Future of STEM Curricula and Instructional Design:

A Blue Sky Workshop

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REFLECTION PAPERS

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Reflections on the Future of STEM Learning – A Cultural Commons

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The December 2009 NSF-sponsored workshop "Future of STEM Curricula and Instructional Design," was markedly different from most workshops. It felt like an awakening, a revival driven by the excitement and opportunity not only to critique and synthesize prior knowledge, but also to dream together some high flying ventures, propose blue sky innovations, and roll up our collective sleeves to design a new model of STEM learning, drawing from a strong base of existing research and evidence-based practices.

This revival didn't need a campfire or tent to gather our collective inspirations and to fuel frank discussions of what works in STEM education. Even though participants represented different fields from science and mathematics education, computer science, informal science education, museums, and public television, there were strong agreements that emerged. For example,

- Innovative interventions work when engagement and learning are central in the design.
- Learning requires social supports. A caring teacher, parent, peer, or coach can scaffold learning and provide access to expertise, knowledge, and physical resources as well as access to broader social networks.
- Learning happens in the presence and availability of rich STEM content that is thoughtfully designed and sequenced. A rich curriculum can be supported by a core set of ideas (thin core) supported by multiple representations, data sets, and modeling tools.
- Technology-rich curricula that support deep understanding are not designed to be "teacher proof", but need highly competent and technology-fluent guides.
- Assessments of learning have to be meaningful and educative for both the learner and the teacher. These assessments not only document and measure performance or depth of understanding, but also inform teacher practice and offer relevant, timely feedback to the student.
- Learning how to learn, critical thinking, higher-order thinking skills, and problem solving skills are just as important as learning the subject matter, if not more important.
- Before we create more curricula or learning activities, we should examine the existing collection of good to great STEM curricula with evidence-

[1] At the time of the Blue-Sky Workshop, Sherry Hsi worked at the Exploratorium in San Francisco, Califorina.

based success that need help in gaining wider adoption and getting to the marketplace.

- Technology provides new opportunities for teaching and learning, permitting more frequent and sustained learning that requires thoughtful materials, new approaches, and new courses.
- A thoughtfully designed technology-enhanced program can transform STEM learning even for those learners who have difficulty engaging.

But as we were dreaming together, the depressing realities crept into the conversation and Pandora's box flew back open. Why is it so hard to make good STEM learning happen in school classrooms? Participants shared a million personal battles fought collectively by teachers, professional developers, curriculum developers, researchers, and professors.
Our current mode of teaching is failing to reach many students who are fluent in technology, but disenchanted with STEM. How do we prevent lethal mutations and poor enactments of sound curricula? How can we sustain the one-offs and get these innovations to scale? How can we teach when constrained by single period classes, lack of time to prepare, unsupportive district administrators, outdated university faculty reward systems, Internet firewalls, mandated textbooks, high stakes test that don't align with the curricula, consensus-driven standards, high disparate capabilities within a single grade level, no technical support, and no dedicated spaces for science and computer labs? Teachers have limited instructional voices and freedom with curricular choices and little time to actually teach and often undermined by school administrations, school boards, and the community.

Some participants reminded us that there have been many attempts to use technology as a change agent in schools, however, because "teaching as telling" is the entrenched mode of instruction, new tools are often used in the same way that older tools are used and lecturing remains the dominant instructional format. This situation might get worse as economic drivers like state budget deficits drive curricular decisions. For example, the $24B gap in California has influenced Governor Schwarzenegger to favor online versions of textbooks, rather than investing in innovative technology-enhanced curricula and assessments that could vastly improve learning.

A Science Center View

From my current vantage point, working in a science museum, one of thousands of informal science institutions in the U.S., the solution seems obvious. Why try to introduce innovations exclusively into schools when there are many fewer constraints in out-of-school settings? Integrating formal and informal education could result in exciting educational experiences that could benefit all.

Many of us work in informal education institutions (e.g., aquaria, zoos, public television, afterschool organizations, natural history museums, national laboratory outreach centers, etc.) that also develop STEM learning and teaching materials and programs for use by school-aged children, K-12 teachers, and the public. Science centers like the Exploratorium provide both interactive science exhibits, digital STEM resources, a post-doc training program, and inquiry-based teacher professional development programs. The Lawrence Hall of Science, which is well known for its elementary science curricula, also creates programs like *Check out Science!* that provide libraries with children's science books and accompanying experiments that families can do at home, and AfterSchool KizScience for that venue. The New York Hall of Science hosts afterschool science clubs and offers portable lab kits to teachers. WGBH produces children's television shows and digital video libraries with clips from their best media programs available for use by all educators. These are also cultural institutions that have onsite artists, scientists, web developers, craft artisans, and educators who have resident design practices and know how to engineer learning spaces, create phenomenon-based exhibits, and support apprenticeships and experiences that engage a broad range of learners. Science centers seem like a natural place to push some innovation, future research, and blue-sky thinking!

Designing and Architecting a Cultural Commons

A *Cultural Commons* was one compelling idea that emerged from our discussions – community-based consortia of cultural and civic institutions. These Commons would serve students, teachers, and the local community in collaboration with schools, and would be supported by a computer network that hosts a common set of tools - licensed curricula, open content, applications, professional development, online courses, and assessments.

If we carried out this learning design experiment, what would a Cultural Commons look like?

Cultural heritage, community-based, and civic organizations would form partnerships across traditional borders with the goal of fostering positive interdependence, rather than competition, through resource sharing (e.g., trading spaces, sharing online data, and group software licenses.) The Cultural Commons would enable a tighter coupling and partnership between private and public community-based organizations with schools and libraries. This would allow institutions in proximity to each other to trade physical spaces and share time on instruments (like telescopes, microscopes, etc.), as well as sharing digital resources by being on the same network.[2]

For example, the Exploratorium, California Academy of the Sciences, SFMOMA, KQED, and the San Francisco Public Library could form one regional network, while Lawrence Hall of Science, Oakland Museum of California,

[2] NSF has already funded institutional integration efforts through their I3 program, but not for science centers, informal science institutions, and schools.

Oakland/Berkeley Public Libraries, Museum of Children's Art, and the Chabot Space and Science Center could serve as anchors for another hub. Zoos, botanical gardens, aquaria, and performing arts organizations would also be invited to participate. These organizations would work synergistically to support STEM learning programs, spaces for tinkering, studios, interactive exhibits, youth programs, laboratory kits, and leadership/docent training programs.

Engineering such an endeavor would require some key constraints and design requirements, and accompanying implementation research to understand its success. What would be some design requirements?

A. Scheduled learning for 8 hours

To help schools teach STEM, the learning day would be extended to 8 hours (9am to 5pm); however, only four of those hours would be spent in classroom-based or school-like activities, while the other four hours would be spent at any one of the interactive Cultural Commons spaces in tinker studios, imaging facilities, media production stations, computer clubhouses, planetariums, bone rooms, exhibit maintenance shops, and galleries (some school classrooms could also be converted to operate more like these spaces). The student would be viewed as a nomadic inquirer moving among different learning spaces depending on their interests, instructional needs, and social affinities.

In fact, private home spaces in resource-rich homes are commonly used for serious hobbies like building Rube Goldberg marble machines, train set villages, backyard tree houses, bands, collaborative online game playing and hacks. The Cultural Commons would be an attempt to create something like this in civic spaces especially for those children who don't have access to such resources in their own homes.

For the Commons to be available to all students in an area, new resources would be required: more space, more staff, and more materials. The space now available for projects and collaborations in schools and in informal education would have to be greatly expanded. Teachers, volunteers, and professional staff would need to be recruited, trained, and supported.

The role of teachers would also change to include working as guides and coaches in Cultural Commons spaces. One of the most important outcomes of this new approach would be the new ideas and teaching strategies that teachers would bring to their classrooms from work in the Commons.

B. One Cloud + Handheld per Child; Free Laptops for Teachers

Each child would be issued a ubiquitous computing device (e.g., iTablet or lightweight laptop) to access vetted content, thin client tools, and network services. Each learner would also have unlimited space in a "cloud" to store their life's digital portfolio and assessments. Each teacher would, in turn, get free laptops and software upgrades. Quality technology-enhanced curricula (e.g., TELS, SimCalc, Fathom, Molecular Workbench, Connected Math Project, Biologica, Living by Chemistry, WorldWatcher, etc.) would be available on every wireless laptop or PDA supported through the Cultural Commons portal and network.

C*. Customized Learning Plan and Guided Pathways*
Learners would gradually take responsibility for identifying their interests and selecting a plan for learning using a set of online templates, as well as complete projects that would demonstrate the core competencies required for certification or graduation. Teachers would design guided learning pathways that are suggested to learners as defaults. There would also be coaches, perhaps STEM retirees and older kids, who would serve as both onsite experts and online mentors. This would help broaden the social knowledge network of kids. Plans would be designed online with a smart backend and online coaches and range of "teaching for understanding" assessments. There would be assessments that would measure learning along both formal and informal criteria outlined in the recent (National Research Council, 2009).

D. New Media/Engineering Drop-in Studios
One space is necessarily allocated in a Cultural Commons cluster as a production studio to allow opportunities to gain access to professional level media production tools, giving kids access to the tools to be creators, critics, and consumers of web-based new media, games, and simulations. These studios would build new media literacy skills, computational thinking, and technology fluency skills. Similarly, arts and engineering design tinkering studios could be located in different spaces as well for hands-on tinkering with sensors, programmable hardware, and digital arts projects.

E. More cross-trained learning scientists
Concurrently studying and designing learning in these settings would demand more education professionals that are cross-trained in at least two or more fields including STEM and the learning sciences, engineering design, media arts, computer-human interaction, computer sciences, STEM teaching, educational assessment, anthropology, and information sciences. One could imagine universities, professional development centers, and other education institutions that prepare hybrid professionals such as instructional designers who also teach K12 learners, engineers who can design cyber-assessment systems, or researchers who can study everyday learning in museums. It would also take a change in how and where these new cross-trained professionals do their scholarly design work, and how they get rewarded beyond the metric of publications.

Research Questions about Instructional Design and Implementation

A range of interesting research questions emerge in the Cultural Commons environment including issues of theory, design, and practice, as well as research about educational systems, organization, and policy. Informal learning research and research on learning in everyday settings has been largely invisible to the larger community, but with the recent NRC report on learning science in informal environments (NRC, 2009), that is changing.

Museums, science centers, and other informal science institutions can play a greater role in the overall educational system. They provide natural playing and design spaces for conducting large-scale social experiments and also support teacher professional development of K-12 teachers. The Cultural Commons could also help spark a creativity economy – a way of nurturing the type of bright and creative people that generate new patents and inventions, innovative world-class products and services, and further support STEM.

The formation of Cultural Common networks can serve as one experimental model for education that can not only improve STEM education but better address learner motivation, civic engagement, and leadership development through guided apprenticeships, communities of interest, tinkering studios, and hands-on laboratory experiences in museum-like settings. The formation of a network of networks has also the possibility to be scalable to fit changing demands. The orchestration of an education system of civic organizations that, together with schools, support students in STEM learning and teaching all supported by a shared cyber-infrastructure would be a great aspiration to take on.

References:

National Research Council (2009). *Learning science in informal environments: People, Places, and Pursuits.* Committee on Learning Science in Informal Environments, Philip Bell & Bruce Lewenstein, Andrew W. Shouse, and Michael A. Feder (Eds.). Washington, D.C.: National Academies Press.

The Future of STEM Curricula and Instructional Design

June Mark, Senior Project Director
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"Imagine a learning environment that supports generation of and productive work on student-posed ideas."

On December 1-3, 2009, I had the opportunity to participate in an "envisioning the future" workshop to discuss options and opportunities for the future of digital curriculum and learning. The goals of the workshop included:

(1) Stimulating important research and development work on the next generation of STEM instructional designs, including curriculum and instructional materials; and
(2) Evaluating options for investment in that work by the professional organizations and foundations that support research and development in STEM education.

The initial questions that guided the conversations included:

What will a high-impact, technology-intensive STEM learning environment look like in the near and long-term future?

What development and study of instructional materials, models, and technologies will be required to make those future visions possible?

Catherine McEver has created an amazingly detailed documentation of the meeting that captures the resources shared, the nature of the discussions, and the group designs created at the meeting. By contrast, this paper is intended to be a personal reflection on the workshop. I do not try to provide a faithful and comprehensive record of the meeting, but rather to offer my perspective and reflections on the ideas and designs created and discussed at the meeting. I share some background on the structure of the meeting, identify a few cross-cutting themes that I felt emerged at the meeting, and offer my perspective on what is needed to study and test the ideas that emerged.

Structure of the Workshop

The three-day workshop had the goal of stimulating and creating new visions of what might be possible for the future of learning environments and curriculum. Its structure encouraged exploration of a range of ideas, rather than trying to come to consensus on one potential vision. The centerpiece of the meeting was extended time for cross-discipline teams to work together to create a "learning design," conducted in the spirit of a "charrette," a design competition from the context of architecture. Small self-organizing teams of 5-7 people were put together to try to envision the design of a future learning environment and then those designs were shared with the larger group. Further ideas and discussion built on those initial designs.

