The Future of STEM Curriculum and Instructional Design:
A Research and Development Agenda for Learning Designers

Report of a Workshop Series

Center for the Study of Mathematics Curriculum

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Preface

In 2009-10 a series of Workshops was organized to focus on STEM learning design for young students and adolescents. The objective was to provide visionary leadership to the education community by: (a) identifying and analyzing the needs and opportunities for future STEM curriculum development and instructional design given current and emerging technologies; and, (b) recommend policy positions and actions by funding agencies and the STEM research and development community regarding STEM instructional resources. Specific questions addressed included:

- *What will a high-impact, technology-intensive STEM learning environment look like in the near and long-term future?*
- *What materials development and research are required to make this vision possible?*
- *What design, development, and diffusion processes are most likely to produce new approaches to STEM education?*

To address these questions, two workshops were convened to identify and analyze the needs and opportunities for innovative work. The goal was to identify strategies, directions and recommendations about the future of STEM instructional design. Participants included education futurists, researchers in the STEM content and education disciplines and specialists in instructional technology, cognitive psychology, policy, museum and educational media (see Appendix for complete list of Workshop participants).

First Workshop: December 1-3, 2009, Lansdowne, Virginia

The first Workshop solicited perspectives from key progressive thinkers in STEM education and instructional technology regarding the first two questions noted above. A set of five reflection papers resulting from the discussions are available at: http://www.mathcurriculumcenter.org/conferences/stem/index.php

Second Workshop: May 16-18, 2010, Lansdowne Virginia

The second Workshop focused on articulating a research and development agenda for STEM learning designers. Building upon the visions for future STEM educational environments described in the first Workshop, participants identified high priority work (research and development) needed to capitalize on technological advances and produce/deliver/use the next generation of curriculum and instructional tools and environments for advancing STEM learning in formal (school) and informal (museums, community centers, etc.) settings (and across settings).

This report provides a summary of the ideas generated by Workshop participants and offered to the STEM instructional design community and to agencies that fund this work.

Barbara Reys, Workshop Series Coordinator

Introduction

Considering the Future of K-12 STEM Curricula and Instructional Design: Stimulating and Supporting Innovative Research and Development[1]

The rapid growth in features and use of educational media (from e-books to applets) makes it possible to envision dramatic changes in the kinds of instructional environments in support of STEM learning. For example, it is conceivable that a totally interactive, continually up-datable e-book (linked to numerous external sources of data, images, and research tools) will provide more inviting and effective learning environments than the conventional printed textbooks that students currently tote from class to class and home and back. It is also conceivable that a science, technology, or mathematics classroom that engages students in regular communication with teachers, other students, scientists, engineers and mathematicians, and makes accessible data from around the world could be more engaging and effective than an environment bound by the walls of conventional classrooms. Old boundaries may become less relevant, even as new knowledge generated by the learning sciences opens new paths for personalized learning. Effective use of such new instructional resources will require rethinking the ways that education is delivered and managed. Most important, those new ideas and their embodiments in experimental instructional resources must be developed and carefully tested before it makes sense to implement broad transformation of STEM learning both in and out of schools.

In addition to the challenges and opportunities inherent in existing and emerging technologies for learning and working in STEM fields, the current STEM learning system faces the additional challenge of providing enhanced STEM education to a very diverse population of students. Traditional conceptions of education offer sophisticated science and mathematics coursework for future scientists, engineers, and mathematicians and modest content for all other students. But meaningful participation in contemporary life requires strong grounding in relevant STEM disciplines for all students. Vigorous discussions about this issue are taking place in the 21st Century Skills, Quantitative Literacy, Computational Thinking, and Career and Technical Education arenas.

The demands for broad STEM education of all students are accompanied by an expectation that today's learning institutions will provide enhanced STEM education to students from very diverse cultural, linguistic, and socioeconomic backgrounds. These demands are a significant challenge for developers of curricula and instructional materials. New instructional designs must be developed in ways that broaden access and increase rich learning opportunities for all students. They must also connect with and take advantage of the interests and extracurricular experiences of students growing up as cyber-savvy digital natives.

Careful development and effective dissemination of innovative STEM instructional resources and experiences require sustained effort and support that is quite different from the typical 3 – 5 year time frames of standard research projects. Comprehensive curriculum products take

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[1] Workshop series supported by NSF Grant No. 0958058 (Center for the Study of Mathematics Curriculum)

longer to create, test, revise, disseminate and implement. Materials that make innovative use of contemporary technologies need almost continuous revision to assure they remain au courant. Furthermore, effective dissemination of any innovative instructional resource requires building community and business models that can overcome the adoption barriers of schools and districts and insure continual improvement of the materials. Therefore, support for major instructional design and development projects needs to reflect a special kind of funding commitment.

These issues raise four fundamental questions:

- *What kinds of research and development work should be encouraged and sponsored in order to assure that educational experiences and practices reflect the best of current knowledge about the STEM disciplines, STEM learning, and STEM teaching?*
- *What advances in the practice of curriculum and instructional design research, development, and evaluation will be required to assure that investments in that work produce relevant and useful results?*
- *How can funding agencies and professional organizations best stimulate, respond to, and develop the community of STEM educators to assure that important innovative curriculum and instructional material development and research is conducted and widely disseminated in a timely manner?*
- *What kinds of projects can both develop new instructional design ideas and materials and successfully facilitate implementation of those innovations so students will be well prepared for the demands and opportunities of future study, work, and personal life?*

To consider these important questions, two workshops were convened. Participants of the first STEM Workshop focused on needed research in four areas:

STEM Learning Goals for a Technology-Enhanced Society and Educational System. How does the emerging information, communication, and technology-driven environment change the nature and relevance of STEM learning goals for students and thus the objectives of the various educational institutions they will encounter? What new organizations or sequences of core curriculum are viable and relevant? What topics within the STEM disciplines should receive increased attention, less attention? What is the impact of new (or current) technologies on the prioritization of learning goals? For example, if young students use technology to calculate or do symbol manipulation, how does it change their view and understanding of important mathematical concepts (e.g., place value, meaning of operations, "symbol sense")? What are the critical core knowledge areas that cut across multiple disciplines (e.g., mathematics, science, literacy and social studies at the elementary level) and represent a "thin core" of vital STEM learning goals? In what ways does integration across multiple disciplines strengthen or enhance student motivation and learning outcomes?

STEM Digital Textbooks/Learning Tools for Students. The next generation of instructional resources will likely be delivered through current or new forms of technology (e.g., laptop computer, iPad) that support technology-based features and options (e.g., applets for visualizing mathematics concepts, links to additional information about the context of problems, short clips of master teachers or scientists introducing or applying ideas). Given these new platforms, what topics, levels, audiences are good starting points for building and testing e-resources that capitalize on these new formats/learning environments? What is the impact of e-resources on student motivation and learning outcomes? What resource development is needed to enhance the quality and impact of these technologies? What is the impact of cutting edge prototypes of curriculum resources focused on core STEM topics?

STEM Teachers as Learning Guides. How will digital curriculum resources shift thinking about teaching and what implications do they have for the professional development of teachers? In what ways can technological tools be used to support teachers' customization of curriculum and instructional resources? Can new technologies provide data to support teachers' understanding of their students' grasp of content? How can technology be used to support teachers' learning? What opportunities does technology offer in connecting teachers within professional learning communities?

Designing and Testing a STEM Cultural Commons. Community-based consortia of cultural and civic institutions could serve students, teachers, and the local community in collaboration with schools. This effort to design and test a "cultural commons" could be supported by a computer network that hosts a common set of tools - licensed curricula, open content, applications, professional development, online courses, and assessments. What design features and elements are critical to the integration of the cultural commons with other educational environments and its success in fostering increased interest and expertise of students?

