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Three strategies for interdisciplinary teaching: contextualizing, conceptualizing, and problem-centring

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This paper distinguishes among *contextualizing*, *conceptualizing*, and *problem-centring* as three basic approaches to interdisciplinary curriculum. This typology is based on the type of inquiry that takes place in the classroom. For example, if the guiding epistemology in the interdisciplinary work is that of the humanities, the mode of connecting disciplinary material is likely to be *contextualizing*, or embedding the facts and ideas 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-development, the integrative process will take the form of *problem-based* investigation of urgent or tangible issues. Using empirical data from exemplary university, pre-university, and professional programmes in the US, I describe three integrative strategies and comment on their strengths. This basic typology provides alternative approaches to interdisciplinary material based on the purpose of the class inquiry. In the hands of a good instructor, several interdisciplinary strategies could be used together for mutual benefit.

Keywords: epistemology;instructional methods; interdisciplinary approach; problem-oriented instruction

No one close to interdisciplinary work fails to notice that it has many faces. Different schools and programmes conduct it in vastly differing ways and reach different results. 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 laboratory, or a professor in a lecture hall can bring together ideas from different disciplines. My purpose 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. Klein (1990), Klein and Doty (1994), Kockelmans (1979), Lattuca (2001), and Newell (1998) have all proposed conceptual categorizations that distinguish among 'interdisciplinary', 'metadisciplinary', 'informed disciplinarity', 'synthetic interdisciplinarity', 'transdisciplinarity', 'conceptual interdisciplinarity', and other such categories. These authors base their classifications on

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the tightness or looseness of the connection among disciplines in an integrated curriculum. Kockelmans's (1979: 127) typology proposes that in 'multi-disciplinary' work, for example, 'there may be no connection at all between disciplines involved', while 'pluri-disciplinarity' implies some co-ordination or juxtaposition. In 'interdisciplinary' work parts of existing disciplines are 'totally integrated' (p. 128) into a new discipline or a solution. 'Cross-disciplinary' and 'pluri-disciplinary' work for Kockelmans involves tight co-ordination among disciplinary parts, either in the form of finding a solution to a problem or in the form of 'the discovery of overarching conceptual framework' (p. 142). Lattuca's (2001) classification is based on a similar principle and somewhat overlaps in terminology with Kockelmans's classification ('transdisciplinarity', 'conceptual interdisciplinarity'). Lattuca also looks at the 'level of integration' (p. 113), and 'the epistemological commitments' (p. 118). Thus, for instance, 'informed disciplinary' work asks primarily disciplinary questions, while 'transdisciplinarity is the application of theories, concepts, or methods with the intent of developing an overarching synthesis' (Lattuca 2001: 79). In other words, Kockelmans (1979) and Lattuca (2001) focus in their classifications on how closely the disciplines bond in the interaction, and what is produced as the result of this bonding.

My classification of interdisciplinary strategies, while also attentive to the nature of bonding among disciplines, looks primarily at the disciplines themselves and their role in guiding the quest for knowledge. The guiding disciplinary epistemology is its starting point: the mechanism of connection, the questions asked, the nature of the inquiry that takes place, and the standards of validation applied. Thus, my proposed strategies—*contextualizing*, *conceptualizing*, and *problem-centring*—reflect respectively the nature and structure of knowledge in the humanities, sciences, and the applied fields. My typology, however, is not incompatible with those of Klein (1990), Klein and Doty (1994), Newell (1998), Lattuca (2001), and Kockelmans (1979) who take a closer, and perhaps a finer-grained, look at the mechanism of connection itself. It is probable that *contextualizing* efforts could proceed along both 'cross-disciplinary' and 'transdisciplinary' lines, depending on how close a tie between disciplines is deemed to be. Kockelmans (1979: 124) 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' (i.e. arts, humanities, social sciences) (p. 145). 'Cross-disciplinary' work, on the other hand, according to Kockelmans (1979: 140), is designed to attack problems and issues 'found in the realm of the natural sciences or the 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 an introduction. The first strategy, *contextualizing*, is a method of embedding any 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 centring context (*metaphysics as context*). Another context could be systems of knowledge and modes of reasoning about the world (*epistemology as context*). All 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 their mathematical or empirical core and discovering that behind different systems of notation and symbolic representation in science there are common patterns and processes.