Among several strengths in the design of the conference was the attempt to bring together a diverse set of perspectives and experiences to bear on the task of coming up with future learning designs. The invited participants included cognitive scientists, educational futurists, mathematicians, scientists, engineers, mathematics and science educators, curriculum developers and researchers, technology developers and researchers, museum and out-of-school educators, and educational media developers. Participants were encouraged not only to share their perspectives but also to work together to create new ideas, think outside the box, and listen to others' ideas. The framing of a design challenge as the backbone of the workshop worked well to allow these different perspectives to emerge, and to generate stimulating discussions.

Following introductions and the sharing of resources on the first evening, the group of approximately 35-40 people convened the following morning and began with a sharing of Powerpoint slides, one slide per person, responding to the question:

> What is your "dream state" regarding future educational settings -- that is, what would you like to see in terms of instructional designs that factor in the reality of kids and learning as you anticipate them to be 7-10 years from now?

Participants approached this task in various ways. Some offered visions of how they thought learning might be different than what we see in K-12 schools today, others shared ideas for materials, tools, or a specific aspect of the learning environment, and still others reminded us of important ideas and issues to keep in mind in designing future learning environments. The sharing of these "slides" was particularly effective in raising some key ideas to seed further work. A number of ideas that were introduced in this session (e.g., thin core, 4x4 design for learning day) were later picked up and modified, refined, and elaborated later in the workshop.

The "dream state" activity led to more focused work by the six separate design charrette teams, followed by short presentations by each of the design teams. Jim Fey and Dennis Bartels offered reflections on the designs, and then other participants had an opportunity to comment on the designs. The workshop closed with discussion about implications and recommendations for the STEM instructional design community.

Workshop Themes

For me, a few big themes emerged during the workshop, with tremendous convergence in the conversations and design scenarios developed by the different teams. These themes include: *blending formal and informal learning, customization, the "thin core" of content, and teachers' roles in future learning environments*. Each is elaborated below.

Combining formal and informal learning

> As many people have said already, the learning environments are changing and include school, virtual environments, studios, museum and community centers. There will be a lot of interaction with peers (kids teaching kids), interaction with teachers, and we felt very strongly that there should be interaction with experts as well. We learn best by actually solving problems, real problems, not made-up problems, and maybe some problems that the teacher doesn't know the answer to so that you can't go up and ask whether your solution is right, you have to verify it yourself.[3]

One theme that came up frequently during the workshop was that of breaking down barriers between formal learning environments (e.g., schools) and informal ones (e.g., museums, afterschool programs, community centers, hospitals). Sherry Hsi suggested a new design for the learning day – with 4 hours spent at school (9 am-1 pm), 4 hours spent at a museum or community center (1 pm-5 pm), and 4 hours (5 pm-9 pm) spent at home. Other participants shared ideas for blending or blurring the boundaries between informal and formal learning, and encouraged greater connections between formal and informal learning environments. This thinking was prompted in part by the observation that a tremendous amount of learning occurs outside of school. Often, children are more highly engaged in informal learning environments, and also able to pursue projects or activities that are driven by their own interests. Time is often structured more flexibly in informal environments. Another motivation for blending the in-school and out-of-school experiences for students was the opportunity to provide students with access to expertise from practicing scientists, mathematicians, engineers, computer experts, and other professionals in STEM-connected fields.

Customization: What could it look like?

> As Janice Earle said, we need to customize instruction, not individualize it. We need to customize instruction with rich resources to enhance that thin core of math and science that Jeremy Roschelle described. Going back to one of Jim Minstrell's points, it's absolutely essential that we make sure that kids are learning, so it has to tie back to assessment to make sure that we're really checking for progress while we're doing all the cool things we want to do.

Central to many of the visions of alternative learning environments was an assumption of learning customized to the individual. Learning that is more differentiated, driven by students' interests, project-based, and is engaging to individual students. Learning paths would be designed for students, responsive to assessment data that would inform students' progress along learning

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[3] The quotes and excerpts that appear in the boxes throughout this paper are drawn from Catherine McEver's documentation.

trajectories, and that would indicate students' learning needs in specific content areas.

These potential learning environments are very learner-centered, environments where kids are engaged and curious, are listened to, participate in directing their own learning, and use their interest to drive further learning. Students would engage in deep learning of content, build and demonstrate expertise, design experiments, and solve problems in project-based environments. Learning in this environment is also multi-directional, not as much from teachers to students or even just between teachers and students but also with an emphasis on peer teaching and learning.

"Thin core" of common content

> **Identifying the Thin Core:** One of the things I heard, probably a little bit less than I would like because it happens to be my pet peeve, is serious questioning of what all of the changing technology environment says about what it is that we want kids to know. It seems to me that all of the technology, the access to information, the access to data suggests that you really have to ask hard questions about what it is that we want all kids to know. We talked about this before, the *thin core*. What is the thin core and what kind of understanding do kids need in order to access all of the information that is going to be available? (Jim Fey)

Along with notions of deep learning, there was an acknowledgement of a need for a "thin core." Jeremy Roschelle first suggested an "incredibly well engineered thin core" of mathematics for STEM that would be "open source" and that teachers and students would build upon. This idea of a thin core generated much discussion within the design groups. There was a lot of appeal in this notion of a "thin core" (an agreed upon common set of content, perhaps for each discipline area) that would be important for all students. One group modified the notion of a thin core to include a long tail that involved individualized experiences based on student interest. However, even a determined effort to take seriously this idea of a thin core, and then try to flesh out what that might look like proved challenging. People had different ideas about what's most important, what's important from mathematics, from the different disciplines within science (chemistry, biology, etc.), and the importance of overarching skills and practices such as mathematical habits of mind, or problem solving. What might be the basis of this thin core ranged from standards, learning progressions for key mathematical and scientific concepts, performance objectives, assessments, and more.

Teachers' roles and teacher quality

> I was struck by the issue of teacher quality and teacher competency. We talked about it quite a bit in our group. I think it's important to acknowledge in this blue sky framework that we collectively weren't willing to settle for anything less. I feel very strongly that as a country we keep trying to sidestep the essential issue, and that is that there is no industry or profession where we don't recognize the importance of professional competence and choose to invest in it except education, where we try to come up with methodologies and strategies around that. It is particularly striking and important for us to acknowledge in this group, which is sort of heavily technology skewed, that we don't want to sidestep this issue. (Margaret Honey)

Another important theme that came up often was the role of teachers in these new learning environments. Contrary to what one might expect in a view of a highly technological and digital learning environment of the future, teachers are accorded a very central and quite skilled role as educators, with teachers commanding a high level of knowledge and flexibility. It was generally agreed that the envisioned learning designs are going to necessitate rethinking about the role of the teacher, and also the professional development and preparation of teachers. In various scenarios, experts and practicing scientists, mathematicians, and engineers were assumed to also play roles in "teaching" and supporting the learning of K-12 students, but teachers still had a significant role in orchestrating and supporting the progress of students' learning.

Another thread of thinking about teachers and the future of curriculum and instructional design focused on the role of technological tools to support the work of teachers. How would technology provide data to support teachers' understanding of their students' grasp of content? What ways could technological tools be used to support teachers' customization of curriculum and instructional materials? How could technology be used to support teachers' learning? What opportunities does technology offer in connecting teachers into professional learning communities? How would technology enable teachers' access to expertise? Thus, one key challenge identified by workshop participants is the need to consider how to shift thinking about teaching and how to change preparation and professional development for teachers.

How do we get there from here? Personal reflections

The creation and discussion of learning designs highlighted these central themes and also raised many questions. After the various designs of the charrette teams were shared, commented on, and discussed, participants were encouraged to push their thinking a bit further in terms of implications and next steps. Newly formed groups were invited to offer recommendations, advice, and cautions to the STEM instructional design community. The questions considered included:

> *What are the implications for research and development?*
>
> *What presently impedes high-quality R&D in experimenting with the types of instructional designs we've been talking about?*
>
> *What knowledge is still missing?*
>
> *What is the health and state of affairs for the instructional design community and what is impeding its robustness?*
>
> *If time, attention and resources are always limited, what priorities for research and development would you suggest?*
>
> *Were there any conceptions or directions of instructional designs that you found particularly powerful or most worthy of further development?*
>
> *Is there a high-risk but potentially transformational concept on the table that*

we might take a flyer on?

What big mistakes can we make if we are not careful?

One of the reasons the meeting felt productive to me is that participants achieved a good balance between, on the one hand, encouraging risk-taking in envisioning the future without too many constraints, and, on the other hand, respect and acknowledgement of the current reality of schools and teachers, with serious attention to how do we get there from here. For someone like myself, who has a very pragmatic point of view, grounded in the realities and challenges students and teachers face in today's schools, it was both liberating to take away constraints, and challenging to imagine how the ideas discussed could become reality in the near to medium-term future. Here, I share some of my own reflections on and questions about issues that would need further consideration as we move forward in realizing the goals and visions expressed at the workshop.

Coherence of curriculum and instructional materials. The notions of customization of students' learning interested me very much. I find very appealing the idea of students pursuing age- and knowledge-appropriate problems and ideas that *they* pose and are interested in — e.g., an exploration of the implications of climate change in their own community. I also think creating this kind of rich learning environment is quite challenging, particularly when we look beyond individual students and try to imagine implementation for a classroom of students or for classrooms across a school district. I wonder about issues of coherence and quality.

My own work for many years has been in supporting and researching the work of district mathematics leaders who select and implement high-quality comprehensive mathematics curricula as a mechanism for improving their schools' mathematics programs. Some of what we've learned through that work is that coherence and consistency matters. In our recent research, we found that districts across the country are increasingly making centralized, district-level decisions about mathematics instructional materials—with the intention that all teachers in all schools will use those materials. Curriculum leaders we interviewed believed that consistency in the use of well-aligned materials would lead to improved student outcomes, and provide more consistent opportunities for quality mathematics learning for all of their students. This centralized decision-making makes possible a re-alignment of policies and practices, using the adoption of well-aligned instructional materials as a driver for program improvement. A common set of instructional materials provides a mechanism for a district to align curriculum, instruction, and assessment.

We need to think carefully about coherence in STEM learning experiences. We need to build onto what we - the NSF, and developer and research community - already know and have learned through the development of high-quality instructional materials in mathematics and science. How can coherent curricula, e.g., the NSF-funded instructional materials in mathematics and science, serve as the backbone for the learning designs that have been envisioned? How can we meet individual student learning needs, yet provide access to a coherent core of curriculum?

Teachers' roles. Another lesson learned through recent curriculum implementation efforts is that asking teachers to assemble lessons, and bring coherence to their curriculum is extremely challenging. High-quality instructional materials provide teachers with a coherent core of mathematical content and well-crafted, sequenced activities to prompt students' thinking about important mathematical ideas. The implementation of instructional materials also creates opportunities for teacher learning, and enables teachers to focus on the work of adapting the curriculum to best meet their students' needs. Access to high-quality, well-sequenced instructional materials in mathematics can provide a tremendous support for teachers' work by enabling teachers to focus on adapting and differentiating the materials to meet the needs of their particular students. It can also provide a focus for teacher professional development and support, creating opportunities for teachers to learn about the mathematical ideas underlying the materials and how students develop these mathematical ideas. How can future instructional designs and technologies support teachers in focusing their work with students? What resources can provide teachers with data on students' understanding and needs in their development of particular mathematical ideas? What supports are possible that enhance teachers' learning and their connections to other teachers?

Learners' roles. In addition to the complex and sophisticated roles for teachers, the design scenarios we have imagined also call for highly developed student learning skills.

- What dispositions and skills do students need to possess to be able to work productively in such learning environments? How do we develop the kinds of critical learning dispositions (e.g., persistence, curiosity) to support learner-directed learning environments. What does that development look like across grades K-12 (or across that age span)? We need a better understanding of learning and the learners in these environments. How do we help students learn not just content but also how to learn?
- Can we provide these rich learning environments for all students? How do we manage to provide high-quality teaching and learning to an increasingly diverse student population?
- How do students develop their own sense of what is productive learning. At what age does that happen? Are we talking about visions that are more doable at high school or possibly at middle school? What might this look like at the elementary level? What are the advantages and downsides of this customized learning? What is the role of teachers in shaping the direction of that learning? What about parents?

The vision is appealing and worth having articulated. We've hardly figured out what the practical side would look like. In designing experiments to test the vision, we will certainly want to engage teachers and students as co-designers.

Defining the thin core and keeping the focus on what we want kids to learn. One challenge that I see is that of creating and coming to consensus on what's contained in that "thin core." I expect that coming to agreement will be quite challenging, perhaps even more so than was the case with the earlier disciplinary standards (e.g., NCTM's Principles and Standards, Science standards) and with recent efforts to develop common core state standards in various disciplines. Are the common core state standards what the thin core would be? Beyond the thin core, how do we ensure that kids are getting productive learning on that "long tail"?

Thinking about these questions should be driven by what we want students to know, not by what's possible with the technology (technology for technology's sake). That is, keep the focus the kids and their learning rather than on the technology.

