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Being in Uncertainties: An Inquiry-based Model Leveraging Complexity in Teaching-Learning

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Abstract

Education is traditionally structured as a closed system, privileging result-driven methods that offer control and predictability. In recent decades this reductionist approach has been effectively challenged by interdisciplinary work in complex systems theory, revealing myriad levels of *orderly disorder* that make either-or, linear instruction an inadequate norm. Narrowing the broad implications of a complexity lens on education, this paper focuses on generative uncertainty in teaching-learning, a paradoxical state of epistemological and creative growth described by English poet John Keats as "the negative capability of being in uncertainties, mysteries, doubts." Opportunities to advance this potentiating capacity are especially abundant in constructivist curricula, for example the *Methods of Inquiry (MoI)* program discussed herein. *MoI*'s open, complexity-based approach foregrounds uncertainty-tolerance and other interactive dispositions, providing a fluid structure for the emergent, often turbulent nature of meaning production. Such dynamic attitudes and strategies are seen as essential for any classroom practice that seeks to transform as well as inform, to guide and also empower.

1. Introduction

> We have conjured up the ghost of objective culture, and now we do not know how to lay it to rest (Bakhtin 1993/1999 p.55).

"Is this right?" one of my art students asked, showing me her beautifully expressive drawing. The assignment was themed but open-ended, with no restriction on style (realistic, abstract, etc.), so the question was both surprising and disturbing. By definition, creative ideation in the arts and sciences alike defies absolutes and rigid categories, emerging instead from an unpredictable interplay of rational, affective and intuitive ways of knowing (Bruner 1979/1962; Perlovsky 2010; Freeman 2011). Yet such nonlinear dynamic thinking is largely subverted more than supported by traditional outcome-driven classroom practice, deploying factory-style linear methods (Callahan 1964). As a result, even in explicitly creative contexts the only available options appear to be either *right* or *wrong*. The exchange with my anxious student crystallized this reductionist mindset, a

legacy of the same flawed universe of standardized control-measurement-conformity lamented by Russian philosopher Bakhtin almost a century ago.

Over the last several decades, a complexity perspective on education has reinvigorated this inert paradigm. Complexity theory, essentially, illuminates the intricacies of nonlinear dynamical systems, natural and social, whose myriad interactive parts self-organize spontaneously and unpredictably just at the edge of chaos where creative leaps and higher levels of complex behaviors emerge (Kauffman 1995; Prigogine & Stengers 1984). Basic complexity principles have enriched such areas as education philosophy (Mason 2008; Semetsky 2008); structured but flexible curriculum design (Doll 1993, 2012; Gough 2013); gifted education on the chaos-order continuum (Ambrose 2015); nonlinear transactional literary experience (Hayles 1991; Gillespie 1999); reciprocally interactive teaching-learning dynamics (Steenbeek & van Geert 2013); and doctoral programs that prepare educators "for one of their most important roles: to disrupt, to challenge, to disorient-- in service of enhancing critical reflection, creativity, and transformative learning" (Wergin 2011 p.126). Placing education within the fluid frame of a creative turbulent universe, complexity gives educators insight into teaching-learning as an adaptive open system in which passively receiving information is less meaningful than actively contextualizing, connecting, and co-creating knowledge.

Thus the complex *learning system* of teacher-student-peers-content-environment is inherently chaotic *and* determined: sensitive to initial (and ongoing) conditions, bounded by pre-existing standards and goals yet evolving unpredictably over time. Particularly in English literacy instruction, the transformative synergy of literature, language, and reader/writer/learner (each inherently complex itself) arises through nonlinear dynamical processes. In this sense, the more pedagogy is attuned to its own complexity, the more apparent is the significant role of *uncertainty* in any process of *coming to know*--whether academically, artistically, socially, or personally (self/identity). For students, generally drilled into re-producing "the" right answer, being asked to think pluralistically and generatively is liberating yet also stressful. Any open, relational pedagogy entails such tensions, and capacities for handling them are therefore crucial. English poet John Keats described this as the paradoxical "negative capability of being in uncertainties, mysteries, doubts" (1964/1817 p.304), a requisite state for epistemological and creative productivity.

This paper, whose title derives from Keats' term, centers on "being in uncertainties" as a conceptual link between complexity, inquiry-based teaching, and dispositions that empower learning. Inquiry is first placed in context of major process-oriented learning theories. Then *Methods of Inquiry (MoI)*, via engagement with *habits of mind* that undergird all learning, illustrates a complexity-informed practice successfully integrated into an upper school English

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curriculum; student work and process reflections represent key features of the program. Concluding thoughts review what is gained by using this complexity-based approach in language arts practice, and implications for subjects across disciplines.

2. Process-Oriented Learning Theories

While education ossified within its closed frame, prominent early 20th century philosophers and psychologists crafted process theories that would disrupt the entrenched linear model. Prefiguring complexity, they saw cognitive, social and academic systems as open, complex and often unpredictable, with change emerging from multiple elements interacting dynamically over time.

Arguably the most significant, **Constructivism** grew from Dewey's holistic philosophy of inquiry as active, experiential learning (1910), and Vygotsky's theory (2004) of interdependent sociocultural factors contributing to creative and cognitive development. Moving beyond the behaviorist idea of education as a stimulus-response function, constructivism shifted the emphasis from knowledge as *product* to knowing as a *process* of active engagement, meaning construction, and lived-through experience in relationship with others and the natural world; classroom, teacher and students (inter- and intra-personally) are seen as a network of dynamically interrelated elements. **Reader Response** theory likewise emphasizes the complex, transactional nature of learning generally, and reading specifically: "Even as we are generating meaning, we are reacting to it" **(**Rosenblatt 1978/1994 p.48). The text is an event in time not an object or ideal entity, and meaning is continually co-[re-]determined through nonlinear transactions between reader and text.

Inquiry-based learning (IBL), a primary form of constructivist learning, has been of recognized value for education at least since Dewey, who describes the very origin of thinking as "some perplexity confusion or doubt" (1910 p34) stimulated by a meaningful problem that disturbs equilibrium, and the ensuing search for understanding. IBL in practice ranges from simply accommodating student questions to entire courses using an inquiry-based approach: question-driven, research-focused, and predicated on a belief in learners as agents in their own *becoming.* Numerous studies provide evidence for the positive effects of IBL on students' self-directed and life-long learning skills, including attitudes that develop critical and creative thinking (Thompson 2011; Montuori 2012; Lai 2011; Hung et al. 2008). Overturning the historically linear schema in which teachers transmit information to passive recipients, IBL facilitates student agency and co-creation of meaning.