A summary of needed research and development in each of these four areas follows. The summaries were compiled based on Working Group discussions held during the second STEM Workshop.

STEM Learning Goals for a Technology-Enhanced Society and Educational System

Working Group[2] Summary

The notion of a "thin core" for the curriculum, raised in the first Blue Sky Workshop[3], was a way of expressing the need for a rich curriculum that leaves room for additional topics of interest of individual students. It might be compared to the college model: a thin core, plus room and requirement for greater depth in areas jointly negotiated by students and faculty.

The task for the Working Group was to give some definition to this thin core—not to specify it, but to make the thinking concrete enough to suggest possible directions in which research and/or development might proceed. The initial discussions focused on the implications of a "thin core" – is it a viable idea? How thin can it be?

Even such broad questions can be researched, if they are operationalized. It was suggested that, for example, "what can be 'left out' of a core (of any thickness)" can be investigated by experiment: leave out a reasonable candidate and examine the consequences. The difficulty of performing such experiments is obvious - if we really don't know the consequences, it would be hard for researchers to propose such an experiment, unlikely for reviewers to accept it ethically, and unimaginable for schools to sign on. Curricular change is naturally conservative, partly because one does not know the consequences of omitting things that (seem to) have served the population in the past.

An important distinction exists between content that's on a list of standards (the official "thin core") and ideas that make up a curriculum to achieve those standards. The core is to be thin so that the curriculum can be rich. Designers of curriculum, not standards, often face this distinction. A standard can specify, for example, merely that children learn to multiply: the curriculum can use array images and connect this model with area; it can use pairings (e.g., flavors of ice cream and toppings, word parts, Lego towers) and images that foreshadow ideas from other parts of mathematics. The standard is limited—thin!—but the curriculum that "delivers" that standard can be quite rich.

In preparation for the discussion, the Working Group raised and addressed the following questions:

What assumptions cause us to think about a thin core?

New technology exists; students will likely have access to it; the technologies give kids access to knowledge, each other, computational power, visualizations, simulations, a tsunami of data (not often well organized, not necessarily accurate); educational settings can be less rigid, more creative, more integrative, more inclusive of diverging talents and interests, more responsive to the available resources. The fundamental question is, "How

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[2] Working Group Members: Janice Earle, Jim Fey, Brad Findell, Paul Goldenberg, Barbara Reys, Jo Ellen Roseman, Peter Turner and Zalman Usiskin.

[3] The "Blue Sky" or First Workshop was held December 1-3, 2009 in Lansdowne, Virginia. For a full report see: http://www.mathcurriculumcenter.org/conferences/stem/index.php

do new opportunities affect the fundamental ideas that we're trying to get kids to learn in school or other learning environments?"

Should the focus be on a 'thin core' or on an 'essential core'?

This was partly a question about focus, and came up multiple times in different contexts. Race To the Top funding requires that states make *Common Core State Standards* (CCSS) 85% of their program, but are "free" to use the other 15% as they like. But assessment, especially if it is connected to accountability, drives many school decisions. Unless schools must add variety in the other 15%—which is to say, unless the tests reward them for doing so and punish them for not doing so—their entire curriculum will consist of the "thin core."

What criteria should be drawn upon for deciding, within a discipline, what should or should not be in the essential (thin) core?

One consideration is with regard to the purpose of acquiring knowledge - for citizenship, career, and/or scholarship? We agreed that the core should be coherent, regardless of its thinness or thickness. What's important is to identify a set of conceptual models that are "good enough" for students to use to think about phenomena at a particular grade range. Logic can be used to estimate what the elements of a "good enough" model might be, but ultimately this is an empirical question.

What are the implications of different visions of the thin or essential core?

Might the nature or meaning of thin (or essential) core be differentiated across the grades? Two opposing arguments were made about the organization of instruction and the question about grade levels. On one hand, young students natural learning tendencies are not bounded by artificial categories. Putting mathematics, science, making things, or even language into separate boxes may be artificial and unhelpful. Perhaps that is where the integration of content would work best. On the other hand, children know there are categories, even when they are very young. What does and does not constitute science, as opposed to opinion or story-telling, needs to be established while children are creating the meaning of that word. The same argument applies in mathematics - the mathematics one naturally encounters while working on age-appropriate projects in science or engineering would be limited and not likely to include anything about the *structure* (orderliness, pattern) behind age-appropriate mathematical ideas.

Should any core, thin or otherwise, be discipline-based or "integrated" or driven by other factors such as context?

This question has been debated for some time. It can be operationalized by asking: What are the affordances of using a disciplinary approach versus a non-disciplinary approach in defining some core requirements? What are the nature and affordances of a mixed strategy?

The Working Group suggests the following areas of needed research and development.

Directions for Research and Development

Curriculum Standards

1. *What is the core set of curriculum focal points for mathematics, science, technology and/or engineering education and how might this core be identified?*

Both the product and the log of the difficulties and controversies in creating such a document would be a valuable source of information for the R&D community. A joint effort, combining the knowledge and expertise of that group and forcing either (1) the resolution of ideas or (2) the articulation of differences that require study, could be a concrete way of pushing both research and development into new territory. This approach might be fruitful because, on the one hand, the group has a great deal in common so enough consensus could be expected to create a core. On the other hand, the group does not represent total uniformity so enough difference could be expected to keep that core thin. Articulating and arguing about the differences would generate questions that clearly need research. The group would be obligated to three products: a standards document that represents their version of “focal points” or a “core”; an example document that shows how parts of curricula might be constructed in a rich way to achieve the (necessarily narrower) standards; and a document that lists the places where disagreements remained to be settled by research, with enough rationale behind these disagreements to suggest what research questions require answers.

2. *In what ways should the Common Core State Standards (CCSS) for mathematics or other STEM content areas be modified in light of new or emerging technologies, needs of society, and the field itself?*

As the processes for modifying CCSS in the future are developed, it is essential that it is informed by technological advances as well as feedback from the field, research on student learning and needs for particular kinds of content expertise.

3. *How can space be created in existing curriculum to allow increased focus on new ideas and emerging priorities?*

The difficulties of testing new organizations or sequences of core curriculum (deletions, moving stuff around, additions) are great but not insurmountable. Projects that explore and test new organizations of curriculum need to be longitudinal, extending beyond current limits of funding. It takes a substantial amount of time to develop and refine materials, even on a fairly “standard” model, still longer if the model, itself, requires departure from the familiar. It takes time to implement at a level of quality worth researching. Research that seeks to understand the consequences of particular changes must be long enough to detect more than the most immediate consequences.

4. *What if the entire structure of the curriculum were sliced a different way, allowing parts of (what is now) the mathematics curriculum to drift into contexts in “science” or “social studies” and parts of (what is now) the science curriculum to drift into appropriate parts of “social studies,” and so on?*

This approach gives engineering, which mostly has no place in current curricula, a natural home. The task then is to conceptualize a common (coordinated) core that includes mathematics/science/social studies, developing one or more exemplars, and researching such a structure.

Impact of New Technologies

5. *What is the impact of new (or current) technologies on learning important concepts?*

For example, what is the impact of children using technology in new ways (e.g., to calculate or do symbol manipulation) on development/understanding of important ideas/concepts of mathematics (place value, meaning of operations, "symbol sense")? This may be a way to test the value/need for some "traditional" emphasis in curriculum.

6. *Can creative use of current and emerging technologies serve traditional curriculum goals (e.g., use of "games" aimed at elementary mathematics skill development)?*

We encourage projects that design, develop and test a segment of curriculum that focuses on new goals for mathematics or science education or on a new organization of the sequence of curriculum or uses new medium to engage students and/or structure instruction focused on traditional goals.