The third strategy, *problem-centring*, involves enlisting the knowledge and modes of thinking in several disciplines (i.e. biology, chemistry, political science, economics) to examine messy real-life problems (such as water pollution, genetic engineering, or AIDS in Africa) that require more than one discipline to solve. The tenor of this strategy is that of an applied social science that pursues the goal of producing tangible results (i.e. 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 and social change.

In all three approaches, I argue, the way in which knowledge is generated and the connections among ideas are made is different because of difference in the epistemic *goals* of the inquiry. What counts as a solid and meaningful way to connect ideas in the humanities (e.g. metaphor, triangulation of several accounts, multiple resonance) may not even be a plank in the construction of the bridge connecting mathematics and physics. And, conversely, what mathematics and science validate as a true and reliable connection (i.e. a 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 understanding, but rather to point to the different epistemological requirements and expectations that they impose on the interdisciplinary process and curriculum. I should stipulate, however, that the disciplinary distinctions I draw here (humanities, sciences, and social sciences) are very broad-brush,[1] and distinguish among large divisions of knowledge:

- the humanities;
- the sciences—both empirical and analytical; and
- the applied fields, including the applied social sciences and fields aimed at product- or policy-development.

Research study and data collection

The above framework emerged from the study of interdisciplinary undergraduate programmes, part of a larger 3-year project examining exemplary practices of interdisciplinary work at the collegiate, pre-collegiate, and professional levels in the US. The overarching goal of the larger project is the empirical investigation of the psychological, organizational, pedagogical, and epistemological aspects of interdisciplinary work on all three levels. This so-called 'Interdisciplinary Study' is carried out at Project Zero, a research branch of the Harvard Graduate School of Education.

In identifying sites for this study, we looked for institutions and programmes that met certain stringent criteria:

- existence of the programme for at least 5 years;
- unswerving commitment of the part of an administration and a faculty to doing interdisciplinary work, stated in the mission statement or articulated by key personnel;
- some continuity in the direction and execution of the programme;
- deliberate efforts to forge new pedagogy and assessment standards to support interdisciplinary learning; and
- appreciation of the cognitive, institutional, and pedagogical complexity of the interdisciplinary work, and continued critical reflection about future development of the programme.

The pre-university, high-school programmes explored in this sample include Suncoast Community High School in Florida and Lincoln Park School in Chicago (Theory of Knowledge [TOK] course developed by the International Baccalaureate Organization), St Paul's School (Interdisciplinary Humanities Programme), and the Illinois Mathematics and Science Academy (IMSA) (the Scientific Inquiries [SI] and Mathematical Investigations [MI] Programmes, the Perspectives Programme). The undergraduate programmes include Swarthmore College (Interpretation Theory), San Francisco State University (SFSU) (NEXA Programme), Stanford University (Human Biology Programme), University of Pennsylvania (Center for Bioethics), and the Massachusetts Institute of Technology (MIT) Media Laboratory (Toy Symphony project). It was also very useful for this research, given its limited scope and in-depth focus, to capture programmes that differed in their interdisciplinary approach, disciplinary orientation (humanities, science, social science, applied science), and organizational structure. This, on the one hand, provided opportunities for tracing some fundamental similarities (in cognitive effects, or in forms of collaboration across different sites), and, on the other, offered an insight into cardinally different approaches to interdisciplinary instruction applied with different disciplinary agendas in mind. The wide range of educational levels, institutional frameworks, disciplinary agendas of participants and programmes in the study guaranteed a broad (albeit by no means exhaustive) palette of integrative strategies for this systematization.

The different research sites had distinct disciplinary orientations. Some programmes, 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 Programme at SFSU, the Interpretation Theory at Swarthmore, St Paul's Interdisciplinary Humanities Programme, the IMSA Perspectives curriculum, and the TOK courses which are part of the International Baccalaureate curriculum. Other programmes such as MI and SI 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, that is to find precise yet universal correlates of core concepts in several (mostly scientific) disciplines. Another cluster of programmes and courses—Economics and Ecology at IMSA, Bioethics at the University of Pennsylvania, the Toy Symphony project at the MIT Media Laboratory, and Human Biology at Stanford University—fell into the category of programmes 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 programmes determined the unique paths towards integration.

