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Three Strategies for Interdisciplinary Teaching: Contextualizing, Conceptualizing, and Problem-Solving

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Abstract

In this paper, I distinguish among *contextualizing*, *conceptualizing*, and *problem-solving* as three basic approaches to interdisciplinary work. This typology is based on the kind of inquiry that takes place. For example, if the guiding epistemology in the interdisciplinary work is that of the humanities, then, I claim, the mode of connecting disciplinary material is likely to be *contextualizing*, or embedding the facts and theories in the cultural, historical, or ideological fabric. If the scientific method guides and sets the standard for integration, *conceptualizing* work typically takes place. Finally, if the spirit and mode of inquiry is that of the applied sciences or creative product/policy development, the integrative process will take the form of *problem-based* investigation of urgent or tangible issues. Using empirical data from exemplary collegiate, pre-collegiate and professional programs, I describe three integrative strategies and comment on their unique strengths. This basic typology provides teachers and researchers with alternative approaches to teaching the interdisciplinary material depending on the purpose of the inquiry. In the hands of a good instructor, several interdisciplinary strategies could be used together for mutual advantage.

Introduction

No one close to interdisciplinary work fails to notice that it has many faces. Different projects and programs engaging in such work do it in different ways depending on the goal of the inquiry and the topic they choose to pursue. So, even when one upholds a fairly rigorous definition of interdisciplinary work as dependent on the mastery of several disciplines (as I try to do), one still encounters myriad ways in which a teacher in the classroom, a researcher in the lab, or a professor in a lecture hall can bring together ideas from different disciplines. My goal here is to propose a way of accounting for different approaches of interdisciplinary teaching by tying it closely to the nature of the inquiry that takes place.

The literature on interdisciplinarity contains many attempts to organize the multiplicity of forms of interdisciplinary work into a coherent framework. Lattuca (2001) and Kockelmans (1979), Newell (1998) and Klein (1990, 1994) have all proposed conceptual categorizations that distinguish between "interdisciplinary," "metadisciplinary," "informed disciplinarity," "synthetic interdisciplinarity," "transdisciplinarity," "conceptual interdisciplinarity" and other such categories.

Most of these authors base their classifications on the tightness or looseness of the connection among disciplines in an integrated whole. Kockelmans' typology (1979) proposes that in "multidisciplinary" work, for example, "there may be no connection between disciplines involved," while "pluridisciplinarity" implies some coordination or juxtaposition. In "interdisciplinary" work parts of existing disciplines "are totally integrated" into a new discipline or a solution. "Crossdisciplinary" and "pluridisciplinary" work for Kockelmans (1979) both involve tight coordination among disciplinary parts either in the form of finding a solution to a problem or in the form of "development of an overarching framework" (Kockelmans, 1979). Lattuca's classification (2001) is based on a similar principle and somewhat overlaps in terminology with Kockelmans' classification ("transdisciplinarity," "conceptual interdisciplinarity"). It also looks at the "level of integration," and "the kinds of questions asked." Thus, for instance, "informed disciplinary" work asks primarily disciplinary questions, while "transdicsiplinarity is the application of theories, concepts, or methods with the intent of developing an overarching synthesis" (Lattuca, 2001). Both Kockelmans (1979) and Lattuca (2001) in their classifications focus on how closely the disciplines bond in the interaction, and what is produced as the result of this bonding.

The typology of a different nature, much closer to the one I am offering here, has been proposed by Veronica Boix Mansilla (2004). It considers "epistemological mechanisms for inquiry" and different "validation criteria" as the basis for distinguishing among such categories as *conceptual bridging interdisciplinarity*, *comprehensive interdisciplinarity*, *problem-solving interdisciplinarity*, and *interpretive interdisciplinarity.* This classification also stems from the Harvard Interdisciplinary Study and similarly insists on continuity between disciplinary and interdisciplinary knowledge, and the disciplinary roots of the interdisciplinary inquiry. It is empirically grounded in the analysis of expert interdisciplinary work performed at such institutions as Xerox Park, CIMIT, Santa Fe Institute and others. As my empirical base is primarily collegiate and pre-collegiate programs (listed below), I pay particular attention in my categorization of interdisciplinary efforts (*contextualizing*, *conceptualizing*, and *problem-*

centering) to identifying the disciplinary "center of gravity" in the interdisciplinary curriculum.

Thus, there is a natural conceptual and terminological overlap (as both pay close attention to the epistemological bases of inquiry and are empirically grounded) between these two classifications as well as some notable differences. My classification establishes a more direct and obvious link between the disciplinary foundations for integration, be it in the sciences, humanities, or the applied fields of knowledge. Boix Mansilla's categorization, addressing more experimental and fluid forms of interdisciplinarity practiced at the professional level, does not attribute *conceptual bridging*, for example, specifically to disciplines using the scientific method, but rather, more broadly, describes it as an approach used by "formal" systems of knowledge, comprising "mathematics, informatics, logic, and analytical philosophy, and to a great degree physics. *Comprehensive* approach, likewise, encompasses an array of disciplines such as "anthropology, sociology, geography, history, and naturalistic biology," charged with producing "rich characterization and empirically sound explanations of a complex topic." The advantage of this approach is in a much finer grain view of the mechanism of inquiry and validation itself.