Poststructuralist literary theory, steeped in the same ethos of indeterminacy, similarly rejected the notion of "objective" meaning inherent in the

text or authorial intent; rather, it stressed the text's multiplicity and openness, and the reader's dynamic role as producer of meaning. Like the infinitely significative possibilities of language itself, the text is "a system with neither closure nor center" (Barthes 1978 p.159). In Barthes' often-quoted image, "the plural of the text depends on its weave of signifiers: etymologically, the text is a textile, a woven fabric" (Ibid. p.159). Extending the metaphor, the *texture* or character of its evolving pattern is raveled, unraveled and reconstituted in a cascade of ever-renewing interpretations. With no abiding metanarratives, meaning is not dictated but co-created in each reading experience.

Brazilian educator Paulo Freire took student agency a step farther, seeing it as a mandatory corrective to the intrinsic disenfranchisement of hierarchical education. His theory of **Emancipatory Praxis** argues for "problem-posing education" that breaks the traditional vertical pattern; "students, no longer docile listeners, are then critical co-investigators in dialogue with the teacher" (1974/1968 p.67). Freire advocated democratizing classrooms, with teachers and learners as intentional co-producers of knowledge through participatory dialogue, reflection, and action. True dialogue, he believed, could bring about personal and social change, but only if educators and students together are involved in thinking critically, i.e. thought "that perceives reality as process, as transformation, rather than a static entity" (1974/1968 p.80).

These cross-pollinating pedagogical currents all resonate with the generative power of complex living systems. Inquiry-- by definition an open process of questioning and seeking-- requires a willingness to act from uncertainty, to "engage in research as an emergent process, to start from where you are without necessarily knowing where you are going" (Marshall & Reason 2007 p376); it entails staying open to the unknown, being "open to surprises and to engage in ongoing cycles of exploration [that are] never finished" (Eoyang & Holladay 2013, p.39). Both a method and philosophical stance, inquiry embraces the turbulence of uncertainty as a signal state for change; this was a guiding principle of the curriculum discussed herein.

3. *Methods of Inquiry (MoI):* An Example of Complexity in Practice

> Open systems function to keep the right amount of imbalance and creative dynamism. In terms important for education, closed systems transfer and transmit, open systems transform. Direct instruction exemplifies a closed system approach while interpretative inquiry, with its complexity, exemplifies an open systems approach. (Doll 2012 p.19)

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3.1 Background and rationale

NYC Lab School for Collaborative Studies ("Lab") is a small urban high school (grades 9-12) where students and teachers share ideas through active discussion and an interdisciplinary approach to subject matter. Students are mostly high achieving and highly motivated; classes are inclusive, with a diverse mix of students whose individual perspectives are valued. In 2007, however, Language arts in most upper schools-- including Lab-- had moved away from the extended discussion and writing necessary to explore ideas or develop arguments in depth, toward a much narrower focus on answering types of standard test questions (Applebee & Langer 2006). Dissatisfied with this diminished approach, Lab's Principal wanted a revitalized English curriculum that would allow extended time for research and more challenging writing. She asked Columbia University's Student Press Initiative (SPI, a nonprofit promoting literacy in public schools) to be involved. As an SPI consultant at the time, I led the re-design project in 2007-2008.

Many alignments between core concepts of complexity theory and authentic teaching-learning informed my development of the program: education seen as a *complex open system* (multiple interactive factors, information flowing in/out) that is *conditions-sensitive* and *unpredictable* (small initial causes having unforeseen effects, irreducible to original parts); *relational* and *adaptive*, constantly in dynamic interaction with the environment; s*elf-organizing* in the spontaneous emergence of new, higher-order patterns over time (i.e. comprehension/ insight); and optimally functional with enough order for stability, yet ample flexibility to provoke transformative growth (Prigogine & Stengers1984). Moreover, nonlinear process, encompassing the multiplex nature of branching, feedback-inflected change, is valued as an energetic creative force beyond linear cause-and effect logic. Guided and autonomous, standards-compliant and yet student interest-driven, Inquiry based learning virtually embodies these open dynamics.

Thus *Methods-of-Inquiry (MoI),* as I named the new curriculum, emphasizes *process*. It supports intellectual curiosity and understanding through research, discussion and writing as forms of nonlinear exploration; student agency through active engagement and reinforcement of long-term learning capacities; collaboration through regular small group work. In the belief that questioning and learning should not remain siloed, students shared their inquiry journeys and resulting work with teachers, other students, and families at celebratory culminating events.

On a pragmatic level, *MoI* innovations were introduced to supplement and enhance, not replace, existing content-goals. The focus was less "what" than "how," i.e. building, along with content knowledge, vital competencies that

facilitate all learning whether in the sciences or humanities; enabling students to explore interest-driven paths related to coursework; and providing teachers with ongoing possibilities for varied, nuanced authentic assessment. In collaboration with the full-time English teacher whose class it was, I co-taught *Methods of Inquiry* for its first two-year arc spanning grades 11 and 12. The pilot inquiry model-- featuring habits of mind-- was launched within the English language arts experience based on its strong focus on research and writing, but domain-appropriate iterations were later incorporated across curricula.

3.2 Implementation

> [In a complexivist] curriculum order is not imposed, as has been the history of curriculum development. Order emerges from interactions having just the 'right amount' of tension, difference or imbalance among the elements interacting. (Doll 2012, p25).
>
> Curriculum should be flexible, open, disruptive... and also accepting of tension, anxiety and problem-creating [as the norm] for transformative learning (Iannone 1995, p.544).

Methods of Inquiry launched in 2008 with an 11th grade English class of 32 students. Classes met 45-minutes every day first semester, four days a week second semester. Grounded in the spirit of what makes us *want* to learn, *MoI* emphasized intrinsic motivation like natural curiosity over necessary, but often less effective, extrinsic goals like knowing answers for an exam (Amabile1997). The program embraced participatory (teacher-focused but open, nonlinear) constructivist practice, rather than the transfer (teacher-dominated, linear) model. Complexity's emphasis on variation as a source *and* outcome of thinking (Davis et al. 2004) helped inform the curriculum regarding the role of nonlinear interactivity and uncertainty in cognitive processes. As in Doll's "right amount of tension," *MoI* aimed to spark and support a form of productive disequilibrium, the generative state between order and chaos. While hewing to essential academic skills, instruction strove to minimize over-attachment to "the" right answer, allowing students to experience the value of process. A syllabus excerpt provides an apt summary:

WELCOME to Methods of Inquiry! This is a rigorous two-year writing/language arts course, similar to a college level class. It requires you to take an independent and active role in your learning, tracking your own research and writing, reflecting on successes and struggles. In part, this class is intended to give new life to authentic ways of seeing and knowing that you may not have

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had time to experience meaningfully before. Philosophical goals include understanding that knowledge is inherently inter-disciplinary; reflection, thinking about your own thought process, is essential to learning; the nature of learning is social and interactive, and Inquiry is a fluid process ingrained in all aspects of life.