- How do we decide what's important for students to learn in these learning environments? Who makes that determination? Who develops the materials and tools that supports development of students' learning of particular ideas, connecting those ideas together into a coherent view of the discipline, and building knowledge within and across disciplines?
- Central to many of these visions was a system for keeping track of students' learning across multiple contexts, an electronic record of students' progress and a plan for their learning. What does that look like?
- We need to build on the existing work aimed at defining learning progressions and learning progressions for the development of important mathematical ideas (e.g., the synthesis of rational number research done by Jere Confrey and others), and the thinking about the development of key mathematical ideas and concepts in various curriculum development efforts. Similar efforts likely exist in the other STEM disciplines.

Equity and access issues. Not much attention was paid in the discussions at the meeting to issues of access and equity. However, as we try to realize elements of the designs that were generated, we'll need to pay much closer attention to issues of access and equity, especially in regards to those students who have traditionally had less access to technology and learning opportunities. Questions such as the following will need to be explored:

- How are the technologies and learning environments that will be built made accessible for English Language Learners (ELL) students?
- Students from different ethnic and socio-economic backgrounds will have different access to a variety of technologies. We heard the claim that in many African American and Hispanic communities there is more

widespread access to cell phone technology than to computers. What technologies will provide the best access for various communities?

- What differences are there in considering these design scenarios in various communities? We need to play out the scenarios in urban, suburban, and rural areas where we may encounter considerable variety in the distribution of resources.

Rethinking the role of schools. A push for greater integration of informal and formal learning contexts is certainly not new. How can we effectively bridge the relationship between school and out-of-school? How does the availability and access to information, knowledge, and expertise in so many various places facilitate the integration of formal and informal learning? What can we learn from existing experiments and partnerships that grow out of merging high schools and community colleges, charter schools, virtual schools, and school/museum partnerships. In what ways can virtual learning communities be used to enhance learning opportunities for kids? In what ways are "virtual high schools" effective? What models of schooling have been effective at addressing individual students' particular needs? What can we learn from new experiments that explore cross-centered learning environments (home, school, museum/community centers, e.g., projects such as "Tech Shop", the Learning in Informal and Formal Environments (LIFE) Center, and At-Your-School (AYS) afterschool programs)?

Many people were quick to move away from schools as the primary place for children's learning because learning doesn't just take place in schools. Still, what is the role of schools in the future? What functions do schools serve in our society beyond that of education? How does the learning from different contexts get integrated and aligned? As my colleague Paul Goldenberg says, "For me, the issue is that the *real* "owner/operator" of the schools is the public: they fund the schools, staff the schools, vote up or down the school boards, support or harass the school staff, and weigh in on school policy even in passive ways. If they *expect* school to be a certain way, and it is not, they change it (by revolution or just by wearing it down). If some group wants education to be different, it will have to sell the *demand* for that change before it can sell the change, itself. The public must want the change, or the change will either be rejected at the very start (i.e., not adopted) or more slowly over time." How can we *market* to parents and public our visions for education and school. How do we change peoples' conceptions of school? What can/should be the relationship between families, communities, and schools?

Conclusion

Thinking about the future is hard work. We've had a wonderful opportunity to imagine the elements of future learning designs, designs that would significantly transform and improve teaching and learning of the STEM disciplines. Now comes the hard, and interesting, work of defining models that can be developed and tested, determining where to invest further resources, and figuring out how to actually implement these ideas. We are fortunate to have the varied visions and powerful ideas generated at this blue sky workshop that provide a considerable foundation on which to build.

Moving from a Focus on Teaching to an Environment for Learning

Jim Minstrell and Ruth Anderson
FACET Innovations

"The best way to predict the future is to invent it."
--Alan Kay

Overview

Few would argue against the observation that we are living in an ever more quickly changing world. Yet, as someone once observed, to any 19th century time traveler, even the most modern of public school classrooms would appear familiar: Teacher in front of 25-40 students in a closed classroom, isolated from other subject areas and instructors; students moving from one class to the next, negotiating a series of changing environments (and related expectations) and left to independently make the connection between learning taking place from one room to the next (if in fact it is occurring). Despite what we have learned in the last twenty years of research on learner cognition, learners are still largely left to sink or swim in learning environments that are largely teacher or curriculum driven (rather than learning driven). Our system is not yet responsive to what we have learned.

We know, for example, that most learning takes place outside of school and yet little to nothing is in place to help connect the learner's formal and informal learning experiences to help them complement and build upon one another. Although we know that learners need to become independent critical thinkers, the system does not readily support their development in this realm; We recognize that teaching doesn't necessarily result in learning, yet we continue to focus on instructional behaviors in an effort to improve the learner's experience and understanding; We recognize that reflective collaborative groups of teachers are often more effective than individuals working in isolation and yet the system does not consistently facilitate collaborations among teachers; We know that instructional decisions should be based on evidence, implying that there should be an ongoing research component to instruction (see Japan's model including lesson study) and yet no allowances are made for the additional time and attention this must take from the present work schedule.

A few key differences that would help to align future schools with what we know about learning, learners and learning environments:

1-Shifting from a view of school as a factory to school as living system in which multiple "species" thrive rather than factories that produce a certain product (e.g. graduates). The learning environment as a sort of ecosystem is useful because it implies an adaptive and flexible entity that changes due to other factors in the system. Shifting from a vision of schools as mechanistic (made up of multiple intersecting cogs) to one of an interdependent system of living and growing organisms may be more useful. A mechanistic system values consistency and maintenance of status quo whereas an ecosystem is a living, learning, adaptive place that recognizes the value of diversity and the need to constantly strike a balance between diversity and redundancy in order to remain healthy. Within this vision of school systems, a research component fits in well. In order to make changes based on evidenced need, research would need to be an integral part of what educators (or educator teams) do.

2-Blur the boundaries of formal and informal learning and those that are imagined between school and the "real world." Subject learning STEM and beyond, would be better integrated so that students readily see connections between the various fields. By the same token, school would be better integrated into the community so that "real world" learning experiences are more than simply "applications" of classroom learning. Learning would be ongoing and have multiple sources and complementary, connected environments. Science centers would not necessarily be separated from science classrooms and engineering students would be included in engineering businesses. Vocational programs of 30 years ago or more were attempts to bridge this gap in certain realms. It may be time to take the notion further in order to ensure that the whole workforce is better prepared to follow a continuum of integrated learning and practice rather than move forward as if practice is something that only comes after learning.

3-Broader assessment and better tracking of leaner development and needs.

The diagnosis of learner needs has to extend beyond assessment in individual subject areas. In order to "work smarter" with regard to addressing individual learning needs, we need to better understand what individuals and groups need in order to move forward in all their learning. The system needs to know when and in what ways literacy problems or numeracy issues are inhibiting progress across the curriculum in order to be successful in a certain realm of STEM learning. In our current system, this is accomplished at times through multiple programs. Ideally, such information would be centrally held and be available through the education of a student so that a change in schools does not interrupt the learner's progress.

Just as modern information systems track users' habits and desires related to consumption in order to direct them toward products and services they will want and need, so our educational system would be able to track learning developments and deduce learner needs regardless of location.

4- Instructional Teams. They say "it takes a village to raise a child." Why then do we think it takes less than a team to educate her/him? There have been many small experiments in team teaching and other collaborative approaches to instruction or creating communities within the school in order to keep students from “falling through the cracks.” What if there were a team of distributed expertise at work in every class? This team could not only provide a higher ratio of adults to students And model the sort of team work and collaboration that we hope learners will develop in their various courses. Moreover, a team would provide greater opportunity for not only collecting data on student learning, but more effectively interpreting and acting on that data.

A vision of three students in a learning environment

Herb has been a good student since elementary school, especially in STEM related learning. He will likely go on to a university and head for a STEM related career. Susan on the other hand, although she is enjoying Biology, is more interested in arts and humanities. She is also a good student. John is younger, seems capable and very creative but has not shown interest in school until last year. In fact, three years ago he was considering dropping out of school and going to work. He is likely headed for the trades. All three are part of the cultural transformation that includes heavy use of technology. Each has a cell phone and a computer that they use for access to friends and information. All three attended elementary and middle schools that are remarkably similar to the schools their parents attended. Now they are in Learning Environment High School (LEHS), an experimental learning environment that is significantly different from other high schools. It is a part formal and part informal environment and is increasingly blurring the boundaries.

In the “learning environment” educational system, as students mature and show they can take responsibility for their learning, the structure moves from being more controlled by the educative system to being more open to learner control. Two years ago in their prior schools Herb, Susan and John sat through multiple cylowed classes each day, five days a week. Because Herb has demonstrated he is particularly good at managing his time he has more flexibility. For example, he and other students in his math learning group have more control, setting their own times for meeting together and choice of math tasks in an open math workshop designed to address the core mathematics ideas. John who has not yet demonstrated good time management and is more prone to getting off task, has a less flexible schedule. But, basically all the students are focused on learning the common narrow core of ideas and skills in the morning. When it makes sense, topics from different core disciplines are integrated, e.g. mathematical modeling in science learning and communication skills during discussion and writing exercises in all their learning experiences.

In this learning environment, the afternoon is more flexible for all students as long as they show they are responsible. The activities are more integrative. For example, John, Susan, and Herb all go to a local engineering company in the afternoon for the entire semester. They have chosen a product that represents a common interest of theirs and actually may result in an improvement in small system generation of fuel. In the previous year in a common core workshop on design processes of engineering, they met, worked together and became good friends. They are learning to work together as a team with distributed expertise and interests within the project. Susan with her interests in design and biology is leading the team, while John is more skilled at building the system, and Herb, with his strong academic interests across STEM is working on modeling the systems to explain how it works. There are many groups of students in this workshop. Meanwhile, STEM teachers from other disciplines are available to and engage with students and other faculty to help address on-demand needs for deeper understanding of particular disciplines and to model the value of distributed expertise within a team.

All three students see the learning goals of the core curriculum as attainable and know why that learning is important to their future life and work. The students also see assessment of learning differently from their prior schools. It is integrated throughout their learning experiences and functions to elicit their initial and developing thinking around particular big ideas. It is formative to their learning, noting attainment of learning goals and identifying apparent problematic thinking. Data on activities and tasks addressed, data on learning goals apparently attained, and data on problematic thinking are all kept with an electronic Learning Account Manager (LAM). LAM reports to each student and to the humans and other guides who participate in that student's learning. Based on the assessment results from LAM, the learning guidance system suggests possible next tasks for attainment of the narrow core curriculum learning goals. Diagnoses and suggested feedback or next lessons by the system are based on research on learning progressions and problematic facets of thinking. Human guides (teachers) and electronic system guides have been trained based on the research on human cognition and learning in STEM content.

Parents have been required, and the community has had opportunities, to experience the learning environment for themselves. The parents of our three students came to extensive workshops wherein they experienced learning through interacting with the systems in the learning environment. They noted the need for learners to take risks and be challenged but also to be supported by the system and by fellow learners. Also, they saw that the process of making a prediction or conjecture or concept design motivated their desire to investigate and know. During discussions with other parent learners, they could see the diversity of ideas and the value of evidence in argumentation. When they tested their tentative hypotheses, conjectures and designs, they felt the power of discovering an idea that made sense of experience. They recognized that every bit as important as knowing something is knowing how they know or why they believe that idea. They recognized the value of grounding their knowledge in experiences and rational argument. They experienced the formative assessment system monitoring their ideas, confirming and recommending next experiences to extend their understanding and sometimes challenging present understanding and suggesting what they still had to learn. There too the emphasis was on learning rather than merely producing a correct answer the first time.

The expectation is that Susan, John and Herb will come out of the learning environment understanding the narrow core of content and more. They will have benefited from the experience of seeing and applying in context what they are learning in this learning environment. They will have skills for communicating and working as part of a team and will see the value in collaboration. They will be prepared to be life-long learners, possibly all three in STEM related careers.

Environment for Learning Rather than a Place for Presenting

Broad and ongoing diagnostics to determine learning needs

Research on human cognition and learning are at a point where it is possible to do diagnostic assessment. We have knowledge and capabilities to assess initial and developing conceptions and skills in at least elementary mathematics, algebra, and physics now, and other presently funded projects that are pushing those capabilities in other areas of STEM. Data bases exist that will allow micro analysis of primitives and macro analysis of an ecology among facets of students' thinking. Diagnostics exist in literacy and other more general aspects of human cognitive functioning. In the future systems will be integrated to focus on identifying cognitive and experiential needs within and across disciplines. Assessment will have moved from its prime focus on accountability to a focus on identification of learner needs, not whether they "got it" or not, but on if they don't yet have "it" what is the "it" that the learner does have, and what does the learner need to move forward.

Facilities to support an environment for learning

One should be able to expect environments for learning to be interesting places with lots of resources and tools for learners to use while exploring the interesting places and activities in the environment. Settings for learning environments needn't be school buildings, but if they are schools, to qualify as an environment for learning they must be different from the typical schools of today. STEM learning environments in the next decade could include facilities more like environments of museums, research facilities, work places, community centers, homes, or virtual environments. Environments will function more like studios or workshops for learning with learners interacting with other learners and with guides/coaches/mentors who support learners individually and within a learning community as they observe events, participate in activities, use high and low tech. tools and interact with interesting materials and with each other in the process of learning core ideas and skills that will serve learners in future learning, in work, in professions, and in personal lives.

