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Diverse Learning and Learner Diversity in "Informal" Science Learning Environments

This paper lays out a theory of (re-)generative learning to explain how families and communities socialize young learners into thinking like scientists and mathematicians. Cultural communities and their families orient their young in varied ways toward the language, behaviors, and self-theories about the future presupposed in the learning of science and mathematics. Certain socialization processes and norms correspond closely with those that scientists and artists use in laboratories, studios, and rehearsals. Certain norms of politeness and patterns of language differ significantly from habits of scientific thinking as practiced in formal settings, such as schools, research laboratories, and organizations whose products and services derive from scientific experimentation. Critical for equalizing the chances of learners from diverse socialization backgrounds for advancement in the sciences, will be creation of community learning environments that allow for sufficient linguistic modeling and practice in scientific and artistic pursuits. The paper closes by proposing three types of community-based and collaborative learning environments in the sciences and arts to ensure wide-ranging learning across learner diversities.

Culture and Socialization

In the public media and basic scientific research, *culture* stands as a term both contested and proclaimed. By the mid-20th century, the professional organization of anthropologists (American Anthropological Association) ruled that it would no longer accept articles that deliberated the meaning of *culture*. Literary theorist Raymond Williams noted the term as "one of the two or three most complicated words in the English language" (1985:87).

Yet the term persists and continues to slip easily into popular "culture" and to be used to refer to everything from the climate of business offices and water-cooler breaks to the qualitative dimensions needed in historically quantitatively oriented disciplines such as sociology.[1]

What matters for the purposes of this paper and the work of this NRC committee extends far beyond arguments surrounding *culture.* A concept much more to be embraced and examined by this committee is *socialization.* This term refers to the processes, agents, and contexts through which individuals come to know, use, adapt, replace, and supplement what most social scientists regard as the major components of *culture.* These are the symbols, stories, rituals, material culture, and modalities (including language and other symbol systems) that people use to act, consider, communicate, assess, and understand both their daily lives and their images of the future.

Throughout the life span, s*ocialization* continues, and it encompasses the processes by which individuals acquire and learn the uses and meanings of the tool kit of resources in the body and the brain. In the earliest years of life, one's socialization depends on agents or others who are caregivers and, as one grows older, associates, friends, organizations, and institutions.[2] Socialization unendingly depends on access and opportunity. These are determined by location of birth (particularly in relation to climatic and geographic features) and possibilities for geographic mobility. These, in turn, shape probable interactions within different economic systems (local, regional, and global) that in turn shape material spaces and personal resources. Also critical are institutional constraints (e.g., imposed by religious and political dictates in relation to gender and age prohibitions, economic roles, transport, etc.).

From around the world, anthropologists have documented vast differences in socialization practices of communities. Though increasingly rare, isolated groups totally dependent for their survival on hunting and gathering ensure that their young learn primarily through observation and trial and error. Groups whose economic survival relies on seasonal labor orient their children to space and time in ways that bear little connection to those of formal institutions, such as schools. Within post-industrial societies whose economies depend on information, creativity, and technologies, parents immersed in organizations within these economies orient their children toward future achievement, marked initially by school success and participation in wide-ranging out-of-school activities. Yet such broad sweeping descriptors do not capture the amount of variability that comes about through individual differences, as well as religious, economic, and social histories and current circumstances. Most sensitive to this range of differences are patterns of child socialization, especially those linked to *language, self-agency,* and *a sense of the future*.

Across communities and within families, these three arenas of ideology and communication largely determine "what doesn't meet the eye" (Ferguson, 2002). Such factors range from bedtime hours for children to politeness norms to the presence of television sets in bedrooms. Belief systems, sometimes termed "child-rearing logic," lie behind "invisible" factors such as these along with how parents and children tell stories, ask each other questions, and express their curiosity about the world (Laureau, 2002, 2003). The combination of these factors builds children's self-theories about the future. These theories enable them to think about what they will and can become in terms of family hopes and values as well as communal membership across the life span. For example, within some communities, the young are exhorted to aspire in general terms beyond their parents' achievements, while in others, the young may be guided along gender lines toward specific occupations. Both regularity and adaptability shape ideologies, agents, and activities behind the socialization practices of cultural communities. These practices of socialization also fashion the biological and neurological nature of individuals into pathways for lifelong learning. Socialization practices are incredibly difficult to tease apart and to locate within any system of "logic" or coherent ideology. But we do know that certain practices—most notably those that we can link with the three arenas noted above of language, self-agency, and a sense of the future—cluster together to be identifiable as both family and community "culture" in stable and fluid ways. This may be the case, because together they largely account for how individuals perceive, abstract, and express operations and entities in their worlds in relation to their own intellectual and physical capabilities.

Recognizing these complexities of family and community socialization along with the ambiguities of the term "culture" imposes on us the obligation to resist social and political pressures to bind in any fixed way ideas about how people learn to what are often prejudicial and ethnocentric assumptions regarding their cultural membership. [See Ladson-Billings, 2006 on the risks inherent in linking policy decisions with categorical assignment of cultural membership.] Such assumptions generally disregard the intensity of external societal forces that determine time, agents, and activities of socialization within families.[3] Moreover, these assumptions can easily lead to valuing some "cultures" as "enriched" and others as reflecting various degrees of "cultural poverty."

The challenge that follows for those who want to understand how to enable more young learners to pursue learning in mathematics and sciences is three-fold: 1) to understand within families and cultural communities the coherence of socialization practices (especially those tying language, self-agency, and a sense of the future together); 2) to identify socialization presuppositions of institutions and organizations tied to national and international economic growth; and 3) to acknowledge the critical interdependence of practice, models, and opportunities to play multiple roles that enable young learners to learn to think like scientists.

(Re)generative Learning

In post-industrial societies, particularly those regarded as being the most "advanced" economically and committed to democratic principles, formal schooling has in recent decades come to be regarded as the great leveler. Schooling is politicized as enabling individuals to overcome whatever limits they may have encountered in their backgrounds, including early socialization. But the organization and operation of formal schooling as well as the sets of norms, skills, and content areas selected for study there reflect a time-locked mainstream set of courses and values. Dominant among these is the idea of scope-and-sequence and the equation of sameness with fairness. Not far behind this idea is the view that individualism and individual achievement outside pre-determined and "normed" limits in material and method must be pursued around and beyond formal instructional settings and not within. Consider, for example, that standardized tests keep skills and content bounded. An exceptional student in mathematics, music, or science may not, for example, contest the underlying premises of a particular question or offer alternative answers that may be technically correct but not within "standard" ways of approaching the question at hand.

Formal instructional contexts have since the 1990s been increasingly contrasted with *informal* learning environments (generally perceived to take place around and beyond school as out-of-school, extracurricular, or leisure activities). Yet research across disciplines has shown that the bifurcation of formal-informal to describe learning environments is highly imprecise, and delineation of the nature of learning environments grounded in varying purposes and situations does much more to advance understanding of how learning works than application of any simplistic dichotomies. Moreover, studies from contexts as varied as innovative businesses and grassroots community organizations illustrate core principles that bear little relationship to the broad features thought to separate formal from informal learning.[4]

What matters is that learning environments will inevitably include moments that slide in and out of any strict notion of *formal* or *informal*. Combinations and gradations of these will characterize learning environments with high success rates in terms of skill and information gains. Moreover, these environments will invariably sustain for themselves the idea that they have to keep on learning as an organization in order to provide the optimal context for knowledge and skill gains of individual members or internal group projects. When scientists describe their own favored learning environments, they note features listed in Figure 1.[5]

Figure 1: Features of (Re-)generative Learning Environments ***Key motivational frame: what do we know, what do we need to know in order to do what we want to do, and how do we learn what we need to know***[6]
Successful and pleasurable learning depends upon: • range of roles available to members (e.g., expert, apprentice, skeptic, critic, etc.) • multiple agents with diverse skill sets and knowledge bases • collaborative practices • multimedia communication (both internal and external to local environment) • goal agreement on desired outcomes and standards to assess attainment of these • high valuation on iterative learning • means of learning that draw upon observation and trial-and-error opportunities • focused study of printed materials and targeted attention to instruction from experts

Critical to establishing these features of learning environments is acknowledgement of felt needs and incentive to set goals to meet these. With this foundational base, however, comes recognition that diversity of talents, backgrounds, and paths of socialization will be essential in the learning pool.

Middle-and upper-class families make available to their young sustained participation in learning environments that display these features. These parents enlist these environments in order to help ensure that their children take part in learning experiences that may advance them on the path toward successful academic and career achievement. With discretionary time and money available, these parents choose after-school experiences that often come in the form of lessons in specific sports, arts, or other domains. Many involve team or group seasonally-based experiences for which parents must pay to have their children take part. Providing such opportunities falls within the child-rearing logic of “concerted cultivation” that middle and upper-class families provide their children (Lareau, 2003). Deliberate, systematic, focused, and often competitive, these activities and the breadth of experiences they offer fit the belief system of families who see expanded opportunities as leading to wider education and employment options.