To support students' growth as agents in their own learning, nine *Habits of Mind* (detailed in next section) served as the core of *MoI*. Along with the importance of these capacities, guiding pedagogical principles included:

• **Dialogic vs. monologic discourse.** Language is seen/used as an epistemological tool, a way of thinking, exploring, co-constructing meaning. In contrast with the traditional monologic model (teacher transmits, lectures), dialogic discussion is not finite but open. Prompting students to consider alternatives, question assumptions, speculate on implications, this animated dialectics of action and reflection fosters higher-level thinking and comprehension far more effectively than a linear model (Soter et al. 2008). Among dialogic "discourse moves" *MoI* incorporated were: (1) authenticity- open-ended prompts/questions with indeterminate (not pre-scripted, test-type) answers; (2) uptake-- teachers build on students responses in follow-up questions; and (3) flexibility-- encouraging exploratory, speculative, elaborative thought, promoting multi-participant discussions, and allowing student responses to alter the trajectory of classroom discourse (Nystrand & Gamoran 1997/2012; Nystrand 2006).

• **Extended Time.** Whether in discussion, reading or writing, complexity teaching and learning values the temporal factor of cognitive development, allowing time to puzzle through uncertainties or follow nonlinear routes in unexpected directions. "Time to think beyond," according to one cognitive neuroscientist, "forms the basis of our ability to propel knowledge, which then builds the next platform from which we dive below or soar above," particularly in the "neuronally and intellectually circuitous act" of reading (Wolf 2007 p.229). Writing, intrinsically time-linked, also requires willingness to work recursively toward comprehension and clarity, to begin tentatively, persist in cycles of drafting and revising, exploit surprise.

• **Diverse opportunities for *authentic* assessment.** Active student engagement in research, writing and discussion affords numerous and nuanced types of assessment possibilities, not merely summative but formative; e.g. portfolios, filled over time, provide global insights inaccessible to sporadic quantification; mini-presentations for peer feedback on work-in-progress; collaborative projects for sharing new knowledge; multiple thesis drafts and revisions. Students' ten-page papers were conceived as *Creative/Literary Nonfiction*, a form of academic writing that invites “the poet’s attention to

language, the novelist's power of storytelling, the journalist's pursuit of fact, and the scholar's reliance on research" (Perl & Schwartz 2006, p.2). This multi-facetted genre offers many options/avenues for assessing student's varied strengths.

Because IBL is highly responsive to text and context, class readings ranged from Leonardo da Vinci's notebooks to a textbook on research, and essays from publications like *The New Yorker* on salient contemporary topics. Mentor texts exemplified rigorous research, writing excellence, and an author's passionate exploration of crucial issues. From analyzing and responding to texts, to writing their own articles, students gained and/or built on a wide array of skills including: problematizing and articulating effective research questions; managing time independently and appropriately to suit the nonlinear qualities of inquiry; seeing questions as tools for thinking. Coming to understand learning as emergent process, students were more likely to view "meaning" as possibly multiple or indeterminate rather than only a definitive quantum.

4. Habits of Mind: The Dispositional Factor in Dynamic Learning

> It is essential that schools equip students with long-term *dispositions* and *capabilities* to make full use of their varied ways of knowing… Society requires, above all, an educational system that equips all young people to deal with uncertainty. (Claxton 2000 p214-215)

As students progress to higher levels of cognitive development, uncertainty and tension increase along with the complexity of challenges. Thus dispositions (habits or qualities of mind) learners can call on when they *don't* immediately know a solution become paramount (Costa & Kallick 2007; Claxton 2000). Collectively, they comprise the negative capability of *being in uncertainties*, a level of comfort with *not-knowing* that supports flexible thinking in unstable phases of knowledge-construction. While logic and analytical skills have long held center stage in the sciences, d*ispositions,* or propensities to approach problems in different ways, are increasingly recognized as crucial not only to **creative (CvT)** but **critical thinking (CT)** across disciplines, including science, technology, engineering and math (STEM).

Finding the traditional 'criticality-creativity' dichotomy to be problematic if not counter-productive, many researchers view them instead as inextricably intertwined attitudes that advance engineering (Terkowsky et al. 2014; Terkowsky & Haertel 2013); mathematics (Leikin 2007; Mann 2006; Ervynck 2002); and scholarship generally (Bailin et al. 1999; Bailin & Siegel 2003; Ennis 1985; Root-Bernstein 2003; Paul & Elder 2006, 2008; Montuori 2012). Higher order thinking,

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studies show, transcends the supposed gap between scientific and creative ways of knowing, synergistically co-involving unconscious phenomena and conscious/ rational control functions (Smallwood & Schooler 2015; Freeman 2011; Rothenberg 1979; Perlovsky 2010; Bruner 1962/1979); emotion and reason (Damasio 1994); intuition and aesthetics as well as objectivity (Hadamard 1945; Poincaré 1908/1955); imagination and logic (Dewey 1910). All are integral to innovative thinking that transforms its constitutive elements over time.

In practice, then, creating and evaluating are two aspects of "good" purposeful thinking, which may be seen as an emergent property of nonlinear dynamical interactions between intuitive ("lateral") and analytical ("vertical") functions. Indeed, the twinned generative-evaluative nature of serious thought is embodied in the etymology of *figure out*: 14c. "to represent" [in painting or sculpture] or "make a likeness," from L. *figurare* "to form, shape;" 15-16c. "to picture in the mind;" and [19c.] to "work out a sum" by means of arithmetical figures. This dynamic interplay between logical and generative modalities is, in pedagogical terms, perhaps the most important sense of a creative attitude.

Unsurprisingly, many dispositions commonly cited in the literature as conducive to **CT** are also known to enhance **CvT**, including: inquisitiveness/ intellectual curiosity**;** problem-framing; open-mindedness; resisting premature closure (navigating uncertainty); flexibility/ imaging/ imagining novel connections; questioning/ challenging givens and assumptions; willingness to entertain multiple and opposing viewpoints; reflection and self-correction; careful observation; collaboration; responsible risk-taking; persistence in seeking results that are as fit and accurate as a subject or domain permit (Lai 2011; Facione 1992/ 2015; Giancarlo & Facione 2001; Costa & Kallick 2000). Based on these, I selected nine *Habits of Mind* that served as both the foundation and goal of *MoI*: Curiosity/ questioning, Exploring multiple perspectives, Observing closely; Playfulness, Taking risks, Collaborating; and Uncertainty-tolerance, Reflecting, Persisting.