Data were collected during one research visit[2] to selected sites that took place over Spring–Fall of 2001/2002. Project Zero researchers conducted one interview with each faculty member and student participant in the course of a 3–4-day visit to each site. Visits also included 23 classroom observations (all sites included), discussions with programme administrators, and examination of student work. At all institutions together, 98 faculty members and administrators and 52 students have been interviewed. In addition, I also observed one joint grading session with two NEXA faculty members. Interviews with faculty members and students were 1–2 hours long, and focused on the following topics and questions:

- Organization and administration of the interdisciplinary programme; participants' history of involvement in the interdisciplinary work:
  - What is your role in the interdisciplinary programme design?
  - How do you understand its mission?
  - How has the programme evolved over time?
  - How does the programme/institution support or facilitate faculty collaborations? What are the provisions for joint research and teaching?
  - What are specific recruiting policies, reward and promotion system, and evaluation practices in the interdisciplinary programme?
  - What is the relationship between the programme and academic departments, how do their cultures differ?
- Pedagogical design—description and critical analysis of interdisciplinary pedagogy:
  - How are different bodies of knowledge brought together and integrated in your classroom? How do you specifically facilitate connection-making? Could you describe a project or a unit, which successfully brought different 'modes of thinking' together?
  - Could you compare your teaching of an interdisciplinary course to teaching a traditional disciplinary curriculum?
  - Why do some interdisciplinary units/projects fail? How would you describe the particular challenges of an interdisciplinary curriculum?
  - How is interdisciplinary work assessed? What evaluation criteria do you set for students? How do teaching partners arrive at a joint grade?
  - Can you describe your collaboration with your teaching partner in this course? What were its impacts on your teaching?

- Cognitive impacts of interdisciplinary learning or collaboration—description of challenges and opportunities offered by an interdisciplinary inquiry to students and faculty:
    - Could you comment on what is difficult about teaching/learning in the interdisciplinary programme as compared to other kinds of instruction?
    - How would you describe the outcomes of an interdisciplinary course? How has this mode of learning/teaching impacted you as a learner or a teacher?
    - Could you describe moments of integration and disconnection or confusion? What do you think contributed to them?
    - Is there anything in the cognitive profile of a learner that predisposes him or her for interdisciplinary exploration? What cognitive qualities need to be in place to cope with the challenges of interdisciplinary work?

Given the focus of this paper on the integrative teaching strategies, the middle portion of this protocol yielded the most useful data as it prompted both faculty members and students to reflect upon how the disciplines actually came together in the curriculum.[3]

Close attention was also paid to collaborations and knowledge-sharing, and the forms that they took in different settings. It became clear early in the study that programmes differed deeply not only along administrative lines, but also, significantly, according to their epistemological commitment. Thus, the nature of this commitment became the focus and a framework in the analysis, resulting in follow-up coding aimed at capturing the particulars of the pedagogy in the humanities, sciences, and social science programmes.

While resonances in findings across different sites provided some measure of validity, they also highlighted the need for more research to substantiate this framework. Short site-visits, few classroom observations, and single interviews are a concern in terms of generalizability of findings and viability of theory-building. A study of larger scope, with a more representative and varied sample of curricula in each category, as well as the introduction of quantitative measures, would be very useful in follow-up research.[4]

The proposed framework emerged from the initial insight that a primary epistemological commitment may be responsible for varying strategies towards interdisciplinary teaching, which was corroborated by observations and interview data gathered at the different research sites. While certainly requiring further substantiation, the framework has so far generated positive responses on the part of some participant institutions and interviewees: they found that it captures the essence of their efforts and is easy to apply. My hope is that this categorization would serve as theoretical compass for future map-making of this complex terrain.

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. In that the primary goal of the human sciences is to interpret the human condition, the end-product of the humanities enterprise (i.e. the work of historians, writers, philosophers, poets, etc.) is 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: 269). Bridges and connections in the humanities are typically made up of chains of associations, multi-causal hypotheses, and metaphorical linkages.

