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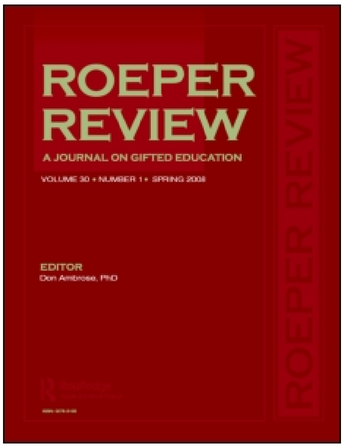

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Re-Imagining Specialized STEM Academies: Igniting and Nurturing *Decidedly Different Minds*, by Design

Stephanie Pace Marshall

This article offers a personal vision and conceptual design for reimagining specialized science, technology, engineering, and mathematics (STEM) academies designed to nurture *decidedly different* STEM minds and ignite a new generation of global STEM talent, innovation, and entrepreneurial leadership. This design enables students to engage actively in the authentic work, modes of inquiry, and practices that distinguish four STEM learning cultures, environments, and communities: (a) Inquiry and Research Laboratory and Interdisciplinary Learning Center—develops disciplinary, interdisciplinary, and inquiry-based thinking; (b) Innovation Incubator and Design Studio—ignites innovative and design-based thinking; (c) Global Leadership and Social Entrepreneurship Institute—nurtures change leadership and systems-based thinking; and (d) Leadership, Innovation and Knowledge (LINNK) Commons—connects the knowledge, innovation, leadership resources, and networks of the global STEM commons to collaboratively solve complex problems that advance both the new STEM frontier and the human future.

Keywords: complex problem-solving, design-based thinking, entrepreneurial leadership, generative assessment, global leadership, innovation, inquiry, inquiry-driven instruction, interdisciplinary research, learning environment, design studio, systems-based thinking, STEM talent, inquiry-based thinking, illinois mathematics and science academy

We live in a time of escalating and converging global crises, and "wicked" problems (Kao, 2007, p. 24) so complex, interdependent, and resistant to traditional modes of thinking and problem-solving, they seem to render us impotent. Yet, there is growing evidence that our cultural and cognitive paradigm may be shifting. Tiny fault lines are now appearing in what were once unquestioned policies, institutions, and lifestyles.

Unprecedented connectivity, undisputed global interdependence, and the emerging realization that our scientific, economic, sociopolitical, and environmental futures are inextricably linked are causing us to re-evaluate policies and redesign strategies historically viewed as "off the table." We are slowly beginning to change our minds, reinforcing Einstein's prescient declaration that the thinking that created our seemingly intractable problems will not be able to solve them. Impoverished thinking appears to lead to impoverished problem-solving and "world shaping."

Decidedly different global STEM (science, technology, engineering, and mathematics) minds that can critically discern, analyze, and integrate patterns within vast amounts of unstructured data; deftly and responsibly change course when hypotheses, predictions, and "proven strategies" fail; ethically unravel and resolve complexity; creatively generate new knowledge, new questions, and new ideas; and globally collaborate to wisely improve the human condition are essential to our future. Wise world shaping requires that our students think in *decidedly different* ways. This is the cognitive context within which the imperative to reimagine and redesign STEM academies now resides.

As human beings, our genius lies not in predicting the future but in imagining and creating it. It is the nature and quality of our thinking that shapes who we become, and who we become shapes the world. Research in neuroscience tells us that the structure of our brain is not fixed; it is sculpted through experience and habitual behavior. Thinking and learning can change the structure and function of the brain and alter its cortical map (Begley, 2007). Our habits of mind, innate curiosity, and ways of thinking and acting are shaped and developed through immersion in experience and repeated practice. So the learning experiences of our students—"how" we ask them to learn—matter profoundly.

When children engage in deep disciplinary inquiry, investigation, and experimentation, they learn to inquire,

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explore, and invent; when they creatively practice framing and solving challenging and messy real-world problems, they learn to innovatively resolve complexity; and when they collaboratively wrestle with moral and ethical dilemmas, they learn to more imaginatively and wisely grapple with issues of social justice. They learn to become more autonomous, improvisational, and metacognitively aware and in control of their own minds and behaviors. The locus of control for learning shifts from the teacher to them and they accept responsibility for shaping the nature and quality of their thinking and manifesting it in action. "Every way of knowing becomes a way of living," Parker Palmer (1993) wrote. "Every epistemology becomes an ethic. Every mode of education, no matter what its name, is a mode of soul-making" (p. 2). Simply, we get what we design for.

What we have designed for up until now is neither the *epistemology* nor the *mode of education* that will ignite and nurture minds able to imagine and set our desired future in motion. To educate our children as STEM knowledge creators, innovators, entrepreneurs, and global change-makers with the capacities to understand complex issues, creatively invent solutions, and ethically catalyze change requires their immersion in mind and practice fields *rooted* in *meaning*, not memory; *engagement*, not transmission; *inquiry*, not compliance; *exploration*, not acquisition; *personalization*, not uniformity; *interdependence*, not independence; *collaboration*, not competition; *challenge*, not threat; *questions*, not answers; and *joy*, not fear.

Our future will belong to *decidedly different* minds that are knowledgeable, creative, innovative, ethical, integral, and wise (Marshall, 2005). This "new" mind is the new breed of talent. It is globally networked, agile, intuitive, risk and novelty seeking, creative, collaborative, failure resilient, analytical, playful, and problem focused. In this cognitive, collaborative, and digital age of innovation, our mind—the nature and quality of how we think and what we think about—is the new "currency" for breakthrough research, "radical collaboration" (Kelley, 2007), sustainable innovation, and transformative large-scale global change.

This article is about reimagining specialized STEM academies and redesigning what they could or should look like. To be sure, they will nurture and develop expertise, advanced levels of STEM inquiry, research, and achievement and prepare gifted and talented students to create new STEM fields and pursue careers in science, math, engineering, and technology. But they will do more. They will (a) stimulate imagination, creativity, and breakthrough innovation in STEM learning; (b) encourage multigenerational, cross-sector collaboration, and problem-solving by diverse multidisciplinary, multistakeholder, and multinational (cyber) teams of students, faculty, and partners; (c) nurture social entrepreneurship and moral change leadership "for" the world; and (d) serve as catalysts for the transformation of STEM teaching and learning and the development of a new generation of collaborative and innovative STEM educators.