Given the pedagogical orientation of my typology and focus on the fundamental purposes of the inquiry (to explore the human condition, to explain the natural world, or to create new policies or products) rather than its mechanism, it was important for me in my categorization to keep the disciplinary affiliation of each strategy crisp, broad-brush as it may be. The hope is that it will help potential users – teachers and college instructors – to identify with each strategy through their own professional training in the sciences, the humanities, or the applied fields. *Contextualizing* or *context building* tend to be the kinds of activities that humanists typically engage in (the term *contextualizing* itself is recurrent in the descriptions of interdisciplinary humanities classrooms in our data), while "*concepts"* and "*conceptualization*" are elemental building blocks of any scientific thought. Much as these are broad generalizations, they are useful for teachers to make quick and intuitive distinctions among the three basic ways of knowing and to set clear inquiry-based curricula goals, course structure, and standards of assessment.

Both of these inquiry-based typologies arising from the Harvard Interdisciplinary Study can be seen as continuous and complementary with classifications offered by Klein, Newell, Lattuca, and Kockelmans, rather than disjunct. It is probable that *contextualizing* or *interpretive* efforts could proceed along both "crossdisciplinary" and "transdisciplinary" lines depending on how close a tie between disciplines is deemed to be. Kockelmans (1979) himself suggested a connection between the two lines of thinking about interdisciplinarity when he described "transdisciplinarity" as guided by the humanistic goal "to bring about an all-encompassing framework of meaning," which is most often used in "sciences concerned with man" (arts, humanities, social sciences). "Crossdisciplinary" work, on the other hand, according to Kockelmans (1979) is designed to attack problems and issues "found in the realm of the natural and social sciences." Future studies will hopefully provide a better mapping of the epistemological agenda of an interdisciplinary inquiry onto the mechanism of connection among disciplines.

The three interdisciplinary strategies described in this paper can benefit from a proper introduction. The first strategy, *contextualizing*, is a method of embedding disciplinary material in the fabric of the time, culture, and personal experience. As such, *contextualizing* can have different faces depending on what the context is. History of science may be a canonical example of using time and history as a vehicle of integration (*history as context*). Core metaphysical beliefs, personal or cultural philosophies could be another centering context (*philosophy or metaphysics as context*). Another context could be systems of knowledge and modes of reasoning about the world (*epistemology as context)*. All of these contexts are vehicles for humanizing knowledge or engaging in a humanities-type inquiry.

The second strategy, *conceptualizing,* involves identifying core concepts that are central to two or more disciplines (e.g., *change*, *linearity*) and establishing a rigorous quantifiable connection among them. For example, the concept of *change* may connect evolutionary theory in biology with learning about the physics of compression, with the law of periodicity in chemistry, and ultimately with the mathematics of differential equations and number series. Students in *conceptualizing* classrooms become adept at abstracting the physical data to its mathematical or empirical core and discovering that behind different systems of notation and symbolic representation in science there are underlying patterns and processes.

The third strategy, *problem-solving*, involves enlisting the knowledge and modes of thinking in several disciplines (biology, chemistry, political science, economics) to address messy real-life problems (such as water pollution, genetic engineering, or AIDS in Africa) that take more than one discipline to solve. The tenor of this strategy is action-oriented applied social science or the applied fields that pursue the goal of producing tangible results (products, technologies, policies, methodologies) aimed at improving the human condition. The goal of such fields is not as much to deepen understanding of the self or the natural world (as it is in the humanities and the fundamental sciences), but to apply this understanding to action, creation, and social change.

In all three approaches, the ways in which knowledge is generated and connections among ideas are made vary depending on the epistemic goals of the inquiry. What counts as a solid and meaningful way to connect ideas in the humanities (metaphor, triangulation of several accounts, multiple resonance) may not even be a plank in the construction of the bridge connecting mathematics and physics concepts. And conversely, what math and science validate as a true and reliable connection (quantifiable, replicable relationship) may have little meaning or integrative power for the humanist. The goal is not to discourage or dispute the value of any mode of inquiry, but rather to point out the different epistemological requirements and expectations that such inquiry imposes on the interdisciplinary process and products. The disciplinary distinctions I draw here (humanities, sciences, and social sciences) are very broad-brush[i], and distinguish among 1) the humanities; 2) the sciences – both empirical and analytical; and 3) the applied fields, including the applied social sciences, product and policy development.

Data collection and paper organization

The conceptualization of the three strategies is the result of close analysis of exemplary teaching designs at several collegiate and pre-collegiate sites we have looked at as part of the Harvard Interdisciplinary Study. Data was collected through classroom observations as well as through semi-structured interviews with instructors, teachers, administrators, and students. In the interviews, which lasted 1-2 hours, subjects were asked to describe the pedagogical and cognitive aspects of interdisciplinary work they engaged in. Classroom observations proved invaluable for this research, as they have actualized the use of different integrative pedagogies and provided distinct portraits of the integration in action.

Pre-collegiate programs included in this sample include Suncoast Community High School in Florida and Lincoln Park School in Chicago (Theory of Knowledge course developed by the International Baccalaureate Organization), St.Paul's School (Interdisciplinary Humanities Program), and the Illinois Mathematics and Science Academy (Scientific Inquiries and Mathematical Investigations Programs, Perspectives Program). Collegiate programs that contributed to this research include Swarthmore College (Interpretation Theory), San Francisco State University (NEXA program), Stanford University (Human Biology Program), University of Pennsylvania (Center for Bioethics), and the MIT Media Lab (Toy Symphony project). These programs and institutions have been selected for their excellence in interdisciplinary teaching, long-standing commitment to integrative goals, and work to improve their interdisciplinary methods. The wide range of ages, educational levels, institutional frameworks, disciplinary agendas of participants and programs in the study guaranteed a broad (albeit by no means exhaustive!) palette of integrative strategies for this analytical systematization.

