# Interdisciplinary Learning: A cognitive-epistemological foundation[1]

Veronica Boix Mansilla,
Project Zero,
Harvard Graduate School of Education

> 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

> A more robust understanding of human-resource interactions is needed to strengthen theories about collective action and sustainable governance…. This comparative study [of publicly shared environmental resources] highlights how trust, communication, and social obligation depend on social histories of resource systems and types of collective action problems, largely explaining why local institutions [in Ecuador] encourage individuals to uphold mangrove forest conservation but have little effect on cooperation in fisheries.
>
> Christine Beitl, *World Development*, 2013

## Overview[2]

Preparing individuals to lead informed and fulfilling lives in dynamic knowledge societies requires that we nurture synthesizing minds. We must nurture individuals' capacity to to knit together knowledge from vast and disparate sources into coherent wholes in order to address pressing issues of cultural and natural survival (Gardner 2006). Synthesis is a fundamental human capacity. It manifests early in life, when children engage in symbolic play, create artistic compositions, or learn the rules of a new game. To a certain extent, we learn to synthesize rather effortlessly by participating in societies where analogies, rich visual representations, and simple systems are ubiquitous. *Interdisciplinary* synthesis, however, presents heightened cognitive demands and requires deliberate instruction. It implies the integration of knowledge and modes of thinking in two or more disciplines in search for better understanding. Understanding how individuals learn to integrate different forms of expertise to create a work of art, explain a multifaceted phenomenon, fashion a new technology or propose a sustainable environmental solution is essential if we are to cultivate this capacity among collegiate and pre-collegiate youth. What cognitive processes are central to interdisciplinary integration? What kind of "knowing" is embodied in a historical

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monument, an explanation overfishing or a sustainable development policy? On what basis can we discern the relative success of such form of integrative cognition? Ultimately, how can we design instruction to nurture potent forms of interdisciplinary integration?

Characterizing interdisciplinary integration is complicated by the vast and diverse array of intellectual endeavors the term denotes (Frodeman, 2010; Klein 2010). Maya Lin's Vietnam Veterans Memorial in Washington DC departs from traditional monument architecture by presenting visitors with two granite walls forming angle below ground level and in open-air. Lin describes her creation as "scar". Her metaphor frames the war experience in terms of a country divided in need of healing. 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 human experience past and present. Her integration differs greatly from that of environmental economists interested in explaining the conditions that will prompt a community to act to protect natural resources at a short-term cost. This work weaves together factors such as a community's social cohesion, levels of trust, communication, and social obligation and biological ecosystems features into a complex causal explanation of why coastal inhabitants in one region may succeeded in organizing to conserve mangrove forests but not to limit over-extraction practices (Beitl, 2013). In this integration individual factors typically studied by sociologists, anthropologists and biologists, complement one another to maximize explanatory power. This example differs from Lin's with respect to its aim, contexts, the kinds of data, theories and approaches they integrate, and the key cognitive processes involved in integration—i.e., a complex explanation here and a metaphor before.

Today, interdisciplinary pronouncements are prominently featured in university mission statements – and capital campaigns –the world over. Understanding how people learn to synthesize is essential, if we are to design quality instruction and support learners to fulfill these institutional aspirations. Because syntheses vary, must investigate the epistemological foundations on which learning to synthesize stands, attend to their common *and* idiosyncratic features of interdisciplinary syntheses and the concomitant criteria by which we might deem them acceptable (Boix Mansilla, 2002). Yet we know little, empirically speaking, about the cognitive mechanisms or the epistemological foundations on which a memorial or a climate change explanation can be deemed an interdisciplinary learning achievement. Seeking to address this gap, this chapter examines interdisciplinary learning in cognitive and epistemological terms. Part one focuses on learning processes, beginning with "interdisciplinary integration" as a key, albeit polymorphous, aspect of interdisciplinary learning. Part two turns to the foundation of interdisciplinary learning and proposes an epistemological approach to characterize the foundations of interdisciplinary cognition. Part three illustrates the proposed approach by revisiting the opening examples. In conclusion, the chapter outlines the implications for instruction that come from this approach.