These families generally consist of two working parents or a single parent whose current child-rearing practices include with regularity (and generally on a fee-for-service basis), *intimate strangers* with diverse talents, backgrounds, and paths of socialization.[6] Whether nannies acquired through an international agency or local karate instructors, soccer coaches, drama institute directors, or youth orchestra conductors, these strangers have their dedicated spaces to which the young must be transported. These intimate strangers impose schedules, norms, standards, and those generally judged most effective hold the young to high standards of discipline and performance with a tough core of ethics, sportsmanship, and spirit of commitment at the center. Though these strangers often have lower levels of achievement than the parents who hire them, they offer specializations—athletic, musical, theatrical, etc. These strangers guide the young in physical exercise, skill development, team-building, and goal-setting. Learning environments in which intimate strangers (such as coaches, music teachers, youth orchestra directors, etc.) work are marked by interactions that resemble those of *formal* instruction. An expert models, explicates, and insists upon certain skills and bodies of knowledge. Flowing around and within direct instruction, however, is the iterative, contingent, and dynamic nature of the whole enterprise they create, sustained by the features noted in Figure 1.

Re-generative learning at work in community grassroots organizations

Rare among discussions of learning in the sciences and mathematics are *longitudinal* case studies of environments that extend beyond the occasional event in the everyday learning of young people living in post-industrial societies. To be sure, upper and middle-level income families offer their children numerous opportunities to see and talk about the sciences and mathematics at work. Within many of these families, however, such talk and observation occur somewhat randomly or primarily in association with visits to "special" places (e.g., museums, wilderness areas, or parks) or with family vacations of a particular nature (such as those devoted to hiking and camping, explorations of wetlands, etc.). Participation in regular "extra" (and often neighborhood-based) activities, such as piano lessons, soccer or swim team, or community youth theatre, comes into family discussion most often on topics related to schedule, internal personalities, and quality of performance. Families rarely identify and discuss specific benefits to science and mathematics in either content knowledge or skills of process that regular "extra" activities bring the young. Yet these families "know" that extras add up for the future in ways that matter, and they often choose their neighborhoods based not just on the quality of local schools but also on available year-round neighborhood out-of-school activities.

For families with neither discretionary time nor money to enroll their young in out-of-school activities such as those mentioned above, *grassroots organizations* of certain types and features can offer benefits rich in experience. Provided here are two brief cases of re-generative learning provided on a sustained basis within under-resourced communities. Both cases demonstrate *grassroots* community organizations at work; such groups are to be distinguished from national organizations, such as Boys and Girls Clubs, YMCA's, or 4-H Clubs, that have local affiliates, that often include set curricula and activities devoted to science learning. Grassroots organizations spring from a combination of inspired and creative leadership by one or more local individuals, a sense of local need, and the collaboration of young people with a sense of need for learning beyond the classroom. Grassroots organizations often recognize that young people in many neighborhoods feel either a need or desire to earn money, and, therefore, these organizations find ways to pay young people for their participation. Leaders of grassroots community groups justify paying their members by pointing out that the work young people do means more to them, their families, and their neighbors than would their employment in fast food restaurants or as stock workers in large warehouse discount stores, etc.

Artists for Humanity
Located in Boston, MA, the grassroots organization Artists for Humanity (AFH) began operation in 1991 as a youth-based visual arts group. Six students in Martin Luther King Middle School in Boston found their creative outlet through the work that freelance artist, Susan Rodgerson, brought to their school. There they created a mural in the school library, but when resident artist Rodgerson's time at the school ended, the boys found their way to her studio in the hope of continuing their art work. For nearly a decade, Rodgerson and several of the original boys worked to build a non-profit organization.[7]

Today young people (ages 14-18) come to work for hourly pay as active participants learning several arts through apprenticeship in the organization's studios (of painting, photography, sculpture, etc.). With professional artists and a young mentor, the incoming artists undertake collaborative work dedicated to creating works of quality within set deadlines. Contracted by both for-profit and non-profit groups to create art—murals, banners, clothing, paper goods, sculpture, and photograph exhibitions, the young people have for more than a decade used their energies and income to build a strong social entrepreneurial organization. Their collaborators include medical facilities, sports teams, veterans' organizations, and community gardening groups.

By 2000, the young people of AFH decided to intensify their work with the arts to spread understanding of the importance of environmental sustainability. With the help of local architects committed to green architecture, the community organization planned and built a 23,500 square-foot *EpiCenter*, where the arts, sciences, business, finance, and organizational management come together. Young people who come to AFH still work through the six studios and focus on what it takes to keep a social entrepreneurship going, but they also consciously demonstrate, practice, and reflect on the ways in which the arts and sciences are "made for each other" and can partner to keep social entrepreneurship creative.

As the young artists work in the painting studio, they talk together about how they have to understand the techniques necessary for their flat two-dimensional images to carry a convincing texture. They experiment and talk through various means of understanding how light illuminates and reflects subject matter as it shines through or bounces off layers of translucent and opaque paint. They study linear perspective through visiting exhibitions, referring to books of artists such as Filippo Brunelleschi, and trying for themselves various ways to use foreshortening techniques by which to create the illusion that an object or distance is shorter than it is in reality because of its angle towards the viewer. Taking in what vanishing points mean comes in the process of fulfilling a contract in which the Boston skyline has to be included.

Studio instructors and mentors guide the young artists in the formal techniques of linear perspective through working one-on-one in mathematical calculations that involve precise measurement. Through numerous reference bases of observation of works in museums or in art books, artists learn how to enlist tone and color, parallel lines, and vanishing points. When their contract involves painting a natural landscape or any other scene that urban youth may have rarely experienced, the group figures out ways to inform their imagination of the kind of scene called for. This kind of challenge forces the young artists to think about atmospheric affects, specifically about how objects in the distance seem to fade or lighten in color intensity in terms of the rendering of time of day, amount of dust, and presence of other elements (such as impending storm) in the background. More distant mountains have to be rendered in a lighter shade than those closer to the viewer; dimensionality, perspective, and proportion come into action through each work created in the painting studio.

It is possible to go through the variety and type of engagement of concepts, practices, and lexicon of the sciences in each of the studios of AFH. But what matters most in the process of instructing and experiencing concepts of science are the uses of language and the varieties and frequencies of different kinds of discourse. Figure 2. (adapted from Heath & Smyth, 1999:67) indicates the frequency and variation of types of language interactions in which the young and their instructors engage. The usual teacher-student interaction of teacher inquiry-student response-teacher evaluation (sometimes referred to as IRE) rarely takes place within AFH except when students or their mentors or instructors ask a question having to do with management, regulations, safety hazards, etc.

Figure 2. The Language of the Studio
In a two-hour work session in any of the arts, young artists hear and use:

- directives to listen, look, feel, imagine—**as many as 60 times**
- spontaneous demonstrations by a more capable adult or peer of what a performance or product can look, sound, or feel like—**15 times or more**
- small-group talk to work up ideas for a project or to develop a demonstration to be given within a deadline—at least once or twice
- verbal illustration or explanation of a routine, technique, or move—**a dozen or more times**
- portrayal or reflection—either serious or playful—on some event of today's practice or work session—**at least 6 times**
- one-on-one attention from an older youth artist or professional for praise, critique, or request for explication of a particular technique, move, or accomplishment—**a dozen or more times**
- metaphors and similes that refer to processes and effects—**at least 6 times**

Such language uses in the process of inquiry connects artists and scientists. Both disciplines require a methodology that leads the enquirer towards a personal or communal enlightenment about life. Each time an artist paints something or a photographer undertakes a project, the subject matter becomes fertile ground for initiating grasps of concepts and deepening this knowledge through attainment of an intermediate status as learner. AFH, in part through the fact that its work products are contracted, involves cross-disciplinary research as well as high standards of achievement for the final arts project.

The combination of demands means that participants have to move beyond beginning steps in both their research and artistic work toward satisfactory completion of a contract. They have to take on a sense of agency and look toward successful completion of the work. Those who move beyond intermediate accomplishment to advanced mastery within one or more of the arts can become mentors within any one of the studios. Here they work beside the professional artists who direct each studio. They lead less experienced young artists in creating plans to fulfill a contract or to undertake a group project, and they go on to advise, instruct, and critique throughout the full process toward completion.

Exploration, hypothesis-building, and deliberative consideration of what-if proposals characterize learning in the studios of AFH. Young artists help obtain contracts, and once the assignment is obtained, the entire studio brainstorms ideas, deliberates ways to transform ideas into images, and considers costs and time against issues of quality, sustainability, and satisfaction of artistic standards and client needs.