Different research sites had distinct disciplinary orientations. Some programs, for example, were fundamentally on the humanities path, asking broad questions of human existence of science, technology, and the arts. Among these were the NEXA Program at SFSU, Interpretation Theory at Swarthmore, St. Paul's Interdisciplinary Humanities Program, IMSA's Perspectives curriculum, and the Theory of Knowledge courses. Other programs such as Mathematical Inquiries and Scientific Investigations at IMSA, and in part Human Biology at Stanford University, went about connection making in a science-based way. The expectation there was not so much to humanize knowledge as to mathematize or empiricize it, but to find precise yet universal correlates of core concepts in several (mostly scientific) disciplines. Another cluster of programs and courses – Economics and Ecology at IMSA, Bioethics at UPenn, Toy Symphony project at the MIT Media Lab, and Human Biology at Stanford – fell into the category of programs that were much more action and application oriented, rooted in the here and now, and tackling complex and urgent problems. Differences in disciplinary orientations and learning goals of these programs determined the unique paths towards integration that each of these programs took.

I. Integrative Strategy #1: *Contextualizing*

Contextualization, understood as the process of embedding knowledge in history, culture, philosophical questions, and personal experience, is the prototypical mode for generating knowledge in the humanities. Another appropriate name for this strategy might be *humanization* of knowledge. As the primary goal of the human sciences is to interpret the human condition, the end product of the humanities enterprise (work of historians, writers, philosophers, poets) is in situating the self in the fabric of history and society. “The discipline [of literature] is organized around the production of consensual knowledge arrived at through contention; text and context are central concepts.” (Donald, 2002). Bridges and connections in the humanities are typically made of chains of associations, multi-causal hypotheses, and metaphorical linkages.

Although closely related in their core goals and epistemological foundations, the humanities disciplines – philosophy, history, and literature - still differ in their specific tools and the kinds of contexts they rely on. History, for example, uses time; cultural studies use both time and space; philosophy mines the fundamental and possibly timeless questions of human condition. As a result, there are different ways to humanize knowledge, and I will only touch upon three contexts here - history, philosophy/metaphysics, and epistemology – for which abundant supporting examples can be found in our data.

History as context

Using history as context means linking different pieces of knowledge to a moment or an event in time. Catherine Rodrigue in the Interdisciplinary Humanities program at St. Paul’s School, for example, teaches Mark Twain’s *Huckleberry Finn* by invoking the backdrop of the Civil War, the condition of slavery and the abolitionist movement in the South, and the historical symbolism of going down the Mississippi River at that point in time.

At the college level, Charles Shapiro and Kurt Nutting in the NEXA course at San Francisco State University describe the scientific development of the atomic bomb against the background of events in Nazi Germany and the exodus of German and

European scientists. Students come out of this class with a sense that a bomb was not just the product of science and engineering, but a cultural artifact, a product of history, political leadership, moral or immoral personal choices.

IMSA's Perspectives Program often took a historical approach to linking ideas, too. It sought to anchor the development of mathematical or astronomical thinking in time by posing questions such as: "Why did scientific thinking and philosophy develop in Ancient Greece? Why did scientific thinking develop in Western Europe, and how was that related to Greek philosophy, revealed religion, and political circumstances up until the 17-18th century? Why is it necessary to understand St. Augustine to understand Isaac Newton?" Not infrequently, the historical context in IMSA's seminars was seamlessly fused with larger philosophical questions explored against the backdrop of time and shifting worldviews. The emergence of the scientific method and the development of abstract thinking about space are fundamental philosophical notions that are big enough to serve as a context for connecting ideas. Tracing the evolution of such notions in the history of civilization provides a doubled context of history and philosophy in which to link disciplines together. For example, one such Perspectives seminar at IMSA brought together astronomy, astrology, geometry, metallurgy, painting, geography, and shipbuilding around a philosophical concept (abstract conception of space) and a historical moment (late Renaissance). A history teacher in this seminar talked about navigational techniques, a math teacher explained the development of graphing techniques that led to two-dimensional representations of latitude and longitude; a physics teacher introduced modern global positioning satellites, and an art teacher demonstrated the representation of three-dimensional space in Renaissance painting.

Thus, it is often the case in *contextualizing* classrooms that several contexts seamlessly overlap.

Philosophy as context

Some interdisciplinary classrooms in our sample exclusively use philosophical questions as a vehicle for connecting knowledge. The context in this case is not so much time, as in the timeless metaphysical questions of human existence. Issues of selfhood, worldview, moral belief, and social responsibility can serve as the connecting glue.

Founder of the Interdisciplinary Humanities program and former Rector of St. Paul's School, David Hicks, in his book, *Norms and nobility: A treatise on education (1981),* defines the key concerns of education as posing broad philosophical questions ("What is the meaning and purpose of man's existence? What are man's absolute rights and duties? Why are we here?") - in front of students, and building the rest of the curriculum around them. Teacher David Pook does just that when he asks his students to ponder the central questions of who they are (as students at an exclusive private school) and what the social implications are.