## I. Learning to integrate: cognitive approaches

Among scholars of interdisciplinarity, "integration" stands as the philosophers' stone of interdisciplinary efforts, capable of turning diffuse disciplinary insights into valuable understandings. "Integration" distinguishes "disciplinary" and "multi-disciplinary" practices from "interdisciplinary" ones. The construct has proven malleable enough to include stakeholders' expertise in "transdisciplinary" work. A focus on "integration" as central to interdisciplinary activity has earned some scholars the title of "integrationists" (O'Rourke et al 2015). And yet scholars differ in whether integration is the aim of interdisciplinary work, or a means to deeper understanding; the result of a stepwise algorithmic process, or a heuristic and iterative effort; a mostly cognitive, or a socio-communicative-cognitive phenomenon.

Characterizing the cognitive processes involved in interdisciplinary integration has proven difficult on multiple grounds: First, interdisciplinary synthesis can only be observed through manifest communicative efforts (a reflection on a work of art or a written explanatory paper). Second, integration is not merely the end-point nor the ultimate purpose of interdisciplinary inquiry, but rather is embedded in complex, often-circuitous investigative processes (Holbrook 2013). Integration in research and learning occurs throughout a given inquiry process—i.e., when describing a problem to be understood, formulating questions, creating theoretical frameworks, combining methods, selecting instrumentation and deploying analytical categories or when gauging the contribution of an interdisciplinary approach (Bergmann et al 2012). Third, and perhaps most importantly, interdisciplinary synthesis embodies a vast array of purposes and disciplinary combinations. It demands a characterization that sheds light on common cognitive processes while respecting the idiosyncrasies of particular disciplinary crossroads. Faced with the complexity of interdisciplinary synthesis as a construct it is perhaps not surprising that cognitive studies of interdisciplinary learning are scarce.

Cognitive psychologists have documented domain-specific learning processes and progressions in mathematics, biology, physics and history among other fields. They have also identified foundational learning principles across domains: (a) Learners enter learning with prior "theories" about the topic under study. Typically invisible, these theories frame and give meaning to new information. (b) Learning is robust when knowledge is organized around higher order concepts and frameworks that facilitate retrieval and transfer. (c) Such learning pivots on metacognitive processes whereby learners take control of their learning, setting aims and monitoring progress (Bransford, et al 2000). "Deep learning" involves the capacity for "transfer," i.e. the ability to use newly learned information in a novel situation. Learning principles and quality markers of this kind provide a strong generic foundation for interdisciplinary cognition.

Interdisciplinary learning has been linked to sophisticated conceptions of knowledge, learning and inquiry and heightened learner motivation and engagement (Baxter Magolda, & King 2004). In fact, interdisciplinary learning involves relatively well-studied processes that operate in and across

disciplines such as evidence-based reasoning, complex causal thinking, temporal and spatial representations and critical argumentation. However, unique to interdisciplinary learning is the fact that these processes *integrate* information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines, typically in order to craft products, explain phenomena, or solve problems, in ways that would have been unlikely through single disciplinary means (Boix Mansilla 2002). How do learners produce such hybrid and informative advancements in understanding?

Available studies of interdisciplinary learning build more or less explicitly on various intellectual traditions. For instance, Neo-Piagetians invoke learning progressions in loose stage-like phases explained by an individuals' growing information processing capacity – specifically, the capacity to operate at increasing levels of complexity and logical abstraction. From this standpoint, the integration of two concepts builds on the more particular understanding of each concept in isolation. Higher order concepts such as "systems" or "systems of systems" organize lower order ones rendering such abstractions a desirable mark of learning success (Fischer et al, 2009). Applied to interdisciplinary learning, this approach proposes that individuals learn isolated concepts and sets of concepts in isolated disciplines first. Only later, the approach implies, are learners able to integrate knowledge from two disciplines around a central and more abstract theme. Ultimately, it is proposed, learners build an overarching knowledge structure of further complexity and abstraction that can be applied to new interdisciplinary themes (Ivanitskaya et al 2002).