However, although closely related in their core goals and epistemological foundations, the disciplines of the humanities—philosophy, history, and literature—nevertheless differ in their specific tools and the 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 of these contexts here—history, metaphysics, and epistemology—for which supporting examples are 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. For example, Catherine Rodrigue in the Interdisciplinary Humanities course at St Paul's School invokes the backdrop of the Civil War, the slavery and the abolitionist movement in the South, and the historical symbolism of going down the Mississippi River in teaching Mark Twain's novel *Huckleberry Finn*.

At the university level, Charles Shapiro and Kurt Nutting in the NEXA course at SFSU describe the scientific development of the atomic bomb against the background of events in Nazi Germany and the resulting 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 artefact, a product of history, political leadership, and moral or immoral personal choices.

IMSA's Perspectives Programme often takes a historical approach to linking ideas. It seeks 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? (Rob Kiely, IMSA teacher)

Not infrequently, the historical context in IMSA's seminars is seamlessly fused with the larger philosophical questions explored against the background of shifting world-views. The emergence of the scientific method and development of abstract thinking about space are the 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 within which to link disciplines. 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 the navigational techniques, a mathematics teacher explained the development of graphing techniques that led to two-dimensional representations in terms of latitude and longitude, a physics teacher introduced modern global-positioning satellites, and an art teacher demonstrated representation of three-dimensional space in Renaissance painting. Thus, it is often the case in *contextualizing* classrooms that several contexts seamlessly overlap.

Metaphysics as context

Some interdisciplinary classrooms in our sample exclusively use philosophical or broad metaphysical questions (Who am I? What is the purpose of my existence? What are my beliefs?) as a vehicle for connecting knowledge. The context in this case is not so much time, as the timeless metaphysical concerns of human existence. Issues of selfhood, moral belief, and social responsibility serve as the connecting glue.

Hicks (1981: 4), the founder of the Interdisciplinary Humanities Programme and former Rector of St Paul's School, in his book *Norms and Nobility: A Treatise on Education*, defines the key concerns of education as posing to students 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?'—and building the rest of the curriculum around them. Thus, using paintings by Manet and Courbet, philosophical theories of Marx and Kierkegaard, and the text of Mansfield's (1988) story 'Garden Party' (first published in 1922), St Paul's teacher David Pook pushed his students to confront the central questions of their existence in the socially-privileged world of St Paul's School.

> Is 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 (1862) 'Concert in the Tuileries' and contrasting that with Courbet's (1851) representation of 'A Burial at Ornans', helps students identify and clarify their own philosophical, social, and moral choices.

Epistemology as context

The distinctive feature of an epistemological survey of the human condition (as opposed to a metaphysical one) is its specific focus on the act of knowing. Disciplinary perspectives in this case are connected not by historical events or ethical or metaphysical questions, but through belonging to a particular mode of reasoning and meaning-making. *Epistemologizing* classrooms typically discuss how different subject areas define and pursue truth, what they count as evidence, and what they deem to be good questions to explore. The connection of disciplines thus happens in the act of identifying and analysing their differences. 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 to express ideas with elegance and economy.

The TOK course designed by the International Baccalaureate Organization was one such course. I had a chance to observe it at the two schools—Lincoln Park High School in Chicago, and Suncoast Community High School in Palm Beach, Florida. Mary Enda Tookey, teacher and TOK co-ordinator at Lincoln Park High School, describes her goal in the TOK as helping students to 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 in his class by first asking students: 'What are the most important five events of your life? Of US 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'. The sustained interest in the act of knowing helps to produce students' deeper understanding of themselves as 'independent knowers'. As Howard describes it:

> [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 judgement; 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 thinks she is close to achieving her teaching goal.

According to Mark Wallace at Swarthmore College, the focus of the interdisciplinary Interpretation Theory concentration, in which he teaches, is the 'self-conscious examination of the act of interpretation'. The programme, in his view, allows faculty members

> to think on a meta-level about the work of interpretation itself. So not just the reading of St Augustine, or the reading of Martin Heidegger, or the reading of Sigmund 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?' Thus, 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.

In all its manifestations, the *contextualizing* strategy allows instructors and students to make far-reaching connections among disciplines. What facilitates this connectivity is the fact that the *contextualizing* strategy taps some foundational aspects of the disciplines, their methodological and philosophical core. 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 laboratory 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?