Using paintings by Manet and Courbet, philosophical theories of Marx and Kierkegaard, and the central text of Katherine Mansfield's story "Garden Party" (1922), Pook pushed his students to confront the meaning of their existence in the socially privileged world of St. Paul's. "Is this life here about the void of the upper middle class as Marx described? Is it an illusion like the kind that Laura and her mother [characters in Mansfield's story] are indulging in? What kind of life do you choose — the life of the surface? The life of ignorance and oblivion? Or is there something else to it?" Reading the story through the eyes of Karl Marx, experiencing Laura's feelings at the party through Manet's *Concert in the Tuileries* and contrasting that with Courbet's representation of *A Burial at Ornans* helps students to identify and clarify their own philosophical, social and moral choices.

<u>Epistemology as context</u>

The distinctive feature of an epistemological survey of the human condition (as opposed to an historical or a metaphysical one) is its specific focus on the act of knowing and the type of reasoning. Disciplinary perspectives in this case are connected not by historical events or ethical or metaphysical questions, but through belonging to a particular way of meaning making. *Epistemologizing* classrooms typically discuss how different disciplines define and pursue truth, what they count as evidence and what they deem as good questions to explore. The connection of disciplines happens in the act of identifying and analyzing their differences and unique ways of knowledge production. It is by learning that poetry and mathematics take different paths towards knowledge, and define "knowing" in different ways, that such classrooms bring students to realize that there are fundamental similarities in the poetic and mathematical enterprises, both of which ultimately seek elegance and economy of expression.

One such classroom in this study was the Theory of Knowledge (TOK) course designed by the International Baccalaureate Organization. I had a chance to observe it at two schools – Lincoln Park High school in Chicago, and Suncoast Community High School in Palm Beach, Florida. Mary Enda Tookey, teacher and TOK coordinator at Lincoln Park High School, describes her goal in the TOK as helping students understand “how different disciplines approach human experience not on the level of the content of ideas but on the level of form and organization of ideas.” In other words, in TOK courses, Tookey does not teach students mathematics, but “actually to think what it means to do mathematics and how do you know there’s a good mathematical proof. It’s the kind of reasoning you use in mathematics that really is the key.” Craig Howard at Suncoast Community High School stimulates discussion by first asking students: “What are the most important five events of your life? Of American history?” After students have a chance to think about it, he asks them to examine “what criteria they used” to make the selection. He explains, “What we’re really talking about is which lens are you using and can you choose other lenses.” Sustained interest in the act of knowing helps to produce in students a deeper understanding of themselves as “independent knowers.” Howard describes:

> “[a student] would sit back and realize there have to be at least two sides to this, and that there is credibility on both sides. At the same time, not coming too quickly to a conclusion; being willing to hold off on passing judgment; maybe being a little bit more willing to toy and play with possibilities; not having to come to closure on something as fast as another student might … Of realizing that, for example, that it could be credible that someone in another part of the world could put the same pieces together and arrive at a different conclusion.

Sandra Luft in SFSU’s NEXA courses hopes to help her students “see that in any discipline, in history, anthropology or whatever, you have to adopt certain assumptions that delimit the subject matter and force you to look at it in a certain way.” Uncovering the difference in the underlying assumptions of different disciplines helps the instructor and the student see different systems of knowledge as complementary or connected as ways of making meaning of the world around us. When Sandra's students begin "asking very difficult questions about the process of adopting a methodology, that there are beliefs and assumptions and values outside of science that are necessary before one can adopt a scientific method," she feels she is close to achieving her teaching goal.

According to Mark Wallace at Swarthmore College, the focus of the interdisciplinary Interpretation Theory program, in which he teaches, is the "self-conscious examination of the act of interpretation." The program, in his view, allows faculty "to think on a meta-level about the work of interpretation itself. So not just the reading say of St. Augustine or the reading of Martin Heidegger or the reading of Freud, but actually stepping away from that and saying 'Are there some common interdisciplinary interpretative issues that guide our reading of say those three things?" There is a family resemblance in all the epistemologizing efforts described here. In each the cognitive and interpretive act itself becomes the unifying context in which to talk about different disciplinary theories and methods.

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In all its manifestations, the *contextualizing* strategy allows instructors and students to make broad and easy connections among disciplines, even those with distant epistemologies. The *contextualizing* strategy taps important aspects of the disciplines, their methodological and philosophical foundations. At the same time, it leaves out other crucial elements of the disciplines, such as their specific practices, facts, and proofs. IMSA's historian of science Rob Kiely admits that perfecting particular lab techniques and experimental procedures, for example, is not the objective of the *contextualizing* approach. The purpose of *contextualizing* efforts, according to him, is to place science in the cultural and historical fabric and bring out its social responsibility:

> [Scientists in the 21st century] do not lack technical expertise; they lack wisdom. We live in a world where biology enables our ability to manipulate the human genome … [which] is far ahead of our legal or philosophical ability to regulate how to use this knowledge in fruitful ways. How do we help scientists express the nature of scientific thinking to the general public? How do we help scientists think in an ethical context? How do we help scientists decide whether or not certain questions should be pursued?