This worksheet (Fig. 1) introduced the *Habits*, not as a hierarchy but as reciprocal, interactive tendencies in dynamical, synergistic relationship to one another. The more each habit is engaged, the more others are reinforced in a circular causality supporting multiple ways of knowing that fuel cognitive development. On a Likert-type scale, students indicated where they felt they were with each habit at that moment, and periodically revisited the list. Grounded in these crucial capacities for empowering learning, *MoI* lessons included both explicit teacher-modeled approaches and embedded instructional formats/ activities. Some examples follow.

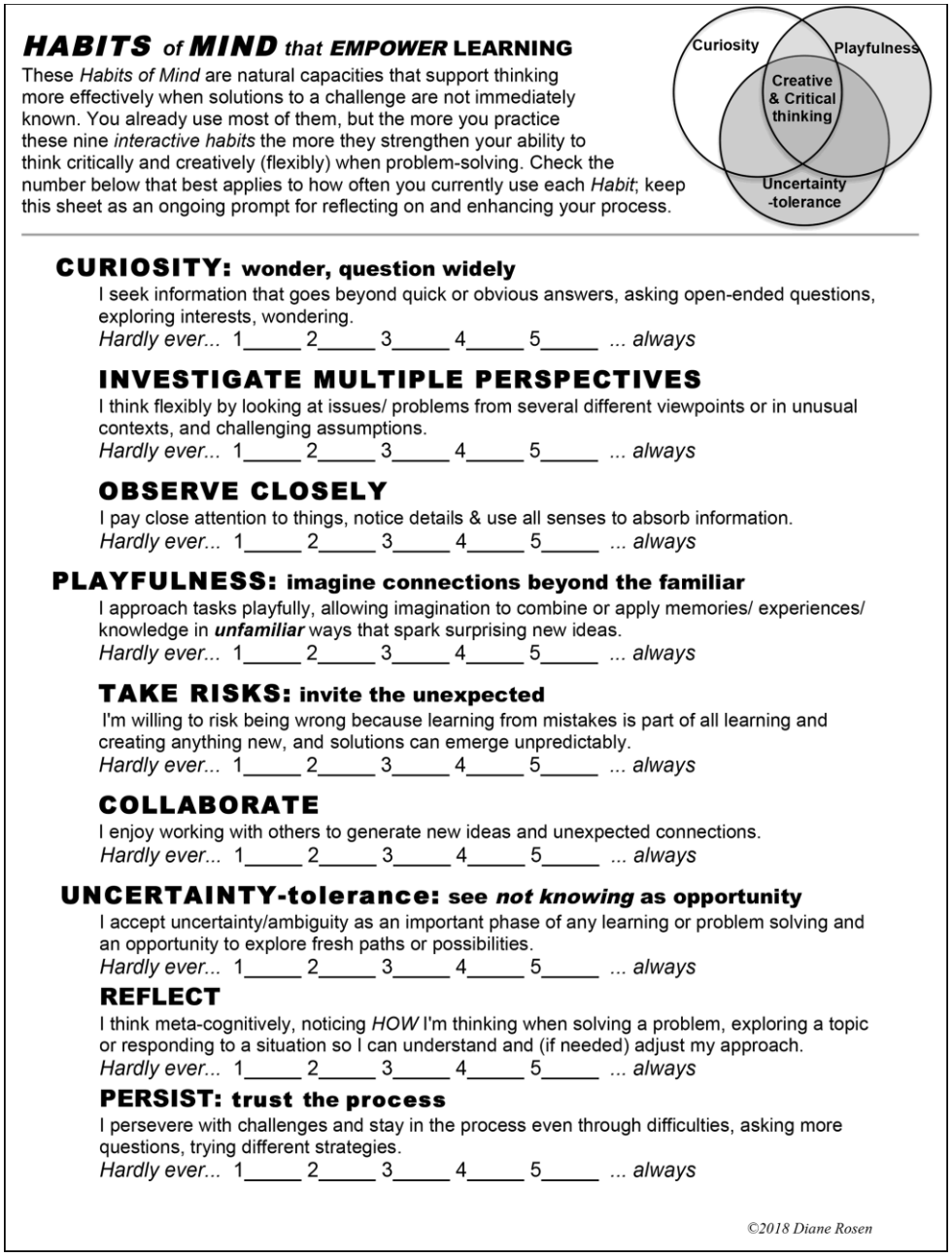

Figure 1. Student worksheet: *Habits of Mind that Empower Learning.*

i) Curiosity: Cultivate wonder, question widely

Bacon's saying that we must become as little children to enter the kingdom of science is at once a reminder of the open-minded,

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> flexible wonder of childhood and of the ease with which this endowment is lost (Dewey 1910 p33).

Curiosity, "the open-minded, flexible wonder of childhood" as Dewey calls it here, is a state of productive disequilibrium. It has an appetitive element, the need to satisfy an urge, allay some confusion, restore a balance that has been disturbed. When that disturbance (existential, biological, intellectual) is intense, yet not so disruptive as to result in utter chaos, it sparks a rhythmic flux between instability and order that is not merely the return to a previous state, but transformative. To stimulate this generative form of dissonance as it pertains to learning/seeking new knowledge, *MoI* lessons often began with a "trigger" question aimed at perturbing the status quo; for example, "When you open your hand, where is your fist?" Discussing its "disappearance" led to reimagining *fist*/noun as a segment of the action, "hand-in-most-closed-position." Like a phase portrait in dynamic state space, "fist" has no actual fixed existence but is more a snapshot of one moment or waypoint in a process of change. Likewise, the study of Conrad's novel *Heart of Darkness* started with open-ended questions about what/where the heart of darkness might be. Through various lenses (historical, psychological, philosophical), students examined the concept of moral ambiguity and with it, the need to reflect critically on our own and society's motives.

A primary goal of *MoI* was to move research and writing from routine capture and reproduction of information, to student-driven production of meaning through active Inquiry. For this, the prompt was broad: problematize a social justice issue of personal interest-- from local (family, school, sports, community) to national or global (environment, economic inequality, racial/ religious/ gender bias), and shape a question or problem. Inquiry, a "progressive determination" of problem-*posing* not just problem-solving (Dewey 1939 p109-10), proceeds nonlinearly from vague anticipatory notion to meaningful question and active investigation, until the "functional fitness" of an emergent idea presents a solution. Encouraging students in this dynamic process included open-ended strategies like mind-maps/webs, journaling, and free-writing-- an organic outward spiral from initially indistinct thoughts or interests.