7. *What is the use, potential, and quality of current commonly used (and new) technologies for supporting STEM teaching and learning? What new development is needed to improve the quality (and impact) of these current technologies?*

We're seeing, in some instances, recent technology becoming a conservatizing force. For example, there are classrooms in which interactive white boards have become the driver of instruction and have led formerly student-centered teachers into a more front-of-the-room, teacher-centered, pre-planned-lesson-centered structure.

8. *Are there ways in which new technologies hide or confound reality?*

For example, using dynamic geometry software, a figure consisting of a triangle with a single segment parallel to one side and connecting the other two can be manipulated in two different ways, one of which demonstrates a mathematical theorem, and the other of which demonstrates a software artifact: there is no experimental way for students to distinguish these two results. The simulation, *necessarily*, confounds mathematics and non-mathematics.

Assessment

9. *What insights and trends can be identified with well-constructed technology to assess student learning? How can technology be used to produce informative assessment results that support teachers planning and instruction?*

Current computer-based testing relies on banks of problems and provides limited diagnostic information. In what ways can assessment systems be developed to allow teachers and others to know what students are thinking, not what they are not thinking?

STEM Digital Textbooks/Learning Tools

Working Groups[4] Summary

In the very near future the core set of instructional materials used in schools and in other environments to guide and monitor K-12 mathematics learning will be interactive digital texts or modules. As the medium for learning materials shifts from print to digital, opportunities arise for advances in mathematics teaching and learning.

Although the term "digital text" is used in this report, it represents a broad and far-reaching learning tool including (but not limited to): multi-media, interactivity, customization and adaptive systems, storage of information by and about student work, and intelligent agents. Future core instructional materials will be "delivered" through current or emerging technologies (e.g., laptop computer, iPad) that support a variety of features and options such as probes, applets for simulation and visualizing physical phenomena and mathematical ideas, tasks permitting reasoning with multiple representations, links to additional information and video clips related to the context of problems, short video clips of master teachers or scientists introducing or applying ideas.

Four overarching questions are discussed here to provide background and context for recommendations regarding needed research and development efforts.

> *What are viable possibilities for future digital resources given current and emerging technologies, and what are features that show promise for further development and/or customization?*

Digital resources in the future should take advantage of a platform that allows connection between the teacher and student environment as well as use of content tools and digital media. Use of multiple representations and tools such as simulations, mathematical tools, animations, and visualization models should be standard. Digital resources drawing from Universal Design for Learning could include features such as learner-controlled scaffolding for tasks, use of text-to-speech software that reads aloud the written digital text, and translation software that translates from one written language to another. Digital resources could support students' texting questions to each other and to the teacher on a monitored network using mobile devices. Other communication and collaboration digital resource ideas incorporate public and private student work environments, a network of embedded links allowing immediate access to specific sections within the resource (including a glossary), and means for transmitting homework between teacher and

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[4] Two Working Groups focused on this topic independently and took slightly different directions in their discussions. This report represents the ideas and recommendations that emerged from both Working Groups. Members of Group A: Dave Campbell, Jere Confrey, Chad Dorsey, A.J. Edson, Mike Haney, Chris Hirsch, Joe Krajcik, Chris Rogers, Susan Jo Russell. Members of Group B: Jacqueline Barber, Bill Finzer, Glenda Lappan, Robert Reys, Jeremy Roschelle, Gerhard Salinger, Gabbie Schlichtmann, Louisa Ann Stark, Eric Wiebe.

student. Resources should support students and teachers through use of electronic resources, interfaces allowing customization of notes, and embedded assessments.

"Intelligent agents" (IA) provide another venue for supporting STEM learning. The term defines a wide range of tools or applications that deliver customized support and are used everyday by millions of individuals (e.g., search applications by Google, texting correction tools on the Apple iPhone, URL completion tools on Firefox web browsers, movie recommendations on Netflix). They are often embedded in the interface of a tool, not front and center. They can be thought of as intelligent media or embedded advice that directly supports both students and teachers, though often in different ways.

> *What are some of the challenges to development, dissemination, and implementation of digital resources? Including parent acceptance?*

Some technical challenges include the design behind the usability of different devices, such as the interconnectability of cloud computing, standards, and sharing of digital resources. Challenges in the use of digital resources in classrooms include a lack of access in many schools to consistent, up-to-date technology and barriers to deploying such technology (e.g., IT support staff). Teacher professional development is also needed to change the mindset toward the use of digital resources as well as provide expertise in their use. In addition, it is essential that changing public expectations of schools precede serious attempts at changing the nature of schools. This highlights the need to include administrators, parents, and community members in the discussion. Other challenges include strategic use of data and the need for data management (e.g., servers, data size, and security).

> *How can collaborative development of model digital platforms as "base templates" for STEM curricula be encouraged?*

We suggest support for the development of three or four digital resource platforms for different STEM disciplines. Digital platforms for each discipline could then be customized by a particular curriculum development project. One advantage is that these base templates would reduce technical development time and expense for individual projects and accelerate small-scale initial trials. Another advantage is that each discipline could customize the platform and increase the connections between the technological differences of separate projects. In terms of dissemination, the platform could be distributed to many more classrooms and be accessible to a wide range of devices. Some questions include: Will curriculum development slow while the development of platforms is happening? What about satellites for digital platforms that could be accessed by curriculum developers with content and R&D knowledge/expertise? Key ideas to be addressed include the likely involvement of smaller companies in the creation of interactive designs with the intent that they would be an open source open access. What are the advantages and disadvantages of platforms designed to be open access instead of open source, allowing a slice of the market to update and extend the digital resources and provide continued support revenue for professional development?

What curriculum design principles and development processes have potential for transfer to design and development of interactive digital textbooks and other resources?

Curriculum designs could capitalize on the promising design principles of the NSF-funded curriculum materials of the 1990s and their later editions and be adapted for digital resources. This approach would reinforce the need for partnerships between curriculum specialists and computer scientists. Multiple questions arise: How do we connect prior knowledge with digital resources to students? How do we identify "interesting problems"? How do you ensure student-student interaction with digital resources? How do you "digitalize" our current successful work and not just "pdf" it? How do you allow personalized learning without losing sight of the end learning goal? How would our model (curriculum, theory, implementation, outcomes) for assessment have to change in this new medium? Are elements missing, such as interface with technology and school? What metrics would be used?

Directions for Research and Development

Research and development is needed that integrates learning science research into effective designs for learning; that supports teachers in developing their understanding; that facilitates meaningful learning opportunities for students; and that engages the educational community in ongoing improvement of the resources. Key questions include:

1. *What are the affordances of digital texts?*
    - In what ways can multimedia materials best support learning?
    - How do learning support tools integrate with content? What tools bring the content alive and make it immersive, interactive, engaging, and a medium for student learning and expression?
    - How can electronic media and digital resources promote, support, and afford different and richer problem contexts?
    - How can we represent possibilities and connectedness in digital texts in ways that facilitate meaningful navigation, choice and content that resides both locally in the classroom and "in the cloud"?
    - In what ways can smart, adaptive representations minimize the cognitive overload factor while still allowing the user to dive in? How can search, filtering, and recommendations work towards this end?
    - In what ways can digital media provide opportunities for the entire community (parents, business, informal science education, after school programs, scientists, other researchers) to support, engage, and contribute to student learning?

2. *In what ways can digital texts lead to students and teachers having a coherent and comprehensive understanding of STEM content and processes?*
    - How can we support students to be metacognitive, intentional, and self-regulating in their learning with digital texts?
    - How can digital technologies be used to engage students while accommodating individual differences?
    - What are the issues around equitable access and digital texts?

