by putting forth robust and relevant standards of acceptability across interdisciplinary endeavors.

To shed light on knowledge integration in interdisciplinary learning, an epistemological theory must neither limit its reach to the realm of empirically validated propositions, nor reduce all forms of knowledge to a privileged one, such as biology. Such emphases, as we have seen, constrain the types of interdisciplinary learning that can be legitimately examined. Instead, a productive epistemology offers insight into how understanding of a subject matter can be advanced, whether such understanding entails an aesthetic interpretation of the Vietnam War or a comprehensive explanation of freshwater shortage. Relevant to interdisciplinary learning is an epistemology that sheds light on how humans can make increasing and better sense of the world, themselves and others through the integration of available disciplinary insights.

A *pragmatic constructionist* epistemology rooted in the work of philosophers Nelson Goodman and Catherine Elgin meets the criteria above (Goodman & Elgin, 1988). 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 (Elgin, 1996, p. ix). Building and validating understanding involves 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 paint a telling picture) which include findings, statements and observations, as well as useful analogies, telling metaphors, 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 implications of a *constructionist pragmatic* approach for interdisciplinary learning theory are potent. By shifting our attention from accumulation of propositional knowledge to deep and broad understanding, the proposed epistemology recognizes that prior knowledge matters in the ways in which individuals make sense of the world. Prior knowledge sets the stage for the insights to come, by informing questions, affording hypotheses, and providing an initial representation of a problem under study. By broadening the admissible sources of knowledge and inquiry beyond strictly certified propositions, this pluralistic epistemology invites the inclusion of other symbol systems (visual, musical, kinesthetic) and ways of knowing such as artistic interpretations or literary fictions. Interdisciplinary understanding can thus be viewed as a “system of thought in reflective equilibrium”— embodying insights and tensions across disciplines, representing an improvement over prior beliefs and remaining open for review. A cognitive process for interdisciplinary learning can be derived.

Interdisciplinary learning as the construction of systems of thought in reflective equilibrium

The epistemological framework outlined above offers a dynamic picture of interdisciplinary integration (see graph). Four core cognitive processes are involved: *establishing purpose*; *weighing disciplinary insights*; *building leveraging integrations*, and *maintaining a critical stance*. In interdisciplinary learning such processes interact dynamically, informing one another as learning progresses. The result is a system of thought in reflective equilibrium—an improvement in understanding vis a vis prior beliefs as well as an understanding subject to further revision. How do these dimensions of learning play out in the construction of two interdisciplinary artifacts--a historical monument and an explanation of climate change? What learning demands does interdisciplinary learning present? To test our proposed epistemology’s capacity to illuminate interdisciplinary learning and the challenges it presents, we now turn to the learning examples earlier described.

Crafting historical monuments or memorials

Successful historical monuments or memorials integrate an understanding of the past, and use of space, symbolism, and materials to advance evocative interpretations. Four cognitive processes are involved in their creation:

(a) Establishing purpose

The *purpose* of a monument is to commemorate the memorable, to make past experiences part of our present. Memorials—a particular kind of monument–offer a special precinct, a segregated place where we come to honor the dead and reflect about past present and future (Danto 2005). A study of interdisciplinary learning must examine how learners set their epistemic intention. For example, Lin seeks to re-represent the past aesthetically to invite reflection about war and reconciliation. Other potential intentions such as to *explain* why the war happened are not addressed. The success of a learning enterprise of this kind will be measured by the monument's effectiveness in provoking thought rather than by the explanatory power or the level of abstraction and generalization of her vision. In turn, the process of interdisciplinary learning often requires a readjustment of its purpose.