Why is it imperative to reimagine and redesign specialized STEM academies now? Because the multiple contexts—educational, technological, economic, and political—within which STEM innovation and talent and leadership development reside are changing significantly.

1. In their report, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*, the National Academy of Sciences recommended "statewide specialty high schools to foster leadership in science, technology, and mathematics education" (Committee on Prospering in the Global Economy of the 21st Century, 2007, p. 7). The United States Congress has included this recommendation in approved legislation, the America COMPETES Act (2007).

2. Unparalleled global demand and competition for STEM talent and intellectual capital have catapulted STEM education, research, and innovation to the top of our nation's agenda, and our president has declared mathematics and science to be national priorities.

3. There is a clear recognition that in a knowledge-based, innovation-driven, and digitally networked world, talent, expertise, innovation, creativity, and intellectual capital move seamlessly—anywhere and any time—and trump national size, wealth, power, and any presumption of national privilege, position, or superiority. The playing field has been leveled and our nation is once again focused on ensuring that all students acquire the knowledge, skills, and habits of mind essential for scientific research, creative exploration, complex problem-solving, and breakthrough innovation.

These converging contexts are catalytic and provide significant impetus for the expansion of specialized STEM Academies. We must ensure that these academies are grounded in what we know about learning and the development of STEM talent so we can ignite and nurture our students' inventive genius and enable it to flourish *by design*.

The editors invited me to be personal, reflective, and future focused. My thinking and reimaging, however, are not merely personal. They are grounded in recognized principles of human learning and emerging advances in the learning sciences that can inform educational system design and pedagogical practice. They are grounded in the context of *real* science and current knowledge about developing talent, disciplinary expertise, creativity, innovation, and leadership in STEM fields; and they are framed by my experience in and with specialized STEM institutions, most deeply the pioneering work of the Illinois Mathematics and Science Academy®.

What this article is not grounded in is certainty. It is not about answers, remedies, or fixes—it is about possibilities. It is about telling new stories, designing new maps, and creating new landscapes for igniting and nurturing *decidedly different* global STEM minds—disciplinary, creative, innovative, entrepreneurial, integral, and wise—that are able to knowledgably, ethically, and nimbly navigate, lead, and advance both the new STEM frontier and the human future.

What I offer is my perspective only. My intent is to provoke and catalyze a conversation, to invite us to think differently and to reimagine and redesign the learning and teaching contexts and conditions of specialized STEM academies so they can ignite and nurture the kinds of thinking required to resolve the problems before us and invent new solutions. Our most gifted and talented STEM students must be able to develop the knowledge, skills, and habits of mind needed to set our desired future in motion by engaging in it now.

The paradox and the challenge for STEM academies is that in many ways our students already come to us with minds decidedly different from our own; they seamlessly and naturally interact and navigate with parallel and multiple forms of digital technologies, almost as if they and their tools are of one mind. They are in constant communication with their peers through multiple social networks. They are fluent in video gaming, simulations, 3D modeling, and multiuser virtual environments. They are globally connected and not bound by place, time, culture, or age; even their identities are adaptive and more fluid, enabling them to be at home in multiple geographies and cultures. They are on Facebook, MySpace, Twitter, YouTube, and Second Life, and often their Second Life avatars can fly.

Then they encounter school and "school" science and mathematics, and unless we are intentional about aligning learning design to their interests and motivations, the learning chasm will get wider and deeper. The terrain will become alien, irrelevant, and even inhospitable, and neither they nor we will know how to navigate it together.

Our students' minds are being cognitively wired in ways ours simply have not been. Their digital fluency; growing convergence between learning, work, social relationships, and play; and their comfort in 24/7, ubiquitous, on-demand, and increasingly multigenerational learning environments bring remarkable assets and critical cognitive predispositions to learning. Yet, we must ensure that their impatience, speed-of-light multitasking, often cursory information surfing and scanning, superficial engagement in knowledge and meaning construction, and almost immediate skepticism toward traditional authority and expertise do not lead to shallow inquiry, unreliable data and evidence assessment, and simplistic, ethically agnostic problem resolution.

What is becoming clear is that the current minds of our students are well *positioned* but not yet well *prepared* to integrate the dazzling speed, fluency, and ubiquitous context of global collaboration, networking, and innovative problem solving with the deeper, slower, longer, and more reflective learning required to develop deep disciplinary expertise and use it wisely. The danger of a shortened time horizon is that it limits our sense of what is possible.

Deep learning is holistic, inclusive, and relational. It is rooted in the awareness that it is often through the integration of polarities, paradoxes, and seemingly disparate ways of knowing that genuine understanding, creativity, innovation, and wisdom can emerge. Deep learning is both active and reflective. By immersing learners in the complexity and challenge of consequential real-world problems and meaningfully engaging them in the big ideas, questions, and ambiguities of the human experience, deep experiential learning can transform their thinking. It can reignite their passion and insatiable curiosity and weave a tapestry of connection that grounds their learning in the roots of personal meaning and purpose. Deep engagement in learning provides a context of connections and integration that reconnects children to all the ways they come to know and ignites and nurtures decidedly different *both/and* minds.

BOTH/AND MINDS

By design, we must create STEM learning environments and experiences that invite children to develop the full range of their talents and potentials by cultivating the adaptive expertise of integral and wise both/and minds. These *decidedly different* minds integrate and validate (a) the power of the intellect *and* the power of the imagination; (b) the power of information *and* the power of relationships; (c) the power of research, hypothesis testing, and experimental design *and* the power of prototyping, simulation, problem-solving, and storytelling; (d) the power of observation and evidence-based truth *and* the power of improvisation and experiential truth; (e) the power of analytical measurement *and* the power of aesthetic insight; (f) the power of observation *and* the power of intuition; (g) the power of reason *and* the power of passion; (h) the power of curiosity and skepticism *and* the power of wonder and awe; and (i) the power of expertise *and* the power of wisdom (Marshall, 2006).