Out of this work arose self-selected topics that were perceptive interrogations of compelling issues. Most were also prescient in their continued relevance, e.g.: political activism and the arts- *Speaking Out Through Spoken Word;* technology and photography- *From Bearers of Truth to Conjurors of Fiction;* media and racism- *The Princess is Always White*; erosion of civil freedoms- *USA Patriot Act: The New Constitution?* Students honed an attitude of questioning ("how, why, what can be done?") to produce research-based, effectively argued writing that would convey their own interests and in turn capture the reader's. A short excerpt from one paper, on undiagnosed student-

athlete concussions [used with permission of the original student author] is illustrative:

> *High school Athletes are in Danger--Are You Ready to Help?*
> *"I'm okay," the words come stuttering out. "What's the name of the school we're playing?" the coach asks. There's a long pause. A blank look runs over the goalie's face: "I have no idea." That goalie was me. In my mind it's a skip in time. This retelling is the story I got from one of my teammates... Why are there basically no precautions taken in managing concussions in high school sports? Injured athletes can walk back onto the field of play whenever they say they are ready. That responsibility should not be left in the hands of a minor... In order to shed light on this, Outside The Lines reviewed the medical records of a high school senior from western Pennsylvania who suffered his first concussion in a football game, [but] did not exhibit the classic signs associated with concussion. He came to University of Pittsburgh Medical Center, where a specialized test revealed "dramatic deficits in memory, processing speed, and reaction time. Though doctors called this a temporary decline, they were stunned by the numbers: 40% below expected brain function" (ESPN 9/24/00)... Getting a free tool kit [from Center for Disease Control and Prevention] and being informed is enough to make a difference in a concussed student-athlete's life. It's a preventable danger, so why wouldn't you do something to help keep high school athletes safe?*

Students channeled intellectual curiosity into research and writing that reached well beyond the formulaic five-paragraph essays routinely assigned. The attitude of inquiry, an "endowment" easily lost (Dewey), was cultivated through authentic work built meaningfully on students' interests, facilitated by teacher modeling and encouragement. Teachers' willingness to express *wonder*, or to say that they *didn't know* something and would inquire further, demonstrated and reinforced the process of curiosity in action.

ii) Investigate multiple perspectives

> Embracing complexity, the aim is for a process of cross-fertilization, pollination, catalyzation of ideas over time... Learning now occurs in a non-linear manner through exploring a situation/ problem/ issue together, and indeed from multiple perspectives (Doll 2012 p25).

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In his quest for deeper understanding, whether dissecting a corpse or creating a painting, Leonardo da Vinci would consider his subject from several different perspectives, e.g. above, below, sideways. *MoI* asked student to do the same with their beliefs and opinions, to challenge assumptions and received ideas, to question beyond stated boundaries everything from literature to the media. Exercises requiring repeated shifts in focus reinforced this habit. For example, thinking-- and literally drawing-- outside the (implied) box to solve the classic 9-dot puzzle, or responding with several "right" solutions to ambiguous visuals like surrealist paintings or optical illusions. This capacity for perceptual multi-stability supports robust both-and ideation and also satisfies evolutionary needs, enabling "rapid revision if a situation requires, in order to respond to unexpected objects, events, or to discover new aspects to familiar ones. Multi-stability is a sign that flexibility is at work in our perceptual system" (van Leeuwen & Smit 2012 p123). From easy to obscure, experiential activities immersed students in pushing beyond superficial impressions.

Lessons segued from perceptual to conceptual shifts, discerning hidden patterns or relationships between, among, and across seemingly unrelated ideas. One literary entry point was Borges' *Garden of Forking Paths* (1941/1964). In this visionary short story, multiple causes/ choices generate bifurcations and unpredictable outcomes, creating multiple diverse futures, times and universes. It is a powerful metaphor for the dynamic self-organizing properties that characterize life far more accurately than simple cause-and-effect, or the categorical dualisms of Cartesian thinking. Complexity restores our primal understanding of, and approach to, living systems as interconnected, frequently complementary and/or synergistic.

Taking multiple vantage points helps destabilize conventional thinking by shedding new light on what we thought we knew. Given opportunities for investigation without pressure to find "the" correct answer, students move from simple description to a more open, interpretative stance. Most *MoI* texts and activities prompted examining multiple perspectives within and beyond the academic context, building not only cognitive strength but also empathy, an imperative for participating in the larger world as thoughtful compassionate citizens.

iii) Observe closely

When formulating a question or hypothesis and analyzing evidence, direct observation is a basic tool across disciplines. Researchers gather details and heighten awareness by taking on information from/about the environment using all senses (visual, auditory, tactile etc.). Such diverse modes of acquiring and expressing knowledge tap multiple strengths and intelligences (Gardner 1993/

2006), and were especially relevant at Lab where inclusive classes aim to cognitively engage all students. One exercise treated familiar objects (e.g. oranges or pears) as "alien" items in need of intense, multisensory scrutiny to discern essential characteristics, and differences within *apparent* sameness. Based on their careful observations, students prepared detailed written and drawn or diagrammed descriptions to share with the class, an interdisciplinary approach that validates varied ways of knowing and communicating. Close Observation gleans precise, abundant data and potentially fuels insights of higher *qualitative* value, such as perceiving hidden relationship*s* within or among discrete objects. This *MoI* habit is highly correlated with several others, particularly Curiosity and Investigating Multiple views.

iv) Playfulness- Imagining connections beyond the familiar

> Play is a creative reworking of acquired impressions, not simply a reproduction of what is experienced... Feeling as well as thought drives creativity (Vygotsky 1967/2004 p21).

> The human brain is not only capable of perceiving what is called objective reality, but also can create new reality. It is a hermeneutic device (Erdi & Tsuda 2002 p10).

Neuroscience brings to light that the brain does not just store and reproduce information; it originates new artistic and scientific realities through a synergy of endogenous and exogenous factors. Deeply intertwined in chaotic dynamics, relevant brain regions of emotion and cognition each influence the other, mutually shaping our understanding of the world and generating new knowledge (Levine & Perlovsky 2010; Freeman 2001). This complex, largely unconscious combinatorial activity molds what is remembered, experienced or already known into new products of imagination, a creative reworking that parallels Vygotsky's notion of *play*.