A culture focused on learners and learning

STEM learning environments for the future will need to involve a critical transformation from the culture today's typical schools. Currently schools, administrators, teachers and curricula function a deliverers of knowledge. That expectation is built in students from an early age as they look to teachers to confirm their knowledge. In the future we need to redirect the expected source of learning and develop learners' abilities to draw on multiple sources. Likewise, teachers and researchers will have an opportunity to learn more about the nature of learning and more effective ways of fostering learning.

To the present, learning has largely amounted to accretion of declarative knowledge and memorization of procedures. Based on what we know about learning from the last thirty years of research on learning and learner cognition, STEM learning for the future will involve a perspective that is focused on what is going on in the learners' heads rather than a focus on what a teacher/professor is presenting. A team of teachers or learning guidance systems will be thinking about learner thinking and acting to facilitate further learning by setting the opportunities from which learners can generate and test their ideas on the way to constructing conceptual understanding. Learners will develop new schema and strategies that will serve them in creating robust explanations/interpretations of complex phenomena and in creating solutions to authentic real world problems. Part of the learning environment will be the physical environment, the activities within which learners will be challenged. But, since many of the learning tasks will be served through technology, the location within which learning will take place can be a seamless blend of formal and informal, including home environments. Another part of the environment will involve the social network within which learners will further generate and test their ideas through listening, argumentation, and collaborative construction of explanations and problem solutions among a community of learners who share responsibility for their own learning as well as that of others in the community.

Interaction and discussion focused on learning

Culture of the environment for learning will be based on research and best practice for supporting the development of understanding and skills. The environment will be safe for students' exploration of ideas. The disposition and actions of all those in the learning environment will be consistent with an open, interactive, reflective environment of exploration, discovery, and development of ideas and products. Learners will be expected and encouraged to share their ideas (hypotheses, conjectures, designs, solutions). And they will be expected to justify why their ideas make sense. They will have opportunities to design to conjecture, to hypothesize and test their ideas. At the same time, guides and other learners will be expected to ask for clarification of ideas. They will also be expected to critique ideas while at the same time encouraging and supporting the learner who is sharing them. To build their ideas, learners will have opportunities to interact with discipline experts as well as peers and with those who have expertise in guiding learning. The medium of interaction will be questions and opportunities for learners to respond fully with the guide and others listening respectfully, valuing the sharing, and possibly expressing interest in the ideas.

Discussions as well as experiences with natural phenomena and man-made environments will provide information for determining validity and reliability of generated ideas.

Curriculum and activities aligned with a thin core of content
Although some learning activities will come from sources within the community, those activities will be built on a foundation of a common narrowly focused curriculum, a thin core. The content and sequence of the required common curriculum will be developed around big ideas and process skills that have been distilled from history, best practice and from cognitive research, to serve humans in the present and for the foreseeable future. Once initially decided upon, the effectiveness of the core content and activities will continue to be studied. Iterative cycles of redesign and redevelopment will be needed to maximize effectiveness and to take advantage of latest research on learning and cognition and on development of new technologies. Activities will be motivationally designed to stimulate thinking and provoke learning. It will be an environment in which "having ideas" and testing their validity and reliability is encouraged and supported. There will be a focus on knowing how to generate new knowledge and on developing a complete and coherent understanding of the thin core of powerful ideas.

In addition to learners experiencing generation of knowledge in the thin core, learners will have opportunities to generate new knowledge that goes beyond that of the guides in the environment. Learners will tinker with man-made things to see how they work and think about how they might be redesigned for improvement or for other uses. To prepare learners for work and advanced education, learners will have opportunities to work with practitioners in STEM disciplines, sometimes as observer helpers and sometimes as a team member, and sometimes conducting independent research or development with assistance from professionals.

Parent and community knowledge and support of a learning focus
The learning environment will be supported by, and integrated into the community at large. Business of all sorts, knowing that their work force and product innovation depend on quality STEM education, supports the learning environment with funding and other human and material resources. Community government, knowing that their citizenry needs knowledge, skills, and interest to solve local and regional problems, supports the day to day sustaining of the learning environment. Parents and their organizations, wanting the best for their children, will have opportunities to understand the nature of learning and how learning environments are different from when they grew up. Within businesses and professional environments the community will support the learning environment with technical resources and opportunities to experience the disciplines in the workplace. For example, local companies have technology that will also provide learners with access into the unseeable worlds of sub-micro and macro scales.

Learning guides that know the terrain of the curriculum and the discipline
While the long-range goal is to have our learners be independent of any structured guidance for their learning, there is still a need for guides/coaches to help learners attain the desired thin core of content understanding and to gain the skills for learning independently and in teams with a diversity of capabilities. The guides may be human teachers or they may be technological systems.

Guides need to have extensive knowledge of the places (big ideas) to visit and what is important to know and understand about each place. In addition to knowing the curriculum, they need to know the content of the discipline and connections to related disciplines and to applied contexts in the natural and human-made worlds. For example, guides to understanding physics need to understand how particular ideas of physics are related to specific applications in other sciences, in mathematics, in engineering, and in technology. Experts in different disciplines will model for learners how differently they think, yet how they work in teams to produce a deeper understanding or a better product.

Also, of great importance to understanding the discipline is knowing how we know what we know within the discipline. Why do we believe the ideas we do in each of the STEM disciplines? What are the similarities and differences in how knowledge is generated and in what it means to understand among the STEM disciplines? Guides also need to be aware of the knowledge and skills that are prerequisite to the desired part of the thin core. They need to know what it takes to get to the desired learning goal. Ideally the human guides would have had considerable experience in learning this way themselves. Technical guidance systems will be programmed to be interactive and have response/feedback capabilities that foster learner development. Finally, the guides need to know the language of learners as well as the language of those in the discipline. They need to recognize words learners might use for particular ideas and the extent to which the words used by learners have the same or different meanings when used by discipline experts.

The guides will have knowledge of possible routes (trajectories or progressions) to developing core ideas and skills. On the one hand they need to know a coherent story of the development of explanations or models or prototype products. On the other, their knowledge should be sufficiently flexibility to follow the lead of a learner and guide them back out of swamps of misdirection and failed ideas, putting forth alternative routes and challenging the learner to make the best sense of the experiences along the way. Learners will feel the fun, struggles and control of discovering for themselves without feeling the constraints of the guidance.

The human guides in addition to curriculum and disciplinary knowledge will serve motivational, emotional and psychological needs of the learners. They will be skilled in verbal interaction, listening, questioning and feedback to keep learners responsible for learning while guiding their development. Human guides will also be able to integrate content and feedback regarding communication skills.

Roles of guides and learners in the learning environment-
The learning guidance system (human or otherwise) will motivate and guide learners in creating, testing, and having wonderful ideas. Learners' initial and developing ideas will be elicited and clarified. Their skills at interacting with phenomena, equipment, materials, and each other will be fostered to help them learn to respectfully argue from an evidence base. Questions will be the medium of exchange, questions that not only ask for recall of observational facts and procedures, but will also help learners explore their own schema (mental models) and the conditions under which they apply.

Teachers/guides will have/know various ways of arriving at a coherent understanding of the thin core of powerful ideas. In addition to knowing the typical progressions or trajectories of development, guides will know alternative routes that learners may take to get to understanding. Typical misconceptions and errors in reasoning will be explored to help learners know how they know that some alternative ideas do not make sense as well as knowing evidence based arguments for how they know what does make sense.

The guidance systems will be skilled at scaffolding the learners' construction of knowledge, but allowing learners freedom of exploration on their own as they learn skills for independently generating their own knowledge. The role of the system/teacher will be to guide and support rather than lead. They will set experiences before learners that are related to developing, testing, and applying the desired learning core and related to testing problematic alternative ideas along the way. The role of learners will be to engage, and share ideas and to question the validity, application and utility of ideas suggested by themselves and others. In the interest of learning, students need to know that it is OK to have failed ideas. That is how we learn.

Teacher guides will have experienced such learning roles and environments themselves as part of their preparation. Electronic guides will have research and best of practice designed and programmed into them. Feedback will not only suggest what is correct or problematic about solutions but what might be done to extend correct understanding or what needs to be thought about or done to address problematic concerns.

Instructional teams of teachers, discipline experts, technologists, and researchers will also function as a research team to monitor the effectiveness of the guidance system in meeting the needs of learners. Learners will readily participate in the research in the interest of improving their learning and improving the effectiveness of the learning system. This will allow a quick turn-around for redesign and implementation of the guidance system. Research will be a function of the guides in the learning environment.

Assessment for learning embedded in the guidance system
There will be electronic learning account managers (LAM) that will "know" not only the route and status of completion of activities but more importantly the learning goals achieved and the problematic ideas and skills yet to be improved. Through elicitations administered prior to or early in lessons and "checks" administered during or after lesson activities, the system will collect data and make diagnoses based on research on problematic and goal understandings. The LAM will give information to teachers on the "lay of the land" of groups of learners so the teacher/guide can better choose or adapt large group activities. More diagnostic assessment on students' understanding embedded within or after activities will help monitor learning and give the guidance system information from which to make decisions on an individual or group basis. This again will help the system make decisions for what activities might next be served. There will also be an individual LAM to provide learners and their guides with information on the understanding and skills of the individual learner. The LAM technology will provide records of past achievement and will provide documentation of the route taken for learning in the past as well as suggest next lessons. As learners become more independent and able to use such information, they will become more in control of their own learning. Learners will take responsibility for their own learning.

Learners will become intelligent novices in novel learning situations
A goal of the system is to develop intelligent novices, learners who will have experience developing deep understanding in one content or situation and will be able to use that knowledge to independently develop their understanding of different content or of a novel situation. They will know the questions to ask. They will know when they understand, and when they don't they will know what to do to develop understanding. They will have become masters of learning, not simply masters of knowledge. They will know what it means to understand something and the power of that understanding will help them become more flexible, more capable, and more confident learners in new situations, be they formal or informal. Documentation of past learning through the LAM will provide tools for remembering past learning and will help monitor subsequent learning. Having learners take responsibility for learning will involve scaffolding learners in the kinds of habits of mind (metacognition, drawing on multiple sources of information, collaborative problem solving) that allow students to become learners who are independent of teachers.

How do we get to the 'Environment for Learning' philosophy of schools?

We need to build public understanding of what it means to learn, transform the culture from a focus on what the teacher is presenting to a focus on what students are learning. We need to change the expectations of students, parents, teachers, administrators, and the general public. We need public demonstrations for parents and the community at large so that they can get a glimpse of the vision of what learning environments might be like. Focus on what a learning environment can be. Communicate to the stakeholders the best of what research on learning and human cognition has to offer to environments for learning.

Regarding curriculum materials, first we will need to identify a thin core of content around which the materials will be designed and constructed. The present curriculum is too thick. The thin core should focus on the big ideas and skills involved in quality stem learning. The new materials will need to keep the learning targets in focus as well as attending to problematic ideas and scaffolding development of ideas and skills.

Regarding assessment, the primary role will be to promote and monitor learning. To foster learning we need to move from accretion of rote knowledge to diagnosis of what learners understand with respect to the learning goals, interpreting what the cognitive or experiential need seems to be, and identifying feedback or lessons that will address the learning goal and the identified need.

Kids are already embracing and using technology for learning in the social arena. We need to take advantage of their facility with technology by intelligently and creatively using technology in learning STEM content and processes.

Teachers will need to be prepared for operating in the new environment for learning. They will need training in moving their focus from their own performance to attending to student learning. That suggests the need for measures of teacher capabilities for attending to and promoting student learning.

Sites for designing, implementing, and testing new environments will need to be carefully chosen. Early sites (probably blending formal and informal) may need to demonstrate that they are already implementing aspects of the new environment. Site readiness measures will help.

Finally measures to evaluate the effectiveness of the new learning environment will be needed. Teachers, researchers and developers need to put their engineered learning environment to the test. Measures of hypothesized related outcome variables and independent variables will be needed. As with any engineered product, design and implementations will require iterations and time.

Blue Sky STEM Content for the Emerging CyberLearning Landscape: The Need for a Timely, Targeted and Ambitious Investment

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Past waves of federal investment—in the Internet, Learning Sciences research, and in instructional materials—set the stage for a transformation of STEM education. However, despite widespread enthusiasm for the potential of cyberinfrastructure in learning and strong efforts to conceptualize the infrastructure of networked learning communities, existing reports do not have a strong vision for the ***instructional content*** *of networked learning. This essay argues for a timely, targeted and ambitious initiative aimed at Blue Sky STEM Content—content deeply reconceived for the age of cyberlearning.*

Although technology always carries the potential for profound societal changes, the biggest changes have a way of sneaking up on me. It seems that new possibilities, unmet needs, and participatory enthusiasm suddenly align and change accelerates. For example, I would not have guessed how quickly paper maps have become irrelevant to me, all my music listening involves Apple products, and I watch more movies streamed over the Internet than I watch on cable TV.