Both/and thinking creates self-directed, adaptive, reflective, inquiring, creative, and resilient learners. Howard Gardner (1993) reinforced this: "In science, mathematics, and the arts, there is widespread recognition of the significant place occupied by intuition, unconscious promptings, inexplicable insights, and the sudden awareness of relationships. Scientific discovery and artistic creations are hardly the result solely of rational considerations" (p. 390).

LEARNING LANDSCAPES THAT FOSTER INNOVATION

We know what it takes to develop talent and expertise and support and sustain creativity and innovation. What is becoming clear is that there is a huge disconnect between the vibrant, experiential, and collaborative mind and practice fields so essential for developing STEM talent and creativity, igniting inquiry, and nurturing innovation and the current culture, climate, and conditions of schooling—especially in most high schools.

Innovation happens at the edges and intersections of disciplines. It happens when new and irreverent questions are asked and when conventional wisdom is challenged. It happens when disruptive hypotheses are courageously voiced and tested and when we become captivated by possibilities of *what if* or *what might be*.

Innovation also happens when we feel safe to risk, to dare, and to venture into unexplored territory. It is a messy, unpredictable, and nonlinear process; it requires a generative learning habitat and innovation ecosystem that invites experimentation, celebrates failure, rewards invention and irreverence, and encourages the passionate pursuit of often absurd questions wherever they may lead.

For many children, especially our most talented, the context and conditions of the current schooling story and the fragmentation, prescriptiveness, and formulaic nature of school math and science are far too constrained, uniform and risk averse and, as a result, actually mitigate against deep understanding, innovative thinking, and creative and collaborative problem-solving. They also mitigate against the experience of joy, wonder, and awe so integral to authentic scientific engagement and discovery. How we currently teach science has created a mental model incongruent with what science *really* is.

What is the difference between school science and "real science"? Currently, most school science is experienced as (a) passive acquisition of large amounts of often unconnected, sterile, and topical content; (b) devoid of emotion, joy, and wonder; (c) irrelevant and detached from the human experience. In addition, (a) students are disengaged and compliant recipients; (b) information is inert and not connected to the real world—students' needs, interests, curiosities, or questions; (c) content is decontextualized and prescribed so there is little time for exploratory forays or following intriguing questions because the focus is on excessive coverage; and (d) the science disciplines are taught within very tight boundaries. Interdisciplinary science is often viewed as less rigorous and soft.

School science is all about rotely—mindlessly—following the prescribed steps of the scientific method, getting right answers, and memorizing taxonomies, periodic tables, and algorithms. It is isolated from its social context and viewed as an individual endeavor, and there is a pervasive belief that either you are good at science or you are not, and you cannot do anything to get any better. School science has become a spectator sport, even for our most talented students.

This stark disjuncture between school science and real science is fundamental to our ability to transform STEM education for all students (and teachers) but especially for our most academically talented. The mental model of school science often discourages them from wanting to advance and explore careers in science because it has completely misrepresented and distorted the nature of the scientific enterprise and its contributions to the human experience.

Why is it that 40–50% of students entering undergraduate science and engineering programs soon shift to another area? This statement by an undergraduate student gives us a hint: "Why did I have to wait so long in my study of science," she says, "to be connected to something so awe-inspiring?" (K. Sawyer, personal communication, September 24, 2006).

There is an enormous disconnect between our nation's needs and expectations for breakthrough STEM research and innovation and the demands and expectations of the current story (cultural narrative), map (design), and landscape (learning environment) of school science and mathematics. We have a seriously flawed design and we are getting precisely what we designed for—a nation of students either disinterested in, fearful of, or convinced that they are not good at science and mathematics.

Tragically, the very system that is designed to pump talented students into the STEM innovation and talent pipeline is actually filtering them out. To be sure, innovation drives economic development and wealth creation; it also can enhance the quality of life. STEM education must engage students in understanding and experiencing the human consequences of innovation and its essential value in advancing the human condition.

There are, of course, numerous models of exemplary programs in STEM talent development (National Consortium for Specialized Secondary Schools of Mathematics, Science and Technology [NCSSSMST], 2006), but there is no national system. This results in an idiosyncratic and nonsystemic approach to STEM talent development incongruent with what we know about learning and developing innovation, entrepreneurship, and change leadership and at odds with what we do to more coherently and systemically ignite and develop other talents—most notably in music, athletics, and the visual and performing arts. The good news is that by design we can transform it.

What is missing from our current thinking and design of STEM innovation and talent and leadership development? I believe it is the intentional nurturing of our students' *both/and* minds. We must invite and connect our students' *interior* (more perceptual, experiential, and intuitive) ways of knowing and their *exterior* (more analytical, observational, and objective) ways of knowing, and we must invite them into the big story of science as a portal to belonging and to understanding and advancing the human condition. *Decidedly different* both/and minds are both S.M.A.R.T. and W.I.S.E. They have developed the knowledge, skills, and habits of mind of *S*cience, *M*athematics, the *AR*ts, humanities and *T*echnology; and they have developed their capacities for *W*isdom, *I*nnovation and *S*ocial *E*ntrepreneurship.

Currently, our national rationale for aggressively developing STEM talent focuses largely on global and technological competition and economic superiority. This exclusively instrumentalist and utilitarian context completely dishonors who we are as learners and devalues the innate drive and desire of the human mind and spirit to seek to contribute to a better world. It does not offer talented adolescents a compelling rationale to devote their lives to science.

To develop the STEM minds our global community requires, we must create conditions by design that invite our students' sense of wonder, awe, creativity, playfulness, and mystery into STEM learning. We seemed to have walked away from the *long science story*, decoupling it from our emotional connection to the human experience. It is immersion in this side of the story that can often ignite and engage the boundless energy and commitment of our youth to use their knowledge, curiosity, and passion in STEM to make a positive difference in the world. Our commitment and strategy for developing STEM innovation, talent, and leadership must also be S.M.A.R.T. and W.I.S.E.