These are the questions that the *contextualizing* strategy can effectively address, and these are the guiding questions of a humanities inquiry. It would be unreasonable to demand mathematical rigor or policy recommendations from a contemplative investigation of the philosophical roots of scientific beliefs or an interpretive study of literary narrative. By the same token, it would be unfruitful to turn a science lab into a venue for a philosophical debate. Social, historical, or epistemological *contextualization* does important work in its own right, and cannot be viewed as a replacement for other integrative strategies. The coexistence of different modes of integration, perhaps even in the same classroom, could potentially maximize the strength of each strategy while compensating for some of their natural limitations.

II. Integrative Strategy #2: *Conceptualizing*

Conceptualizing is an integrative strategy designed to take scientific and mathematical thinking beyond the facts and singular theories to the level of the underlying concepts. Such core concepts such as *linearity*, *change*, and *scale* can effectively tie together algebra and geometry, physics and biology, illuminating a hidden pattern of relationships. Leonardo Frid (1995) summarizes the thrust of this strategy in an elegant image:

> Science, like other mythologies, attempts to retell this story in its own vocabularies: in numbers and formulas, in the documentation of pattern and repetition in Mathematics, Physics, Chemistry, and Biology; these are the dialects with which we retell our own existence; these are the links with which we write our scripts. But each discipline alone tells only one fraction of the story; harnessed together they give rise to depth, and tone, and color.

Relating concepts in physics, for example, means uncovering interdependent relationships, justifying and mathematizing differences among them. This is how knowledge is generated and validated in science. "There is a high requirement for coherence or internal consistency among concepts," writes Donald (2002) about physics, where one needs to "work out, complete with great detail, exactness, or complexity the joining of parts in the whole."

With science as a guiding epistemological paradigm, *conceptualizing* connections are anything but metaphorical or suggestive; they need, instead, to meet a stringent standard of verification, replication and mathematical expression. Concepts here are not philosophical suppositions but empirical data stripped to its core, mathematical base, common denominator that defies difference in symbolic and notational systems. The goal of this mode of integration is not to interpret human experience, but to understand essential laws of the world that operate regardless of our perception and interpretation. This sets interdisciplinary efforts into a very different key than *contextualization*.

<u>IMSA: Scientific Inquiries and Mathematical Investigations Programs</u>

Conceptualizing the content of the different disciplinary vocabularies or "dialects" to patterns that "tell a story" is at the heart of such programs as Mathematical Investigations (MI) and Scientific Inquiries (SI) at IMSA. "The main building block of the MI curriculum," – describes the official brochure, "is the content/concept unit. Each unit addresses different content ideas centered on a single mathematical concept. This gives students insight into how different areas of mathematics fit together. For example, the *Linear Thinking* unit explores equations and inequalities, graphs, geometry, data analysis, and modeling into which the concept of linearity gives insight. The Function unit tackles functions and more general relationships from graphical, tabular, and algebraic viewpoints" (Mathematical Investigations, 1997).

In the SI program students are asked to draw connections among scientific concepts that are quantifiable and generalizable. For example, to answer the question of how the atmosphere acts as a radiation filter, students bring together chemistry (how bonds between the oxygen molecules in the ozone can be broken), physics (how ray energy makes molecules vibrate similar to string action), and math (to calculate the frequency of these vibrations or oscillations per second) in order, as one student explains, "to find the wavelength necessary to break the bond between two atoms." This figure is then translated back into chemical terms helping to conclude that the "free oxygen atom (the result of an ozone split)" could potentially bind with an oxygen molecule in ClO and release into the atmosphere an unstable and polluting gas Cl_2. The implication of this chemical reaction for the environment is deduced from that: "Since the chlorine ends up unbonded at the end, it continues to destroy ozone." It is not just a collection of chemical, physical and biological ideas that the student brings together, but a tight mathematical matrix of relationships that the student constructs using the tools of different scientific disciplines. The end product of this effort is a "strong correlation" between atmospheric pressure and atmospheric temperature, between chemical reactions and the probability of the preservation or destruction of ozone.

This example shows that conceptual links demand a rigorous effort. Compared to more intuitive connections between ideas and its historical and cultural roots, *conceptualizing* connections in science are produced "by design" (Marshall 2001), and not by happenstance. The role of the teacher as a translator across different systems of disciplinary representation is crucial and needs to be emphasized. According to Yates, who teaches mathematics at IMSA, "Students on their own often don't see the connection between using different variables to describe the same underlying pattern. They don't see the pattern. They don't see the transfer." To them, the same notations have very different meanings in mathematics and in the natural sciences. "The subscripts in chemistry," Yates points out, “mean something entirely different than subscripts in mathematics. Exponents in chemistry or the positives and negatives for the molecules, we use them differently in mathematics.” Teachers in both disciplines often fail to stop and think through the connections with students. “On the mathematics side,” Yates adds, “I don’t think we go around looking for those things necessarily. And if mathematics teachers don’t talk about the nature of connection and disconnection between mathematical and chemistry concepts, the chemistry and physics teachers who use mathematics as a tool “don’t pick it up on the other end either.” Their thinking is, Yates describes, “I should not have to stop to talk about how I have to connect statistics to be able to come up with a regression equation to explain what I’ve done in the lab. It should be automatic transfer.”