For example, when a non-profit organization helping homeless families in one inner-city area asked AFH to paint a mural representing their mission, the interlacing of arts, sciences, and social understanding began. A small group of artists and a mentor examined the client's brochures and brainstormed ideas relating to the mission. The group's members considered questions related to the mission's use of symbols, possible choices of colors and images likely to be soothing and comforting, and the client's vision of size and placement of the final product. Review of sketches and ideas with the client led to an amalgam of ideas. Together, the young artists compiled the ideas into a larger image as the final design. From the idea came a sketch that had to be transformed through projecting the image on the wall, tracing the outline, and applying paint to the selected surface to create the final project.

The iterative process required teamwork achieved not only through hours of deliberating, but also through careful observation of details within each stage of the planning. Following review and ultimate approval by the client, the group of artists from the studio celebrated with members of the mission. The final product is public, accessible, and reviewed daily by everyone who knows the mission and uses bus transportation in this inner-city neighborhood. A young member of the organizational learning staff of AFH summarized one of the many connections between the arts and sciences in the following way: "in both fields, we explore and investigate the order and beauty inherent in nature to broaden and deepen our communal knowledge and appreciation for the natural world."[8]

The Food Project

Similar processes that enlist observation, trial-and-error, direct instruction, and use of reference materials (e.g., books, charts, maps, museum exhibitions, documentary films, etc.) take place in grassroots organizations committed to sustained meaningful investigation-based projects. Situations that call for new learning and refinement of skills and gains in knowledge come up weekly, if not daily. Instruction flows in and out of experience. New vocabulary, innovations in organizational processes, and inventive ways to handle tiresome tasks come along with sustained meaningful uses of oral language across genres and with different audiences.

The Food Project (TFP), located in inner-city Boston, MA and in the suburban community of Lincoln, MA, is a community organization devoted to sustainable agriculture. Agricultural sciences, mathematical calculation, and salesmanship, along with product information, characterize the regular work of the young people within TFP. A complex organization offering ample opportunity for advancement from entry-level worker to crew leader, TFP pays its members an hourly wage for work accomplished under a rigorous set of standards of group behavior and effective worker participation.

Young members take part in group decisions that are influenced by a wide range of types and sources of information. These may include charts of planting schemes used on the farm in past years; records of fluctuation of climate; comparative analysis of past years' application of nutrients, number of pounds harvested of particular crops, and general productivity and sales relative to costs. Here as within AFH, the outcome of the work of the group of young people engaged in the farming matters, for their sales in farmers' markets and Community Supported Agricultural Shares, help sustain the budget of the social entrepreneurial organization.[9]

School-oriented Middle-class Families and Non-school Activities

AFH and TFP depend, in large part, on young people from under-resourced communities. Though young people in these organizations receive pay for taking part, it is worthwhile to compare opportunities afforded within these two grassroots groups with the experiences noted in an earlier section discussing out-of-school opportunities provided by parents for children in well-resourced communities.

Both kinds of experiential opportunities offer expansion (literally and figuratively) beyond the home and family into participation with "intimate stranger" adult experts in domains of activity (whether sports, arts, environmental agriculture and sustainability) valued by society at large. Quibbling with a would-be buyer in a farmer's market, deliberating with a client over content and color of a mural, or assessing a group member's series of photographs for exhibition foreshadow responsibilities of adults working in and building organizations. The same is true for the young whose parents pay for them to take part in community youth theatre, orchestral programs of performing arts centers, or environmental science or wilderness camps. Meaningful role-based language-rich out-of-school community and work experiences embed mathematics, sciences, and the arts within processes, products, critiques, and bottom-line realities. Yet the specifics of these behaviors as they directly relate to "school subjects" are almost never specifically identified as such by the young, adult leaders, or even family members.

To underscore the socialization potential of out-of-school learning environments bearing the features noted in Figure 1, it is worth taking note of the contrasting provisions of *after-school programs* (often physically located within school buildings). Research and evaluation reports on these programs generally indicate that children in attendance have no feasible and accessible alternative learning environments during these hours. Their families have neither time nor money to provide enriching and expansive out-of-school opportunities, and their neighborhoods offer no parallels to AFH and TFP.[10] In many after-school programs, the young face reductionist (and highly *formal*) practices of classroom life that extend the school day with homework, remedial academic classes, or study halls. Individuals guiding these extended day or after-school activities are often untrained and disconnected in their own interests to specialized work in sports, arts, or sciences. Moreover, the after-school contexts in which they work have little incentive to replicate features of highly successful and sought-after out-of-school learning environments.

Throughout this paper, the term (*re)generative learning* applies to learning environments where we may find active practice of the principles set out in Figure 1 and the language features described in Figure 2. What is gained in skills and factual understanding within such locales carries generative power, enabling learning to keep moving, self-correcting, collecting, and critiquing. For many individuals whose early socialization includes such environments, along with affective support from family members for learning that takes place in these locales, subsequent learning in school is familiar in process and language. Ongoing learning *regenerates* motivations, incentives, and pleasures experienced earlier. Case studies of individual scientists consistently point to these continuities (see, for example, "Forgotten Genius," the 2007 documentary film on the life of Percy L. Julian (1899-1975, pioneering black research chemist; and Austin, 2003).

Learning Environments of the Sciences and Arts: Laboratories, studios, and rehearsals
Why link the sciences and the arts? Aside from the fact that the two fields have moved hand-in-hand across the centuries from Leonardo daVinci to David Hockney, experts in both fields today see the two as interdependent in innumerable ways. In this section, we explore some specific reasons for their linkage that come from recent findings from the cognitive and linguistic sciences, as well as from reports of scientists themselves and of social scientists studying the learning environments of scientists and artists. These findings illustrate principles of (re)regenerative learning that support gains in skills, knowledge, and creativity within the primary physical locales in which scientists and artists work—laboratories, studios, and rehearsals.

Critical to mathematics and the sciences are the arts; critical to the arts are mathematics and sciences. From initial envisionment through experimentation to presentation of findings for critique, scientists and mathematicians depend on drawing and sketching, choreographing movement, hearing and seeing patterns, and integrating metaphors and analogies. Whether anatomy and medical sciences, geology and climatology, or biomechanics and instrument design, all the sciences work hand in hand with the arts. Scientists parallel artists in their dependence on precision in rendering detail, use of close and repeated observation, and conviction of the merits of inquiry into non-ordinary combinations.

Laboratories, observatories, studios, and rehearsals are taken here as model environments of (re)generative learning. Projects within these sites depend upon diverse routes to originating, critiquing, and testing ideas and facts. This learning moves "around and beyond" as well as with support of formalized instruction. The arts and sciences as disciplines or fields of study diverge primarily in terms of the extent to which the sciences tend to rely more systematically than the arts on continuous refinement of complex technologies, driven by potential advancement of economic, communication, health, and military interests.

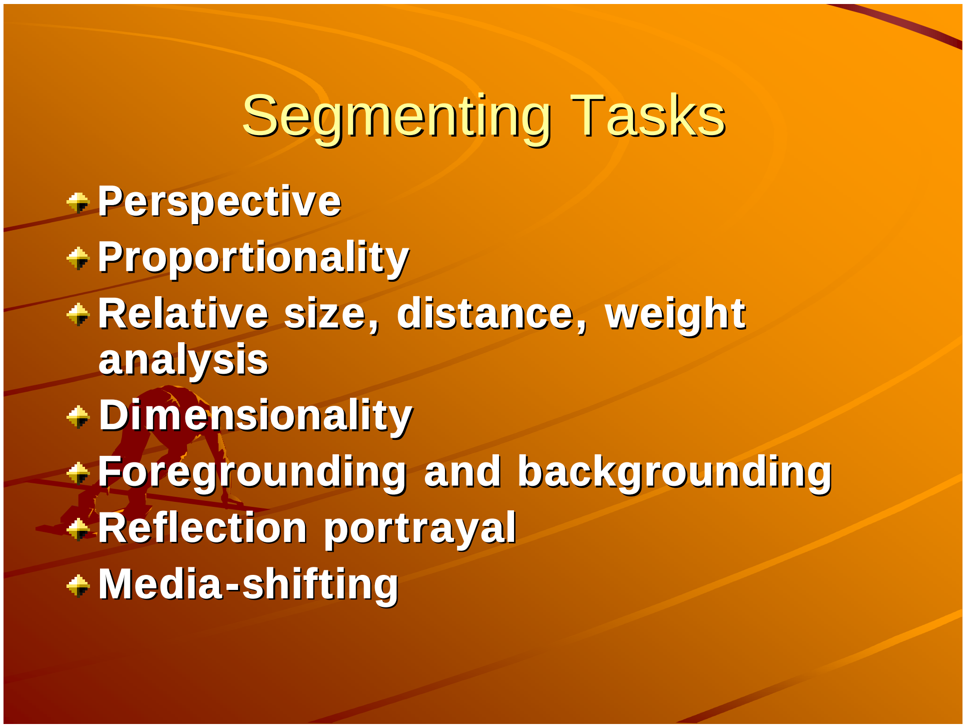
The sections below lay out some key findings on ***(re)generative learning*** from the cognitive and linguistic sciences as well as from scientists and artists themselves (as well as social scientists who study their laboratories, studios, and rehearsal spaces). These findings center on *how* the generative learning of the arts and sciences takes place. Processes include those pertaining to visual learning; talk and texts (including the vital importance of language socialization); imagination and embodiment; and roles and rehearsals.