IGNITING AND NURTURING DECIDEDLY DIFFERENT STEM MINDS, BY DESIGN

So what might we do to design STEM learning environments that authentically ignite and nurture the creative minds of our most talented STEM students? Although I have long advanced the idea that every school must redefine itself as a "Center for Inquiry and Imagination" (Marshall, 2006), reimagining a new system for STEM innovation and talent and leadership development is unchartered and risky. Nonetheless, I am ready "to implicate myself in the consequences of my imagination" (Mau & Leonard, 2004, p. 18). In so doing, I relinquished certainty and any sense of correctness. Over time this became easier; this is a design prototype, not a prescription. In the end, I simply claim responsibility for seeking to set a new conversation in motion, to name and illuminate fundamental design principles of STEM learning and teaching, and to open safe space for our collective imaginings.

Winston Churchill said, "The empires of the future are the empires of the mind" (1943, p. 715). Despite our students' often dazzling fluency in accessing and navigating the design tools, knowledge networks, advanced software, and innovation platforms of current and emerging digital technologies, their multitasking prowess and speed do not necessarily help them to develop their minds well; nor do they better prepare them to (a) understand context and discern and illuminate subtle and elusive patterns significant for complex problem-solving; (b) understand the global consequences of their thinking and action; (c) identify and imaginatively resolve increasingly complex and interdependent human-centered problems; (d) analyze and wisely evaluate large complex multidisciplinary data sets for problem identification and framing; (e) develop deep competence in disciplinary domains and in creatively integrating ideas from disparate fields; (f) illuminate new problems and new "what if" and "how might we" questions; and (g) design scenarios and build simulations, models, and innovative prototypes for ethical social change.

Much of our students' learning power comes from their automaticity in and comfort with accessing the intelligence, knowledge, and creativity of the emerging global STEM commons. What they do not know or cannot figure out, they pose to their peers through peer-interest and knowledge-generation networks. The generative learning environment(s) we design for and with them must enable them to develop habits of mind commensurate with their current cognitive abilities and the new capacities needed for deep disciplinary mastery and expertise, ethical leadership, innovation, critical and creative thinking, and problem-solving. We must educate them as the knowledge creators, innovators, inventors, and ethical change-makers they are.

The rationale for reimagining STEM academies is to ensure that we design learning conditions essential for igniting and nurturing 21st-century global STEM minds—ways of learning and thinking that "dare to think of the welfare of the whole human race as a practical objective" (Toynbee, as cited in Mau & Leonard, 2004, p. 15). In addition to developing the next generation of pioneering scientists and researchers, new STEM academies must also invite the emergence of a more "hybrid" generation of STEM innovation talent—those who represent a synthesis and blending of creative scientists and researchers, innovative engineers and inventors, designers and architects, and social entrepreneurs and public policy strategists, and they must create conditions for their seamless navigation within and advancement of these diverse and interdependent terrains.

To do so, we must immerse our students in the intense practice of disciplinary and interdisciplinary thinking, creative problem-solving, innovative system and process design, and ethical change leadership. Such environments (a) mirror the principles of dynamic living systems (learning ecosystems) and how we learn; (b) ignite and nurture inquiry, innovation, and ethical leadership by fostering self-directed inquiry and research, problem-based learning, experimentation, and the rapid prototyping of innovative products, models, systems, and processes; (c) immerse students in the habits of mind, knowledge structures, and ways of constructing and verifying knowledge within each STEM domain through extended student-directed and mentor-supported investigation; and (d) ensure continual, transparent, and open access to the collective intelligence, creativity, and inventive potential of the emerging global mind through robust virtual networks and immersive technology platforms.

Our nation must create a seamless STEM innovation, talent, and leadership development system and support the creation of specialized STEM academies as regional and national innovation hubs for the transformation of STEM teaching and learning. Specialized STEM academies not only uniquely serve students academically talented in STEM, they also build the innovative capacity in our communities, regions, and states. They (a) serve as catalysts—laboratories, incubators, design studios, and think tanks—for excellence and innovation in STEM teaching and learning; (b) foster the creation of STEM partnerships and networks by engaging the intellectual capital and resources of universities, corporations, museums, laboratories, and the philanthropic community; (c) stimulate, support, and scale promising policies and practices in STEM education; and (d) serve as powerful conveners of local, state, and national dialogues on STEM education for all students. Together these specialized STEM institutions are fueling a powerful national network—the National Consortium of Specialized Secondary Schools of Mathematics, Science and Technology, whose purpose is to transform STEM education in our nation.

THE FUTURE OUR STUDENTS WILL SHAPE IS ALREADY IN MOTION

Profound global mind shifts and unique collaborations are gradually becoming visible in many arenas of human endeavor: (a) dialogues between frontier neuroscientists and spiritual elders, such as the Dali Lama, seeking to understand whether compassion alters brain wiring and whether it can be taught; (b) social entrepreneurs bypassing positional leaders to create innovative solutions to critical local, national, and global problems (microfinancing); (c) technology designers and inventors creating empowering opportunities for learning and job creation in underdeveloped communities; (d) biotechnology and nanotechnology breakthroughs; (e) partnerships between ecologists, engineers, and urban planners; and (f) the integration of sustainability principles into business strategies (Institute of Noetic Sciences, 2008, pp. 33–50). These are some of the emerging contexts in which our students will work, imagine, create, invent, and lead; new STEM academies must enable them to do so now. What are the learning experience and environmental design principles that will make this more likely?

THE MAP: DESIGN PRINCIPLES

We design because we want what we care about to live. Design is a map of our deepest beliefs and commitments, and these commitments are embedded in principles. Although the manifestations of this vision will creatively unfold in a wide variety of ways, its integrity and coherence reside in its fundamental design principles.