b) Understanding and weighing disciplinary insights

To construct such a system of thought in reflective equilibrium learners also come to *understand disciplinary contributions and weigh* their role in informing the whole. Contributing disciplinary insights vary. They may take the form of theories, findings, models, methods, tools, techniques, characteristic modes of thinking, applications, discourses, languages, exemplifications, powerful analogies, or explanations. The Vietnam War memorial example, challenges the learners to distill the *significance* of the Vietnam War and identify a relevant story to be told about it. The cognitive demands are not minor. Without inquiry experience in history, even post adolescents tend to view significance solely as an intrinsic quality of key events, not one *attributed* to them in light of their consequences or shifting interests in present societies (Seixas, 2006; Danto, 1985). Similarly, learners may construe historical accounts as stories un-problematically pasted together from literal interpretation of primary sources. In fact historical accounts are constrained by historians' choices of perspective (military persons, political leaders, Antiwar youth) time frame (the Tet offensive vs. Colonialism or the Cold War), and forms of explanation (individual triggers or long standing cultural forces). These too become options for the learner who must, through considered judgment, decide on a representation of the past that will inform her monument. Weighing options is not simple. Deciding for instance, where to draw the line marking the beginning and the end of the Vietnam War is still a contested matter.

The arts and architecture too impose important challenges on monument design. They call upon the artist to envision detailed versions of the monument in her mind; consider competing materials and techniques as well as provocative symbolisms . She will need to overcome deeply rooted misconceptions such as believing that the quality of art depends merely on its decorative beauty or that an artist's intention is unequivocally the last word on a piece. Thinking aesthetically will require a commitment to multiple interpretations, some intended, some emerging.

(c) Building leveraging integrations

Interdisciplinary learning yields a system of thought in reflective equilibrium typically organized around a preferred form of disciplinary integration. Learning to create a historical monument involves learning to reframe a significant past in terms of a central visual metaphor that drives the aesthetic design of a piece. In Maya Lin's work, the devastating consequence of the Vietnam War on the individual minds and social cohesion of American society is represented as a scar—a cut in the earth to be healed by time. When the purpose of learning is aesthetic synthesis, examining how the mind constructs metaphors becomes key.

Metaphors frame reality in terms of similarities between constructs pertaining to different realms. In them, a *vehicle* concept (e.g. the scar) highlights certain features of the *topic* one (e.g. the consequences of war), while obscuring others (Goodman, 1976). Framing the Vietnam War as a scar sheds light on the personal emotional experience of war and its long-lasting impact. It does not illuminate, for instance, the political and military connundra that the war presented to American administrations at different points in time. To the extent that the mind can explicate the tacit analogy presented by a metaphor, the metaphor offers parsimony and impact in our representation of reality. Visual thinking metaphors create a holistic synthesis and operate in a physical medium—in this case, the landscape, the stone, the engravings. (Arnheim, 1966, Bruner, 1986, Hetland et al 2007).

Learning to interpret and produce metaphors of this kind imposes important challenges on the developing mind. Early in life children can make sense of metaphors based on concrete similarities "the wrinkled apple is an old lady." However, the sophisticated interdisciplinary synthesis of the Vietnam war as a scar requires that learners understand the content of each portion of the statement to establish adequate analogy between vehicle and topic (Vosniadu, 1994) Furthermore, creating a workable metaphor about the past involves assessing tenable metaphors for their capacity to portray essential aspects of the past accurately, to lend themselves to powerful visual representation and to maximize the likelihood that the overall purposes of commemoration, healing, and reconciliation are served. A workable metaphor stands in a delicate tension among these three forces: historical accuracy, visual generativity and power to heal.

(d) Critical stance

Understanding is an endless and cyclical task. Our informed conclusions about a topic are challenged by novel contexts, insights or experiences. A pragmatic constructionist epistemology draws its strength not from the attainment of final infallible truths but from the recognition of the limitations of our knowledge. Understanding must stand the test of competing interpretations of the subject matter. The debate that followed the publication of Lin's design centered on a reflection about the purpose of a veteran's memorial and the aesthetic choices that were or were not fit.