Visual learning

To link the sciences with the arts initially invokes concepts such as “visual,” “choreographic,” and “rhythmic.” But scientists expand the narrow range of meaning generally ascribed to such terms in the arts. Within the sciences, what one sees in the laboratory, specimen, exhibited behavior, or x-ray is layered with other types of information. For example, diagnostic medicine, as well as laboratory experiments, must be choreographed—created in combinations of small units that will ultimately work together to give a full picture. Musical terms mark scientists descriptions of what they do; they listen to the “rhythm,” “pace,” or “cadence” of ideas as they flow through their heads when they are outside the laboratory or the experiment-in-action (see Root-Bernstein, 1987).

When we study what goes on in the workplaces of scientists and artists, we find that within studios, rehearsals, observatories, and laboratories, vision is the major channel for learning. Envisionment (“seeing in the head”) both precedes and complements systematic observation within laboratory experiments, in astronomical observatories, and studios of visual, dance, and dramatic artists. Visual discernment needs extensive modeling and reinforcement; only through practice does one become a truly discriminating observer. Professionals across fields that depend on keen and consistent observation (e.g., those in navigation, surgery, radiology, etc.) invariably admit that their talents and natural abilities have to mix with extensive training and practice as well as careful attention to language (on navigation, see, for example, Goodwin, 2007; Hutchins, 1995).

Certain core concepts in science lie deeply embedded within visual metaphors. Consider the figure below listing abstractions attended to within focused looking.



Several learning theorists stress the importance of visual attention to detail as both a key precursor and ongoing competence in oral and written language. Some researchers in Education, most notably Kress, 1997 and Kress & Leeuwen (1996), have taken apart visual interpretation and externalized its components into a "visual grammar" or "grammar of graphic design." Their description of the nature of visual literacy emphasizes meaning-making resources and the ways in which the movement of the eye into and across visual representations (largely in support of written text) gives rise to ideational or thematic, interpersonal, and textual meanings, such as those of perspective, foregrounding, and reflecting. We have only to think of the importance of visual illustrations in science textbooks or scientific texts writ large to grasp the co-dependence of science on the arts--graphic, photographic, and schematic—and printed text.

Increasingly, ideas from educators who study learners' integration of image and word parallel in several ways research of neuroscientists striving to improve understanding of neurological and biochemical activities involved in seeing and, most particularly, in focused, extended observation (Levin, 2004; Turner, 2006). Neuroscientific research forces attention on how what is observed visually ties to what we can recapture verbally and remember in our meaning-making through symbol systems. Consider, for example, what neuroscientists have shown through their studies of how important it is for young children, when they come across a new word, to acknowledge they do not know what it means. It appears that these children, as distinct from those who do not seem to understand that they do *not* know the meaning of a word, also tend to be close visual observers. They appear not only to want to see themselves as participants in reading, but they also have a propensity toward learning by observing "the scene," whatever that may be—page, page plus illustration, or the entire book.

The "admitters" and "observers" try to figure out what unfamiliar words mean by searching about for both visual and verbal cues that might improve their understanding. Much of this work on close looking suggests that sustained attention to visual representation carries over into metacognitive processing linked with verbal behaviors, such as reading or drawing the meaning of a word from associated visual stimuli (see Merriman & Marazita, 2004 on links between visual perception and awareness of one's own lexicon, and see also the section below on language socialization and its importance to thinking in the sciences). Scientists and artists consistently attend to the visual content of their work, and both depend on linking visual stimuli with verbal recall when they publish or exhibit their results (see the section below on roles and rehearsals).

The visual learning of scientists and artists is often interdependent with material objects in their workspaces. Telescopes, microscopes, cameras, and the like come to mind first, but numerous other objects, such as glass beakers, instruments of measurement, and means of precise cutting, make the work of laboratories and studios possible. These objects carry values that may be accepted without much thought or consideration by individuals familiar with the need to maintain and respect them. Scientists and science educators (including makers of documentary films and nonfiction books for children and young adults) find it difficult to imagine that the material objects familiar in the marine science center, laboratory, museum, or astronomy center reflect particular organizational approaches and ecological relationships not only with one another, but also with highly specific norms of socialization.

For example, use of objects that make observation of details and processes possible depends on language socialization that reinforces and values questions such as "how do we know?" and "how can we find out?" In science, most material objects relate to making finer and finer distinctions visible or evident as the data undergo varying conditions. Looking long and intensely at objects, as well as valuing objects for what they enable one to see, depends on socialization over the early years, as well as an inclination to be curious about how details relate to one another and how patterns emerge. Only questions of a certain sort can make the symbolic and material work together to tease out co-occurrences, mutations, and shifting effects of varying conditions.

Three findings from the work of neuroscientists are most relevant for thinking about visual learning in studios and laboratories.[11] These and other spaces of the arts and sciences make evident at a common-sense level the following research directions.

1) Vision is our most efficient way of gathering information about the world around us. However, observing requires the mental work of filling in gaps or fitting observed details into a sense of a whole and of an implicit narrative in which we may or may not see ourselves as playing a role.
2) Within these environments, each learner has to take on the self-perception of being a unique learner. This *role of self as observer* opens awareness that intake of information depends largely on the extent to which fixed theories attached to individuals easily enter mindsets—of both the observed and the observer. Psychologist Carol Dweck (2007) has shown that middle-school students whose educational placements have given them a sense that they were "dumb" or just expected to have low performance, will, upon learning that such labels do not relate to the capacity of growth and learning of the human brain, move forward. Changing an individual's self-theory about the malleability of

intelligence can build a self-as-agent in charge of one's own future. These changes, in turn, can bring about behaviors identified as pushing the brain to be stronger and the individual to be in charge of that strength-training (see also the numerous publications of psychologist Claude Steele on this point). The sense of this kind of ***role*** encourages learners in the spatial environments of science and art to stretch, to go beyond what they may believe is expected. Here the fact that every observer will not see the same thing, that there will be different perspectives, is highly valued. Observers in arts studios and rehearsals or in science laboratories are expected to learn through taking unto themselves a role that will lead them to know how to follow along when necessary, but also--and equally important—how to be different. This "learner diversity" leads to discovery, exploration, invention, and creation. This sense of role means seeing the self involved in the scene, thereby upping the ante on both memory retrieval and storage. Learners ask themselves and others: where have I (we) seen this before? what are we reminded of here? what do we know that will help us discover what is new here or what may be relevant to the felt need and goals at work in the current undertaking? how might we look at this scene or situation in a different way? [See the lead-in question of Figure 1.]

3) Visual focus, motivated by the intention take up roles, thus enables the viewer to take on a sense of ***agency*** critical to putting roles into play. When called for frequently and within a developing sense of agency, sustained visual focus and perception of detail correlate with a gain in fluency in later language development, particularly in forms and genres related to envisioning a future (e.g., knowing how to lay out a plan verbally, develop a scenario, or sketch a series of actions through to an imagined outcome). [See Heath, 2000, 2006; Turner, 2006.]

These principles of learning receive support not only from scientists, artists, and neuroscientists, but also evolutionary biologists. The latter point out that both archaeological evidence and extensive computer simulations of the development of the human brain suggest that, in evolutionary terms, extensive engagement with both rapid scanning of a visual scene as well as holding visual focus co-occurred with the increased human capacity for long-term memory and targeted retrieval (Deacon, 1997; Donald, 1991, 2001). A highly simplified way of putting this idea might be that as humans moved beyond the hunting and gathering stage, they had to focus more on details, remember more, and play more roles. Settlement, agrarian life, and commerce demanded different kinds of "brain work," and over tens of thousands of years, the visual, linguistic, and memory capacity within humans moved more and more to be in sync with one another.

Talk and written texts

Artists and scientists have multiple overlaps in the kinds of vocabulary and syntax they use in their talk and (written) texts. Both the arts and sciences depend upon the "three C's" of creativity, continuity, and critique and thus have to take advantage of the work done by certain kinds of oral collaborative language. Central in the talk of both the arts and the sciences are frames for information that relate to process as well as to outcomes; these frames become especially evident when experts work with novices or newcomers.