But this kind of transfer is far from automatic. The transfer of knowledge to new disciplinary material or “subscripts” is “hard” (Yates), and cannot be taken for granted. It pays to take the time and effort to guide students through multiple representations of the same concept, and then have them discover the underlying coherence among facts and theories they had earlier regarded as unrelated. For example, student Danny Yagan describes how, with the help of his calculus teacher, he began to see that “when you are talking about magnetic waves, you are talking about flux in the mathematics class, which is exactly the same thing — exactly the same mathematical representations:”

> My calculus teacher would always refer to calculus problems in physics as well as give us real-world examples of this abstract [notion]. He would put up on the board two ways of arriving at the same fundamental equations for projectile motion: ‘This is the calculus way, and this is non-calculus way. And, this is how it makes sense.’ Both ways. Literally, step by step

on each way. He was a really good teacher in that respect. Even in the physics course, algebraic equations were introduced. And it made sense to me. Later on in calculus, my teacher applied what we learned in calculus to those motion equations.

The example of the Scientific Inquiries and Mathematical Investigations Programs at IMSA reveals both the potential and the challenge of applying the *conceptualizing* strategy in practice. Both the potential and the challenge clearly stem from the standards set by the scientific method for any type of inquiry.

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Conceptualizing provides a strong model for integrative work. It proceeds from factual and technical information to the level of conceptual abstraction from which transfer and generalization become possible. The scientific method sets a high standard for making and validating connections, demanding their replicability, generalizability, and quantification. The specificity of terminology and the cumulative nature of knowledge in math and science make a *conceptualizing* strategy a substantial pedagogical and curricular effort. It requires the coordination, re-sequencing, and restructuring of the material around unifying concepts rather than disciplinary lines. MI and SI teachers and administrators, for example, commented on how hard it was to organize the mathematics curriculum conceptually, citing that this was not at all how they were trained to teach mathematics. And if this is difficult within mathematics, teaching physics, biology and chemistry through investigating core concepts is no less daunting both in terms of curriculum development, teacher training, and the intellectual content. Links among ideas in science are built one plank of solid proof at a time, and therefore the process is laborious and time-consuming. Instructors need to engage in the deliberate translation of disciplinary languages so that the students can piece together a coherent story told, as Frid put it, in different disciplinary "dialects."

III. Integrative Strategy #3: *Problem-solving*

Problem-solving uses an ill-structured problem as an axis of connection among disciplines. Unlike the *conceptualizing* or *contextualizing* models, which are guided by a more contemplative task of building coherence among ideas or promoting self-understanding, *problem-solving* is aimed at generating tangible outcomes and social change. The pragmatic real-life orientation of this pedagogy gives it its unique impetus and flavor. *Problem-solving* most readily captures the spirit of the applied sciences, technology, and the fields of applied social science that aim to create new products, improve on existing conditions, or develop policies for social change. It is no surprise that such disciplines as economics and ecology, technology and engineering, or such areas of study as bioethics and public health are natural users of this strategy. The epistemological goal, inherent in this strategy, is not so much to advance fundamental knowledge, nor to make it personally meaningful, but to attack a pressing problem and, drawing upon on all useful disciplinary tools, to solve it.

University of Pennsylvania: Center for Bioethics

The applied and activist essence of the *problem-solving* strategy is clearly revealed in the field of bioethics. Interviews with faculty and students at the Bioethics Center of the University of Pennsylvania describe how this field is intent on bringing together all the disciplinary tools it can to bear on such complex and vital issues as human cloning, stem cell research, or organ transplantation.

A case in point, the *Controversial Issues in Bioethics* course offered by Glenn McGee, is anything but your typical academic offering. Handing in a paper at the end does not quite suffice in this course. This course demands a lot more participation and involvement with the issues than a typical philosophy or biology course. Students are expected to participate in the discussions and to produce at the end of a class an analysis, which is nothing short of a call for legislative change. For example, Vail Miller, a student in this class, proposed to modify "current legislation known as the Uniform Determination of Death (for humans born with anencephaly) Act," which she tried to bring to the floor of her local government. Writing a proposal like this involved converging the lenses of "the Catholic Church's point of view;" "the organ donors' point of view;" "the parents of the child's point of view;" and "the [encephalic] child's point of view," and generating a strong personal stand, and a recommendation for action defensible in the courts of law. Miller came out of this experience feeling more action-oriented in her spirit than her biochemistry background or an ethics course would have prepared her for.

<u>MIT's Media Lab: Toy Symphony project</u>

The Toy Symphony Project at MIT is a case of *problem-solving* in the development of tangible products, rather in the proposal of a change to a law or policy. Guided by pragmatic questions: How do we translate graphics into harmonics? How do we amplify violinist's impact on the bow? How can children exchange rhythmic signals on stage? How to make musical composition available to children at an early age? – The Toy Symphony project, under the direction a composer of Tod Machover, brings together musicians, engineers, graphic designers (graduate and undergraduate students at MIT) who address these questions through a collaborative effort of building computerized musical "toys."

Such an objective gives a very different pace to the process of integrating ideas compared to what one encounters in a humanities or a science classroom. The process of the development of "toys" that ease children's transition into music makes all participants focus closely on the tools that they need from each of their respective fields, rather than on the fundamental concepts or foundations of their disciplines. For example, the sound engineer Tristan Jehan and a classically trained pianist Mary Farbood trade their respective knowledge of acoustics in the process of designing the computerized violin called *Hyperviolin*. Jehan describes:

> She [Mary Farbood] would try to understand what's in the music in terms of score. But what I'm doing you can't do on a score, you can't read it. I am analyzing the pitch, which is a perceptual feature.