These are the principles that ground the learners' design of new STEM academies:

1. *Create conditions to develop a generative innovation and talent and leadership ecosystem*. Learning and teaching environments are bioresonant. They are designed with nature in mind (Benyus, 2002) and are rooted in the dynamics and self-organizing properties of living systems. STEM academies function as learning and innovation ecosystems. They are sustained by continuous knowledge generation and sharing and collaborative learning networks to increase and distribute their intelligence, innovation, and creative leadership capacities; the environment seeds and connects multiple networks and communities of practice.
2. *Ensure that learning is a live encounter*. Learning and teaching environments are congruent with what we know about human learning, mind/brain development, and knowledge and meaning construction. Learners are actively engaged in experiences that identify, ignite, and develop their passion and unique potentials. Students develop strategies for deepening and expanding the nature and quality of their critical and creative thinking, innovation, problem-solving, leadership, and social entrepreneurship skills. Music, the performing and visual arts, and wellness are integrated in learning.
3. *Personalize learning pathways*. Students actively engage in developing mastery in a foundational core of domain specific knowledge, habits of mind, skills and knowledge construction procedures, protocols and tools in each of the three primary learning cores: (a) research and inquiry, (b) innovation and design, and (c) social entrepreneurship and change leadership. Their chosen pathway within each of these cores is informed and guided by a primary mentor/advisor and a cadre of support and resource mentors, practitioners, and graduate students. Personalization is not a process of logistical navigation through a prescribed set of courses. Rather, it is a mentored journey that invites students to discover their own interests, passions, metacognitive predispositions, and learning strategies for developing their minds well.
4. *Engage and connect the community at all levels of scale—local, regional, national, global*. Diverse multigenerational, multistakeholder, and cross-sector communities are intentionally nurtured to increase the intelligence and the creative capacities of the whole system; everyone's work is connected, so silos that constrain people, ideas, and solutions cannot be sustained. Learning and teaching environments foster the inclusive integration and collaboration of the community around shared learning purpose at multiple levels of scale.
5. *Connect and access the global commons*. All forms of information and digital technologies, as well as software programs, social networks, simulations, 3D modeling, and multiuser innovation platforms, are embedded and integrated into learning and teaching. Accessing the collective intelligence, innovation, altruism, and leadership of the global commons is fundamental to collaborative knowledge construction and problem resolution. The system captures the synergy of distributed learning and cognition across time, space, and geography through peer-to-peer knowledge-generation networks and communities of

practice engaged in problem resolution and social activism. Students are engaged in resolving complex, real-world problems in real time through inquiry and research and through storytelling, modeling, simulations, concept and mind-mapping, scenario building, and gaming.

6. *Develop disciplinary knowledge, habits of mind, and epistemological integrity*. The system is focused on deep disciplinary understanding and mastery. Students learn to fluently "speak" the language of each disciplinary domain. Each discipline's epistemology and unique modes of inquiry (designing and conducting experiments, deriving formulas, or researching primary source materials), enduring questions and conceptual organizers (concepts and principles), symbol systems (numbers and musical notation), and strategies for knowing and making sense of the world influence the nature and quality of the minds they will invent (Marshall, 2006).
7. *Develop integrative and transdisciplinary thinking*. Interdisciplinary learning does not homogenize disciplines, it extends a discipline's knowledge into the problems of another domain and deepens the learner's capacity for complex and creative problem-solving. Transdisciplinary understanding goes even deeper by embracing all the ways we come to know: knowing through disciplines, knowing across or between them, and knowing beyond disciplinary boundaries. Transdisciplinary learning enables students to understand the unity of knowledge by identifying principles and patterns that go beyond a single domain and are common to all of them.
8. *Create a holistic and authentic learning landscape in* (a) curriculum, (b) instruction, and (c) assessment. Curriculum design should be competency and curiosity-driven, concept-based, problem-centered, and integrative. The curriculum is coherent and purposeful and designed around the fundamental organizing principles and concepts of each discipline, as well as the habits of mind and modes of inquiry and knowledge that frame each one. It is integrative and linked—linking new knowledge to previous knowledge and linking principles and concepts within, across, between, and beyond disciplinary domains. It is competency and curiosity-driven and focused on developing deep conceptual understanding; students develop the knowledge and habits of mind internalized by thoughtful practitioners. The curriculum is centered on real-world problems and applications framed by the learner's prior knowledge, lived experience, and the world's and community's "real" needs. Instructional design should be inquiry-based, personalized, experiential, and technologically generative. Teaching is defined as a personal and relational process of cocreation between teachers and learners. Teachers are mentors, coaches, instructional designers, and peer learners. Instruction is focused on ensuring that each student acquires knowledge, develops understanding of disciplinary and interdisciplinary concepts and knowledge structures, and learns a broad repertoire of skills and critical and analytical reasoning, inquiry, and metacognitive strategies. Instruction is personalized and centered on the personal and collective exploration of great questions and the creative framing and resolution of complex problems relevant to the learner. Personalized instruction develops each student's confidence, locus of control, and internal authority for lifelong learning by creating conditions, expectations, and norms for students to experience success. Assessment design should be generative, understanding, performance-based, and multidimensional. Assessment is generative, diagnostic, and ongoing; formative and summative assessments are focused on understanding and include objective and quantitative metrics (meaningful, reliable, valid, and fair), as well as personal and qualitative evidence. Students are engaged in monitoring, regulating, and assessing their own learning and creating a digital learning portfolio that includes student-selected samples of work in each of the three core learning areas: research and inquiry, innovation and design, and leadership and social entrepreneurship. Assessment is coherently aligned and integrated within curriculum, personal learning objectives, and instruction and is structured so that students can demonstrate proficiency and understanding through multiple and often novel forms of evidence—research and leadership projects, prototype and product designs, video presentations, exhibitions, and expert panel, peer, and self-assessments.
9. *Ensure that time and place are responsive to the learner*. For each student to demonstrate high levels of proficiency on both internationally benchmarked standards and their own personal learning plan objectives, time and learning place are adaptive. Formal classes, seminars, and symposia (real and virtual) may not meet daily, and time varies by discipline and the nature of the work required. Students may work on or off campus, in innovation hubs (physical or virtual space), universities, museums, research laboratories, engineering and design firms, or nongovernmental organizations (NGOs) for extended periods of time—weekly, quarterly, or semesters. They may participate in long-term mentorships, internships, and apprenticeships (as part of a collaborative global team); the learning calendar is yearlong and time needed to demonstrate evidence of learning is flexible. Time and place are adaptive; learning is the driver.

Manifesting these generative principles in STEM academy design is more likely to stimulate and promote (a) interest and motivation to engage in advanced study; (b) the desire to pursue a STEM career; (c) the love of exploration and the passion to pursue questions wherever they may lead; (d) creative potential and the desire to engage in creative design and production; (e) innovation and design thinking as essential to human progress; (f) a clear(er) sense of personal purpose; and (g) the desire to be pioneers, social entrepreneurs, and change-makers that advance the human condition and the emerging STEM frontier.