Research carried out in design experiments in England with scientists in laboratories and artists in their studios and rehearsals focused on how adult experts worked with novice learners (K-10th

grade) (Heath & Wolf, 2004, Heath, Boehncke, & Wolf, 2007). Parallels show up consistently in all phases of the work from planning through performance and critique. Experts in both fields almost never give the young abbreviated compliments, such as “good” or “right.” Instead, their responses to the efforts or questions of the young include comparative analysis, affective reactions to steps of process, hypothetical propositions for next steps, and requests for reflection on the cognitive or learning processes involved in what the group has just seen or done. Talk sets students up to envision and talk aloud—either now or later and to think about what it might take to work toward solutions of problems.

In the work of experts talking among themselves in laboratories and studios, their language shows the following similarities in structures. [Note that only utterances of more than eight units of meaning (either words or parts of words, such as plural or past tense markers) were used in this analysis (Heath & Wolf, 2004; Heath, Boehncke, & Wolf, 2007). Analysis also excluded “management” language, such as requests for objects, questions related to everyday activities (such as “have you had lunch yet?”).] An 86% overlap of types of syntactic structures and occurrence of “rare” vocabulary exists in the language used in the investigative projects of these learning environments. This language consists primarily of hypothetical propositions, critiques, extended explication, narratives of explanation, and sequences of steps in a process toward a whole (either past or planned). The chart below provides illustrations for each of these forms. [Note that order of frequencies of these forms depends on the stage in the project’s process; e.g., hypotheticals appear with high frequency in planning stages or when repairs become critically evident in a process.]

Hypotheticals of possibility and probability [If we do x, y, and z, could we get p or q, and if we got q, what would be our chances of being able to add p?]
Comparative or analytical critiques [This new way looks to me like it would take the other background. Have you thought about that change, or did you try it and set it aside?]
Future scenario narratives [When we move those chairs to a line-up of four, then we’ve got to think ahead to when those are going to be relocated to the four corners of the stage. And is that space we’ll be working in going to accommodate all four with the full dance troupe?]
Extended explication with temporal and causal dimensions [We had to decide that because that other program wasn’t working the way we thought it would, and when we tried the other way, that didn’t work either. So we went ahead to decide this, and so far, it’s working.]
Step-by-step run-throughs of accumulated data or accomplished steps in a process [As we go from 1 to 4 in what you’ve just suggested, where will we get or how could we do 5 and 6?]

Written texts in studios and laboratories work for various purposes. They serve as memory aid and efficient replication for others removed in time and space from the current collaborative work at hand. Written drafts of ideas or catch-up summations of where a project currently stands catch errors of interpretation and solicit response in deliberative and report sessions. Such drafts are developed for use with individuals internal to the current working group as well as with “critical friends.” Written texts, often including sketches, drawings, and the like, serve as “on-paper” rehearsal run-throughs for performance before others. Written texts prepared for outsiders to the group must go into standard formats and must be highly formalized for a range of types of publication outlets (e.g., program, academic paper or article, report to funding agencies or for public distribution).[12]

A special note on language socialization and learning to think like a scientist

In the introduction to this paper, we noted three critical arenas in socialization that matter most for learning to think like a scientist: ***language, self-agency,*** and ***a sense of the future***. It should be clear now that environments of science learning depend on all three arenas being in the spot light simultaneously.

Every scientist thinks and expresses "what if?" "what about?" and "under which conditions," and "I think I may be able to figure that out." An orientation to what could be and what can be known lies behind the sciences. Scientists begin early with opportunities to think, act, and talk along these lines and have or find opportunities along the way to continue to practice and develop their ideas. Yet very little research attention from developmentalists or linguists has gone to studying the linkages between language socialization before and within learning to think like a scientist.

Aside from the extensive attention that goes to vocabulary, studies of learning in the sciences rarely focus on the extent to which both early and later language socialization matter for taking up the role of science-thinker. What has gone before in this paper has laid out only a suggestion of some of the multiple and interlocking cognitive, visual, symbolic, and behavioral demands that work in science projects takes. Critical to understand, however, is that behind all these are linguistic demands. Only individuals who have had certain kinds of language socialization are likely to be inclined to take up science later in life. Language socialization—meaning both learning to use language and using language to learn—holds the most significant preparatory place in learning to think like a scientist. Vital is later language development, that most likely to take place between the ages of 10 or 11 and the mid-20s. The topic of language socialization therefore merits a special note here in terms of how 21st century employment patterns and income distribution shape individual and societal prospects for science learning.

Language socialization has (more than any other form or focus of socialization) drawn considerable attention since the publication in the 1980s and 1990s of long-term studies of professional, working class, and welfare families (e.g., Heath, 1983, 1990, 1996, forthcoming; Hart & Risley, 1995, 1999). The central outcomes of this research underscore the critical importance in early development of adult-child conversation. Adults with a wide variety of types of experience with key institutions of the larger economy not only talked more with their children, but they also used more words of all kinds than did welfare or working-poor families whose economic demands left little discretionary time or money for extended project- or investigation-based interactions with their children. Families with a greater range of shared experiences used sentences of wider structural variation than did their limited-income counterparts (see Hart & Risley, 1995; see especially chapter 6 and Appendix A).[13]

It is customary to expect little by way of scientific invention or critique from very young children. The hope is to engage them with science from a young age and to build their abilities for later understanding and exploration of fundamental concepts of science, such as cycle, parallel, sequence, etc. What we want is for them to ***engage*** with science and not simply ***encounter*** the language and concepts of science sporadically. Yet if they have not done so in early childhood, the challenge of building from these concepts becomes extremely difficult. For by the age of ten or so, young learners have to begin to think systematically about core notions such as cause-and-effect, interdependence, and co-occurrence in patterning in the natural world for them to apply these abstractions to self-agency and to link current concrete behaviors and interests with a sense of their own possible futures (see Heath, forthcoming).

Later language development is vital and depends on a mix of several essential features of learning environments of the sciences and arts. These components are those noted above and come into play when young people engage on a regular basis with adults in sustained planning toward achievement of a project meaningful to the novice learner. Lengthy treatment is not possible here of the numerous social factors in families and communities of many post-industrial nations that work against frequent project-based engagement between adults and family members at home (but see Sarangi, 2006). Evidence from numerous sources insistently reports the decreased frequency and length of occasions in which extended talk between adults and their children takes place in sustained patterns of engagement.[14]

Studies carried out with a range of research methods (survey, interview, ethnographic, etc.) show that both the quantity and quality of interactive project-based talk between adults and children are diminishing in the United States in families across socioeconomic categories.[15] Numerous reasons lie behind the radically altered nature of time within families and community involvement since the 1990s. The insistent ratcheting up of standardized testing in schools and the consequential decrease in extended hypothetical reasoning and questioning time have serious implications for science learning. Without extensive practice and role engagement in schools, later language development cannot keep pace with the linguistic demands behind learning to think like a scientist. Most worrisome about "fixing" this problem is the fact that language learning is developmental and needs extensive role-based meaningful practice to "take." [16][To underscore this point on the need for practice in order to gain linguistic fluency, consider the dismal state of knowledge of languages other than English by Americans raised in monolingual English-speaking households. Within meaningful long-term immersion within a setting demanding use of a "foreign" language, learners gain limited fluency in complex syntax, hypothetical propositions of creative ideas, or multi-variable critiques.]

In the specific three possible cases proposed in the final section of this paper, socialization for later language development figures centrally around meaningful integrative roles that involve vocabulary density, sentence-structure variation, and intensive use of both declaratives and interrogatives. To think like a scientist, learners have to move ideas collaboratively among themselves and with experts, holding proposals and critiques up for inspection and contradiction as well as clarification.

Imagination and embodiment

But learners also have to imagine and learn to embody ideas. Previously talked about much more in connection with humanistic thinking than scientific reasoning, imagination within the sciences has received mounting attention in the past few years. Two factors account for this relatively recent development. First is the dramatic increase in attention to vision as a strong contributing factor in the creative inspiration of scientists. Second is the work of cognitive scientists who have, through experimental work and modeling or "mindware," shown the extent to which imagination works in the "extended mind" (Clark, 1996; 2007ab).

Those scholars who have both been influenced by and helped shape these factors point to the fact that imagination is socially acquired and that it is a social process that both needs and benefits from association and/or immersion with other socialization patterns. These patterns relate significantly to discourse—to what socializers talk about and how they talk—and, in particular, how they use narratives. As we saw above in the section on visual learning, close visual observation is intimately linked with narrative formation and recall. Narrative, in turn, is linked with embodiment. Scholars working to understand embodiment in learning stress the fact that particular patterns of thinking, such as those associated with the sciences, depend upon the ability to imagine beyond the present and to envision what it takes to follow the imagined path ahead. Such imagination depends on *roles* envisioned as well as the *personae* associated with each of these roles. Many roles are possible, and these need not only material but also symbolic practices to help the imagination enact these roles (see more on roles in the section below on Roles and Rehearsals).