Researchers studying critical thinking and the development of epistemological beliefs have documented the role of meta-cognition in student learning. The capacity to reflect about the nature of knowledge, learning, and thinking has been associated with more complex understanding of subject matter and growing preparedness for independent learning. In interdisciplinary work, navigating multiple knowledge landscapes demands a meta-cognitive –and often a meta-disciplinary -- stance. Students must recognize the preferred units of analysis in different domains or their sometimes conflicting standards of validation. Lin's defense of her design involved a clarification of her view of the significance of the Vietnam War. Lin is also aware of limits in her interpretation—the many Vietnamese lives that were not engraved in her design. Such limitations often function as a pathway to further revision of understanding, new setting of purpose, novel disciplinary insights, integrations and the construction of yet a new system of thought in reflective equilibrium.

Explaining freshwater shortage under climate instability

Clearly not all interdisciplinary integrations seek an aesthetic synthesis of a past or present phenomenon. As the opening excerpt suggests, understanding the availability of freshwater resources during times of climate change involves examining both natural and anthropogenic factors affecting the quality and quantity of available water. Framed in this way, the purpose of learning is primarily explanatory: e.g. to understand why water resources may be at risk in order to decide what to do about it. Advancing an interdisciplinary system of thought in reflective equilibrium in this arena demands that learners make sense of selected concepts and findings produced by fields ranging from climate science to oceanography and chemistry, from demography to economics and political science (i.e., weighing disciplinary insights). It also requires that they integrate such insights in a complex and productive explanation of water availability (i.e., leveraging integration) and that they remain aware of the limitations and provisionality of their conclusions (i.e., critical stance).

For example, understanding this topic invites learners to make sense of observed changes in temperature and precipitation and how these are measured. It demands understanding the chemical composition of usable freshwater and the variations that may indicate particular forms of pollution. Learners will need to understand observed and expected population growth, changes in land use and irrigation demands as well as the role of pollutant emissions such as pesticides and thermal pollution. The insights and modes of thinking depicted above stem from work carried out by chemists, climate scientists, geographers, demographers.

An interdisciplinary understanding of water availability involves more than the juxtaposition of factors outlined above. Learners must integrate these factors in a complex explanation that serves as the driving cognitive structure for integration. In it, climate related factors are mediated by anthropogenic ones in a comprehensive explanation of water availability.

Building complex explanations is a demanding task for learners. Since early in life children are prone to linear explanations in which causes and consequences stand in temporal and spatial proximity (Perkins & Grotzer 2005). Only through careful instruction can they advance explanations rooted in multiple mechanisms and agents. For example, learners face the challenge of understanding reciprocal causality where causes and consequences intertwine in feedback loops—loss of glacial reflective surface contributed to atmospheric temperature rise which in turn augments melting and further loss in glacial reflective loss. Learners face the challenge of understanding causal variations associated with the temporal distance between cause and effect—e.g., glacial reduction increases river flow and flooding in the short term but decrease it in the long run. They face the challenges of understanding multiple non linear causal mechanisms such as the emergent demands on water resources caused by population growth and growing food and irrigation demands.

An explanatory and interdisciplinary system of thought in reflective equilibrium integrates these general and local causes into a complex account of water availability. Yet it also demands that learners remain critical of their resulting conclusion. Important factors may have been missed, evidence used holds varying levels of confidence, future developments may call for revisions in the account proposed. In sum, interdisciplinary learning as here conceived is clearly more than recording information about stated causes of water availability risk.

Toward a research agenda

This chapter has sought to advance an epistemological foundation for the study of interdisciplinary learning. I have argued for a pragmatic constructionist epistemology that offers a pluralistic view of knowledge forms able to account for a broad variety of interdisciplinary endeavors. Moving beyond metaphor, the proposed epistemology offers a dynamic construct to represent the phenomenon of interdisciplinary integration: a system of thought in reflective equilibrium. Its articulation and dynamics invite further empirical work. For example, future research on interdisciplinary learning may reveal additional forms of interdisciplinary integration.