MOVING INWARD—THE CONCEPTUAL LEARNING DESIGN

Four differentiated yet dynamically connected learning and teaching core *complexes* are proposed. Three are core learning domains and one is an integrating hub. Each is a unique learning habitat and work space—real and virtual—that embodies a distinctive learning core, community, and sphere of engagement and is home to the specific work, epistemologies, habits of mind, processes, and tools essential for developing high levels of proficiency in a domain and its unique practice.

1. One complex has multiple inquiry and research laboratories, secure individual and team lab space, and seminar, project, and conference rooms integrated within a disciplinary and interdisciplinary learning center and think tank; another functions as an innovation incubator and design studio; a third as a global leadership and social entrepreneurship institute. The fourth is a hub. Called LINNK, it is a leadership, innovation, and knowledge Commons and Transformation Exchange. Each complex encourages practitioners, visiting teachers and students, scientists, researchers, designers, inventors, and social entrepreneurs into their work. All are places of inquiry, imagination, innovation, and leadership where challenging questions and problems are continuously framed and locally, nationally, and globally pursued. (See Figure 1 for the interrelationships of the three learning cores and the LINNK Commons and Transformation Exchange.)
2. Students deeply engage in and authentically experience the real work that frames and distinguishes each of the three cores and content domains, and they learn the organizing principles, concepts, skills, procedures, and habits of mind required to be successful. Simulating a medical school residency model, students must spend dedicated time in each core, although they will likely have a preferred *residence* to which they can return. At select times, students may choose to "go home" and focus on developing greater proficiency in their preferred domain and discipline, area of inquiry, creative design or production, or leadership. What is essential is that their purposeful engagement in each learning core enables them to experience and try out a range of options for their work and contributions in STEM and uncover their passion.

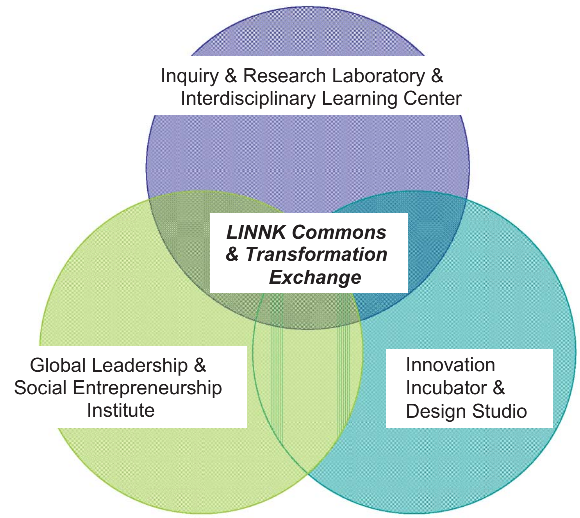

FIGURE 1 Conceptual design of reimagined STEM academy's learning cores.

The three learning cores and the integrating hub are

1. *Inquiry and research laboratory and interdisciplinary learning center* focuses on knowledge and meaning construction and developing advanced levels of competence and expertise in all disciplinary domains, through self- and mentor-guided inquiry, extended internships and apprenticeships, intensive research and investigation, and experimentation and problem solving. The emphasis is on high levels of knowledge and skill acquisition, integration and use, research and scholarly production, and creative knowledge generation valued and evaluated by experts and practitioners in the domain. Focus is on developing disciplinary, interdisciplinary, and inquiry-based thinking.
2. *Innovation incubator and design studio* focuses on creative ideation, production, and the application of science, mathematics, engineering and technology expertise to serve more tangible and pragmatic human needs; focus is on imaginative, improvisational, and creative design; igniting, seeding, "hatching," accelerating, and scaling promising prototypes and innovations in products, services, processes, and systems. Emphasis is on generating disruptive (Christensen, Horn, & Johnson, 2008) new ideas and connecting current ideas in new ways to create useful solutions valuable to others. Students use brainstorming, innovative scanning, modeling, storytelling, rapid prototyping, mind maps, simulations, and multiple innovation platforms; the incubator serves as a magnet, disruption amplifier, and innovation and design

accelerator. Focus is on developing innovation and design-based thinking.

3. *Global leadership and social entrepreneurship institute* (a) focuses on developing the knowledge and skills necessary to be a "citizen in service" (Clinton, 2009) and to proactively work in areas of social justice, fostering meaningful change in principle, policy, or practice; generating changes in thinking and behavior; and creating innovative solutions (new processes and systems) for real-world problems in areas of compelling social need; nurtures high levels of knowledge and competence in complex and adaptive systems thinking, conflict resolution, social and organizational change, and public influence and advocacy; (b) fosters proactive global citizenship, empathy, and diversity of perspective; and (c) serves as a leadership catalyst, change accelerator, and movement generator for social change. Focus is on developing social entrepreneurship and systems thinking.
4. *LINNK (Leadership, INNovation, Knowledge) Commons and Transformation Exchange:* As an integrative hub, LINNK is more knowledge, tool, process, and epistemologically diverse; multiple disciplinary "languages" are spoken and no one way of knowing is dominant. Although central to the integrative work of the Academy, the LINNK Commons is not a *center*; it operates outside the norms, structures, and processes of the other three complexes because it is a *network*. It acts as a global commons and facilitates idea and problem exchanges between individuals, initiatives, or multinational projects that often have their genesis in the work created in the learning cores. Its purposes are to (a) share, integrate, synthesize, and leverage the knowledge, ideas, questions, designs, and innovations being studied, prototyped, and tested in each of the three cores; (b) engage, connect, distribute, and accelerate the collective intelligence, imagination, and creative capacity of the academy community and their regional and global innovation networks; and (c) identify, generate, and solve shared problems of mutual interest.