In contrast, conceptual blending theorists (Fauconnier & Turner 2003) locate synthesis in our capacity to combine two existing concepts into a new unit of meaning. Blended concepts such as "problem-solving" or "hand-writing" are pervasive in everyday language. Miller (2006) showed how compound concepts (e.g., *empirical bioethics*) and concepts of expanded meaning (e.g., *innovation* in evolution, cell development, technology and organizations) enabled individuals to integrate disparate bodies of information. Star and Griesemer (1989) on their part coined the notion of "boundary objects" to describe shared foci of knowledge—plastic enough to be interpreted differently by different actors, yet robust enough to maintain unity across contexts. Similarly, Bromme highlights the construction of common ground—a shared definition of a problem or approach—as an interdisciplinary learning achievement (Bromme 1999).

Considering cognitive development as culturally situated (Vygotsky 1978), some scholars examined progressive appropriations of disciplinary discourses and modes of thinking among individuals trained in different fields. Collins and Evans propose "interactional expertise"— i.e. the capacity to bridge "distinct [disciplinary] practices through a deep sharing of discourse" (Collins and Evans 2007, p. 53; Collins et al, 2010) as an interdisciplinary learning achievement. It enables members of distinct disciplinary cultures to participate in productive conversations while still not reaching "contributory expertise." In turn, studies of social cognition and distributed expertise also show how cognitive apprenticeships, such as collaborations in teaching, enable experts to learn

intellectual practices in neighboring domains (e.g., analysis styles, disciplinary languages) essential for interdisciplinary exchange (Derry et al. 2005).

As the examples above reveal, available empirical studies shed a partial and fragmented light on interdisciplinary cognition. For instance, a Neo-Piagetian commitment to *information processing, complexity and logical abstraction* operate well when systems analysis is the approach of choice to address a given problem. It fails to shed light on other intellectual goals such as creating a beautiful art experience or crafting a workable technology. An emphasis on *boundary* and *blended concepts* sharpens our focus on a key cognitive tool for integration but calls for further study on how such concepts function at different disciplinary intersections as well as the cognitive processes that makes them possible. A focus on *distributed expertise* points to the potentially complementary information held by members of a group, yet further studies need to show how individuals negotiate meaning across varied disciplinary boundaries over time. At the heart of the matter stands the question of what kind of entity interdisciplinary integration is—a well-founded abstraction, a compound concept, a social exchange —and the kind of knowledge or insight it is expected to yield in the cacophonous world of disciplinary specializations. A more integrated view of interdisciplinary cognition demands a discerning and encompassing epistemological foundation.

## II. Epistemological foundations of interdisciplinary learning

Theories about learning embody ideas about the very content being learned – e.g. logical abstractions, distributed representations. Understanding how people learn to create an aesthetic interpretation of past events or to explain human responses to overfishing too invites an epistemological reflection about the nature of interdisciplinary knowledge. Epistemological theories seek to shed light on the nature, justification, limits, and, in some cases, the utility of knowledge and beliefs. Theories differ, however, in the way they characterize the landscape of human knowledge, 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.

For more than a century, for instance, philosophers of science have advanced various articulations of a "unified theory of knowledge" seeking to distill underlying principles across apparently disconnected disciplines. From early twentieth century Logical Positivism, to today's complexity theories, Wolfram's computable knowledge, and E. O Wilson's Consilience, proponents of unity of knowledge theories have deemed their approaches foundational in providing a platform for interdisciplinary work. Each theory has privileged a specific knowledge form (e.g. propositional knowledge, computational algorithms, or biological principles) as the primary guarantee of

credibility and the standard by which to deem explanations satisfactory. Yet they have done so at a cost. These perspectives on knowledge restrict the kinds of phenomena they seek to understand to those that can be interpreted in their preferred knowledge form, thus excluding important human cognitive achievements, especially in the realms of art and normative or moral reasoning (Goodman, 1976; 1978).

Confronted with interdisciplinary phenomena such as the creation of Maya Lin's Vietnam War Veterans Memorial, a sole emphasis on propositional knowledge, computational algorithms or biological principles falls short. Epistemologically speaking, these views of knowledge are unable to make sense of Lin's aesthetic experience in its own right. They remain 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, too resistant to being reduced to an adaptive biological achievement, the monument falls outside the purview of early positivists and more recent theorists of knowledge unity.