Arguably, a similarly broad change, one that has been on the radar for at least 15 years, is about to effect school age children: the change from paper to digital textbooks. Electronic readers, such as Amazon's Kindle or Apple's iPad, are accelerating rapidly in quality and prices are quite reasonable. Today's teachers and students assume an infrastructure of connected digital devices throughout their everyday lives and increasingly expect the Internet to be available at school (Project Tomorrow, 2009). Excellent examples of digital learning tools that deeply enhance STEM education are available to us for uses such as visualization, modeling, and simulation. The technological, social and educational factors that would support a change from paper to digital learning materials are coming together in the environment of education (Lewin, 2009). Yet, the change to digital STEM curriculum has not yet occurred and there is no systemic or planned movement in that direction.

Educational systems are typically very slow and resistant to change. However, an additional factor makes the present time atypical. In the United States, state governments face a budgetary crisis that is severely effecting education. Consequently, states are now willing to question a key financial assumption of the existing school finance regulations: that instructional materials budgets are exclusively for the purchase of paper textbooks (Salpeter, 2009). Because of such regulations, technology has been an “extra” funded in the margins of school finance. States are now willing to erase the line between paper and digital materials and purchase either. Removing a regulatory requirement to buy paper textbooks will increase the market for digital learning materials by orders of magnitude. It is reasonable to expect that rapid investment will follow and the pace of innovation will accelerate as new and old publishers compete to produce and sell digital STEM instructional materials.

Further, the movement to new “core standards” is preparing states to retire old instructional materials (see http://www.corestandards.org/). By all accounts these materials need to be retired. The old paper textbooks have grown bloated, incoherent and almost unusable – an average Algebra text now weighs in at 1000 pages, but covers no more topics than much thinner texts of years ago (National Mathematics Advisory Panel, 2008). It seems hard to imagine how stakeholders could defend purchase of more of today’s textbooks if better alternatives were available. Thus, although educational systems are ordinarily very slow, the funding crisis at the state level and the misfit between existing textbooks and new core standards could make the change from paper to digital instructional materials unusually fast.

This opportunity for change should not be wasted. There is broad agreement that the nation’s STEM programs need an overall in order to produce a steady supply of future innovators and educate all children for a technological world (National Academy of Science, 2005). An opportunity to change the educational content and corresponding instructional approach can offer huge leverage for how teachers teach STEM and how students learn it. In fact, curriculum and digital content are arguably the biggest levers available to reform-minded educators (Schmidt et al., 2001). But there is no guarantee that a switch from paper to digital instructional materials will be transformative: schools could settle for lower cost instead of demanding higher quality.

Consider the change to iTunes or Kindle for music and books. iTunes has not changed the structure of music; we still listen to 3 minute songs, a length that was dictated by recording time available on a vinyl disc spinning at 78 rotations per minute. We still read the same books, too. Quality has not been improved (e.g. music quality is of lower quality than on CDs or vinyl records), rather cost and convenience factors dominate consumers transition to digital media. Following the analogy, it is possible that schools would purchase digital curricula for cost and convenience factors as well and that these materials could be of even lower quality than today’s textbooks. Even if digital learning materials have the same structure and content of paper learning materials, the present opportunity will have been wasted. Our nation’s students will not be better prepared in critical STEM disciplines merely because the same old content is now accessed in digital form. Our children need the transition to digital materials to be a transition to higher quality.

A timely, targeted, and ambitious federal investment in Blue Sky STEM Content could make the critical difference – the difference between "old wine in new bottles" and transformative applications of the new capabilities of digital media to transform how students learn STEM content. The National Science Foundation is already committed to extending its important cyberinfrastructure initiative to cyberlearning (NSF Task Force on Cyberlearning, 2008). As currently conceived, however, cyberlearning remains infrastructural: the focus is on interoperable platforms, promoting open tools and open content, and on infrastructural innovations. ***Should NSF investment in cyberlearning remain confined to "infrastructure" or should NSF embrace the opportunity to redefine STEM content for the age of cyberlearning?***

There are legitimate questions as to whether NSF's mission should include the production of the volumes of material routinely needed by schools. On one hand, proponents can point to the strong role of NSF-funded mathematics and science materials in demonstrating that all students can learn science inquiry and develop a connected understanding of mathematics. On the other hand, opponents could argue that curriculum production is a routine business and NSF should remain focused on the steep, innovative part of the learning curve. While continued work on cyberlearning infrastructure (e.g. platforms, openness, rich data and search services) is certainly needed, the remainder of this essay will argue in favor of a strong, well-funded focus within cyberlearning on Blue Sky STEM Content by advancing four points:

1. Aligning an emerging cyberlearning landscape with scientific research on how people learn offers an opportunity for enormous impact on the pipeline of youth willing and able to pursue STEM coursework and careers.
2. Realizing this alignment requires developing Blue Sky STEM Content that supports students learning trajectories across traditionally separate sites of learning, for example, school, museums, extracurricular activities and peer networks.
3. The federal government, through NSF, has both the research knowledge and the experience in all areas of STEM learning to foster Blue Sky STEM Content, but to date has taken a balkanized rather than coherent view of formal and informal learning settings.
4. Fostering an innovation community focused on connecting learning across a cyberlearning ecosystem through Blue Sky STEM Content could be a game-changing move at a time of rare opportunity, decisively advancing preparation of the next generation of STEM talent.

The Emerging Cyberlearning Landscape

The most striking feature of the emerging cyberlearning landscape is that it transcends school (Chan, et al, 2006). But then, so does the development of childrens' trajectories towards STEM careers—students develop their interests and passions for science in science fairs, museums, robotics competitions, with parents, and through many venues that extend beyond classroom walls (Barron, 2006). The fundamental reason for NSF to take a lead role in Blue Sky STEM Content is this: **Aligning this emerging cyberlearning landscape with emerging understanding of how children learn socially, cognitively, and across settings offers the best leverage for deepening and enhancing the pipeline of youth with the passion and knowledge to continue in STEM education and careers.**

One way to visualize the cyberlearning landscape is according to a graph representing a long-tail learning ecosystem (Brown & Adler, 2008). As represented in Figure 1, the vertical axis of graph depicts the number of students involved in a particular learning experience (or using particular learning materials). Different experiences (or materials) are arrayed on the horizontal axis, from the most common to the most personalized. At the tall part of the curve are learning experiences that are taken "in common" with many other students, for example, courses in K-12 schools that all students take pursuant to core standards. At the short part of the curve is a very large set of highly personalized materials and experiences, but with rather few students involved in each.
A new feature of the Internet age is that problems of distribution no longer limit the market to the tall part of the curve (Anderson, 2008). For example, whereas a conventional bookstore could only afford to have more popular titles, an electronic bookseller can serve the "long tail" of small interest groups. Thus, in general, the Internet allows companies to thrive by capturing markets in the long-tail, not just mass consumption markets at the tall end of the curve.

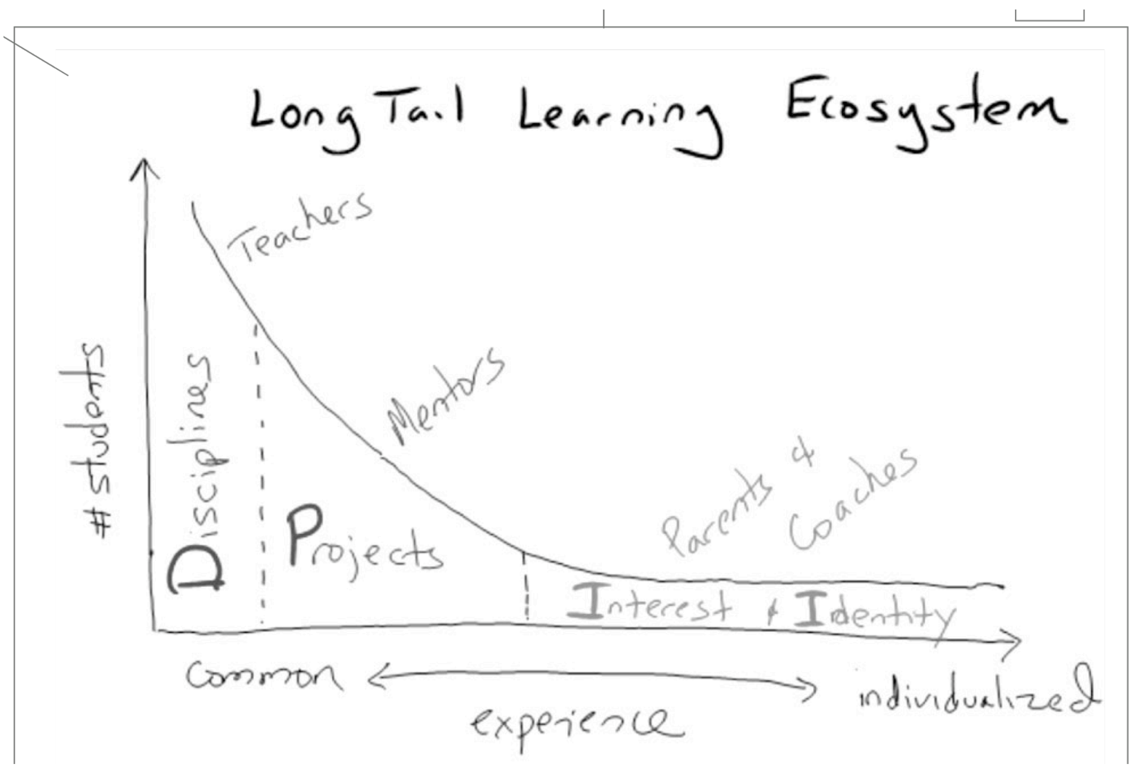

Figure 1: Long Tail Learning Ecosystem

I believe that the long tail curve will shape the landscape for STEM learning as well. At one end, students can have extensive new opportunities to develop and shape their interests in STEM learning. Optimally, there would be niches in the ecosystem that grab the interest of every child and create a powerful, authentic opportunity to learn a little bit of STEM content but equally importantly create the motivation for students to continue to pursue STEM pathways in their future. Thus, some students might play scientifically-inspired games, others might become intrigued by live videos from a scientific expedition, others might call upon a remote mentor for a science project they are doing at home, and others might use fiction or history to develop STEM interests. There is really no limit to how we could personalize learning opportunities to attract many more children and nurture their desire to learn more STEM content in the future.

For interest-driven experiences, the main benefit of digital cyberlearning may be the opportunity for extensive personalization to meet children where they are and develop their passion and commitment for future STEM learning.

It is a mistake, however, to assume that ALL education will be highly personalized. There are two reasons why it won't. First, learning a STEM discipline requires highly coherent, highly structured curriculum over an extended period of time (National Math Advisory Panel, 2008; Schmidt, 2001). Although the best students might be able to learn from bricolage of found materials, most students need to be guided through a very carefully planned and executed sequence to develop mastery of complex concepts and skills. Our society will never be able to afford to provide every student with a uniquely personalized but equally well-planned and executed scope and sequence. It will be more important to provide everyone with a sound scope and sequence (common core). Second, society will insist on standards and accountability for core disciplinary STEM content. This will necessarily drive convergence towards materials that can be shown to work for large numbers of students. Thus, in the tall region of the learning ecosystem, very large numbers of students will be engaged in learning with very similar materials.

These core materials, however, do not have to look exactly like current instructional materials (textbooks). In an earlier article (Patton & Roschelle, 2008), we argue for a "thin core" approach. In this approach, educators agree on a lean foundational learning progression, with the most essential content – coherent and complete in the sense that this would be all that advanced learners would need. In mathematics, this lean content would include key definitions, algorithms, concepts, worked examples, and a few well chosen problems – much like today's Singapore textbooks. Digital media would allow for rich extensions to be embedded and attached to this "thin core" to support a wide variety of learners. For example, extensions could include interactive, dynamic representations, integrated tutors that provide feedback during problem solving, and "Universal Design for Learning" adaptations to ensure opportunity to learn for learner with varying issues and needs. Thus, instead of today's bloated "one size fits all" textbooks, 21st century learners could experience a lean, essential core complemented with focused extensions and adaptations to support their learning needs and preferences.

For common core experiences, the main benefit of cyberlearning may be restructuring around a "thin core" which provides a coherent backbone for an abundance of focused extensions and adaptations for specific learning needs and preferences.

What about the middle of the landscape? Here we will find "projects" that are less formal than disciplinary school experiences but better organized and populated than niche, personalized materials. Robotics competitions (e.g., http://www.usfirst.org/) are present day examples of a non-school, semi-formal STEM activity. These robotics activities engage students in developing designs that address a common challenge over an extended period of time and provide extensive mentoring. Similarly, many serious games will exist in this middle space; serious games can draw large audiences of school-age children and offer a fairly common, long-term experience for the participants, but are not constrained to be structured in the same way as learning a STEM discipline is (Neulight et al., 2007; Squire, 2007; Schaffer, 2005). It seems quite likely that the largest learning benefits of activities in this region will be the opportunity to participate in an authentic learning community with longevity and substance (Barab., et al 2005). Through such experiences, students can develop identities as STEM learners (Gee, 2007).

In the middle, cyberinfrastructure, the main benefit of cyberlearning may be achieved through participation in a social community of learners working on similar challenges, cultivating similar values, and developing identity.