The LINNK Commons and Transformation Exchange invites, perturbs, and catalyzes new conversations, creates opportunities for new thinking, and activates the creation of new partnerships and networks for fluid global knowledge construction, sharing, and collaborative work. Through an innovative Web-based platform and an evolving technology infrastructure, the Commons also seeds, connects, accelerates, and supports the design, development, and scaling of research, innovation, and social entrepreneurial initiatives; it stimulates the emergence of local, national, and global STEM innovation networks; attracts, generates, and sustains intellectual, technological, and financial resources; and connects prototypes and innovations into a dynamic learning exchange network.

LINNK is the intentional boundary-crossing, boundary-collapsing, and boundary-evaporating core whose fundamental purpose is to increase the nature and quality of intelligence available to the Commons. It is a community commons (real and virtual) for seamless idea and inquiry exchange, collaborative problem-solving and pattern and trend identification, and analysis. It is a real and virtual idea repository and a thinking and creating learning space that offers multiple platforms for connection and communication; it is the synergistic hub for transformation and transdisciplinary thinking and problem solving.

LINNK operates through emergence, not mandate, in a transparent, organic, and open-source environment. In business these creative and collaborative innovation networks are called *COINS*—"cyberteams of self-motivated people with a collective vision, enabled by technology to collaborate in achieving a common goal—*an innovation*—by sharing ideas, information and work" (Gloor & Cooper, 2007, p. 23). The LINNK Commons and Transformation Exchange is also a globally recognized STEM teaching, learning, and innovation hub creating new designs, prototypes, and systems for STEM curriculum, instruction, and assessment transformation.

WHAT MIGHT LEARNING FEEL LIKE?

New STEM academies are part of a dynamic national system for STEM talent and leadership development within a globally networked community for STEM innovation. Each is a multiage inquiry and innovation center, embedded in multiple learning networks that connects the community's creative resources with the learner's interests. STEM academies are open, collaborative, and technologically enabled learning environments. Seminar rooms, tutorial hubs, innovation design and production studios, and collaborative problem-solving suites are technologically equipped so that students can create what they need.

STEM academies move beyond the traditional boundaries of place and time and situate learning in diverse locations, institutions, facilities, and on-line pavilions. There are no bells to signal the beginning or end of formal classes, seminars, symposia, or tutorials. Learning time and experiences are driven by the nature and complexity of the student's work and their goals and commitments. Learning objectives are identified and assessed quarterly through personalized learning and assessment plans, cocreated by the students and their parents and advisors. Multiage learning cohorts of students with common learning objectives work together. Age or grade-level distinctions do not determine learning placement. Faculty are invited to hold joint appointments in multiple learning cores and academies.

Achievement of the academy's advanced disciplinary and interdisciplinary learning, thinking, and problem-solving standards and the students' specific competencies (in research and inquiry, innovation, and design, and global change leadership) are assessed when the student is ready. The core curriculum within each learning complex is not textbook driven; learning is guided by specific inquiries—significant questions and problems embedded in curricular frameworks designed by a cadre of faculty, alumni, and expert practitioners. Students are actively engaged in the knowledge generation, modes of inquiry, and problem-solving competencies, processes, and practices that define the essential work within each learning core. Students learn how to learn and creatively integrate ideas within and between domains. They are developing their own internal authority for learning and a fluid repertoire of learning strategies essential for deep conceptual understanding, creative inquiry, innovative problem resolution, and ethical leadership.

WHAT MIGHT LEARNING LOOK LIKE? A SNAPSHOT

Within the Inquiry and Research Laboratory and Interdisciplinary Learning Center

One team of students is working in the nanotech lab on an experiment with a nanotech research scientist, a biotechnologist, and two engineering doctoral students from the local university, doing part of their dissertation research using the students' experimental design protocol.

A team is working with a renowned paleontologist on their yearlong museum mentorship project, catalyzed by his discovery of several intact dinosaur fossils found together in Niger. They will accompany his team on a 3-month dig the following year.

A team of students, faculty, external mentors, and visiting school district teachers and university faculty is analyzing data electronically sent from a laboratory in Finland by students and teachers with whom they are collaborating on a curriculum design project in genetics.

In a weekly seminar, students are exploring the social, ethical, and economic policy implications of their artificial intelligence research with a social science and ethics instructor, framing questions to be discussed the following week with an invited panel of clergy, ethicists, and geneticists.

Within the Innovation Incubator and Design Studio

Multiple teams of students are each constructing a bridge prototype in response to a challenge by a team of math and social science faculty and local engineers and architects. The bridge is essential for an indigenous tribe in a remote village in Ecuador to access fertile farmland across an impassable river. The bridge must be able to be built by the tribesmen with local materials. An additional challenge is the cultural taboo against river crossing. Prototypes were designed online using advanced design software. When completed, it will be judged by an expert panel of engineers, designers, social scientists, and cultural anthropologists.

A team of students and faculty, their international collaborators, advisors from Games for Change, and experts in the global water shortage crisis are engaged in a video design conference, reviewing and modifying specifications for an interactive video game for middle-school students to engage them in understanding and creating solutions to the global water crisis in multiple geographic regions. Later, a patent attorney will meet with them to discuss the patent process.

Within the Global Leadership and Social Entrepreneurship Institute

A student leadership team is meeting with venture capital investors with an expressed interest in supporting their project to help build and equip a residential high school for girls in Kenya. The students will also help to design its curriculum, secure the computers, and research and secure the technology infrastructure necessary to insure internet access.

Within the LINNK Commons and Transformation Exchange

As part of their personal learning plan, a multiage group of academy students are holding a video conference with peers from the Israel Arts and Science Academy and the Jubilee School in Jordan; also in the conference are members of the Chicago Council of Global Affairs. They are discussing the concept of a global Educational Bill of Rights for universal primary education (K–8). They also are designing a conference to be held on Second Life during which they will craft the questions they need to respond to in order to make their case to the United Nations. They already have reviewed prior conference conversations on LINNK's searchable database and have engaged in multiple online forums, beginning to generate principles for the Educational Bill of Rights.

Together these four learning complexes create a dynamic and self-organizing learning and innovation system with the work in each core able to access, "feed upon," integrate, and build the capacities of the others. It is my belief that our unique opportunity and potential for transformative contributions lie at the convergence of these four discrete yet interdependent learning cores and modes of thinking.