Those working within laboratories, astronomical observatories, or entirely with computer modeling need to have extensive practice doing what cognitive scientists term "re-imagining" the life of the work at hand. Facility for figuring out what an adaptation to an existing theory or practice could mean under certain conditions of change depends on envisioning ahead through a web of circumstances past and present. Exploitative problem-solving, a central practice of scientific thinking, depends upon being canny about considering all factors within a context in terms of potential action and bringing into play several cognitive and physical resources linking body and brain in learning.

For example, work on imagination and embodiment (including what many term "performance") has been significantly advanced through experimental studies of gesture (Goldin-Meadow, 2003; Gentner & Goldin-Meadow, 2003). This research demonstrates the ways in which language and gesture work together in communication and, in particular, within problem-solving. The simultaneity, as well as the "match" of language and gesture, co-occurs with successful problem-solving. Exploitative problem-solving appears to spread the load between the control centers for bodily movement and those committed to memory, vision, and language production and comprehension. Behind the external versions of language and gesture lies the internal work of envisioning just how alternative solutions to the problem at hand could work.

Other neuroscientific research is attempting to refine delineations of what goes on within the cognitive processes of efficient approaches to envisionment in problem-solving. For example, those most successful within experiments seem to engage in "just-in-time retrieval" in that even in the presence of a great deal of information, they pull up primarily what they need when they need it. This kind of efficient envisioning ensures, for example, that the number of strategies to be tried will not range across too many possibilities all at once, for to multiple strategies simultaneously in envisionment means having at a later point to manage too many sub-strategies or tactics. This kind of action vision works hand-in-hand with "perceptual coupling" that ensures that notions of change will be kept at any point within a certain range to be sorted out and tried in some way that can be brought under control and some degree of predictability (Pfeifer & Bongard, 2007; Dourish, 2001).

Roles and rehearsals

Noted above as critical in (re)generative learning is access to multiple and shifting roles. Within effective learning environments, each individual or group has a specific role to play, determined in line with the diverse talent range of the group as well as the requirements of the project. Here again diverse learning and learning diversity are inseparable.

Roles also make possible varieties of stances or *personae.* At different points and often within the same role, individuals can move among stances (e.g., oppositional, supportive, skeptical, etc.), ideally when doing so advances the project in process. Lave & Wenger (1991), Rogoff and colleagues (Rogoff, Baker-Sennett, & Matusov, 1994; Rogoff, Gauvain, & Gardner, 1987; Baker-Sennett, Matusov, & Rogoff, 2007), and theorists who examine the role of both planning and play in learning (Sutton-Smith, 1997) have written for two decades about the importance to learning of visual observation, gains in an impending sense of participation, and looking ahead toward "pitching in." This work underscores the vital role that planning—envisionment of possible scenarios—takes on for moving a project forward successfully. Creating scenes in the head or engaging in *scenario planning* has in the past decade taken on intense scrutiny by policymakers and scientists working on global issues of war and civil conflicts, environmental degradation, and energy policies. These sectors see scenario planning as a way to break long-standing gridlocks of short-term goals, powerful self-interests, and limited vision.

Scenario-planning and rehearsals work hand-in-hand. One way to think of rehearsals is as penultimate run-through (or drill) that results from prior scenario planning. Rehearsals may be cumulative, and in the everyday world of scientists and artists, they must add up to a successful final performance. What goes on within final rehearsals differs significantly from early rehearsals and also from the daily work life of studios and laboratories. Final rehearsals can tolerate no more than a modicum of hypothetical thinking. In final rehearsals, it is too late to develop too many possible scenarios or to ask "what if?" or "how about?" with too many ideas of change in mind. These occasions are geared to run-throughs of what is to come in the final performance or the delivery of work that has gone before.

Anthropologist Elinor Ochs and colleagues, in a long-term study of physicists in high-energy laboratories, found that scientists use several rehearsals to work up to a final rehearsal that will precede delivery of scientific papers at conferences or conventions (Ochs Jacoby, & Gonzales, 1994; Ochs, Gonzales, & Jacoby, 1996). The same is true of other types of scientists and especially of physicians who use rehearsals to prepare for their demonstrations and lectures before classes of medical students. Dentists and many other practicing scientists, such as veterinarians, also rely on rehearsals of their individual or small-team performances. Rehearsals have increased drastically in number and in importance with the invention of numerous kinds of new technologies that have to be demonstrated and explained before medical personnel can consider adopting them in their everyday practice. Indeed, with increased dependency on technology for presentations, rehearsals or run-throughs have become ordinary events across professionals of many fields. Such technology provides additional props for use in both rehearsals and final performances.

We may ask just what rehearsals ultimately have to do with learning—that of both the participants within the rehearsal and that of spectators who witness final performances. All rehearsals assume extensive prior practice as well as the assumption of responsibility for roles to be played by performers. Therefore, both practice and a sense of self-assessment ("am I ready?") precede rehearsals. The presence of the following additional features make rehearsals "count" as high-risk and therefore increase the likelihood of improved performance achievement over performances that have not had the benefit of rehearsals.

1. Rehearsals depend in general on written texts as background information. For example, a physician preparing to demonstrate and lecture on new laser technology for knee surgery will have read a great deal of background material as well as tried out the technology numerous times. The same is true for rehearsals before performance of a drama ranging from a script to a program of a dramatic performance previously seen or, in the case of young children, a fairy tale or storybook they know and are now enacting. It appears that the term "rehearsal" in English has come to refer to practice sessions that lead to a final performance that is acknowledged as spontaneous and as unique in the moment (i.e., never performed the same way twice).
2) Rehearsals almost always include one or more individuals playing the role of "expert audience" and "critic" and asked to take a tough stance in providing feedback to a group working together to produce a unified group production after considerable preparation on the part of individuals.

Projects increase motivation and intensity in learning when they involve rehearsals. The above features of rehearsals indicate why this point amounts to common sense. If one is working toward a final performance that has consequences, and rehearsals are needed, affective dimensions matter.

Moreover, research on "emotional literacy" stresses the power of rehearsals and the lead-up work that precedes these to prepare learners to take on self-assessment within learning environments that manage to be both supportive and high-risk (Damasio, 2003; note especially the author's introduction to the book and his emphasis on "seeing inside the house"). Acting out and seeing the self in action (as in the frequent "freeze" commands in rehearsals) intensify the learning that goes on within rehearsals. This "freeze" stance is especially marked today when classes within medical schools watch a surgical or diagnostic procedure on video and stop the "rehearsal" at numerous points for detailed observation. The same is true for dramatic rehearsals or those that precede dance or musical performances.

It is easy to observe a laboratory or physicists and astronomers in observatories or even rehearsals in dance or drama studios and detect nothing particularly unusual about them. However, upon close examination, listening in *and* closely observing when, how, and what goes on within the visual cuing shows the following features at work. Foremost is the fact that all of this language is based on sustained visual focus as well as engagement within the given roles of the task. If someone is not looking, then often the language makes no sense, for it is indexical (that is, pointing to what is going on in a scene or situation, in the most fundamental sense). Listening is secondary to focused attention and participation within role. In short, to understand is to look and to be alert to rehearsing mentally what is to come.

Laboratory, observatory, studio work, and rehearsals are marked by:

- Professionalism (hard work, tough choices); a vision of the self as a "pro"
- Mutually supportive ethos (literally "we're in this together," for experts model and novices query, mime, and try)
- Frequent erasure (often through first person plural pronouns such as *we*) of boundaries that mark lines between expert and novice or apprentice ("what could happen if we…?" "do we know if there are other marine species where the male raises the newborn?"
- Swarming of language (everyone talking at one time to reveal mutual attention and simultaneity of ideas—often within "mindstorms"—a simultaneous swirl of ideas; see Baker-Sennett, Matusov, & Rogoff, 2007)
- Fast evolution of ideas and rapid transformation of abstractions and critique into action (acting, analyzing, critiquing, and reflecting occur at the same time and cross borders between expert and novice)
- Constant calls for narratives to surround movements or to explain details ("where did that idea first develop?" " how does that make a difference to the way we move?")
- Frequent use of similes and metaphors ("watching this is like seeing you ski" or "It's like we're in a fast-moving stream.")

In the physical learning environments of artists and scientists, learners experiment, suggest, demonstrate, write down thoughts, search for inspiration, read widely, and collaborate within roles among colleagues. As in the careers of many famous professionals, there is often a moment of revelation—a combination of seeing, internally narrating the self in action, and moving forward. Professional scientists and artists constantly reinvent themselves as well as their art or science. In all the arts and sciences, trying is critical. But that trying turns into practice and that practice turns into memory and a penchant for envisioning the future toward performance.