To expand "fields of play" for students' imagination, open-ended, explorative tasks ranged from well known (e.g. brainstorming, but recorded in nonlinear webs) to less familiar. Among the latter are: *Enstrangement*- any displacement or odd juxtaposition of unrelated verbal or visual elements that violates logical expectations and familiar associations; *Spoiled drawings*, using the wrong (nondominant) hand; *Puzzles/riddles/counterfactuals* or *nonsensically framed* short narratives, sparking novel solutions or meaning-making; and *Exquisite Corpse*- a collaborative game of blind (folded-paper) composition in images or words, exploiting the creative potential of chance and the collective unconscious (Rosen 2014). Playful activities like these can disrupt rigid,

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consciously controlled thinking, allowing fixed ideas to ebb in favor of the divergent/ flexible/ creative cognition of *Mind Wandering* (Smallwood & Schooler 2015; Rosen 2016; Gable et al. 2019). A productive form of unconscious nonlinear processing (also known as stimulus-independent thought), this fluid neurocognitive state occurs when attention turns away from external tasks toward more remote internal, personally meaningful thought and spontaneous generation of ideas.

Etymologically, tolerating or "going with" ambiguity (derived from L. *ambigere* literally 'to wander, go about, go around' from *ambi-* 'about' + *agere-* 'act, drive, stir up') gives macroscopic expression to the microcosmic functionality of *Mind Wandering.* As internalized play, imagination dynamically combines prior knowledge, intuition and reason to produce surprising, novel ideas**.** Dewey, in *How We Think*, comments on this correlational interdependence between playfulness and seriousness of purpose as the "ideal mental condition:" the absence of dogmatism, the presence of intellectual curiosity and flexibility (1910/ 1997 p218). On imagination specifically, he writes, "it is [the] vision of realities that cannot be exhibited under existing conditions of sense-perception. Insight into the remote, the absent, the obscure is its aim. History, literature, geography, the principles of science, even geometry and arithmetic, are full of matters that must be imaginatively realized if they are realized at all" (Ibid p.224). Like curiosity, this capacity to envision new realities is automatic in young children, but needs reactivating if not relearning in older students and adults.

v) Take risks: Invite the unexpected

> Asking questions makes you vulnerable. The capacity to learn depends, in part, on being willing to run that risk [in] the belief that you have a *right* to be curious, to ask questions, to imagine how things could be different. (Claxton 2006, p.7, italics original)

Being curious/questioning, first of these *Habits* of empowered learning, is not much use if students fear adverse judgments from teachers or peers. If unclear or tentative knowing is devalued rather than seen as integral to critical thinking, and mistakes are always equated with failure, why take the risk? Because, of course, learning and creating anything new require a willingness to think independently, to try new approaches, to be wrong and to learn from errors. One of the greatest obstacles to growth is remaining stuck in past assumptions or methods (functional fixedness), allowing them to dominate future thought and action. Creative problem solving suffers as repetitive exploitation, even of previously successful heuristics, replaces innovative exploration and experimentation (Audia & Goncalo 2007). When, however, teaching-learning is conceptualized as an open

system, where unpredictability and flexibility in the play of classroom relations is the norm, then an ethos of dynamic *process* can override the stultifying effects of conformity for the sake of predictable *products*. The teacher's role is crucial: inhabiting/ modeling acceptance of risk-taking in learning, and staying open to students' questions as well as unexpected nonlinear detours they may trigger. Recognizing that all growth incurs risk facilitates students developing both a spirit of academic determination, and greater compassion for self and others.

vi) Collaborate

> Meaning is not born inside the head of an individual it is born between people collectively searching for truth, in the process of their dialogic interaction. (Bakhtin 1984/1999 p.110)

Inquiry meaningfully promotes social, interactive aspects of learning as it drives momentum to create and communicate knowledge. To celebrate students' first year work in *MoI*, a culminating *Inquiry Symposium* was hosted by Teachers College at Columbia, attended by Lab faculty, students, and SPI consultants. The daylong event opened with a scientist and an opera singer sharing insights from their respective disciplines through the lens of *process*, how research and an attitude of questioning inform their passion-driven careers. The highlight, though, were workshops crafted and led by juniors (11th grade) for small groups of 10th graders who would begin their inquiry journey the next year. With an outline provided to help scaffold their lesson planning, each group of three to four student-facilitators wrote and ran a 40-minute session entirely on their own (an adult was present if needed). Content of their research papers was a starting point, but the essential topic of every workshop was students' experience of inquiry as a process. Designing these *Symposium* workshops was itself a reflective practice.

For senior year final project students probed their thesis topics further, researching new or lingering questions and transforming the writing into various media that would "take the learning off the page." This interdisciplinary work included collaborative documentary videos, interactive games, photography and other visual arts, all shared with the greater school community at "Celebrating Inquiry: A look inside the Process." Invitations to the event read in part: "*Take rigorous research, prioritize process over product, add daVincian curiosity that persists even as questions lead to uncharted territory, and motivate with active engagement. Through this Inquiry process, students interrogated passion-driven issues, from the economic viability of green design, to whether fear-based legislation is displacing Constitutional rights. Join us at Lab Expos for a look inside the process."*

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Other collaborative projects were occasioned by these Expos, for example, eight groups of three or four students working together on an announcement poster. All contributed -- whether concepts, words, or images, building on each other's individual strengths; teams then co-wrote an explication of why/ how their concept represented inquiry. The entire class voted on the final design, selecting *Ideas Emerge* (Fig. 2, reproduced with students' permission), described as follows by the students who created it: *"Our image shows a computer monitor with a word document on the screen, and a person coming out of the screen from the text. This represents inquiry because it shows how ideas emerge from our writing, and that the experience goes beyond just writing. The person is going out into the world learning new things."* Depicting inquiry process as emergence personified, the poster makes visible the dynamic, co-evolving relationship between writer, text, and environment.

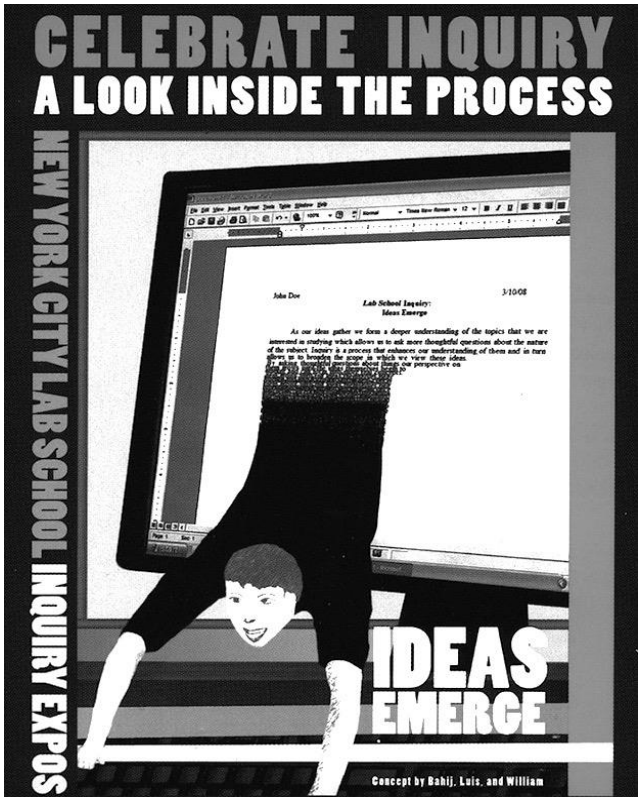

Figure 2. *Ideas Emerge:* collaborative poster design for Inquiry.