The Illinois Mathematics and Science Academy® is in the startup phase of a pioneering initiative to create a real and virtual space that shares many of the fundamental principles and purposes of the LINNK Commons and Transformation Exchange. It is called the CoolHub.imsa, and it:

> will provide opportunities for collaboration and resources that accelerate research, rapid prototyping and program

development, all supported by a dynamic web platform. Specifically, it will (a) create structures and processes that support and evaluate Collaborative Innovation Networks; (b) build communities of collaborators; (c) launch collaborative STEM projects that address societal needs; (d) document and disseminate new models for STEM teaching and learning; and (e) create on and off campus tech-enabled zones called cool spots that will serve as pathways to a robust virtual network that supports innovation and learning using multiple digital technologies and searchable databases." (Illinois Mathematics and Science Academy, 2009)

The design of these four learning cores might not be quite right, but I believe they are close. The point is to name them what the experts and practitioners working in them would and to name them what we want them to bring to life in our students.

It is important to note that although it is desirable for these four learning environments to reside on a single campus, it is not essential; they might need to be distributed within extended "community campuses." For example, the research and inquiry labs could be located on a university campus or a museum laboratory, the incubator and design studio in a design firm, and the leadership institute in a think tank, public policy institute, or nongovernmental organization.

Reimagining specialized STEM academies for the future is not first about strategy. It is about thinking differently about the development of STEM innovation, talent and leadership for our nation's most talented STEM students so that, by design, they develop the scientific, technical, innovative, and entrepreneurial habits of mind essential to become the next generation of STEM pioneers, innovators, and leaders.

WHY THIS CONCEPTUAL LEARNING DESIGN?

There are several reasons why I believe this conceptual framework is fundamental:

1. It is driven by how we learn and by advances in the learning sciences and information and digital learning technologies. It invites students to forge and deepen integrative connections, increase neural network complexity, and strengthen learning associations that facilitate long-term memory and retrieval.
2. It engages students in multiple ways of knowing and thinking and gives them practice in using multiple representational and symbol systems for meaning construction, innovation, and leadership, and it legitimizes, connects, and uses the powerful epistemologies of multiple domains to generate and construct knowledge and solve real problems.
3. It ignites internal motivation and immerses students in real science and mathematics and their application to the real world, and it enables students to authentically explore their interests and passions in STEM as well as the arts and humanities.
4. It nurtures the development of *decidedly different—both/and* minds—students with the knowledge, creativity, innovative design thinking, social awareness, leadership skills, and technological expertise to engage and access the intelligence and inventiveness of the global commons toward the common good.

FRAMING THE VISION: THE FURTHEST EDGE—A NATIONAL SYSTEM FOR STEM INNOVATION AND TALENT AND LEADERSHIP DEVELOPMENT

The *furthest edge* of this vision was advanced in testimony to the Commission on 21st Century Education in Science, Technology, Engineering and Mathematics. I recommended the design of a national innovation agenda and strategy, a sustainable system for STEM Innovation and Talent and Leadership Development and the creation of a National Center for STEM Teaching and Learning Innovation—a strategic innovation hub, incubator, and accelerator within a dynamic national network (Marshall, 2007).

The National Center would be a place—real and virtual—where national and global multidisciplinary and cross-sector teams could engage with peers, experts, and practitioners to design, develop, and refine their ideas and prototypes for the transformation of STEM teaching and learning. It would be part think tank, part inquiry, research and development laboratory, part design studio, and part innovation incubator and accelerator. Through the stimulation and creation of local and national networks for igniting and supporting innovation, the National Center for STEM Innovation would serve as a catalytic and transformative change agent and support system autonomously managed through local, regional, state, and national efforts. It would stimulate, support, and connect innovation within a dynamic system that is coherent, collaborative, synergistic, globally connected, and continuously learning.

COMING FULL CIRCLE

With or without our leadership, our students' unfettered access to the global commons will cause us to redefine and redesign schooling and our STEM enterprise and work. It is time to engage in a new conversation. We know the status quo. Imagine now what could be.

In an article titled "Put a Little Science in Your Life," Brian Greene (2008) wrote:

> In reality, science is a language of hope and inspiration, providing discoveries that fire the imagination and instill a sense of connection to our lives and our world. (¶ 9)
>
> Science is the greatest of all adventure stories, one that's been unfolding for thousands of years as we have sought to understand ourselves and our surroundings. Science needs to be taught to the young and communicated to the mature in a manner that captures this drama. We must embark on a cultural shift that places science in its rightful place alongside music, art and literature as an indispensable part of what makes life worth living. (¶ 22)

This is the message of the new STEM academy.

So—how do we ignite and nurture STEM talent, innovation, and leadership? How do we help our children do great science, great engineering, great mathematics, and great technology innovation? How might we encourage them to "play" math and science with the same enthusiasm they have when playing soccer, tennis, or the flute? How do we stimulate and keep their imaginative fire alive so they remain in science? How might we enroll them in understanding the awesome power of science to serve the public good, advance the human condition, and change the world?

My response is simple—we will more likely fulfill these commitments when we immerse students in learning landscapes where they can learn, play, create, invent, connect, and dream—by day. We shape the world from the inside out. The nature and quality of our thinking shapes who we become. And who we become shapes the world. The future prosperity and sustainability of our global community resides in igniting, nurturing, and connecting our children's creative and imaginative genius in STEM to the needs of the world.

Five years ago, I would have written a different article, but the focus of my awareness has evolved to include attending to "things unseen." Somewhere along the way we and our students missed the real and wondrous story of science, the dazzling story of our mind's capacity to change our brain, and the exhilarating story of our imagination and passionate drive to use our collective genius and goodness to change the world.

When our students graduate from our reimagined STEM academies, I hope that the learning conditions we created, ignited and nurtured their remarkable talents and enabled them to passionately follow their dreams. As Carl Sagan (1992) reminded us, "Dreams are maps. It matters what those visions are" (p. 23).

But hope alone, even if it is audacious, is not sufficient. We must intentionally create conditions by design that enable our children to develop S.M.A.R.T. and W.I.S.E. minds that will commit to using the transformative power of science, technology, engineering, and mathematics to advance the human condition.

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