The potential for different learning benefits in different regions of the learning ecosystem curve argues against the prevalent idea that one region of the ecosystem (or one benefit) will dominate all the others. For example, it is unlikely to be the case that the middle "games" and "projects" region will replace school, or that all learning can become as personalized as it is in the low part of the long tail distribution. In contrast, the exciting fact is that for the first time, all students will have opportunities to learn across all regions. Indeed, because of the distribution efficiencies of cyberlearning materials and experiences, a learning market that was formally balkanized with most the money placed on the tall end of the spectrum can now be more connected across the whole spectrum. ***The unprecedented opportunity is to develop all students' interests and knowledge in STEM by providing students with a full learning cyberlearning ecosystem to learn in, with complementary experiences and cyberlearning benefits across the spectrum.***

NSF's Leadership Position
Due to its responsibility for nurturing future citizens' STEM abilities, NSF has a mission that includes responsibility for the nation's learning ecosystem for developing STEM talent among our youth (National Science Board, 2006; Wing et al, 2010). Further, NSF has always invested across learning ecosystems: in creating new textbooks for mathematics and science (tall region of the curve), sponsoring development of new materials for informal (e.g. museum) learning (middle region), and supporting outreach efforts that engage small numbers of kids with mentors or access to scientific data (highly personalized region). To date, however, NSF has not typically taken responsibility for these activities as a continuum or spectrum that forms a coherent learning ecosystem. **A full spectrum, highly connected learning ecosystem perspective is now needed.**

Without federal investment, we will likely see digital content remain highly balkanized and incoherent. Publishers have already noticed the market shift to digital materials and are making digital science and math textbooks, but these are likely to be much like old textbooks but in digital form that allows for limited degrees of choice and personalization. Other firms will produce highly successful games that attract a large following among youth. Nonprofit organizations will continue to sponsor engineering competitions and the like. But these will not form an ecosystem but rather a montage of almost completely unrelated experiences. For example, a mentor in a robotics tournament will not be able to identify learning modules from a child's core school curriculum relevant to the mathematics of a particular timely engineering challenge, and thus will not be able to link school and out-of-school projects. A teacher in school will have no idea of the personalized niches in which students have nurtured their own interests in science and shown considerable capability (Bell et al, 2009), and thus may miss opportunities to engage and motivate students with disciplinary subject matter. And providers of niche learning experiences may remain underfunded and unappreciated because they cannot show linkages between the ways in which they develop students' interests and "core content" that schools are accountable for. The NSF opportunity it to build the capability to ***address cyberlearning as a coherent ecosystem for the development of K-12 students interests, skills and knowledge in STEM****.* The opportunity will be missed if NSF only supports investment in infrastructure and does not participate in boldly envisioning the shape of Blue Sky STEM Content that coherently bridges across the cyberlearning spectrum of experiences that would draw youth into STEM trajectories and foster accelerated growth in their skills and knowledge.

Here are some examples of research questions that NSF-sponsored grants might address:

1. What structure of digital STEM instructional content could support both the coherence needed in core disciplinary learning but also support reuse in less formal, interest-driven activities?
2. How could cyberinfrastructure enable us to assess students learning across formal and informal settings in ways that inform teaching and increase collaboration across settings?
3. How can cyberlearning environments support learners' processes of weaving together a range of informal and formal experiences that support their growing identities as a STEM learner?

Note that these are all questions that expand across the learning ecosystem – implying that regions of the ecosystem should be related and coherently support students' development in STEM. *The important observation is that without federal investment it is unlikely that any other party in the ecosystem will take responsibility for the coherence of the whole.* Because of NSF's responsibility for nurturing the pipeline of future STEM innovators and the capacity of all citizens to participate in an advanced scientific civilization, NSF is a logical convener of top talent around the issue of structuring the content of the learning ecosystem to coherently and comprehensively supporting all students' development of STEM interests and knowledge.

Investing in a Blue Sky STEM Content Innovation Community

Today's STEM learning technology accomplishments were built upon a large investment in people and innovation that NSF made approximately 15-25 years ago. This investment yielded new inquiry science curriculum, new connected mathematics textbooks, better approaches to teacher professional development and powerful simulation, visualization, representational and modeling tools. Equally important, the investment nurtured a community of people who could think innovatively about the future of STEM education. Of course, at that time, the features and structure of today's emerging cyberlearning ecosystem was not in sight. Many of the people in the existing STEM learning innovation community are now approaching retirement and many of their skills were honed in an era with different possibilities. In the intervening time, funding for innovative STEM materials has been tight; we have been through a time where more focus has gone into increasing the rigor of educational research. Consequently, NSF's high profile Cyberlearning report (NSF, 2008) relies heavily on examples and ideas that were germinated 15 or more years ago.

To address the opportunity for a transformative cyberlearning ecosystem, NSF could foster the growth of a new interdisciplinary community. At a minimum, this community must include:

- Learning Science researchers, and particularly those developing theories that connect formal and informal STEM learning, and include not just cognitive learning, but also social participation and the formation of identity.

- Disciplinary experts who deeply understand the foundations of modern science and can boldly envision ways to restructure the content to address what learners need to know in the 21st century.

- Technological innovators with deep knowledge of the affordances and potentials of cyberinfrastructure and ability to build exemplary new boundary-spanning learning experiences using such capabilities as cloud computing, social networking, and serious games.

- Researchers with expertise in working with schools and teachers but also with museums, community centers, parents and youth.

NSF uniquely has the ability to bring this community together: NSF funds learning science research, for example through the Science of Learning Centers. NSF has an engaged community of disciplinary researchers in all STEM areas with interests in outreach to education. Likewise, NSF's reach already includes innovators and researchers needed to address the challenges of content for the age of cyberlearning.
What is needed is a new interdisciplinary funding program with enough resources and longevity to catalyze connections among different perspectives and focused on the questions of how to structure Blue Sky STEM Content to maximize development of childrens' interests, knowledge and skills in STEM across a cyberlearning ecosystem.

Conclusion: An Opportunity for High Innovation and Impact

The federal government must focus its limited R&D resources in areas where innovation is accelerating. I have argued that innovation is about to accelerate dramatically in the design of STEM learning content because multiple factors are coming into place:

- Technology: emerging infrastructure to support cyberlearning

- Society: digital native kids and their teachers expect ubiquitous connected digital devices throughout their lives

- Learning: researchers are demonstrating that all students can learn more deeply when technology is used to restructure curricular content around such capabilities as visualization, modeling, representation, and simulation.

- Finance: state budget shortfalls embolden legislators to question regulations requiring schools to buy paper books.

- Curriculum: new core standards and unsatisfactory paper textbooks motivate educators to contemplate radical change.

These complementary factors suggest that now is a time when high innovation is possible. Further, NSF has the wherewithal to assemble the interdisciplinary communities that could take on the challenge of Blue Sky STEM Content and create groundbreaking examples that make it real. These examples will be badly needed to prevent a de facto shift to digital curriculum that is simply a repackaging of paper curriculum into digital form, without deeply leveraging the new affordances of the medium. Further, research will be needed to show how we can realize the promise of a STEM learning ecosystem, overcoming a tendency to balkanized models that only examine one region of the ecosystem and fail to trace how learners and teachers can traverse and connect the regions. By sponsoring the development of a coherent intellectual community focused the challenge of STEM content in a cyberlearning ecosystem, NSF could foster a powerful set of examples, research, and advocates that shape the shift from paper to digital learning materials in ways that transform the next generation's opportunities to develop disciplinary, participatory, and passionate trajectories of STEM learning.

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Learning Design: Creating contexts for learning experiences

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We are living in shape-shifting times with a brittle educational structure that is not prepared to respond to the rapid changes in U.S. society and the world context in which we operate. There are many calls for action and many ways we can approach this large, seemingly intractable problem. In its own way and with it's own mission, the Blue Sky Workshop has chosen to "think big" on a crucial piece of this puzzle: how should we be supporting teaching and learning through curricula and instructional design? My role is to reflect back on the activities and outcomes of the Blue Sky Workshop. I will try hard to reflect on and synthesize what seemed to be the collective wisdom coming out of the group. Inevitably, this will be seen through my eyes with my personal passions and biases about these issues. Roughly paralleling the discussions and presentations as they unfolded over the course of the two and a half days, I will do so by first discussing the current state of affairs as they were articulated in the meeting. I will then turn this inside out and outline a vision of what might be. Next, I will outline possible approaches to reach this vision. Finally, I will discuss higher-level strategic issues that relate both to the ultimate goals and what is needed to facilitate this work.

The Current State

Learning is fragmented and siloed. Discipline-based divisions drive both how curriculum is organized and taught in formal and informal educational settings. These divisions, unfortunately, increasingly do not match the realities of how we function in the world outside of school—whether it be at work or as a citizen in the public arena. Even within these discipline silos, instruction is geared around approaches in knowledge organization and use that are optimized for recitation on terminal, summative assessments that bear little relationship as to how this knowledge will probably be used in work and public life.

Learning is also highly fractionated over time and space. What takes place in formal educational settings (i.e., school) often seems to happen in a vacuum without regards to what happens outside of school over the course of the same day, week, or school year. There is an assumption (sometimes) that homework will happen outside of school, but this is an activity that links back to the formal setting and not to the context where the homework is being done. Similarly, there is often no real attempt to leverage the many resources that exist outside of the school day; whether it be museums, camps, organized club activities, or small group experiences with friends and family. At rare and discrete moments, these links might be made, but it is in the form of the "field trip"—again, structured within tight confines of time and agenda. Similarly, organizations that undertake organized, informal education—museums, camps, etc.—whether out of desire or necessity, often function independent of formal educational agendas. Based on their independently derived agendas, they pursue a mission that can end up being driven as much by what formal education is not doing as what they might be doing with them.

In addition to organized educational spaces, formal and informal, there are large amounts of time spent in non-organized educational arenas where, in fact, a huge amount of learning is occurring. This learning is often serendipitous and ad-hoc, but the shear amount of time and the number of media devices that infuse these spaces means the opportunities are immense. Unfortunately, much of this time is at home where parents don't usually exert much influence over how a child might spend their time or how they might facilitate these learning opportunities. Parents, in fact, often don't see much of a role for themselves in their child's education, especially around STEM education. They often don't feel STEM literate themselves, don't appreciate the importance of STEM literacy for all, and don't understand what role they might play in supporting such learning. The "experts" on math, science and technology exist elsewhere, with the child often left to their own devices to seek them out.

Teachers are seen being at the nexus of teaching and learning, but they in fact only hold sway over one piece of this learning time and space—that time spent in formal educational settings and, possibly, homework for classes. The reality is teachers cannot take on any more and may do a better job facilitating learning if they could do less. The overhead of working in the currently designed formal educational settings means considerable amount of time spent on items not directly related to their subject areas and may also not be very related to learning. Curriculum, as designed, contains a tremendous amount of "stuff" that needs to be, first, personally mastered, and then conveyed to their students. School organizational structures leave teachers isolated leading to difficulties with discussing and coordinating their work with other teachers either in or outside of their discipline areas.

Possibly nothing highlights the structural tensions between school and society as a whole better than technology. Technology access and use is distributed in a highly uneven fashion both between classrooms and schools, but also between school and everywhere else. Many technologies are perceived as "barbarians at the gate." So, while a high percentage of high school students in this country may own a cell phone (a powerful computing and communications device), they are essentially banned from school. The information stream of the Internet is slowed to a trickle coming into school by the legal ramifications of CIPA and the lack of technical and leadership infrastructure necessary to make smart decisions as to what information sources might facilitate learning. Even when teachers do have access to learning resources available online, they mirror the chaotic, unstructured nature of the Internet as a whole. The time and knowledge limitations on teachers means that they often can't locate and integrate these sources into their instruction. Similarly, when technology does make it inside classrooms, the limitations of curriculum, school leadership, and teacher's professional capabilities means that it is almost inevitably under-utilized. When technology is leveraged to its maximum capacity, it is usually at the initiative of individual teachers, leaving students with an uneven experience as they go from class to class.

The current state, as outlined here, has used a broad brush to paint a somewhat bleak picture. There are, of course, many islands of innovation occurring out in the formal and informal educational landscape. The challenge, of course, is to find ways of envisioning what our ultimate goals are and finding ways of nurturing the growth of those innovations that will both move this vision forward but then spread to the educational settings that would benefit from them. It makes sense, then, to begin to outline this vision, as expressed by members of the Blue Sky Workshop.

The Vision

At the workshop, participants were launched into their discussions with the question "What will a high-impact, technology-intensive STEM learning environment look like in the near and long-term future?" Long-term, being measured on the technological scale, was set at a reasonable, but still challenging 10 years out. While these ideas evolved and were refined over the course of the two and a half days, many of the central themes that formed the backbone of the deliberations emerged relatively quickly. Probably central was a real need to start fresh about the way we think about schools and curriculum. The phrase "instructional design" was clearly not sitting well with participants. The phrase seemed to be rooted in another time and place, confining how we thought about what it was we needed to be doing. Near the end of the workshop a phrase that I heard pop up in many discussions was publicly coined: *learning design*. Many felt this was a much better expression of what was our charge in this new, evolving educational space.