- What design principles and features have the greatest benefits for promoting coherence and understanding along a range of cognitive and affective differences in learners?
- In what ways should digital texts vary depending on population, grade level, and content area?
- How can educational coherence be developed, maintained, and assured in the context of an evolving educational environment and the changing technology underlying digital texts?
- What are life-cycle models for digital texts in terms of initial development, revision, expansion, and evolution? How do users of digital texts contribute to their evolution?

3. *What would a digital learning environment look like that supported students engaged in the process of science, mathematics, and engineering in asking questions, learning big ideas, and collecting and analyzing data in order to use evidence to develop arguments? What suites of tools should be assembled to create such an environment?*
    - What are the unique challenges of combining these tools into an environment to support student learning?
    - What unique opportunities arise from the integration of these tools/environments?
    - What kinds of supports are needed to help students navigate the range of tools in such an environment?
    - What tools can be integrated into such an environment to support teacher feedback (assessment) to students?

4. *What challenges are posed for teachers and students in working within such an environment?*
    - What scaffolds are necessary to support teachers and students in working with and integrating information and learning among a mix of tools?
    - How can teachers efficiently collect information about student learning and provide timely, useful feedback?
    - How can teachers support differentiation in this environment?
    - How do you ensure coherence within environments that are student-controlled and collaborative?
    - How do non-linear presentations of content support student learning? What unique challenges are posed by these presentations?

5. *How can digital texts support teachers in developing their own understanding, pedagogical skill, and confidence in using appropriate learning experiences?*
    - In what ways can digital texts support and increase teachers' use of effective teaching methods and pedagogical knowledge? For example, multimedia materials that model best practices, provide glimpses of instruction in the classroom, video case studies showing ways other teachers have responded to specific teaching and learning challenges.
    - In what ways can digital texts support teachers' understanding and use of pedagogical content knowledge in their teaching? For example, visualizations

that communicate necessary prerequisite understanding, or what is known about learning progressions and common naïve conceptions of specific concepts.
- What models of teacher content understanding and pedagogical knowledge need to be present in order to build digital media that properly support them?
- How can digital media be used to help teachers make in-the-moment, skilled decisions —"just-in-time" support (e.g., physicians are supported in their decision-making by access to electronic medical records and online feedback to particular questions of practice).
- What opportunities exist for digital media to gather and represent formative assessment data in an ongoing fashion, to inform instructional decision-making?

6. *How might "intelligent agents" (IA) be utilized to support student learning?*
    - What are the possible dynamic relationships between IAs, teachers and student (both individual and groups)? What is the quantity and quality/nature of feedback that provides optimal affective and cognitive outcomes for a particular context?
    - What student attributes do we need to support in order to prepare students to work effectively in IA environments? How do we need to remake the relationships between student and IA and between student and teacher (and across teacher, student and IA)? What are the roles and abilities that are needed for teachers and students to work effectively with IAs?
    - How can the IA be used to leverage human relationships in the classroom? Can IAs magnify positive human interaction?
    - How does the IA interface with longitudinal data (in the form of student portfolios)? How does the IA work with the student portfolio to help transitions between subjects and grades? What does the IA know about teachers to help the student transition?
    - How does the student-teacher relationship change with IAs? How does the teacher work with the IA to guide classroom strategies? How does the IA represent student information in ways that facilitate the teachers' work?

STEM Teachers as Learning Guides

Working Group[5] Summary

What does it mean for STEM teachers to serve as "learning guides?" Mischaracterization could convey a false conception of teachers as "peripheral" in the education process, particularly to novice teachers or to the general public. The working group agreed that when the teacher functions as a learning guide, he or she acts as a mediator in the learning process. We developed the following description, framed around *How People Learn* (Bransford, Brown, & Cocking, 1999).

> The *learning guide* engages students for learning (both intellectually and physically), develops understanding of important content in a meaningful storyline, and facilitates meaning-making by organizing and relating knowledge.

Engaging students is best done in a culture of respect where the learning guide models and guides appropriate behavior. Learners and guides support and encourage others to share, develop, and respectfully challenge ideas in a non-personal manner. Learning guides encourage all students to volunteer their examples, ideas, justifications, analyses, and conclusions. Students and the guide jointly make decisions about procedures for investigation and next directions for investigation.

The learning guide focuses learners on the development of important core content. There is a clear sequence of activities for development of a coherent story line of ideas and skills that makes sense to learners. Ideas are based on phenomenological experiences and developed to organize and understand a range of phenomena. Technical terms are introduced after ideas are developed and terms are used for ease of communication after learners understand the ideas.

The guide helps learners organize and relate knowledge and skills for ready access in subsequent learning opportunities and applications. The guide accesses learners' prior ideas and adapts activities to address learner needs. Connections are made to prior experiences and to future applications and learning opportunities. Multiple forms of representation are used to organize and understand ideas.

The learning guide effectively uses dialogic interaction to stimulate and guide learning. Guides listen respectfully and critically to understand learners and identify their needs. Questions and questioning are encouraged and used to clarify meaning, to motivate inquiry, and to promote deeper understanding and design. Learners are guided to justify their conjectures, to explain why and how their ideas make sense, and to know the conditions of when one idea or procedure applies and when it doesn't.

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[5] Members: Spud Bradley, Kim Lightle, Gladis Kersaint, Alan Maloney, Jim Minstrell, Jeff Shih, Amanda Thomas, Elizabeth Vanderputten, Iris Weiss, Carla Zembal-Saul.

In a technology-rich learning environment where instruction is differentiated and students are given choices, the learning guide helps motivate student choices to maximize learning. The learning guide constantly monitors student progress, including informally assessing student work, and offering constructive, descriptive feedback that supports learners in building on what they already know or can do and in what they might work on to amend or extend their present ideas or designs.

When teachers are effective as learning guides, the complex decision making and expert knowledge underlying their practices is often transparent to the observer and tacit to the teacher. Accordingly, it is essential to delineate the features and identify levels of mastery associated with the construct of teacher as learning guide. Video-based cases can provide images of the possible (Hatch & Grossman, 2009) and complement research protocols/instruments. Having a shared words-to-images framework (Roth, Lemmens, & Garnier, 2009) has the potential to support a common language among researchers and teacher educators, as well as facilitate the development of research tools that can be used across sites/settings to investigate STEM teachers, teaching, and teacher development. Cases and protocols would need to account for where teachers are in their careers, and possibly place them along a trajectory of development toward mastery in the role of teacher as learning guide.

Assumptions

This vision of teacher as learning guide leads to several assumptions about the complex environment in which learning guides must function. Recommendations for research and development that follow assume the following:

- The content for which learning guides are responsible is part of a ”thin core.”
- Learning guides may not be knowledgeable about important content that connects and spans all of the STEM areas.
- Learning guides need support to use formal instructional materials (e.g., textbooks, teacher guides, manipulatives) to their fullest potential.
- Learning guides function within a complex system that includes high stakes accountability and extensive public scrutiny, which may at times facilitate and at other times interfere with attention to individual student needs.

How Can Technology Support the Learning Guide?

Educators at different levels are already exploring Web 2.0 technologies, applications, conceptualizations, and collections of resources – for instance, a number of K-12 educators are using blogs and wikis to engage their students in authentic timely responses to real-world events and experiences. Coupled with increased student use of social networking sites like Facebook, there is an emerging convergence between social phenomenon and educational practices. It is important to design content, tools, and applications so that the entire experience becomes a catalyst for change and supports improvement efforts in STEM classrooms.