Similarly, confronted with the challenge of explaining how a community responds to overfishing, knowledge assumptions underlying unity of knowledge efforts are likely to reduce the problem's richness and complexity to the favored epistemic form. The limitations that early positivist or contemporary unity of knowledge approaches face do not fully invalidate their commitment to derive the best algorithm to model a complex phenomenon or a key biological principle to account for human behavior. Rather, they reveal the boundaries of these approaches' applicability.

Interdisciplinary pursuits are diverse, and substantive cognitive transfer across tasks can rarely be expected. Expertise in memorial art does not correlate with a heightened capacity to explain socio-environmental phenomena. Against this background, what constitutes a productive epistemological framework for interdisciplinary learning? Four principles must be considered: First, a fertile 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 framework 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 logic, mathematics, or biology. Such emphases, as we have seen, constrain the types of interdisciplinary learning these theories can legitimately examine. 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 overfishing practices. 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.

**III. Toward a dynamic view of interdisciplinary learning**

The criteria for an epistemology of interdisciplinary learning established above point directly to *Pragmatic Constructionism*—the epistemological foundation for interdisciplinary learning here proposed. With roots in the work of philosophers Nelson Goodman and Catherine Elgin this approach offers a suitable frame to characterize interdisciplinary learning that is purposeful, pluralistic, and provisional (Goodman & Elgin, 1988). As constructionist, this epistemological framework posits that the purpose of inquiry (and in this case learning) is not necessarily the certification or acquisition of "true" knowledge claims, but the advancement of understanding. Inquiry is not the accumulation of propositional knowledge in search for certifiable truths. Rather, it 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 inquiry -- to create an insightful work of art, explain a socio-biological system, or advance an effective policy. Within this view, understanding can embody multiple forms (aesthetic, analytical, interpersonal, ethical understanding) and materialize in multiple symbol systems (mathematical, visual, linguistic, kinesthetic). As such this epistemology is fundamentally pluralistic.

Ultimately, understanding involves the construction of what Elgin describes as "a system of thought in reflective equilibrium". 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, Elgin notes, affords no guarantees. It is rationally acceptable not because it is certainly true but because it is reasonable in its given 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 understandings of the subject matter. A conclusion is deemed acceptable not through a linear source of argumentation but through a host of sources of evidence which include findings, statements and observations, as well as useful analogies, telling metaphors, powerful exemplifications. Evidence may not precisely "match up," but still paint a telling picture that helps us advance our understanding of the subject, all things considered.

Within the epistemological framework here proposed—i.e., a pragmatic constructionism centered on purposeful, pluralist and provisional understandings—the acceptability of a knowledge system is to be measured against the purposes of inquiry that guide its production. Multiple forms of integration are recognized and their 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 pragmatic constructionism for a theory of interdisciplinary learning are potent. By shifting our attention from accumulation of propositional knowledge (or the search of ever encompassing systems of systems) toward a deep and broad understanding, the proposed epistemology recognizes – as does learning science—that prior knowledge matters in the ways in which individuals make sense of the world. Prior knowledge informs questions, affords hypotheses, and provides an initial representation of a problem under study. By broadening the admissible sources of knowledge and inquiry beyond strictly certified propositions, this pluralist epistemology invites the inclusion of other symbol systems (visual, musical, kinesthetic) and ways of knowing such as artistic interpretations or literary fictions, including a learners' naïve or indigenous beliefs. Interdisciplinary understanding can thus be viewed as a "system of thought in reflective equilibrium"— a complex and dynamic set of connections and mental representations that embody insights and tensions across disciplines, represent an improvement over prior beliefs, and remain open for review.

Emerging is a dynamic and cognitively aligned picture of interdisciplinary integration (see graph). Accordingly, four core processes are involved in dynamic interaction: (1) establishing purpose; (2) weighing disciplinary insights; (3) building leveraging integrations, and (4) maintaining a critical stance. In interdisciplinary learning, such processes interact dynamically, informing one another as learning progresses iteratively. The result is a system of thought in reflective equilibrium—an improvement in understanding *vis à vis* prior beliefs, as well as an understanding subject to further revision. To illustrate how the proposed view of interdisciplinary learning functions, we revisit the opening examples next.