Projecting into the future, whether as a defining feature of being human, or in terms of a specific future planned action (such as a surgical procedure or a deadline of a theatre or dance performance), determines in large part how memory and recall work neurologically. In essence, one learns to "see reason" (Stenning, 2002). David Ingvar, a psychologist from the University of Lund writes about "memories of the future," and he argues that along with the capacity of the brain to imagine the future comes its capacity to provide a sense of possible time paths for actions toward that future.

But development of both these capacities needs practice through socialization opportunities, and such learning has to emerge from outside the usual existing forms of everyday interactions. Acting in roles is critical to gaining fluency. In the project work of the sciences and arts, role-taking by all parties helps contain ambiguity and also provides intricate interpretations of possible futures. This future envisioning of both task and self-in-task sets off neuronal connections that provide increasing efficiency as these connections become automatic through repeated practice.

Putting (Re-) generative learning into practice: Three possible cases

We close this paper by framing several impertinent questions within the embracing big question of "so what?"

Following a review and set of arguments such as those of this paper, what do we make of the principles derived from studies of (re)generative learning environments? What do these principles suggest in terms of programs, practices, and promises for making such environments accessible for young people? How can we create out-of-school opportunities that merge two such self-interested disciplines as the arts and the sciences for the benefit of expanding the numbers and values of young science learners? On what bases can we expect diverse learning environments with learner diversity in talents, interests, and backgrounds to improve the nation's hope that more and more youth will eagerly and creatively engage in learning science?

The following three possible cases offer answers to these questions. All these cases put into practice the "principled eclecticism" of routes of access and confirmation that (re)generative learning embodies. Such routes amount to repertoires of heterogeneous learning resources and avenues of activity (Cazden, 2006; Luke, Abdul Rahim, Koh, Lau, Ismail, & Hogan, 2005).

Briefly outlined below are three age-graded possible cases of learning environments that embody the principles of learning noted throughout this paper. All cases depend on envisioning innovative ways to deepen and sustain the scientific knowledge of professional personnel within partnerships. All these cases partner the arts and sciences within existing "around and beyond school" organizations (such as libraries, museums and aquariums, and higher education institutions); cases 1 and 2 are under discussion, and case 3 is fully developed within one site.

The first case relates primarily to children between the ages of 3 and 8 whose families' employment, socialization norms, or economic means make extensive practice in later language development highly difficult to achieve. The second case partners an aquarium with its marine biology resources with community arts groups. The third case comes from the work of the UCLA Migrant Student Leadership Institute inspired and studied by Professor Kris Gutiérrez of UCLA, who has kindly agreed to the inclusion of this case and its principles here. These three cases are presented with the hope that they demonstrate the extent to which putting principles of learning science into practice in (re)generative learning environments is a matter of will and imagination. In all these cases, diverse learning and learning diversity work together for maximal benefits from "informal" science learning environments.

Case 1: Neighborhood Libraries (Visual and linguistic socialization, ages 3-8)

In a long-term study of factors at work in the lives of young people who succeeded academically and in career choices, neighborhood libraries emerged as central (Heath, forthcoming). Free, open, and often with relatively easy access to public transport, libraries have for decades been the refuge of children who need supportive adult models, have no place else to go, and need additional resources for projects (for school as well as personal interests). Currently, libraries are looked upon primarily as places where the young can gain public access to technology if they have no internet access in their homes. Neglected, however, in much public thinking about libraries, is the reservoir of will, commitment, and professional expertise of librarians (especially those in children's literature). Parents often see this body of work as a valuable source of entertainment as well as exposure to the humanities, but children's literature can play a vital role in visual and linguistic socialization for science learning of very young children.

Imagine that NSF or any other large funding agency were to link with the American Library Association to sponsor five summer institutes in different regions of the United States and in association with university departments of science. The goal of these institutes would be to enable every library to provide intensive programming for young children in children's literature with a strong orientation toward socializing children to the kinds of visual, gestural, and linguistic attention needed to grasp and apply *core principles of science* (such as patterning, interdependence, cause-and-effect, sequencing, etc.). Partnering in this work would be libraries and community artists, both of whom would take part in the institutes

Within the summer institutes of six weeks, librarians and artists would undertake (for work toward a Master's degree) four strands of course work simultaneously. The first would be focused on core principles of the sciences and arts (such as those noted above). A second would center on children's literary works in which a dozen or more principles of science are illustrated and embedded within the stories. The third would be devoted to child development principles relating to linguistic, visual, gestural, and cognitive development of young children. The fourth would be devoted to understanding the learning parallels of the arts and sciences. Within the institutes each summer would be embedded several short-term workshops devoted to topics such as collaborative learning, apprenticeship, program implementation, and community development. The goal of these workshops would be to help librarians consider ways in which they could enlist parents and older children and adolescents in the programming they would undertake within their libraries.

Coupled with these institutes would be longitudinal research on both the learning gained by the librarians and follow-up of groups of children within several sites around the country. Significant outcomes from this deep and content-based infusion of science learning in neighborhood libraries would depend on the cooperation of local pediatricians and other child healthcare professionals, social workers, and community civic and religious leaders. Especially important to the success of this programming within libraries would be enlistment of local artists to work with librarians to ensure that children learned to draw and sketch as well as to study details within illustrations and to learn for dramatic role-play and retelling stories from the children's literature.

Case 2: Museums, studios, and aquariums (Imagination, embodiment, & roles, ages 8-18)
Sites such as museums, public studios, and aquariums draw in the public (including multitudes of school children) primarily for passive and short-term viewing of displays. Any long-term learning or motivational gains that come from such visits rarely undergoes scrutiny or reconsideration of whether all the transport, worries over security and safety, and time away from school is really worth the effort.

Yet, the pedagogical value of the various types of sites that display (and do often enable short-term and limited interaction with) science and art—its results, processes, and products—is widely advocated. While many identify display centers for science as sites worthy of study on how young people learn, how much they gain, and how long and in what ways they remember either specific or general information, few scholars have actually undertaken such studies. This is particularly difficult to understand, since the two decades after 1985 saw an unparalleled increase in the number of museums throughout the world and a rapid expansion and diversification of their activities (Sherman & Rogoff, 1994, 2003). Many of these museums have been devoted to the building of identities of certain groups (consider, for example, the history of the development of the National Museum of the American Indian in Washington, DC) as well as to intensifying awareness of particular historical events (consider, for example, the number of museums devoted to the Holocaust, slavery and the slave trade, and revisionist views of particular periods of history as well as to the displaying of objects sacred to one or another social group).[17]

Studies of "learning in the museum" generally take one of three directions. The majority look broadly at all types of museums. Such works have a special value, for their authors often have access to studies done within museums and not widely circulated. Though many of these studies seek to evaluate particular programs or exhibitions, they offer numerous insights on the "pedagogy" of museums (see, for example, Hein, 1998; Falk & Dierking, 1992, 2000). Pedagogical process that receive the greatest amount of attention include: "discovery learning" or exhibitions that allow moving back and forth among exhibit components, interactive technologies, advance organizers, and programs that allow learners to assess their own interpretations along with those of the "experts" (see, for example, Falk & Dierking, 1992, 2000). The second group centers on the use of particular kinds of display in line with currents of public preference for edu-tainment. Here display and the philosophy beyond display draw attention primarily in terms of "post-modernism" and the changing draws for attention in urban settings. These works offer useful comparisons between internet offerings that may be akin to those that museums can provide and how museums can do what the internet can never do (e.g., create members who gather in a familiar place for which they feel deep responsibility). Scholarship and a certainty of who the experts are and where sources of information come from figure largely in these debates about museums (see for example, Barker, 1999). The final group of studies devoted to "learning," though small and generally published only in refereed journals in relevant fields (such as visual studies), examine communication and interactivity and the relationships between means and methods of transmittal and what participants show they have learned by pre-and-post tests (see, for example, the journals *Mind, Culture, and Activity* and *Journal of Visual Studies).*

These general points precede the illustrative case here in the hope that their consideration will lend support to the partnering of museums and aquariums, generally thought of as *science* sites, with museums and studios, or *arts* display or performance centers.

Imagine a major aquarium or science museum partnering on a sustained basis with four youth-oriented community arts organizations (one each in drama, dance, visual arts, and videography). On a rotating basis, for each major exhibition, a subset of each youth arts organization's members would apprentice with curators and scientists of the aquarium or museum. Together experts and novices would plan, develop, and evaluate the exhibition. The drama group would be commissioned to develop several pieces related to the exhibition. The centerpiece might be a drama performed at regular intervals, particularly on weekends, in the foyer of the building and serving as orientation and invitation to the exhibition. Other dramas to be developed would be for targeted audiences and perhaps in coordination with principles of the secondary science curriculum. [In the late 1990s, the Field Museum in Chicago carried out such a program for years, and the local youth organization served as both orientation and ambassador for the installation of the full dinosaur skeleton in the museum.] The same could be done for dance, visual arts (including development of comic books, posters, murals, etc.).