We envision resources that will allow teachers to enhance both their understanding of the content and of pedagogy through their interactions with them (Davis & Krajcik, 2005; Minstrell, et. al., 2008). We discussed the potential of a smart system that would (a) allow learning guides to ask questions and input information about instruction, and then (b) propose options grounded in research and expert practice (technological diagnostic system). Options include coherent content storylines, key representations for core ideas, assessments to use with students, strategies for remediation or enrichment, etc. The content associated with the system would be linked to the thin core for STEM education. Assessments could also be embedded in the system and allow for research on teacher development, with appropriate attention to issues of privacy.

A sense of community is essential in the success of ongoing professional development. We discussed the possibility of using technology to support virtual communities that would be structured around shared problems of practice. Research-based resources and supports would be available to learning guides as they attempt interventions to improve learning, collected data on their experiences, share their findings back with the community, and propose next steps for improving STEM instruction.

Directions for Research and Development

1. *What does a learning guide look like?*
    - What new visions for "teacher as learning guide" are appropriate and applicable in a technology-rich STEM classroom?
    - How does the learning guide notion vary among groups of teachers? For instance, a learning guide in an elementary classroom might look very different from a learning guide in a high school classroom or in an out-of-school setting. Beginning teachers may perceive or function as learning guides differently than experienced teachers.
    - What models need to be provided (e.g., video-based cases, to help teachers and teacher educators develop images of teachers effectively functioning as learning guides) with appropriate commentary on the rationale for particular instructional moves in order to promote student learning?

2. *How can existing resources be leveraged for maximum impact?*
    - What initiatives are proving effective and how can we connect, refine, and implement past, present, and future research and development in order to maximize impact?
    - In the short term, how can technology assist in pooling existing research and tools for wide dissemination to teachers?
    - What additional resources and tools need to be developed for teachers, students, curriculum designers, and teacher educators?
    - How can the learning guide adapt to evolving student communication in a technology rich environment (e.g., IMs, Twitter, YouTube, Facebook, Wikis, texting, etc.)? How can these emerging student communication platforms be leveraged in the classroom?

- How can technology help learning guides make effective choices among the wealth of existing resources? Can tying digital libraries to common core standards, diagnostic tools, and/or research provide learning guides a context for entry to existing collections?

3. *What does the learning guide need in order to support increased student learning?*
   - What experiences and scaffolding do learning guides need to develop the skills and habits of mind that enable them to meaningfully integrate digital tools into their own classroom instruction?
   - What technological tools are needed to collect the data to address critical teaching and learning questions?
   - In addition to developing tools, there must be ongoing assessment of the many facets of the tool and its application. How do we know when a tool is effective? Under what conditions or with what users is it effective?
   - To what extent can technology help the learning guide anticipate or know how students might respond to instructional events? How does the learning guide interpret student responses in terms of strengths as well as the problematic aspects of students' thinking? How can technology provide feedback to the learning guide to make instructional decisions on the fly? What support can be made available for learning guides to adjust lessons to address students' misconceptions?
   - What are the consequences of learning guides' choices regarding scope and sequence of STEM content? How can technology inform the learning guide about the tradeoffs inherent in these decisions? Can an application be developed to highlight the implications of curricular sequencing (e.g., "By sequencing content as proposed, the following concepts are not addressed…")?
   - How can technology help the learning guide weave elements such as big ideas, objectives, and key questions to develop a coherent content storyline? What kind of supports can be packaged with curriculum materials to help them discern coherent content storylines?

4. *How can professional development promote and support the learning guide?*
   - What tools do learning guides need to inform their own teaching and learning? How can technology allow for the learning guide to continue learning content in deeper and different ways while improving practice?
   - What are the challenges that learning guides face in making effective use of digital resources in their own professional development as well as for supporting diverse learners?
   - How can professional development promote and support the learning guide to help students develop competency with unifying STEM threads such as data analysis, modeling, and heterogeneous approaches to problem solving? How can professional development support STEM educators in creating learning contexts that build robust quantitative thinking across the STEM content areas?
   - What are the challenges that learning guides face in making effective use of digital resources in their own professional development as well as supporting learning for diverse students?

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Designing and Testing a STEM Cultural Commons

Working Group[6] Summary

We interpreted “cultural commons” as an ecosystem of individually tailored, community-based learning environments. As complements to in-school learning, these individual learning environments - comprising community-based organizations, museums, libraries, etc - form the backbone of a larger societal learning ecology. Using Sherri Hsi’s “Reflections on the Future of STEM Learning – A Cultural Commons”[7] as a point of departure, the Working Group considered the goals and attributes of the Cultural Commons and discussed what existing barriers to actualization must be addressed. We then brainstormed how those barriers might be overcome, leading to our recommendations for immediately-actionable research and development.

We see an immediate opportunity/need for a combination of research and development into the larger concept of the cultural commons. We suggest that development take the form of a series of local, smaller-scale pilot programs, leveraging existing resources and infrastructure whenever possible. Research and development should be targeted towards:

- Building a deeper understanding of the potential impact of the Cultural Commons on STEM learning;
- Developing the tools necessary to assess the impact of a larger, more integrated learning ecosystem;
- Initiating individual community-based learning environments as pilot programs;
- Developing tools, materials and curricula that work in a multiplicity of learning environments (including in and out-of-school settings); and
- Designing professional development programs that enable teachers, volunteers, mentors, facilitators and community-based professional staff to work comfortably in either in or out-of-school settings.

Intersection of Formal and Informal Learning Environments

A larger learning ecology must, by definition, be interdisciplinary in many ways, and we found particular need to focus on the intersection of in-school and out-of-school learning environments. A consistent theme at both STEM Workshops is that there exists a wide gap between how students learn in and out-of-school, and this gap is only widening. We believe that a viable, sustainable learning ecology must find ways of successfully integrating in and out-of-school learning.

We were particularly interested in how the existing boundaries between in-school and out-of-school learning can be broken down. We acknowledged the learner-directed, project-based inquiry embodied in such movements as the “maker-culture”. We also

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[6] Working Group Members: Julie Benyo, Marta Civil, Andy diSessa, David Hanych, Margaret Honey, Sharon Lynch, Bill Neufeld, Brian Smith, Didem Taylan and Adam Z. Tobin.

[7] See: http://www.mathcurriculumcenter.org/PDFS/ReflectionSTEMblueSky.pdf

recognized that STEM content, particularly technology and engineering, is embedded in these activities, yet rarely do these activities directly correlate to specific STEM content, and we currently have no way to formally assess what STEM content learning is actually taking place. Those of us in the informal science education field have a strong, intuitive sense of the learning engendered by such activities, but our formal education system has no means of assessing or validating these activities from a STEM content perspective.

As Mike Haney pointed out, if members of the formal education community (i.e. curriculum developers, teachers, policy makers) don't find ways of somehow validating out-of-school learning, it will self-validate, and quite possibly in ways that are not consistent with in-school curricula. If schools are to participate in a larger, more integrated learning ecology, two critical areas for research and development must be addressed: 1) How to introduce some form of STEM curricula into informal learning environments, and how to introduce it in a way that honors student agency, student-directed learning and does NOT transform these environments into schools; 2) How to recognize/validate informal learning from within the formal education system. We suggest that if we are to fully realize the potential of this larger ecology of learning, in-school and out-of-school learning cannot be as cleanly bifurcated as they are now.

What are the Barriers?

The most challenging barriers are not technological, they are largely not fiscal, rather they are barriers of infrastructure, professional development, and culture. The tools, curricula, technologies, materials and even teaching professionals of in-school and out-of-school environments are currently developed in near complete isolation from one-another. Tools, materials and professional development programs that bridge the boundaries between formal and informal learning environments are necessary. For example, we talked specifically about the need for technologies that work well for both in-school and out-of-school environments. These tools would be built upon core functionality that is then extensible, customizable, and subvertable enough to adapt to multiple environments/settings.