Their exchange is not about reflecting on the complexities of music theory or on the limitation of computer intelligence at this point in history, but rather, as Jehan describes, about "giving her [Mary Farbood] the pitch … for her input." A fine musician, Farbood "doesn't really need to know how [she's] going to do that," but she "just needs to know how accurate it will be … so that she can adjust the algorithm to do the right thing."

Disciplines here are used precisely and expertly, but only to the extent called for by the task of finding a way to encode music harmony, or to program string tension, or to translate the squeeze on a plastic shell into a pitch of a note. This pragmatic narrowing of disciplines that tends to happen in this kind of applied integrative work raises a concern on the part of some educators as to the disciplinary preparation of students. Media Lab professor David Shaffer comments that in applied projects students "haven't necessarily staked a particular piece of turf and claimed it as a discipline, nor explained what the key tenets of that discipline are." However, this may be the price one has to pay for the high degree of motivation and creativity that happens in *problem-solving*. Perhaps no other integrative strategy calls as powerfully for innovative resolution of disciplinary differences and finding imaginative fits of ideas as *problem-solving* does.

Stanford University: Human Biology Program

The Human Biology program at Stanford is another example of *problem-solving* at work. The program's integrative modules make students confront such questions as: "Why is lactose intolerance endemic in some cultures?" "Why is there an incest taboo?" – and build their learning and actions around them. The core curriculum in Human Biology is structured as a sequence of A (biology) and B (social science) sections presented in back-to-back lectures by two professors. Course assistants are assigned to each section to help students work through the content of each lecture and sometimes make cross-lecture connections.

As in Bioethics, the professors' expectation in Human Biology is that students will emerge from this process not just with a solid understanding of biology and the social sciences, but also with an activist view of how to put biology at the service of health problems and other human concerns. In their focus on the human predicament, *problem-based* programs may seem similar to the humanities-based *contextualizing* efforts. However, the two approaches act on human concerns in a different way. In *contextualizing*, the goal is to attain deeper understanding of the human condition, while in *problem-solving* work the fundamental existential questions of "who we are" and "why are we here" are distinctly secondary to the primary goal of finding causes and cures for human calamities.

For example, Tess Bridgeman (a former Human Biology student and currently a course assistant in the program) went to do field work in Southern Mexico with the goal of addressing endemic birth defects in the local population. Understanding the causes of the problem served only as a tool to solving it, not as an end in itself. After she traced the problem back to "a chain of causes"– lack of folic acid in diet, poverty, no vitamins, "unfair trade agreements," people not being able "to make a living growing corn anymore" - Tess went on to identify a local grain that contained a lot of folic acid. So, she and her friends started "a program to promote the use of this grain in terms of getting more folic acid in the diet but also protein and a lot of other things that are currently lacking in the local diet by reintroducing something that was native to the region already." Tess' solution turned out to be a good solution in the applied social science sense – its beauty was not in the conceptual elegance or generalizability, nor was it in the breadth and depth of cultural associations that it made, but rather in the effectiveness to handle an urgent social problem there and then.

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The advantage of *problem-solving*, similar to *contextualizing*, is that it easily brings together a wide range of disciplines. Learning becomes personally meaningful and highly motivated by a desire to address an important social concern. The tools and methods of the disciplines in *problem-solving* are used with precision and rigor rather than in a generalized and abstracted way. Students in *problem-solving* classes perfect their disciplinary skills and acquire specific disciplinary knowledge – a skill of statistical analysis or knowledge of molecular weights as they assess the contamination of groundwater, for example. At the same time, similar to students in the Toy Symphony project, Human Biology students are likely to get an abbreviated view of the disciplines that they draw upon because they focus on a few relevant tools and theories. Educators need to make special efforts to help students fill in the disciplinary blanks by urging them to build more of a disciplinary *context*, or by engaging them in *conceptualizing* work.

Strengths and Weaknesses of the Three Strategies

The three vehicles of integrating disciplines described here serve different epistemological purposes, promote different kinds of connections, and make use of different parts of the disciplines in an exchange. The table below provides a summary description of the unique strengths and weaknesses of each of the described strategies and proposes ways to address their inherent limitations. It may also suggest useful questions that educators of all levels could be asking themselves as they embark or continue on their interdisciplinary journey with students. Those questions include:

- What is the goal of my inquiry? Is this course a humanities-based, a science-based or an action-oriented enterprise? Is the primary objective to interpret, to explain, or to create?
- What constitutes a good connection among ideas for this type of inquiry? What kind of disciplinary connections will I be looking for when assessing students' work?
- What are the potential blindspots or challenges inherent in this type of integration? What parts of the disciplines will be less engaged in the exchange? How will I compensate for the blindspots in my inquiry and pedagogy?

As the table summarizes, *contextualizing* strategy is strong in building broad connections among different disciplines using culture, history, and philosophy as contexts. Typical of a humanities inquiry, it focuses on the fundamental questions of human existence and interprets all other facts and ideas in relation to them. Connections are associative in nature and gain validity through multiple reference and triangulation in individual or shared cultural experience. The weakness of this form of integration is that connections may sometimes be arbitrary and speculative, often based on metaphor or association rather than objective proof. *Contextualizing* efforts do not typically lead to the mastery of lab techniques or disciplinary practices; instead, they help situate those practices in a broader philosophical or historical framework. What *contextualizing* can learn from the other strategies is more rigor in the connections and a deeper engagement of the substance of the disciplines rather than their philosophical foundations.