**Learning to create memorials**

**(1) 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). To establish her purpose, Lin works iteratively, seeking to re-represent the past aesthetically to invite a reflection about war and reconciliation. The success of her interdisciplinary learning is thus best measured by the monument's effectiveness and her reflections about it, rather than by he monument's capacity to explain the Vietnam War, nor the level of abstraction and systematicity of her vision (goals she did not pursue). Similarly, when students learn to create a monument, clarity about purpose enables them to determine the focus and scope of their investigation, find intrinsic meaning in their efforts, and set parameters for success. What is the purpose of your monument? What are you hoping it will help people understand? What might a

May 2009

a model of

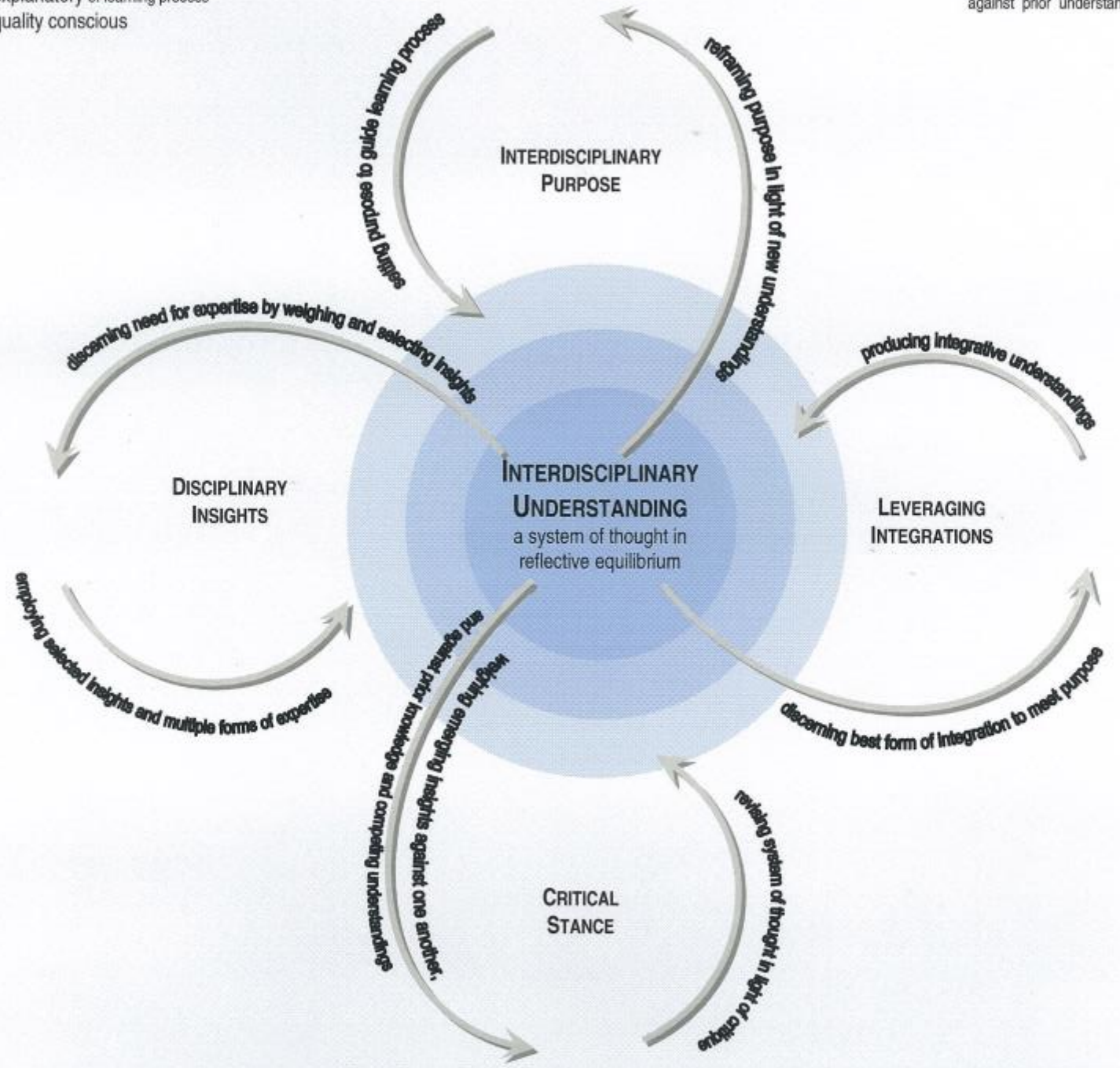
# INTERDISCIPLINARY LEARNING

## A Pragmatic-Constructionist Theory

Model Qualities:
- pluralistic vis-à-vis disciplines
- relevant to interdisciplinary integration
- explanatory of learning process
- quality conscious

Prior Understandings
initial intellectual commitments
set starting point for meaningful learning

Learning
Delicate adjustment by which new insights are weighted against one another and against prior understanding




**A System of Thought in Reflective Equilibrium**

components are reasonable in light of one another

account is reasonable in light of antecedent convictions

embodies insights and tensions across disciplines

represents improvements over prior beliefs

remains open for review

**Establishing Purpose**

Question or problem that:

frames learning agenda,

calls for interdisciplinary approach

informs standards for learning success

is open to revision as learning progresses

**Disciplinary Insights**

Concepts, theories, findings, images, data

methods, techniques, tools, assessments

applications, analogies, discourse, language, genres

**Leveraging Integrations**

Can take the form of:

telling aesthetic interpretation

more comprehensive explanation

predictive integrative models

informative contextualization

practical problem solving

**Critical Stance**

Acceptable understanding is measured against:

purposes of inquiry and learning

multiple sources of disciplinary evidence

leverage offered by disciplinary integration

understanding is provisional, can be criticized, revised, and abandoned when more reasonable ones are conceived

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successful monument look like? Questions of this kind can orient learners as they embark in their learning journey.