As the call for interdisciplinary education expands both to primary education and the graduate years, understanding developmental progressions in interdisciplinary learning capacities will become key. We may expect to see young children able to produce aesthetic syntheses as long as metaphors refer to concrete dimensions of the problem under study—the shapes of leaf cells under a microscope or the reflection of a face on a fishbowl. The pre-adolescent mind may begin to find more abstract metaphoric representations more engaging. As least two dimensions of interdisciplinary learning will need to be addressed in a developmental study: the capacity to integrate disciplines and the capacity to think and act in disciplinary informed ways. On the other end of the developmental spectrum, studies of interdisciplinary learning may examine the ways in which young adults manage the tensions, incompatibilities and complementarities among insights form multiple domains. Studies may examine the role that students beliefs about the nature of knowledge and inquiry may play in their capacity to construct systems of thought in reflective equilibrium. They may address how a given interdisciplinary understanding (a system of thought in reflective equilibrium) moves through phases of stability and contestation.

Finally, challenging interdisciplinary learning often demands collaboration. Research on group learning has addressed dimensions that range from leadership to group composition, from dilemmas of power to the nature of tasks, from the construction of trust to challenges of communication (see Stokols, et al, this volume). A pragmatic constructionist epistemology can add systematicity to our study of interdisciplinary collaborations. It can focus our attention on the key learning demands a group experiences in the construction of systems of thought in reflective equilibrium: negotiation of intellectual purpose, the weighing of disciplinary contributions, the advancement of leveraging integrations, and the disposition toward critical review. Expanding beyond the cognitive realm. Such a study of interdisciplinary collaborations could also benefit from examining how cognitive, social, emotional factors interact to advance understanding.

In sum, whether we focus on the construction of a generative taxonomy of interdisciplinary endeavors or a progression of interdisciplinary capacities over the lifespan or socio-cultural conditions for collaborative work, understanding interdisciplinary learning necessitates a clear articulation of “the kind of knowledge being learned.” The approach promises lines of research in the area of interdisciplinary cognition that are as generative as those in historical, scientific, mathematical or artistic cognition. It also promises to set the foundation for a new form of “pedagogical content knowledge” – an understanding of the unique teaching and learning demands presented by particular kinds of knowledge— to ensure quality interdisciplinary assessment and instruction (Shulman 1987).

References

Arnheim, R (1960) . Perceptual analysis of a symbol of interaction Basel:Krager

Bromme, R. (1999). Beyond One's Own Perspective the Psychology of Cognitive Interdisciplinarity. *Practising Interdisciplinarity*. Weingart and Stehr (Eds.) Toronto: University of Toronto Press.

Burns, R (1994) *Interdisciplinary teamed instruction: Development and pilot.* Washington DC: Educational Research and Improvement Office. Eric RF 90002002.

Danto, A. C. (2005). Mute point. *Nation,* 281(12), 40-44.

Elgin, C. Z. (1996). *Considered judgment*. Princeton, N.J.: Princeton University Press.

Fauconnier G. & Turner M. (2002) *The Way We Think: Conceptual Blending and the minds'hidden complexity* New York: Basic Books.

Fischer, K. W., & Bidell, T. R. (1997). Dynamic development of psychological structures in action and thought. In R. M. Lerner, & W. Damon (Eds.), *Handbook of child psychology: Vol. 1. Theoretical models of human development* (5th ed., pp. 467-561)

Gardner, H. (2006). *Five Minds for the Future*. Cambridge: Harvard Business School Press.

Goodman, N. (1978). *Ways of worldmaking*. Hassocks, Sussex: Harvester Press.

Goodman, N., & Elgin, C. Z. (1988). *Reconceptions in philosophy and other arts and sciences*. Indianapolis: Hackett Pub. Co.

Gould, S. J. (2003). *The hedgehog, the fox, and the magister's pox: Mending the gap between science and the humanities* (1st ed.). New York: Harmony Books.

Hetland, L., Winner, E., Veenema, S., & Sheridan, K. M. (2007). *Studio thinking: The real benefits of arts education*. New York: Teachers College Press.

Huber M. & Hutchings P. (2004). *Integrative Learning Mapping the Terrain* Washington, D.C.: American Association of Colleges and Universities, 2004.

Hursh, B., Haas, P., & Moore, M. (1983). An interdisciplinary model to implement general education. *The Journal of Higher Education,* 54(1), 42-59.