The need to provide scientific literacy to the public is a recurrent call in education. *Contextualizing* work—whether in the form of exploring epistemological bases of science or tracing the history of a particular discovery—may be a way to render science more accessible, and to dispel the false perception in students that they cannot possibly 'question the very presuppositions that underlie science' (Roth 2003: 11). The *contextualizing* strategy is designed to do just this kind of work in the university and secondary curriculum. It would be unreasonable to demand mathematical rigour or policy recommendations from a contemplative investigation of the philosophical roots of the scientific beliefs or an interpretive study of literary narrative. By the same token, it would be unfruitful to turn a science laboratory 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 co-existence of different modes of integration, perhaps even in the same classroom, could potentially maximize the strength of each strategy while compensating for some of its natural limitations.

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 as *linearity*, *change*, and *scale* can effectively tie together algebra and geometry, physics, and biology, illuminating a hidden pattern of relationships. Frid (1995: Appendix 1) 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 formulae, 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 colour.

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: 41) about physics, where one finds 'knowledge structures with clear and explicit concepts, and a high level of agreement about methods of inquiry' (p. 31).

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 their core, mathematical base, a 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*.

IMSA is a good example of the application of *conceptualizing*, especially in its SI and MI programmes. *Conceptualizing* the content of the different disciplinary vocabularies or 'dialects' to patterns that 'tell a story' is at the heart of SI and MI. The official brochure describing the programme indicates that the main building-block of the MI curriculum is the content/concept unit. Each unit addresses different content ideas centred 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 modelling into which the concept of linearity gives insight. The 'Function' unit tackles functions and more general relationships from graphical, tabular, and algebraic viewpoints (IMSA 1997).

In the SI programme 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 mathematics (to calculate the frequency of these vibrations or oscillations per second) in order, as one student explains in her paper, ‘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 she brings together, but also 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 the 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 their historical and cultural roots, *conceptualizing* connections in science are produced ‘by design’ (Marshall 2000) and not by intuition alone. The role of the teacher as a translator across different systems of disciplinary representation is crucial and needs to be emphasized. According to Susan 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.’ As Yates described the teacher’s thinking it is: ‘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.’

However, as Yates notes, this kind of transfer is far from automatic. The transfer of knowledge to new disciplinary material or ‘subscripts’ is ‘hard’, 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, Danny Yagan, a student, 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 SI and MI programmes 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 knowledge of production.

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 mathematics and science make a *conceptualizing* strategy a substantial pedagogical and curricular effort. It requires the co-ordination, re-sequencing, and re-structuring 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 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 and 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 (1995) put it, in different disciplinary 'dialects'.

Integrative strategy 3: Problem-centring

Problem-centring uses an ill-structured real-world 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-centring* is aimed at generating tangible outcomes and change. The pragmatic real-life orientation of this pedagogy gives it its unique impetus and flavour. *Problem-centring* most readily captures the spirit of the applied sciences, technology, and the fields of applied social science that aim to create new products, to improve on existing conditions, or to develop policies for social change. It is no surprise that such disciplines as economics and ecology, technology and engineering, and 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 resolve it.

Centring curriculum on critical issues of public debate (e.g. medical research and ethics)

The applied and activist essence of the *problem-centring* strategy is revealed in many areas of political and social science. It is particularly evident in the emerging interdisciplinary field of bioethics, which takes up some of the most burning issues of public debate of our times, and examines them through discussion and policy recommendations. Interviews with faculty members and students at the Bioethics Centre of the University of Pennsylvania describe how the field of bioethics brings 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 a typical academic offering. Handing in a paper at the end of the term does not quite suffice in this course. Students are expected to produce at the end of a class an analysis which is nothing short of a call for a legislative change. 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 personal stand, and a recommendation for legal action. 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.