Another big idea that resonated with many was a need to rethink how educational enterprise should develop standards and assessments that gauge progress along those standards. There was a clear feeling that the current approaches of developing curriculum within this framework neither reflected the realities of the information age nor served the broad spectrum of student needs very well. Instead, there is a hope that the larger policy forces shaping standards and assessment think about the development of a common *thin core* of STEM knowledge that all students would be responsible for. The goal of the thin core reflects many realities and goals. First is that there is knowledge in all areas of STEM—science, technology, engineering, and mathematics—that students should know about. However, all of these areas have been impacted by the huge knowledge explosion of the last 50 years. So, for example, one small piece of the overall STEM spectrum, biology, has all but imploded under the weight of "all that students should now know.” However, the continued piling on of factual knowledge, or even higher order conceptual understanding, in the curriculum has tended to ignore two crucial facts. Many core ideas claimed by one STEM discipline are also claimed by others, often just envisioned in a slightly different way, approached with a different tool set or with a different problem context. Second, the ready—almost instant, at times—access to information in our wired world changes the nature of what needs to be stored up in one’s head versus being available in external cognitive stores. This second element shifts the balance, in many cases from what information one needs to know to what an individual knows about how to locate and use relevant information. While it is recognized that there is a boot-strapping problem of needing to have some level of mastery of a content area to even know how to approach a problem, there is a belief that there is a common, thin core that both leaves students prepared to continue to expand their knowledge and opens up much more time to pursue other learning opportunities tuned to their interests.

By containing formal knowledge acquisition to a thin core, more time is made available for students to pursue interests that are tuned both to individual and local (i.e., school, community) interests and play to the strengths of students and their teachers and other adults providing instructional support. Here, the interest is less in containing the specific content or context as it is in assuring that through these other learning activities that students have a common set of experiences where they exercise what they know using *ways of thinking and doing* that have been identified as part of the core of STEM literacies. Again, these ways of thinking and doing are distributed across the STEM disciplines, with some weighing more in some areas than others, but definitely overlapping in ways that strengthen a student’s experience. That is, working through problems which involve exercising mathematical, scientific, and engineering ways of thinking both reinforces knowledge in all of these areas and highlights their unique and intersecting contributions.

Learning takes place broadly over time and space, and this issue of context was also central to the workshop discussions. It was clear that no one was looking to the traditional school day as being the sole context in which these experiences of thinking and doing around the common thin core were going to take place. This responsibility needed to be distributed over the course of the entire waking day and, thus, be taking place in multiple contexts. The notion was that productive learning during the K-12 years might, realistically, be taking place over 12 hours of the day—a huge increase over the time currently devoted to formal education. However, simultaneously, the amount of time devoted to what is currently thought of as formal education actually shrinks, to only occupying four hours of the day. Another 4 hours might be dedicated to structured, but informal learning opportunities that might take place at museums, in the out of doors, or in camps/centers also located at traditional schools. The final four hours might be centered around the home, libraries, or other locales where largely individual, but more unstructured activities can take place. This *4x4x4 model of learning* *contexts*, though it is currently happening in fragmented ways for some students, can become a common, scalable model for most students.

This shift of expectations of where learning can and should take place changes not only the context of "educational place" for students, but also changes the context of who they are interacting with, and perhaps most importantly, the adults who are with them. Throughout this time-span and places, adults will have had some role in crafting the learning experiences for students. In formal settings in schools, the role of adults may play out much as we've seen in the past where teachers interpret the intent of curriculum designers as they craft experiences for their students. Most likely much of this time will be devoted to mastery by all of their students of a thin core of knowledge. These same adults who play the role of teachers in formal settings may now join other adults to guide the period of informal learning. Here, curriculum developed by others may still be used, but students may be much more adaptive as to how they utilize this material with the adults playing a different, more removed role in this process. Here, the goal for the adults may be more of assuring that types of experiences are unfolding rather than dictating all of the particulars of content. Finally, personal experiences can be guided by parents and caregivers in one-on-one experiences or with the child largely working solo with little or no oversight. While one possible scenario is played out here, the important message is thinking about a move from a largely binary structure of formal schooling and all the rest of the day/week where all of the responsibility for learning happens within the walls of the school to distributed responsibilities. We now also move from simply teachers—as is now commonly understood—to a larger range of *responsible adults* who bring a range of professional credentials and abilities but all of whom can play a role in supporting students' learning.

Responsible adults, working to create productive learning experiences for students will increasingly be able to make use of the computational power made available through hardware and software. While no one at the workshop envisioned a complete displacement of adults from any of the three previously described contexts, it is clear that for adults to maximize their impact on learning, they must and should enlist the help of the intelligence that resides in individual computing devices and the larger network which they are connected to. Collectively, these information and communication technologies (ICT) can provide many services now and will likely provide many more in the near future. ICT excels as a storehouse of information, allowing curriculum designers, STEM professionals, responsible adults guiding learning experiences, and students places to hold and share their creations and to access content created by others. ICT also provides tools to think about and organize this information, to reconceptualize the numeric as visual, ideas as words, static data as interactive models, and so on. In the current state ICT makes the creation of a *shared platform for learning* a reality right now. However, ICT, as it is currently used, provides little in the way of advice, with students and adults largely left with each other to help decide what information might be of use, where to find it, and how to structure it. It is perhaps in this area of *intelligent advice*, that some of the most exciting strides in ICT will be happening in the next 10 years.

In the end, it is all about creating *rich experiences* for children and young adults through communities of practice. The strategy is one of learner-centered, meaning that the learning environment is designed to provide the right supports and resources to each, individual student. This also means providing the right supports for the responsible adult so they can best facilitate this experience. A well-designed curriculum and its associated materials provides for centers of learning around which learners can organize themselves. Responsible adults, in turn, help learners find their place around these centers, fitting the situations and abilities of the learners. This curriculum needs to establish learning goals that guide students to opportunities that build and demonstrate expertise. Students would do this by engaging in deep explorations of important concepts. These explorations would allow students to understand and engage in ways of thinking, talking, reading, drawing, and writing science and mathematics around social, technological, and engineering problems.

Experiences require establishing context—the context “around” the problem or goal, but also the context “of” the problem or goal. They should require bringing knowledge to bear on a problem, both knowledge the student currently has and knowledge they need to acquire. It should also require a gathering and application of tools. Some of these may be purely mental, while in many cases they will also be physical/electronic tools that magnify and guide and student’s problem-solving process. As the well-worn saying goes, these experiences should be designed recognizing that the journey is often as important (if not more so) than the destination. Journey is an appropriate metaphor because, as noted earlier, these experiences should span time and space. Not only should these experiences not be siloed in individual classrooms, they should also be designed to *engage the whole child all day long*—in (formal) school settings, in informal, structured settings, and at home. While components of experiences may look different, involve different groupings of students, and involve different problem/topical elements, they should be designed to link and weave, creating structures stronger than any individual discrete experience could achieve.

Designing Learning Experiences

When we think about designing learning experiences, there are a number of dimensions of interest. Of course, there is the physical environment in which these experiences occur. One way of thinking about them is the macro environment, such as the school building, museums, parks, home, etc. where the experience is occurring. The other, of course, is the personal-scale environment—the desk, computer, apparatus/equipment at hand. There is also the temporal dimension—what has happened in the (near and far) past that will influence the experience? What, then, is happening right now and what might happen in the short-term future? In designing experiences, it is important to think about which of these temporal aspects one would like to control, which are likely to be able to be controlled, and which can't be controlled and need to be designed accordingly.

There is also the human dimension—what human connections are being made and how tight or tenuous are they? Is the connection being made synchronously (are individuals responding to each other in real time) or is it asynchronous? Regardless of whether the connection is synchronous or asynchronous, the connections can be physical or virtual. While these two dimensions continue to get closer together, for the next ten years, we should probably treat them as distinct spaces. The person-to-person connections can also be described in terms of the relationship of authority to one another. This can be knowledgeable authority—either a more knowledgeable student or responsible adult—or a peer. There are also sub-dimensions of this knowledgeable authority that are worth mentioning. So, while is as largely been taken as a given that a teacher in a formal educational setting is more knowledgeable on all fronts, increasingly teachers are likely to find themselves maybe more knowledgeable on overall goals and instructional strategies, but not necessarily on the particular content that a student or group of students might be working with. When you move into less formal structures, the knowledge authority balance can possibly be even more skewed. However, in using the term *responsible adult*, it is assumed that the adults (teachers or others) in most situations will have a social authority status that "puts them in charge" of guiding and managing the overall learning experience.

Technology, of course, is another dimension that must be taken into account for most all designed experiences. Technology has, by now, infused into most every aspect of first world culture to the point of ubiquity. A newer descriptor of technology that is important to take into account is its fixedness. That is, is the device fixed (you go to it) or is it mobile (it comes to you)? Mobile devices can, of course, be used in a more or less fixed mode, but this tends not to play to its strengths, since usually compromises are made in its interface and power in order to make it mobile. However, the steady march of technological innovation means that some of these trade-offs are also beginning to disappear.

Interactivity is another way of thinking about the technology. While a device, per se, may be capable of many levels of interactivity, what software tools and how one approaches using the device will typically dictate levels of interactivity. Both hardware and software can be thought of as limiting factors to interactivity, but the design of the learning experience too, can either limit or enhance the level of interactivity. Low interactivity activities might include simple storage and organization of information. The technology here is a simple information storage device. Medium level interactivity, is by and large, the current state of the art in the classroom. Here, interactive modeling tools are at the disposal of students and teachers. Students are able to control the flow of information in and out of the model and the model, in turn is responsive to these inputs of information and controls to how this information is processed and displayed. At this level of interactivity, there are still, typically limitations on the customizations of the tool. What customizations that are available are often surface level controls of display or “look and feel.” The future will bring a type of high interactivity that will respond based on a history it has working with individual students. It is able to triangulate information about the individual, the learning experience at hand, and the long term learning goals in order to customize experiences for students. Such systems will have awareness of many students and can facilitate human connections between them to enhance the overall experience.

Interactivity also can be thought of through the modalities the interaction affords. While text continues to be the predominant form in which interactions take place, increasingly, these interactions are becoming more asymmetric. That is, not only is haptic interactions with mice and trackpads being used to control text and graphics, but multi-touch displays are also becoming more common. Here, touch may imitate use of a keyboard, but it can also involve more sophisticated, free-form shaping of finger and hand movement across a screen/interface. Auditory interactions have been part of the landscape for quite a while, though they have often been at odds with traditional classrooms where only one voice/sound (usually the teacher) is supposed to be heard at a time. As new, more open environments are considered, the possibilities and challenges of managing sound becomes of more interest.

In summary, there are many dimensions that can and should be considered when designing learning experiences. Holistically, many of these factors can be considered in terms of how experiences unfold over spatial, temporal, social, and technological dimensions. Where is the experience taking place and how does that speak to the larger goals of the activity? That is, if it is taking place in a formal educational setting, that probably is dictating something about who the responsible adult is, and what the learning goals are (probably around the thin core). It may be more flexible as to what the technology is, how it is incorporated into the activity, and how students may organize themselves around this activity. Informal and home/individual setting, in turn afford other experiences with other individuals, with different technologies deployed in different ways around increasingly various content.

Group Syntheses

The initial small group sessions of the workshop produced some very creative, innovative syntheses of ideas initially presented during the dream-state presentations, along with new ideas that arose out of the conversations. What has been presented earlier in this paper reflects a collective synthesis of the proceedings of the workshop. As such, it attempted to highlight and organize many of the good ideas that came out of the group sessions. So, in turn, I will try to connect the group work back to some of these central ideas.

Coming out of Group D's work was the notion of Dynamic, Flexible, Intelligent Instructional Resources (DFIIR). This would be a central database of instructional objects and learning community resources organized around a thin-core curriculum of mathematics and science. As described, this captures the notion of the thin-core curriculum that, in turn, leverages ubiquitous, networked computing technologies (i.e., the cloud) to organize and deliver shared resources for learning experiences. The DFIIR also has the capability of intelligent advice, not just because of its innate computing power, but also because it has historical knowledge of the students and teachers who have interacted with it. Advice is provided based on the arc of experience each student and responsible adult supporting the students have had. These student learning experiences and the artifacts they produce is not just used by the computing system, it is also organized and displayable as a learning yearbook for STEM, a portfolio which can be shared with responsible adults who are helping guide the students' experiences.

Group E had a vision of a Learning Center of Excellence/Cultural Commons. Such a Center/Commons replaces the traditional public school model and standard learning day, taking advantage of alternative learning times and places and the associated responsible adults available to support learning. The group noted the specific affordances and unique opportunities of the different possible environments. The first environment described by the group was "School," a structured environment where many children could come together and benefit from the social interactions there. Such a place is crucial for fostering civil discourse and democratic process. More specifically, it is a place where students can learn how to talk science and mathematics within the disciplines. Such an environment needs experts skilled in both their content areas and fostering learning within such formal environments. "Learning Centers" are a structured, but informal spaces such as museums, after-school clubs, studios, playgrounds, etc. While they can still happen within the confines of a school building, they do not share the same organizational structure or learning contexts. Here, students would have access to the unique expertise of artists, artisans, builders, scientists and where they can engage in building, making, and tinkering while working on technological and engineering problems. Here is also a place where the whole child can be nurtured through play, sports, art, and the like. The Learning center is also a place where longer duration projects and apprenticeships can occur. "Home" represented personalized, customized learning spaces where private work on personal passions can unfold. Through networked media, this private work can be published and get critical reviews by peers and experts. This new design of the Center/Commons will require a rethinking of the roles of teachers and the recruitment of additional responsible adults to participate in the shaping of learning experiences. It follows that professional development now also needs to be rethought.