**(2) Weighing disciplinary insights** Throughout her investigation, Lin construes successive and revisable systems of thought in reflective equilibrium—tenable and iterative representations of the memorial idea and execution. In doing so she must work with disciplinary ideas, weigh them against her present understanding, and assess their role in informing the whole. For instance, Lin must distill the historical significance of the Vietnam War – a relevant story to be told through art. At the same time, she must weigh aesthetic options regarding symbolism and materials. In learning to create a historical monument less seasoned learners must do the same.

The domain-specific cognitive demands are not minor. Shorn of research experience in history, even post adolescents tend to view significance as an intrinsic quality of 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 (political leaders, Antiwar youth) time frame (the Tet Offensive vs. Cold War), and forms of explanation (individual triggers or long standing cultural forces). The learner must, through considered judgment, decide on a representation of the past that will inform her monument productively. Educators may ask: What does the historical record tell us about what happened during the war? What is the powerful story to be told about this period? What is special or unique about this particular war? What are the stories worth telling to the audience you have in mind?

The arts too impose cognitive demands. The artist must envision detailed versions of the monument in her mind; consider competing materials, techniques, and provocative symbolisms. She will need to think aesthetically, move beyond naïvely privileging "decorative" beauty, commit to multiple interpretations, some intended, some emerging. Here too the learner weighs options through an iterative interaction that must keep Vietnam and the purpose of the monument in mind. What aesthetic tools, materials or images can help you create the experience you seek to create? How does an artist think about this War? What is the value added of an aesthetic lens and what would be lost if the arts were not included?

**(3) Building leveraging integrations** Interdisciplinary learning yields a system of thought in reflective equilibrium typically organized around a preferred form of disciplinary integration. Throughout the learning process leveraging integrations are assessed, considered, revised. Learning to create a historical monument involves learning to reframe a significant past in terms of visual metaphors that drive the aesthetic design of a piece. In 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. Supporting learners to produce telling aesthetic syntheses requires some understanding of how the mind constructs metaphors.

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 the military actions or political conundrum surrounding the war. Visual thinking metaphors create a holistic synthesis and operate in a physical medium—in this case, the landscape, the stone, and the engravings (Arnheim, 1966, Bruner, 1986).