Intergovernmental Panel on Climate Change. (2007). *Climate change 2007: Synthesis report* (No. 4). Geneva, Switzerland: IPCC Secretariat, World Meteorological

Organization. Retrieved from http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

Ivanitskaya, L., Clark, D., Montgomery, G., & Primeau, R. (2002). Interdisciplinary learning: Process and outcomes. *Innovative Higher Education*, 27(2), 95.

Klein Julie Thompson (2005). *Humanities, Culture and Interdisciplinarity.* Albany, NY: State University of New York Press.

Lattuca, L. R., Voight, L. J., & Fath, K. Q. (2004). Does interdisciplinarity promote learning? Theoretical support and researchable questions. *Review of Higher Education*, 28(1), 23-48.

Lin, M. Y. (2000). *Boundaries*. New York: Simon & Schuster.

Miller, M. L. (2005). Harvard University Graduate School of Education. Qualifying paper. *Integrative concepts and interdisciplinary work: A study of faculty thinking in four college and university programs.* Submitted.

Minnis, M., & John-Steiner, V. (2005). The challenge of integration in interdisciplinary education. *New Directions for Teaching & Learning*, (102), 45-61.

Perkins, D. Grotzer, T (2005). Dimensions of Causal Understanding: The role of complex causal models on students' understanding of science. *Studies in Science Education* 41 (117-166).

Popper, K. R., Sir. (1965). *The logic of scientific discovery*. London; New York: Routledge.

Seixas, P. (1997) 'Mapping the terrain of historical significance', 5oc/a/ *Education* 61, PP22-28.

Snow, C. P. (1998). *Two cultures and the scientific revolution.* Cambridge ; New York: Cambridge University Press.

The National Academies. (2005). *Facilitating interdisciplinary research.* Washington, D.C. 20001: The National Academies Press.

Vosniadu S. (1995) Analogical Reasoning in Cognitive Development. *Metaphor and Symbolic Activity* 10 (4), 297-308.

Wilson, E. O. (1998). *Consilience: The unity of knowledge*. New York: Knopf: Distributed by Random House.

Cognitive learning theory merges cognition and learning to explain the different processes involved in learning effectively. The cognitive learning process aims to chart the learning process for optimal thinking, understanding and retention of what we learn. When you master the fundamentals of cognitive learning, it becomes easy to maintain a lifelong habit of continuous learning.Â Similarly, collaborative learning is a cognitive strategy in which a resource person teaches a group how to develop their ideas on a specific skill or knowledge area. For instance, your company could train a colleague on a new production process so they can pass on the knowledge to team members. 5. Discovery learning. In 2011 the NSF convened the â€œLearning Progressions Footprint Conferenceâ€ with two purposes (1) to examine the impact NSF research was having on LP (science) and LT (mathematics) research, and, (2) to provide guidance for NSFâ€™s future investments in LP and LT research and development. Three contexts were taken upÂ In contrast, LP research reports employing â€˜cognitive learning assessmentâ€™ models such as the â€˜assessment triangleâ€™ (National Research Council, 2001) adopt longer instructional sequences timeframes employing multiple units of study that are implemented across on months and years.Â More research on disciplinary, interdisciplinary and transdisciplinary science practices is needed. Learning to synthesize: A cognitive-epistemological foundation for interdisciplinary learning. In Frodeman, R., Klein, J. T., & Mitchman, C. (Eds.), Oxford handbook of interdisciplinarity (pp. 288â€“306). New York, NY: Oxford University Press.Google Scholar.Â Interdisciplinary Learning at University: Assessment of an Interdisciplinary Experience Based on the Case Study Methodology. Sustainability, Vol. 12, Issue. 18, p. 7732. Learning strategies are special ways of processing information that enhance comprehension, learning or retention of information. If a teacher applies cognitive strategies, he/she tries to find the best channel the learner perceives the information through. Some students are auditory learners, others are visual or kinesthetic ones (read more here). Through the cognitive approach strategies, the learners retain and apply new concepts more successfully and develop a deeper insight into the learning process itself. Cognitive strategy activities.