More than anything, we need to create the right conditions for a *willingness* on the part of both in-school and out-of-school educators to work with each other. With regards to in-school environments, attempts at integration in ways that pose any additional challenges in the classroom will not be well received by teachers. With regards to out-of-school environments, we must not integrate in way that makes out-of-school environments begin to feel like a conventional school classroom. Successful integrations will take into account real challenges on the ground, directly addressing issues of infrastructure and culture, and directly addressing existing needs of schools and teachers. One suggested approach is that of partnership, asking this question of schools and classroom teachers: "What can we help you with?" That is, informal communities should be positioned as resources for in-school educators. Particularly from the standpoint of the teacher in the formal classroom, how can participation in a larger ecosystem support them in the classroom as opposed to creating additional challenges? Conversely, in what way could the introduction of STEM curricula build specific content understanding within the context of student-driven, project based learning, without transforming what is already fun and engaging work into something dry and boring?

We talked about the immediate possibilities to build relationships between formal and informal professionals. Sharing of tools, materials, technology, and even professional staff will build bridges. We could begin immediately by finding ways of getting members of the larger community into classrooms and facilitating movement of teachers out of the classroom and into the Cultural Commons. We recognize that professional development is a key component to making these programs successful, and we see these types of exchanges as a potential first step in the professional development of teachers. A logical next step would be to professionally develop teachers/educators/facilitators so that they are natively comfortable in both in-school and out-of-school educational settings.

Directions for Research and Development

1. *What are the existing boundaries between formal and informal learning environments?*
   - Why are they there? How can they be bridged?
   - Which aspects of boundaries must be maintained and why?
   - What ongoing infrastructure, systems, culture reinforce this boundary?
   - How persistent/universal is boundary? Are there any examples of successful collaborations across boundary?
2. *How can distributed/integrated educational communities be initiated and sustained?*
   - What universal characteristics of distributed/integrated communities would lead to feasible/replicable/scalable/sustainable models and how can they be developed?
   - What are the core elements that successfully connect/unite a great multiplicity of learning environments? What pedagogy? What systems? What assessment? What curricula?
3. *What curricula/activities need to be developed in order to effectively bridge formal and informal learning environments?*
   - How can formal curricula be effectively introduced into informal learning environments?
   - What would be an appropriate selection of subject matter from formal environments that would work well in project-driven informal environments (without forcing a school-like environment)?

4. *What models can be developed that allow for the ongoing integration of emerging technologies into learning environments?*

5. *How can access for underrepresented students be maximized by bringing collaborations into their own communities – leveraging funds of knowledge from within the community?*
6. *How can students, community members and community-based educators be attracted to the cultural commons?*

7. *How can the validity of more distributed learning within the classroom be recognized?*
8. *How can educators foster engagement, motivation, empowerment, as pathways to STEM dispositions? How is this assessed?*

Suggestions for Initial Development

- Develop new models of materials & tools that cross the in and out-of-school boundary, tools and materials that work well in both formal and informal settings.
- Develop and pilot programs to get teachers and students out of the classroom and into community-based informal environments.
- Develop and pilot programs that introduce informal or non-professional educators into formal learning environments.
- Design and test professional development models that prepare educators/facilitators/teachers that are fluent in both informal and informal environments.
- Investigate ways to capitalize on existing technology (mobile devices, social networking, etc) for use in both formal and informal environments.
- Leverage existing programs such as community service requirements, national labs, current curriculum research and development projects to develop community-based learning environments.
- Assemble consortium of informal and formal educators, representatives from local industries, publishers, community groups, etc. to suggest next steps.

Brief Reflection

Jere Confrey, North Carolina State University

We have a short window of opportunity to prepare for, and interpret to our STEM education community of researchers and practitioners, what should occur between the impending release of the *Common Core State Standards* and the development and implementation of the new generation of assessments slated for 2015. We need to draw on the expertise of the community to identify the lessons learned both about technology development and curricular materials that can help us refine our strategic priorities during this precious interval of opportunity. Given the current state of development, it appears that we need to hedge our bets on the *Common Core State Standards*, at least in mathematics: simultaneously treating them as they are intended - a means to accomplish fewer, clearer and higher standards - and as potentially too conservative (based on their omission of adequate attention to a) probability and statistics and early algebra in early grades, b) modeling, and c) use of technology). Thus, we need to view the impending four- to five-year interval as an opportunity to 1) transition the field to common standards and 2) make good and aggressive use of the non-determined 15% of standards left to individual states, to accomplish some of our most cherished goals. The message is: we must move this agenda forward, with and in front of the proposed first generation common standards.

But before I could reflect on this challenge and discuss the components of new generation materials, I needed to clarify and express my overriding goals for education. That is, *schooling is about modeling our world, encouraging active citizenry, building opportunities for expressiveness, fostering collaboration, designing and testing solutions, and feeling engaged and empowered.*

So, the question for us jointly to consider is:

What <u>are</u> curricula in this new generation of rich and expansive access to resources and interactive technologies? What is the role of a problem sequence? How does it link to the concepts of learning trajectories? How can they help us accomplish these broad goals?

Reflecting on these issues and on the discussions and presentations over the last two days, I identified six primary components that should be addressed and researched in any major forthcoming initiative. These are identified in relation to both what we have learned from previous efforts in curricula design and implementation, and what new foci the new technological tools and arrangements afford. The six components focus on:

1. Designing and using rich problem contexts including simulations, dynamic displays, and different extensions of problems, especially as they are positioned between formal and informal contexts (in relation to the "cultural commons")

These problems should also set new expectations in terms of student outcomes, including performances, productions, and demonstrations of proficiencies. Part of the goal is to support varied levels of customization and adaptation to interests and passions.

2. Capitalizing on massive opportunities for interactions, fostering of discourse and new diagnostic and formative uses of assessment.

These opportunities contribute to "making thinking visible" and include the collection and interpretation of student ideas. The development of diagnostic assessments, built on empirically validated learning progressions, can provide instructional guidance that was previously only learned over years of reflective practice. Affordances that could be built for or into such activities include artifact galleries, communication methods, commenting capabilities and opportunities for private and public communication and display spaces. Another aspect of this component would be to support peer to peer exchange of information, posting of ideas, answering of questions and/or multiple forms of mentoring (by peers, parents, significant others, teachers).

3. Developing new means in which curricular and classroom materials can promote professional development, strengthen capacity, and share best practices among teacher communities.

Similar to some of the NSF-supported curriculum materials, this new generation of materials can provide a seamless relationship to professional development by providing a resource for teacher planning and the means to share effective approaches and to reflect on practice. The need will likely continue to increase for teachers to have at their fingertips information on student progress, learning trajectories, analyzing and interpreting data in real time. Our professional development efforts must keep pace.

4. Implementing a systems-based approach.

To a degree, these next generation technologies will involve combining components previously treated independently - such as instructional materials, assessments, and dynamic links among planning, teaching and reflection - to create a single integrated system. This can be facilitated by mutual and collaborative, cost-effective efforts to construct platforms engineered across projects and accessible to a variety of users. These platforms should be informed by up-to-date approaches to cloud-computing and promote inter-operability across a variety of devices in the classroom or at a site (e.g, database construction and tagging, identifying common tools and linking to common standards). This focus also involves the development of teacher planning tools, the construction of libraries, galleries of artifacts, records of student work, and a broad base of on-demand tools and resources. It will be critical that these platforms are built to ensure the security of data files and deal with the accumulation, access and transfer of records and results.