Centring curriculum on product development

The Toy Symphony Project at MIT is a case of *problem-centring* 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 of Tod Machover, a composer, brings together musicians, engineers, graphic designers (graduate and undergraduate students at MIT) who examine 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 help introduce children to music makes all participants focus closely on the tools that they need from each of their respective fields rather 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*. As Jehan describes it: '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 analysing 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 I'm 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 that they are 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 raises a concern on the part of some educators as to the disciplinary preparation of students. Media Laboratory professor David Shaffer comments that in the 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 to be paid for the high degree of creativity that characterizes *problem-centring*. Perhaps no other integrative strategy calls as powerfully for innovative resolution of disciplinary differences, and finding imaginative fits of ideas as does *problem-centring*.

Centring curriculum on intervention designed to improve health and well-being

The Human Biology Programme at Stanford is another example of *problem-centring* at work; it focuses on critical interventions that could improve human health and the standard of living of peoples of the world. The programme's integrative modules and field experiences make students confront such questions as: 'Why is lactose intolerance endemic in some cultures?'; 'Why is there high incidence of spina bifida in the newborns of Southern Mexico?'—and build their learning and activities 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 the 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* programmes 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 the *problem-centring* work the fundamental metaphysical 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 programme) went to do field-work in Southern Mexico with the goal of resolving endemic birth defects in the local population. Understanding the causes of the problem served only as a tool to solving it, not 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 programme 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's 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.

The advantage of *problem-centring*, similar to *contextualizing*, is that it easily brings together a wide range of disciplines in the curriculum. Learning becomes personally meaningful and highly motivated by a desire to resolve an important social concern. The tools and methods of the disciplines are used with precision and rigour rather than in a generalized and abstracted way. Students in *problem-centring* classes may 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. Table 1 provides a summary description of the unique strengths and weaknesses of each of the described strategies and proposes ways to resolve 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?

Table 1. Characteristics of the three strategies and their application.

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

- 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 blind-spots 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 blind-spots in my inquiry and pedagogy?

As table 1 summarizes, the *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 laboratory 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 rigour 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 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-centring* or *contextualizing*. What instructors can do to compensate for that is 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-centring is as strong as *contextualizing* in terms of making broad and far-reaching connections among the disciplines. The connections that are established in *problem-centring* 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 the disciplinary breadth that it could bring. Often, the urgency of the problem, 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. Mathematics and science teachers, for example, can draw upon the humanities for gaining a broader *context*, and also centre their curricula on problems from the real world. Instructors in social sciences applying a *problem-centred* pedagogy could benefit by 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 members exerting *contextualizing* efforts, in turn, may profit by more careful justification and verification of the connections they make among ideas, inspired by the rigour of *conceptualizing* efforts. In the hands of many good teachers, several strategies can work together to mutual advantage.

Future directions

This attempt to organize interdisciplinary teaching into three main strands based to the disciplinary agenda can benefit from a more detailed exploration of each of the strategies, as well as from extending this basic typology beyond the three knowledge systems. 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 *contextualizing* has multiple forms depending on what serves as the context, *conceptualizing* efforts can take different forms as well. *Problem-centring* efforts are likewise significantly shaped by the nature of the problem. Thus, the basic insight offered here serves as a guiding compass for further elaboration.

Another important question to explore in future longitudinal studies might be a question about the existence of a typical recurring sequence in the application of different strategies by the teacher in the learning process. Carefully tracing the development of an interdisciplinary research project or a class, one may observe, for example, that different types of inquiry are called for at different points of investigation to serve different purposes. Does context-building typically ground or precede deep conceptual work? Is *problem-centring* deemed to be the culminating point of interdisciplinary efforts that builds upon *conceptualizing* and *contextualizing* work? These are fascinating questions that can yield valuable information for curriculum development and classroom practice. The development of a pedagogical framework that makes systematic and deliberate use of all these strategies could be the next challenge for research.

The chief contribution of the proposed schema is in pointing to the importance of investigating the disciplinary foundations of the 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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Notes

1. Very generally, this typology invokes Habermas's (1971: 308) 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's view of the social sciences as action and social transformation-oriented suits this typology especially well, much as it is an arguable claim, given that a lot of work in social science is not prescriptive or directly actionable.
2. The Media Laboratory was visited several times for data collection.
3. Interviews have been transcribed and coded, and a cover sheet was prepared for each participant and classroom observation.
4. There is currently a close observation-based study of interdisciplinarity at high schools under way at Harvard Graduate School of Education which will consider some of these issues.

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