Conceptualizing, by contrast, is designed to build coherence among facts and practices in a rigorous way. Guided by scientific method, this strategy imposes stringent standards on the connections that are generated. The strength of this model is in the richness of disciplinary content that is being represented and in the tightness of correlations that are established. The downside of this, however, is that connections arrived at through *conceptualizing* are typically not as broad or far-reaching as the students expect them to be. Students often fail to see the effort that goes into re-arranging the mathematics curriculum along conceptual lines as interdisciplinary. The bridges are too short, they believe, and the combinations of ideas less daring or personally referenced than they encounter in *problem-solving* or *contextualizing*. What instructors can do to compensate for that is to actively introduce methodological discussions about the nature of the scientific method and the differences among the disciplines. Guest lecturers, knowledgeable in the history of science or theory of knowledge, could help bridge this gap for students, and make the inquiry gain a broader perspective and a sense of personal relevance.

Problem-solving is as strong as *contextualizing* is in terms of making broad and far-reaching connections among the disciplines. The connections that are established in *problem-solving* are not speculative or metaphorical in nature. Rather, they are connections that have to withstand the test of use – either as a product, model, or a viable policy. Where this form of instruction may have a blind spot is in the disciplinary breadth that it could bring. Often, the urgency of the problem or the production deadlines make deep and broad exploration of the discipline impossible. Instructors need to compensate for that and either make time for the deeper disciplinary learning or send students to other *contextualizing* or *conceptualizing* classes to bridge gaps in their perspective.

A lot of productive synergy can be gained by combining these strategies. Math and science teachers, for example, can draw upon the humanities for *context* of their material, and also center their curricula on problems from the real world. Instructors in social science applying a *problem-centered* pedagogy could benefit from a richer historical *context* (e.g., discussion of the culture of Wall Street and how it evolved in the context of a capitalist economy) and *conceptualizing* efforts (e.g. exploration of the mathematical concepts and axioms behind the statistical methods) as they try to generate practical solutions. Humanities faculty exerting *contextualizing* efforts, in turn, may profit by more careful justification and verification of the connections they make among ideas, inspired by the rigor of *conceptualizing* efforts. In the hands of many good teachers, several strategies can work together to mutual advantage.

Strategies	Strengths	Weaknesses	Ways to compensate for weaknesses
Contextualizing	• Ease of making external connections among unrelated areas of knowledge • Philosophical roots of disciplines are explored • Students' awareness of the implications of knowledge for society is heightened	• No intensive exploration of the disciplinary facts and practices is undertaken • Disciplinary dialogue happens at a metadisciplinary level — level of social meaning	• Methodological discussions and lab assignments can help ground generalizations
Conceptualizing	• Rigorous correlation of related knowledge areas • Exchange is rich in discipline-specific content (e.g. facts, theories, practices)	• Limited breadth of connection • Does not provide a personal reference point for the learner	• Discussions of scientific methodology and historical circumstances of discoveries • Present some of the content through real-life problems
Problem-solving	• Students' attention and creativity are mobilized by the urgency of the problem • Mastery of the specific disciplinary content is often a pre-requisite • Unrelated disciplines come together easily, and differences among them are addressed decisively and pragmatically	• Learning is highly targeted to the problem and therefore coverage of the field is limited to relevant tools and theories only • Reflection and deliberation on the discrepancies in the disciplinary approaches is minimal	• Historical and cultural survey of the problem can help find additional solutions or understand the complexity of the problem more fully

Future directions

This attempt to organize interdisciplinary work into three main strands based to the disciplinary agenda can benefit from a more detailed exploration of each of the described strategies, as well as from extending this basic typology beyond the three knowledge systems. The development of a pedagogical framework that makes systematic and deliberate use of all of these strategies could be the next challenge for research and practice.

Ways of knowing are much more varied and multi-faceted than the broad-brush classification of them into humanities, sciences and the applied fields. Also, just as c*ontextualizing* has multiple forms depending on what serves as the context, *epistemologizing* and *problem-solving* efforts can take different forms as well. It is only natural that *mathematization* of knowledge, for example, looks very different from its *empiricizing* in science. *Problem-solving* efforts are significantly shaped by the nature of the problem as well. Thus, the basic insight offered here serves as a guiding compass for further elaboration.

The chief contribution of the proposed schema is in pointing to the importance of investigating the disciplinary foundations of interdisciplinary inquiry. Identifying the central epistemological agenda of interdisciplinary work can help educators to find the right pedagogical approaches to facilitate it in the classroom.

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[i] Very generally, this typology invokes Habermas' (1971) classification of knowledge systems into three main categories: 1) a humanities (hermeneutic) tradition; 2) "empirical-analytic sciences," based on the "deduction of law-like hypotheses" establishing predictive correlations among phenomena; and 3) "sciences of social action", which include economics, sociology and political science. Habermas' view of the social sciences as action and social-transformation orientated suits this typology especially well, much as it is an arguable claim, given that a lot of work social science is not prescriptive or directly actionable.