5. Designing for sustainability of materials and resources.

One possible scenario is that increasingly in education, services will be paid for and content will become freely available. If this becomes the case, then there is a question of whether and how to use the distinction between open sources and open access to ensure that design efforts build income streams to permit constant updating, revision and improvement of materials and resources.

6. The capability of data mining provides amazing opportunities for automatic data collection, what one group referred to as forms of "intelligent agency."

The new CIT-based systems will permit us to bootstrap to better designs, to identify both weaknesses and effectiveness in materials and assessment, and to troubleshoot various bottlenecks or sticky design characteristics. A particularly interesting question for us to consider is how the theories of curriculum evaluation might become revised in light of the new technologies. For instance, if we use the NRC model of program theory, implementation, and outcomes, how will this play out when program implementation can be done automatically by the system and when frequency of use could be correlated with student outcomes? This provokes a whole host of possibilities; it will be imperative to ensure that our research capabilities evolve with our materials and resources, and important student variables are linked to teacher and district variables to permit us to draw valid and reliable conclusions.

Finally, I would encourage a call for research and development of courses called MAD-STEM, (Modeling and Design for STEM), and for these courses to be taught outside of regular STEM classrooms. In this way, we can demonstrate what is possible, freed from the tendency towards reductive standards and/or the limitations inherent, at least to date, in large scale assessment.

Brief Reflection

Iris Weiss, Horizon Research, Inc.

Mike Haney made the point that there will be a next generation of instructional materials capitalizing on new technologies, whether or not NSF supports their development. The challenge and the opportunity for our community is to develop instructional materials that incorporate in new, technology-infused forms what is already known about effective STEM teaching and learning, and to conduct additional research to enhance the knowledge base for future development. My expertise is in research, not development, so that will be the focus of my comments, considering what has limited knowledge generation in our field in the past, and the implications for future research on instructional materials.

First, I think it is important that we be both more open and more explicit about the development process, acknowledging what aspects of a particular design are "research-based," and where the development is based on the intuition of experts. In the past, for example in the development of the national standards documents, I believe we overstated what was known, including not only elements with solid research support, but also elements where effectiveness was far less certain, or at least more conditional. Over-promising comes back to haunt us when things don't play out as we had hoped.

I recently attended an AERA session on an IES-supported project to test whether revising middle school science materials based on findings from cognitive science research will lead to greater student achievement. One of the key points was that even where the research basis is solid – for example, there is no longer any serious doubt that student prior conceptions need to be taken into account in instruction – the research is not anywhere close to fine-grained enough to guide the myriad of decisions/negotiation of trade-offs involved in the design process (e.g., how many and which learning experiences students need in order to let go of a particular misconception). As much as I appreciated that insight and the candor of the presentor in sharing it, I am not optimistic that curriculum developers will document their rationale for particular decisions, as it was clear that they already have more than enough on their plates. It would be helpful if some instructional materials projects funded by NSF or others in the future had this level of detail about the development process, and subsequent reflections from the development team about how the various decisions played out.

As our "teacher as learning guide" group described our vision, I was struck both by the similarity of our views/intuitions and by how scant the empirical support was for some of the elements of the teacher role we were suggesting. Richard Elmore's notion of points of expert consensus as "sensible propositions" came to mind; he suggests using those ideas as best bets to guide practice and at the same time treating them as hypotheses for research so future practice can be better informed. In the case of teacher as learning guide, we need to find out if in fact student outcomes are better when teachers play that role, and whether individual elements of the role as we envision it are particularly important. And when professional development efforts, including "educative" materials, attempt to prepare teachers to serve as learning guides, we need to find out if those efforts have the desired results. In particular, we need to find out what elements of educative materials are most important for producing the kinds of enactment and impact the materials designers intend, and for whom, so we can learn to maximize impact for a given level of professional development resources.

Second, we need to think seriously about the development of appropriate instruments to measure the enactment and impact of the instructional materials that are developed. At one of the early research conferences for the Center for the Study of Mathematics Curriculum, Alan Schoenfeld suggested that instead of each project focusing on assessing achievement of the specific goals of their materials, we should identify the union of the goals and assess each of the materials on all of them. Consumers would then be able to use the results profiles to choose the materials that are strongest on the goals that they consider most important. Supporting the development of such a suite of instruments informed by but separate from the instructional materials development projects would likely produce better measures and add credibility to the results.

But before we can develop instruments, we need to define the constructs we want to measure in order to generate the knowledge we seek, including characteristics of the materials, and the nature and extent of their enactment, as well as student outcomes. What do we mean by coherence, and would the focus be within a unit, across units within a year, and/or across K-12? What criteria would we use to assess the extent of alignment between learning experiences in the formal and informal sectors? What does fidelity of implementation mean in an environment that expects very different pathways for classes, groups of students, and even individual students?   And we need to consider both how to take advantage of the opportunities technology-infused instructional materials provide to improve the quality and reduce the burden of data collection, and the associated challenges of informed consent.

Finally, I hope we can take advantage of the opportunity to cumulate knowledge more effectively and efficiently than we have in the past. For example, it would be helpful if the field could come up with a set of descriptors with clear definitions for use in “coding” instructional materials design and implementation both so if something is effective we know what “it” was, and so we can begin to aggregate results across studies. Similarly, while no study is “perfect,” setting up an expectation that research proposals and results reports be explicit about how threats to internal validity are being addressed (and which ones remain), as well as the limits of generalizability of the results would help improve the quality and aggregability of research results.

Brief Reflection

Julie Benyo, WGBH

- STEM continues to suffer from a lack of focus on technology and engineering. Engineering appears to be receiving more attention in recent years. But, while a couple of states have it in their standards, it is conspicuously absent from the K-12 curriculum overall. I've heard very little discussion of technology as a content area at the two STEM Worskhops. What does it mean to be technologically literate? Is it the ability to use or consume technology? If so, our students are already there. But if it means being able to understand and create technology, then this is even more invisible in the curriculum than engineering.
- I've read that by the age of 18 a child has spent only 20 percent of his/her life in a classroom. This highlights the fact that a significant amount of a child's time is spent outside of school. How can we capitalize on this to reinforce, enhance, and extend what goes on during classroom time?
- There is a wealth of individuals, national organizations, and local groups that are working to improve STEM education during outside-of school hours. Among them are DoE national labs, NSF research PIs (all of whom have a requirement for public engagement), scouting, Boys & Girls Clubs, churches, and more—each with varying degrees of ability, effectiveness, etc. Outside of some museum representation and one person from public media (me), these voices, needs, and abilities were unfortunately absent from the STEM Workshop series. I look forward to one or more future sessions that will include these groups.
- It's well-known that many adults in STEM-related fields point to one or a few key moments in their childhood that inspired them to pursue a particular path. This may be a classroom teacher, but more often than not, it's an out of school experience. If this is the case, we need to make sure that opportunities for these experiences are ubiquitous, not just for the upper SES groups, and that they don't always require that kids come to our museums, our libraries, our television channels. How can we go to them?
- Where are kids after the bell rings? The answer is different at different ages—from organized afterschool programs for elementary and lower middle school grades, to a wider range of venues for high school youth. We need a better understanding of youth culture to help inform our approaches to reaching youth outside school. How are they using social media? Saying we want to infiltrate Facebook may not be appropriate if we don't understand why kids are going there and what they're willing, and not willing, to do. Marketers of products like soft drinks know exactly how and where to target kids and build brand loyalty. Are there any lessons we can learn?
- What about parents? Many surveys and studies indicate that adolescents report parents – before teachers or peers – are most influential in their career choice. What implications does this have for those who work to improve STEM learning opportunities for students?
- One way many participants in the workshop characterized STEM education was as empowering. Can we empower as many segments of our communities as possible?