Collaborative work in small groups or pairs was ongoing. The synergy of combined efforts supported deeper learning, helped overcome restrictive effects of prior experience on innovative thinking, and enabled social-emotional growth in the chance to hear and interact with all voices.

vii) Uncertainty-tolerance: See *not-knowing* as opportunity

> When a problem is intricate, the ability to tolerate uncertainty-- to stay with the feeling of ***not-knowing,*** to let a mental process that can neither be observed nor directed take its course-- becomes all important. **(**Claxton 2000 p75, bold added)

A lesson from the poets for the professor is how to be present

> while ***'not knowing,'*** in different frequencies than the rational and categorical. Former certainties crisscross in a fluctuating and destabilized landscape, but this uncertainty opens the way to fully embrace the ever unstable relationships between self and other(s). (Irving & Moffatt 2002 p8-9 bold added)

Complexity in neuroscience has shown that higher cognitive functioning arises from chaotic interactions between unconscious/ primal affective processes (disorder) and conscious awareness/ reason (order) (Perlovsky 2009, 2010; Freeman 2008, 2011), functioning as a liminal state of disequilibrium or *not-knowing* that is a vital pre-condition for change. In Keats' formulation, this is the potentiating *negative capability* to be in uncertainty, to refrain for a time from *grasping at reason* for closure/certainty, while allowing imagination to galvanize creative thought. Referencing the poet explicitly, Dewey (1934/2005) states, "no 'reasoning' that excludes imagination and sense can reach truth" (p34).

The bedrock disposition of uncertainty (not-knowing) tolerance is so entwined with *Habits* of questioning, seeing multiple perspectives, risk-taking and imagining beyond the familiar, that classroom strategies and techniques supporting it were similar: engaging with puzzles, optical illusions; responding to ambiguous artworks or texts; discussing seemingly irresolvable or self-contradictory issues. One lesson used Chuang Tzu's ancient teaching, "a path is made by walking on it" (a metaphorical prefiguration of default-mode neural wandering), to prompt questions and discussion. All such activities had a dual goal: inducing a sense of uncertainty as *productive disequilibrium,* and validating those uncertain phases as part of persisting in a task. In math and sciences, such instructional stimuli may include "ill-structured" problems, i.e. a problem or set of materials that is uncertain, ambiguous, disorganized, has more than one defensible solution, and relies more on multi-perspective exploration than recall or restatement. Problems that embed such structural contradictions or inconsistencies have been shown to activate critical thinking more often than consistent and coherent stimulus materials (Lai 2011; Hung et al. 2008).

Rothenberg, in pioneering studies on creativity (1979), found that this ability to actively engage the tension of two or more antithetical concepts simultaneously is fundamental to, and operative in, all creative cognition--scientific and pragmatic as well as artistic. He named this both/and process *Janusian,* after the Roman deity Janus whose two faces look in opposite directions at once. Sometimes referred to in organizational management as a *paradox mindset*, this capacity to accept and feel energized by tensions (e.g. scarcity of resources or time) can leverage conflict to improve performance and innovation (Miron-Spektor et al. 2011; Miron-Spektor & Paletz 2017). In other words, how we think about a problem rather than the problem itself, can be the

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wellspring of successful school or workplace performance (Miron-Spektor et al. 2017). Smith & Lewis (2011), also using a paradox lens, propose a dynamic equilibrium model in which cycles of attending and adapting to complex challenges "enables sustainability by fostering creativity and learning, flexibility and resilience, and unleashing human potential" (p394). Thus problem solving relies heavily on the capacity for holding the tension of not- [yet] knowing.

Self-organized criticality in complex systems illuminates how such uncertain threshold states can catalyze growth and change, with minor ongoing disturbances in a system [first order changes] gradually evolving to a state of critical instability that results in higher-level qualitative [second order] change. New order is not externally imposed; it emerges once a critical state is attained internally through interconnections within a system, up to the point of change at the border of chaos (Bak 1996). Vygotsky's zone of proximal development (ZPD) (1967/2004) exemplifies this dynamic (van Geert & Steenbeek 2006; Koopmans, 2014). Through an interactive "scaffolding" process, teachers enable students to build on their own learning to the point of an imminent leap that surpasses current capabilities. Although teacher-assisted, students' navigating tensions of the ZPD nevertheless calls for a measure of ease with uncertainty.

Academically, uncertainty-tolerance manifests in students' heightened ability to accept phases of irresolution while grappling with increasingly complex tasks. Socially-emotionally, its benefits are particularly important during adolescence, inherently an unsettled, transitional time fraught with myriad changes-- from obvious physical ones, to the fragility of evolving ego-identities. Uncertainty, viewed as an empowering liminal state where thought and action are more open-ended, fluid and diverse, fuels both cognitive and affective development and resilience.

viii) Reflect

> Reflective thinking is always more or less troublesome because it involves the willingness to endure a condition of mental unrest and disturbance... To maintain the state of doubt and carry on protracted inquiry- these are the essentials of thinking (Dewey 1910 p13).