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 issue well enough to establish an adequate analogy between vehicle and topic. To create a telling metaphor about the past—in other words, a leveraging integration—learners must assess initially tenable metaphors for their capacity to portray essential aspects of the past accurately, to lend themselves to powerful visual representations and to maximize the likelihood that the overall purposes of commemoration, healing, and reconciliation are served. A workable metaphor stands in delicate tension among these three forces: historical accuracy, visual generativity, and power to heal. In other words, the metaphor stands in a system of thought in reflective equilibrium.

**(4) Maintaining a critical stance** Understanding is endless and cyclical. Our informed conclusions about a topic are challenged by novel contexts, insights and 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. Meta-cognition—the capacity to reflect about the nature of ones knowledge, learning, and thinking—correlates with understanding preparedness for independent learning. In interdisciplinary work, navigating multiple knowledge landscapes demands a meta-cognitive – and often a meta-disciplinary – stance.

In Lin's example, her understanding of the long-lasting process of healing after Vietnam is enriched by an awareness of the limits in her interpretation—the many Vietnamese lives that were not engraved in her design. Such limitations often function as a pathway toward revising one's understanding, calibrating one's purpose or including new disciplinary insights toward the construction of yet a new and improved system of thought in reflective equilibrium.

**Explaining a community's response to overfishing**

Clearly not all interdisciplinary integrations seek an aesthetic synthesis. Students of socio-environmental systems seek to advance our understanding of phenomena that live at the intersection of humans and their natural environment (Palmer, 2015). For example, to explain the conditions that enable a given community to self-organize to avert a critical depletion of their natural ecosystems, environmental anthropologist Christine Beilt asks: To what degree do community members assess the expected benefits of managing a resource against the perceived costs of investing in better management practices? How are such benefits –e.g., economic, social, identiary-- perceived? What role does the nature of the environmental problem (e.g., mangroves conservation vs. cockle fishery extraction) play in making action possible?

**(1) Establishing Purpose** Beilt's purpose is to advance a complex explanation of the social and environmental factors underlying collective action. Hers is not a contemporary art interpretation of environmental fragility geared to provoke and feed the imagination in the style of David Buckmans series on ice and climate change (Buckman 2012). Rather, she seeks to advance an empirically grounded and illuminating explanation of the conditions that lead local fishing communities in Ecuador to participate in the protection of mangrove forests that are at risk of being transformed into shrimp farms, while disregarding policy limits on the harvesting of small shells essential to fishery regeneration. It is against the background of this explanatory aim that Beilt's interdisciplinary success should be assessed. Learning to synthesize demands an analogous clarity of purpose. Purpose is iteratively constructed and progressively clarified through the dynamic calibration of prior understanding of the subject matter, inquiry interests, practical considerations of viability. When articulating the intrinsic purpose of their synthesis efforts, learners also establish the epistemic form–i.e., a complex explanation coupled to a practical policy solution—on which their synthesis will stand as a system of thought in reflective equilibrium.

**(2) Weighing Disciplinary Insights** In advancing their explanations of socio-environmental systems, researchers and learners can draw on a broad repertoire of factors, typically studied in economics, sociology and anthropology, physical sciences, chemistry, and biology. Disciplinary contributions vary as do the specific combinations of disciplinary perspectives relevant to address a given question. Disciplines embody distinct sensitivities about which matters to study, preferred units of analysis, available theories, methods, data and discourses, as well as about what counts as a satisfactory explanation. Understanding how marine ecosystems might set conditions for collective action implies considering factors such as an ecosystem's size, boundaries, fish mobility as well as equilibrium, resilience and growth—typically studies by ecologists. Yet because a community's propensity to self organize is mediated by its members' understanding of the issue at hand, a more satisfactory understanding the problem would need to include fishermen's perceptions of their changing environment, typically revealed through ethnographic case studies, interviews, focus groups and observations characteristic of anthropology. Advancing a plausible and satisfactory explanation demands that learners weigh the explanatory contributions of various disciplinary insights. Experts tend to identify key insights in disciplines other than their own

through interactions with peers, among less experienced learners, weighing disciplinary contributions often requires deliberate guidance. Not all disciplines will prove equally relevant to an explanatory model, nor will the individual findings, theories or methods provided by a selected discipline.