Advantages of this kind of merger should be both evident and capable of multiplication and expansion in creative ways. For example, botanical illustration, as well as medical illustration, can easily be a sub-component of all work by dance or visual arts youth organizations tied to science museums. Traveling performances (in shopping malls, city centers, fair grounds, etc.) by these groups advertise and circulate information about arts and sciences museums and current exhibitions. Such involvement builds long-term committed audiences and attendees for museums of sciences and the arts.

Case 3: UCLA Migrant Student Leadership Institute [From Professor Kris Gutiérrez, UCLA]: Building from community through the sciences, ages 18-24)
Perhaps one of the best-known and most widely respected programs in science, the work summarized in Appendix B demonstrates how a world-class state university can provide innovative integration into science for students whose families are migrants. The research of Gutierrez, as well as her influential role in the program, is known to this NRC committee. However, Appendix A supplies details of how the practices *as well as the principles and substantive content* derive from the community background of the students. Schooling has not been prevalent in the families of migrant students entering the University of California, and many of these young learners struggled in secondary school, often working in collaborating teams to study and to pool resources. Many have served as interpreters for their families, mediating with medical, legal, and community personnel. These roles have brought them face-to-face with medical "science" in many cases, while they have also been immersed in practices and beliefs in alternative approaches embedded in community and family history. Keenly aware of their unique and spotlighted role in their families as the first to enter higher education, these young people want to relate what they learn to family needs, community values, and local situations they know well. No topic is more evident or ready as context for science than migrant health and relationships between medical concerns and use of pesticides and fertilizers.

Of special note in Appendix A should be movement back and forth between performative or role-based learning, later language development (in "rare" vocabulary and specific syntactic forms, oral and written), and linkages between visual observation (e.g., representations of lung tissue, x-rays, etc.) and personal and professional narratives. Within the UCLA Migrant Study Leadership Institute, drama is central, for small-group and full-group work is sometimes directed toward production of dramatic enactment of situations in which principles of medical "science" and personal considerations come into conflict.

All three of these cases of possibility demonstrate how to put to work the principles of *(re)generative* learning. All engage the arts and sciences in interlocking embrace through dependence on multiple and diverse ways of knowing and extensive diversity in background experiences of learners. In all these cases, participants play meaningful roles in which they observe, imagine, practice, talk, and create within projects that matter. Language, self-agency, and a sense of the future not only make these investigative projects happen, but they also take young learners of science away from empty promises of ***possible*** futures into the work and play of ***probable*** futures.

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[1] Entire books lay out the history of uses of the term *culture*, but a useful contemporary reference that shows the multiple sides of issues most affected by use of the term can be found in Friedland & Mohr,2004. See also Eisenhart, 2001 for a discussion of changing conceptions of culture and their implications for research on teaching.

[2] This paper uses the distinction of meaning between *institution* and *organization* that sociologists generally use. The former term refers to entities of long stability and inertia: government (or the State in modern times), the family, religion, formal schooling, The latter term takes in entities that spring up in response to a felt need either within institutions or beyond them. Examples include corporations, fraternities and sororities, clubs and voluntary or community organizations, arts groups or buildings, historical societies, and the like. Organizations come and go in accordance with their facility for adaptation to shifting needs, whether climatic, scientific, social, or commercial. Both institutions and organizations now have their theories, and cross-overs in usage of the two terms are frequent; see 1995 for one comprehensive discussion. Scott (1998) argues that organizations came about through the same changes that brought the development of individualism and the freeing of resources from tight social structures. Their flexibility enables them to take advantage of elaborating division of labor, while also calling for new cognitive and control challenges (p. 180).

[3] This portion of this paper has been developed in association with Kris Gutiérrez, Education UCLA, and Barbara Rogoff, Psychology UC Santa Cruz. Their hospitality at the Center for Advanced Study in the Behavioral Sciences in early 2007 provided general time for deliberation around just what is meant by "the cultural nature of human development" and the influences on everyday life of learning of social and economic factors (Gutiérrez, Izquierdo, & Kramer-Sadlik, 2007; Rogoff, 2003). For more on the ecocultural approach to studying cultural communities, see Arzubiaga, Cega, & Artiles, 2000 and Gutiérrez & Arzubiaga, forthcoming.

[4] The rich literatures on what makes for successful/effective business organizations or grassroots community youth groups cannot be included here. However, aside from the features of these organizations as learning environments given in the body of this paper, two other factors receive consistent attention in these literatures: the role of leadership and the power of "having a vision." Bibliographies of both these literatures are available upon request.

[5] This literature is extensive, often with an orientation toward creativity, discovery, and innovation. In spite of such "headlining" orientations, however, these reports from scientists (and artists) consistently show that their laboratories and studios, as well as those of valued colleagues, reflected central features of (re)generative learning. See, for example, Austin, 2003 and this author's list of recommended readings.

[6] Publications and Working Papers from the UCLA Center on Everyday Lives of Families provide numerous case studies and comparative analyses of dual-earner and single-parent families whose daily schedules illustrate the extent and variation of interactions of children with intimate strangers.

[7] The story of Artists for Humanity appears in the documentary film *ARTShow* (2000) and its accompanying resource guide (Heath & Smyth, 1999), as well as numerous other publications reporting features of the organization as learning environment. A DVD, *ARTShow 2 Grow* (2005), includes the original documentary plus an updated account of Artists for Humanity and a case of The Food Project, a Boston-based youth organization committed to sustainable agriculture.

[8] A two-year study of arts projects and science projects carried out in studios, laboratories, and rehearsals in a secondary school is reported in Heath, Wolf, & Boehncke, 2007.

[9] For analysis of the daily life of The Food Project, see the documentary and accompanying pamphlet, *ARTShow 2 Grow* (Heath, 2006). See also Fisman & Heath, forthcoming, for a variety of analyses of types of learning of spatial relationships, perceptions of space, and concepts of urban and suburban spaces.

[10] Numerous studies of after-school programs indicate that though exceptions exist, the majority of such programs do not reach the children for which these programs were developed (e.g., "latch-key children), have few incentives for regular and sustained involvement by the young, and do not produce significant

gains in academic skills or information for children. See, for example, reports listed on the website of the W. T. Grant Foundation and the Rand Corporation.

[11] The literature on “the visual mind” in the arts and sciences can most readily be reviewed in Emmer 1993, 2005; and issues of *Visual Studies*. For more on the uses of talk for making “visible” what is envisioned, see Kawatoko & Ueno, 2003.

[12] Studies of laboratories and studios (especially in architectural schools or firms) rarely delineate in detail the nature of oral and written language uses. However, ample evidence suggests the kinds of language described here; see, for example, Fleck, 1979; Latour, 1987; Latour & Woolgar, 1979, and see Eisenhart & Finkel (1998), especially chapters 4-7 on discourse within “women’s science”).

[13] These points parallel in several ways the work of linguistic Catherine Snow and colleagues who have argued (primarily with regard to later literacy development) that both quantity and quality matter in early language socialization (Snow, Barnes, Chandler, Goodman, & Hemphill, 1991; Snow, Burns, & Griffin, 1998).

[14] See, for example, the 2007 UNICEF report on the well-being of young people in the top twenty-one developed nations (UNICEF, 2007). The United States and Great Britain were at the bottom of this ranking on a host of features having to do with material well-being, health, education, relationships, etc. Of particular note is the fact that children in the US and Great Britain eat and talk infrequently with their families in comparison with the young in nations such as the Netherlands, Sweden, Spain, and Hungary, nations whose students outperform those of the US on science and mathematics.

[15] See publications from the UCLA Center on Everyday Lives of Families, Laureau, 2003; Heath, forthcoming, 1990).

[16] See Viechnicki & Kuipers, 2006 for discussion of talk behind the collective, intertextual negotiation of a “fact” in science. In spite of repeated failures at an experiment, students did not question the authority of the conclusion they felt they were “supposed” to reach. One is left to conjecture direct linkage between later language socialization, as it is discussed in this paper, and this failure, but transcripts of the “science talk” in the classroom reveal few of the features of the language of (re)generative learning environments noted above.

[17] The literature on museums, in particular, is extensive, and much of it includes portions devoted to pedagogical considerations. Of primary concern in recent years has been the politics of display, as well as questions related to the theft of materials from groups or locales previously exploited (or explored) by imperialist states. See, for example, Lumley, 1988; Vergo, 1989, Leon & Rosenzweig, 1989; Karp & Lavine, 1991.