Group B described a world of Every Day, Every Hour Life of Learning. The group organized these ideas around four themes. First, what should be learned should be the skills and content relevant for the 21st century. Second is the question is how learners learn. This centers around engaging activities and problems that merge more open-ended activities with structured learning goals. Learners need materials and content that provokes learning and reflection. On the topic of what tools are needed, the group came up with the notion of the "flight plan," customized learning goals for each student along with guides for responsible adults who are helping to support this learning. It is a integrated means for organizing STEM learning across time and place. How we learn is also influenced by context and includes schools, studios, museums and virtual spaces where students can not only interact with teachers, but also individuals with differing kinds of expertise and experiences. The group envisioned group learning salons, or studios where experts in residence could support focused learning experiences around certain ideas or problems.

Group A worked on identifying essential features of next generation learning environments that would build on children's questions and wonderful ideas. This environment would have interactive learning cycles that fostered varied contexts for exploring problems while also adding to a purposeful long-term cumulative arc of learning. Broad communication networks would support tools for learning and manage the outcomes of these learning experiences. These network-based tools would be used to visualize/model ideas, strategies, and processes on a real-time basis. The environment would also support the pursuit of individual interests and ideas and allow these ideas to be recognized and shared with a larger community of learners. This networked space would allow the creation of extended storylines beyond the boundaries of the typical school time and place. It would allow responsible adults in many capacities and peers to participate in these extended investigations. Flexible tools would allow for creative ways of expressing initial ideas, gathering feedback, and refining these ideas over time and place.

Group F organized their ideas around Design Principles and Core Standards. This group worked under a number of assumptions, among them rich, ubiquitous computing tools and a revised set of standards organized around a thin core of concepts, coupled with robust assessments. These assessments—formative as well as summative—would be adopted by districts and states and used in a way that supported learning progressions in the STEM disciplines. Within this foundational structure, curriculum materials, media, and tools would be coupled with power technology tools in ways that substantively changed the learning experiences of students and the role that teachers and other responsible adults would play in supporting these experiences. Technology tools guides concept-specific learning, the sharing of the products of this work, and organizing input from adults and children on new and better ways to carry out similar work in the future. Three principles for design constraints would guide this work. First, there is a need to figure out how to customize services for particular groups or individuals relative to a set of widely distributed resources (e.g., material from a commercial publisher). Second, there is need for intelligent support locating and then customizing the appropriate resources for the particular learning goals and given context. Finally, these intelligent tools need to be providing evidenced-based feedback. Around the thin core of STEM curriculum, these design principles would be used to create rich, project-based learning experiences. Networked tools would map this student work back to goals defined by learning progressions to be used by responsible adults orchestrating the activities.

Group C, of which I was a member, developed their ideas around the notion of a Learning Ecosystem. Ubiquitous computing tools and networks, along with societal and policy changes will lead to a diffusion of control of learning resources. Their will no longer be a single authoritative source nor will they reside in one form (i.e., the textbook) or in one location (i.e., school). Formal instruction in schools will transform into learning ecosystems. Learning ecosystems, as a metaphor, speaks to the deep, multi-layered, networked, complex interactions that both generate the curriculum driving learning experiences, but also how students and responsible adults use and respond to these materials. These ecosystems are at once interactive, emergent, evolving, creating niches and habitats where multiple players work. The basic “nutrients” of learning will be plentiful, but there is a need for “energy inputs” (personal interests, commercial interest, taxpayer funds, etc.) to make these nutrients available and well utilized. Appropriately, there will be multiple measures that can and should be used to gauge the health of the learning ecosystem.

The learning ecosystem both shapes and is shaped by a number of trends. The democratization of technology means that schools are no longer the provider of all the technology students will use, with students bringing some of their own technology to the table (e.g., cell phones). Access to technology will no longer be as much of a concern as will effective utilization of this technology. The Internet (cloud) will continue to both shape a common experience and allow rich individual expression. It will provide “just-in-time” information, which will become increasingly useful with the help of intelligent advisors. The cloud will hold the thin core curriculum, along with supporting material by authoritative sources and crowd-sourced feedback. It will also be home for student portfolios and the learning progressions associated with the thin core, against which these portfolios will be assessed.

A long tail model was used to describe the context in which learning experiences would occur. The graph model has number of students engaged in a particular activity mapped to the Y axis, with the X axis reflecting the activities and learning experiences they are engaged in. On the left side would be a narrow band of traditional, formal educational experiences where lots, if not all children will all be engaged in learning the thin core of STEM knowledge and competencies. These contexts would be overseen by adults (teachers) which specific training in the thin core and how to reach a broad and diverse audience. In a broader middle are more individualized topics to shape experiences around which kids can organize in affinity groups to share common passions, whether it be robots, hiking nature preserves, etc. In the broad middle, there is a need for a different kind of responsible adult to act as guides, coaches, or mentors. These activities could still be in school buildings, or they could be in museums, or parks. Finally, the long right tail represents all of the individual children pursuing individual interests in the home, library or café. The responsible adults here are often parents empowered with a new set of responsibilities. This would also be a time to work individually on activities associated with the middle or the left sides of the graph. Learning experience architectures guided by the curriculum, mediated by technology, provides for a rich ecosystem to take hold across these learning contexts, groupings, and individuals.

Evaluating and Researching the Design Process

In the end, the goals ultimately point to enhancing student growth and development, primarily around dispositions and knowledge in the STEM topic areas. To that end, what are our expectations of our students at different points in their K-12 experience? From our workshop, we seemed to have identified three areas: *a common thin core of knowledge, common experiences in the STEM areas, and deep knowledge around areas of personal interests related to STEM learning*. Agreement on the thin core of STEM knowledge will have to arise out of national and state-level conversations, but will hopefully result in a coherent national framework that can form a foundational center around which learning experiences can be designed. It will hopefully recognize that current understandings in the learning sciences and the nature of work in the 21st century demands a balance between mastery of specific concepts and facts and being able to spend substantive time learning how to learn using this information. Learning how to learn will be at the heart of the common experiences we hope all children will have. These experiences will include analysis of data, argumentation, synthesis of ideas, and meta-knowledge such as epistemological understandings. At the heart of this design problem will be both how to assure that these productive experiences occur but do so across a range of topical/problem-solving areas with a diverse set of learners. At the heart of the research/evaluation problem is the challenges of formatively and summatively assessing these experiences in a robust and scalable way. There will be a similar challenge is creating motivating and engaging environments that supports students' passions around ideas and lets them dive deep into particular topical areas. This, of course, points to a different set of approaches to assessing student experiences.

To create and support learning experiences that meet these goals, a new approach to the development to curriculum and the development of teachers and other responsible adults will need to be crafted. Teachers will have a different relationship to both the students they teach and the curricular materials they work with. Their role in the larger learning enterprise, though just as critical, will surely change. They will be recruiting and working more closely with a larger contingent of responsible adults who will also be empowered to support elements of a child's learning experiences. Teachers and other responsible adults will also play different roles in assessing students' progressions towards a set of goals that are now more complex than simply the mastery of content knowledge. To do all of this will demand new thinking around initial and continuing professional development for teachers and other adults engaged in supporting learning experiences.

The goals set for the types of learning experiences we want students to have and for the assessment of these experiences speaks to the need for a *shared platform* where materials supporting the learning, outcomes, and assessment of these outcomes can be intelligently managed. The shared platform will need to harness technologies that are largely here now, but not in widespread deployment within schools and other learning contexts. Perhaps the area where new technological breakthroughs are most needed is in intelligent agents that will assist students and adults in their decision-making process around these packages of information. Such a system will provide close connections of data flowing between student, teacher/responsible adult and the learning experience developers. The goal will be able to create continuity not only across space (e.g., between home and school) but also across time—a life-long digital portfolio of student experiences, and feedback from peers and responsible adults.

The shared platform needs to do a number of things. First and foremost, it must support students' learning experiences. As such, it should provide (near) real-time help for students. At first, it may be mostly a "pull" source, where students seek out information they need, but as the power and sophistication of intelligent agents increases, it can also be a "push" source where agents intercede at appropriate points to provide guidance. Similar support is also needed for teachers and other responsible adults, providing them with support that allows them to strategize how to best use curricular materials to create rich experiences for students. Finally developers of these materials also need to use the platform to receive feedback on how these materials might be continued to be improved. At all levels, the information that students, teachers, and developers receive will be a mixture of populist and expert feedback. Peer review and the crowd-sourcing of opinion will be gathered at all levels. This feedback will be intertwined with information from experts, though expertise will need to be conceived more broadly. For example, a student may receive "expert advice" from a teacher, but may also receive it from a more experienced peer. With the move away from a monolithic curriculum where the teacher was expected to be primary provider of expert knowledge, student experiences are now spread over more areas and interacting with more adults, making it impossible for a teacher to be the sole provider of expertise. Now, meta-knowledge of where to seek advice and how to gauge the quality of that advice becomes more important than any particular discrete factual knowledge. Again, this is an area where trusted intelligent agents will be of great value.

To enable these new approaches to learning, new approaches are also needed in the design, development and evaluation of instructional materials. Encouragement is needed for interdisciplinary teams to come together to work as designers, creating learning experiences for students and support for the teachers and responsible adults working with the students. This will mean bringing together cognitive scientists with expertise in developmental, learning sciences, and measurement areas. Just as important, it will mean bringing computer scientists, content area specialists, environmental and interface designers, and artistic professionals of all sorts and stripes to the table with the more traditional educational researchers and developers. These design teams will be guided by standards and goals set forth in national and state-level government policy documents. Increasingly, private foundations and corporations are also demanding a seat at the table to set priorities and strategies. This, among other things, points to a need for “Big Washington” and “Big Silicon Valley” (e.g., Google, Amazon, Microsoft) to come to common consensus and commitment.

Strategically, these learning design teams need to be working simultaneously on new learning priorities, new technologies, and new roles for responsible adults (including classroom teachers). As noted, new models of instruction will also need new models of teacher preparation and professional development. To be most effective, learning design teams supported through federal research and development grants need to stay on the “steep part of the learning curve,” propagating promising and initially proven ideas out to school systems, NGO’s, and private educational businesses. This strategy should engender well-informed risk taking and an awareness of political/policy constraints. It means choosing contexts for research and development that have low resistance to innovation, high need (where possible), and rich opportunities for feedback and data collection. At the same time, a diverse set of contexts should be chosen to guarantee a broad understanding of the potential impact of the innovation. Rapid information sharing should result in quick, agile refinement of methods and approaches that can be fed back into the larger enterprise of designing learning experiences.

Conclusion

Current findings in the learning sciences, exciting new learning contexts developed by instructional designers, and the rapid pace of technological change all point to tremendous possibilities for new curricular platforms. These possibilities continue to face daunting challenges within the structures of traditional educational settings. The vision put forth by members of this workshop looks to work both from within and from outside the walls of K-12 public education as we now practice it. A new, integrated approach will focus broadly on the whole child, all day long. In doing so, a rich set of learning experiences will be provided to children to both assure that they all master a common thin core, but also allow them to dive deeply into individual passions that provide opportunities to engage in important ways of knowing and doing. New common platforms, facilitated by cloud computing architectures, social networking tools and intelligent agents will allow an expanded community of responsible adults the ability to support a coherent arc of learning through a child's formative years. Teachers and other responsible adults, in turn, can use this platform to support their lifelong learning, making them more effective teachers, mentors, and coaches to the children they are interacting with.

The workshop participants determined that what they were interested in being were *learning designers*, not developers of instructional materials. While we might treat this as simply a turn of a phrase, it also spoke to the deep desires to break out of the current confines of how many within the educational enterprise view the role of curriculum. It speaks to a holistic view of the child and the many contexts in which they reside over the course of the day. Workshop participants saw many, many opportunities in all of these contexts to try new approaches to STEM learning. There were many opportunities to enlist and support adults who, in turn, support a child's learning. There were many opportunities to reach out to students who in the past may have felt disengaged from STEM learning and future STEM careers. Making this happen will require, among other things, finally leveraging all that current and future cyberlearning technologies have to offer us. These technologies can not only support individual students at single points of time and space, but be used to create a platform that forms the glue in creating a coherent experience for the child and windows into that child's experiences for adults supporting their endeavors.

It follows that the future work of learning designers will mean forming interdisciplinary teams that harnesses both the on-the-ground knowledge of a diverse set of currently known learning environments, but creative thought that uncovers new possibilities in new contexts. As with all serious design problems, this unbounded creativity will need to be backed by a new set of rigorous tools for both directly evaluating these new learning experiences and looking at student outcomes. These new measures should be responsive to both new ways of thinking about how children learn and a broader set of goals for a future STEM-educated citizenry.