**(3) Building leveraging integrations** Synthesis unfolds throughout the learning process as explanations of collective action are advanced and revised. Explaining collective action is a demanding task for learners who must come to think in complex causal terms. Since early in life, learners are prone to linear explanations in which causes and consequences stand in temporal and spatial proximity (Perkins & Grotzer 2005). Only through careful instruction do learners advance explanations rooted in multiple mechanisms and agents. For example, they find difficulties understanding reciprocal causality whereby causes and consequences intertwine in feedback loops. Learners may fail to see that loss of available fish contributes to poverty and heightened social vulnerability, which in turn deters community members to privilege long term sustainable environmental and economic gains over the satisfaction of their immediate needs. In building complex explanations, learners are challenged to connect factors that stem from difference disciplines and are distant in time and space. They face the challenges of understanding multiple non-linear causal mechanisms such as the emergent demands on fisheries caused by population growth and growing demands for protein around the world. Efforts to integrate are likely to generate new questions that lead them return to a disciplinary inquiry and back.

**(4) Maintaining a critical stance** An explanatory system of thought in reflective equilibrium integrates these direct and indirect causes into a complex account of collective action. It does so through a back and forth process of calibration. In this process, learning aims, disciplinary contributions, and synthesis iterations are weighted, coordinated, and advanced. Yet a pragmatic constructionist epistemology also suggests that understanding collective action in the mangroves of Ecuador demands that learners remain critical of their emerging conclusion. Important factors may have been missed, the evidence used holds varying levels of confidence, future developments may call for revisions in the account proposed. In sum, interdisciplinary learning as here conceived involves more than recording information about collective action. Rather it embodies a pragmatic process of weaving together perspectives that contribute to a richer understanding whose standards of acceptability are constructed and driven by the purpose of learning, intrinsically conceived.

## IV. Conclusion: Implications for instruction

This chapter advances an epistemologically grounded view of interdisciplinary learning that foregrounds the construction of purpose-driven, disciplinary-grounded, integrative and necessarily provisional understandings. For each aspect of interdisciplinary learning specific instructional principles can be derived. For example, a commitment to "purposeful-driven" interdisciplinary learning suggests that rather than beginning a unit or project by teaching disciplinary parts reserving

synthesis for the end of an instructional design, learners may benefit from gaining a preliminary sense of the problems space "whole," even if intuitive, and a clear sense of cognitive destination. Art and history instructors may begin with a deconstruction of an existing historical monument as a preview for the learners' own memorial design. How does this monument make you feel? What is the purpose of this monument? Similarly, in addressing sustainable cooperative practices, an instructor can request that students represent their initial intuitive theories to explain observable variations in the cooperative behavior of fishing communities. What else do we need to understand in order to explain observed differences in fishermen behavior? In each case the form of integration – aesthetic synthesis or complex explanation – point the direction of learning from the start.

A call for a disciplinary grounded understanding requires that instructors select or help select candidate disciplines or disciplinary insights to be introduced in an instructional design. What about the history of Vietnam can inform our monument creation? What artist tools do we have at our disposal to represent the past? What kinds of disciplinary misconceptions should we be attentive to? How can we weigh the relative contribution of constructs stemming across various fields to advance our target understanding? Here learners will benefit from opportunities to delve into particular disciplinary concepts and modes of thinking, able to advance the desired understandings. An iterative process of mutual calibration between disciplinary inputs and the developing integrative understanding can take place, one in which the very purposes of interdisciplinary learning can be adjusted as well.

At the heart of interdisciplinary learning, synthesis is shaped by the intellectual pursuit learners embark upon. These range from complex explanations, to graphic designs, metaphors, and narratives embodying the purpose of learning initially established. Syntheses, small and substantial, must take place along the learning process and with an eye not merely at connecting fields but leveraging perspectives. Finally, attention to a critical stance vis-à-vis an evolving understanding calls for a critical eye that is able to challenge the emerging system of thought, and understand our proclivity to err and the promise of deeper, broader and meaningful learning.

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