Tension is a precondition and stimulant of search and inquiry, but its resolution is not a going back; self and environment co-evolve. Learning and development, as forms of dynamic self-reorganization, are triggered by doubt or disturbance, honed by critical thinking and consolidated by reflection. In this transformative process, reflection is instrumental: how do I know what I know? What am I assuming rather than examining? Where should I go from here? Sustaining this

organic process relies on the capability to tolerate a certain mental uneasiness. For an end-of-year process reflection, students responded in writing to questions including: "Describe how your inquiry topic evolved, came into focus; what was most challenging during the research and/or writing? How did you get beyond this? What came most easily to you? Why? Where could you have used more support? What were some peak learning moments for you?" Many reflections mentioned improved skills, e.g. *"This class taught me how to create better research questions, support my ideas, and cite sources."* But more exciting was the overwhelming number of comments showing remarkable insight into the nature of research, writing, and learning as complex dynamic processes:

- *"I learned a lot about my own thought process while writing because my piece constantly posed new questions to consider."*
- *"I learned from the Inquiry project that learning is a never-ending process. While writing the conclusion I thought I was finally done, but I realized I still had questions and more ideas."*
- *"I learned that during the research process more questions form, and you might feel like you know less than before you started. As you continue most questions will be answered, but it is impossible to answer all the questions."*
- *"Doing this project helped me develop as a writer and a person. Inquiry taught me that research is about interest and persistence; question, and look deeper for what interests you."*
- *"This is the first project where I've had the freedom to challenge my own thoughts. Having extended time opened my eyes to the potential of writing a layered essay."*
- "*I learned to explore a topic more independently. There were very few restrictions on the thesis, which forced me to really think about what I wanted. The freedom was both intimidating and a relief."*
- *"I learned to deal with ambiguity, and still keep searching."*

Reflecting on the inquiry experience increased students' understanding of *how* they think when exploring a topic, responding to a situation or solving a problem. It deepened awareness of what it means to take a creative and critical stance despite doubt, and sharpened their focus on factors underlying key learning moments. Beyond academic benefits, the metacognitive habit enabled students to better assess their uses of communication skills regarding patterns of speech that enhance, as well as bias or thwart, affect and understanding.

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ix) Persist: Trust the process

> Inquiry, in settling the disturbed relation of organism-environment (which defines doubt) does not merely remove doubt by recurrence to a prior adaptive integration... every settlement introduces conditions of some degree of a new unsettling (Dewey 1939 p35).

> To train young people that everything can be neatly answered within an hour is to weaken what Keats called their 'negative capability' (Claxton 2003 p.2).

Inquiry proceeds not in a straight line but in dynamical fluctuations between doubt or disturbance and renewed equilibrium, itself only temporary because, as Dewey suggests, every "settlement" introduces "some degree of a new unsettling." Validating these complex dynamics, between rational/orderly and a-rational/disorderly modalities, facilitates more authentic teaching and learning. It also necessitates an attitude of Persistence. To encourage this disposition, other *Habits* were re-looped into practice, such as boosting Curiosity; building Uncertainty-tolerance/*negative capability*; and positioning the *not-knowing* of Playfulness and Risk-taking as productive phases in relationships of change and emergence. Lessons prioritized questions, dialogic discourse, experiential tasks, and extended writing and discussion as forms of explorative and elaborative thought, thereby stimulating the inclination to value nonlinear process and persist. An environment of intrinsically motivated, authentic inquiry, enabling students as active agents in their own interest-driven learning, contributed as well to their willingness to persevere.

Through purposeful yet flexible instruction-- which at times *perturbed* the classroom-as-system to energize learning-- students practiced sustaining meaningful work at the edge between perplexity or doubt and new knowledge. Better equipped to persist despite tension, they took more time to think beyond *either-or*, test *both-and* or *what-if* perspectives; notice repetitive heuristics or patterns of thought that might keep them stuck; and adjust/adapt strategies. To continue despite difficulties is to trust the process, in turn reaffirming that transformative "leaps" actually rely on preparation occurring over time at both conscious and unconscious levels.

5. Conclusion: Implications of Inquiry Teaching-Learning *at the Edge*

> The principal message of dynamical modeling is that the adaptive possibility of societies is the main source allowing them to survive

> long term, to innovate of themselves and to produce originality (Nicolis & Prigogine 1989 p242).

This article relates the purpose, design and implementation of *Methods of Inquiry*, a 2008 pilot program at a small, urban upper school (Lab). Through an arc of reflective inquiry, basic complexity principles informed curriculum and instruction aimed at developing higher order thinking and key *Habits of Mind* that support it. Ongoing engagement with learning as a complex phenomenon-- enriched by open-endedness, self-organization and unpredictability-- became a living template as students took ownership of their learning, and prepared to participate effectively as autonomous actors in multiple wider communities. Students, with few exceptions, were energized and motivated by learning "at the edge," a space of increased freedom as well as uncertainty. *MoI's* process-orientation facilitated achieving goals while negotiating diverse or even conflicting contexts or constraints. Teachers, bolstered by *MoI*-specific professional development (e.g. a version of Fig. 1 worksheet that I adapted for faculty), were able to draw tighter connections between dynamic inquiry, everyday instruction, and interactive *Habits of Mind* (originally *Habits of Lab Learners/ HOLLs*).

Today, those adaptive learning dispositions remain the core of Lab's instructional approach across disciplines: *"At Lab, students and faculty alike subscribe to what we call the Habits of Lab Learners... These habits guide our learning processes. They help us access challenging academic material, soar intellectually and act bravely in our complex world"* (NYC Lab 2018 Brochure, p.2). A recent Lab school quality review also specifically cites *HOLLs* as a pivotal factor in advancing students' critical and creative thinking across grades and subjects: "Students are taught how to make meaning and create deep understanding by developing habits of questioning, observing closely, thinking flexibly, tolerating ambiguity, persisting, reflecting, connecting, taking responsible risks and collaborating. Students discuss the philosophy behind the habits and are given examples of how habits manifest academically" (NYC Department of Education Review Report Lab School, p.5).

Much was gained in using *complexity* as a generative framework for *MoI*, which maps onto the complex adaptive systems paradigm in many areas including sociocultural interaction, self-organization and emergence. Most significantly, it connects with the primacy of *process and becoming* in all aspects of human existence. In this view, education itself is a highly integrative nonlinear dynamic process that decries the machine/industrial age model. Emphasizing becoming over being expands the focus from mere acquisition of facts, to reinforcement of capacities that underlie all learning over time-- notably the "negative capability" to persist in conditions of *uncertainty*. Such complexivist-constructivist curricula provide a fluid structural approach that promotes understanding of intricacies of

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the learning process; problem-solving as progressively dynamical, wherein doubt may be seen as an iterative phase of resolution rather than a "failure;" and open-ended, multi-modal strategies that more effectively support the development of flexible, independent minds. Adapting classroom praxis to the unpredictability of change dynamics allows for co-existence of disequilibrium and order as the genesis of *becoming anew*, and helps prepare students for the perpetual change and uncertainty of our postmodern, post-normative times.

Students' growth in math, science or literature requires, beyond just accumulation of skills, the strengthening of capacities that empower lifelong learning. Whether complexity-based curricula can be as effective at schools whose learning culture neither communicates high expectations to faculty, students and families, nor provides support to achieve those expectations as they did and still do at Lab, is unclear. What seems certain however, is that nonlinear, open classroom trajectories-- supported as they were with *MoI*-- argue strongly for education that welcomes and adapts to the intrinsic advantages of its own complexity.

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