Summary Reflection

Blue Sky STEM Learning Designs for Emerging CyberLearning: The Need for a Timely, Targeted and Ambitious Investment

Jeremy Roschelle, SRI

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, the field lacks articulation of a strong and clear vision for the instructional content of networked learning. This essay argues for a timely, targeted and ambitious initiative aimed at Blue Sky STEM Learning Designs including learning progressions, instructional activities, conceptual tools, and formative assessments, etc. which are deeply reconceived for the age of cyberlearning. In particular, it argues that a new generation of Learning Designs is needed that responds to the core realization that STEM learners develop the knowledge and passion across settings that include school, outside school projects, and interest-driven informal activities.

Although it is well understood that technology enables profound societal changes, the biggest changes are often unexpected and dramatic. 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 or in theaters. When new possibilities, unmet needs, and participatory enthusiasm suddenly align, change accelerates.

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 affordability. 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 (NSF Task Force on Cyberlearning, 2008). 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, significant change toward 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 "common core state 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 are available, particularly if they are also more economical. Thus, although educational systems are ordinarily very slow to change, the funding crisis at the state level and the misfit between existing textbooks and new common standards could make the change from paper to digital instructional materials unusually fast.

Change and the NSF Context

As Joan Ferrini-Mundy reminded attendees at the beginning of the first Blue Sky Workshop, NSF thrives on the steep part of the learning curve. Once innovation in a field slows down, it is time for other agencies (as well as the commercial market) to take over. This slow down has already occurred for educational technologies and curriculum materials that NSF invested heavily in approximately 15-20 years ago, such as scientific probes, programming languages for children, dynamic mathematical representations and curriculum materials based on new visions of school mathematics and science. These tools are now readily available through commercial and open source vendors and there is less opportunity for discovery and innovation through NSF funding. It is now time for NSF to rethink funding priorities to move back to the "steep acceleration" portion of the learning curve.

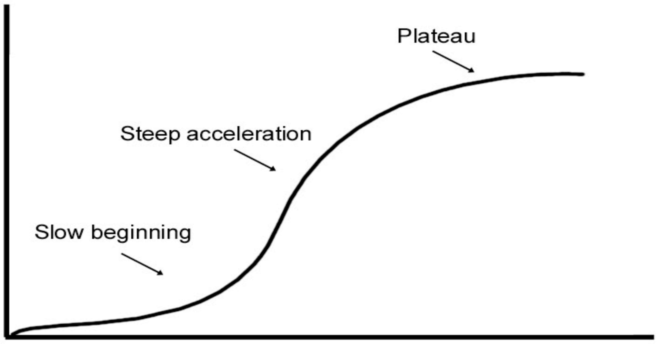

Figure 1: The Learning Curve

Getting back to “steep acceleration” in learning research requires questioning assumptions that are taken for granted in now-mature approaches. For example, educational researchers are asking:

- What can classroom spaces look like?
- How can we better allocate students’ time to stimulate deep learning?
- Is STEM learning primarily in school?
- How should the organizational struture of digital textbooks be different from paper textbooks to enable greater STEM learning?
- Can we connect learning across formal and informal settings?

Getting back to “steep acceleration” in learning research also requires paying attention to powerful trends that are clearly shaping the future. For example, the student body is now mostly Hispanic in large regions of the country. In general, student body diversity is a powerful trend and critical to the nation’s supply of future scientists and engineers. Likewise, personal and mobile technologies are here to stay; students will certainly be carrying advanced communications and computing devices everywhere they go and will expect connectivity, computation and information to be available whenever they need it. “Sequestered problem solving” is increasingly an unrealistic expectation – people will not have to solve difficult problems alone and without computational resources – leading to fundamental questions about the validity of curriculum and assessment approaches that focus on performance in isolated and information-poor settings.

Other factors in the environment are powerful and more stable. Attendees at the first Blue Sky Workshop felt certain that teachers will remain important. Curricular coherence is an intrinsic requirement for STEM disciplines, in which knowledge must be built systematically. Common standards are also likely to be a stabilizing force in years to come.

Getting back to “steep acceleration” requires paying attention to uncertainties in the environment. Budget cuts at the state level may profoundly shape schools in ways that are still difficult to determine. For example, virtual schools may blossom under budget cuts. Trends that seem important now, like the “E” in STEM, may whither given the material costs of providing sophisticated hands-on engineering experiences. We also are witnessing enormous U.S. Department of Education investments through the Race to the Top and Innovation Fund programs. The on-the-ground impacts of these investments are presently very hard to predict.

Foundations for Steep Acceleration

Launching a rocket is impossible without a strong platform and steady scaffolding. Just as the rocket needs a platform and scaffolding, so does a research and development community that seeks to move to the steep part of the learning curve. Continuing the metaphor, the “platform” could be a common knowledge base of how to use technology in learning, grounded in the Learning Sciences. The “scaffolding” could be a set of guiding values and principles that shape the paths research and development projects will take.

Although the Learning Sciences communities have professional organizations, journals and handbooks, there isn’t a grand unifying theory that neatly summarizes the foundations for the future. Nonetheless, a sense of common foundations is palpable. A number of these foundations surfaced as common beliefs during the Blue Sky Workshop, including:

- It is important to find new ways to grab and extend students’ deep cognitive engagement in powerful learning environments.
- The design of powerful learning environments must follow from detailed understanding of how students learn specific content as well as an enriched understanding of what is most important and generative within that content.
- Learning progressions and new forms of learning activities will replace the traditional “scope and sequence” and lesson plans. Progressions highlight subject matter coherence and connections, not just an ordering of topics. Explicit plans for how teachers and students will interact around content and resources are needed.
- The focus of assessments will be increasingly formative; that is, assessments that are timely, meaningful, and informative.
- A focus on metacognition, thinking, and collaboration skills can be as important as a focus on subject matter content.

Learning scientists also tend to share some common values, and these values shape projects that design new learning materials. We tend to value hands-on learning, playful environments, nurturing of students’ curiosity and aesthetics. We also tend to value deep understanding of foundational STEM content and the occasions and conditions that allow students to have wonderful ideas and the respect of their teachers and peers. Most importantly, learning scientists predominantly work in applied settings and therefore base much of what they do in first hand experiences with great teaching and inspiring learning, as well as first hand experiences with the barriers and obstacles in schools and other environments.

In addition, although not exhaustive of technology’s possibilities, there are now a number of links between technology and advanced STEM learning that have been firmly established and form the basis for research-based design principles:

1. Representations (including visualizations, simulations, modeling and graphing tools), when designed around a deep understanding of mathematics and science, can provide powerful opportunities for conceptual learning.

2. Knowledge building tools (including collaboration scaffolds, tools for visualizing shared knowledge, concept mapping tools), when designed around the deep structure of social learning tasks, can enhance students' social engagement in discussing, arguing, explaining, reflecting, critiquing, and other higher order thinking activities.
3. Interactive feedback systems (including intelligent tutors, classroom displays that aggregate student work meaningfully, and formative assessment systems), when designed to deliver feedback rapidly, comprehensibly, and helpfully, can enable student self-regulation and teacher adaptiveness.

The Opportunity

Due to a convergence of factors in school finance, common standards, and technology capabilities, an opportunity for rapid change in STEM teaching and learning now exists. Further, this opportunity is met by a desire at NSF and other funding agencies to move again to the steep part of the learning curve and utilize a body of knowledge from the learning sciences that provides a foundation and guidance to launch of a major new initiative.

This opportunity for change should not be wasted. There is broad agreement that the nation's STEM programs need an overhall 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. 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 a new medium without demanding real innovation and higher quality in the content of the materials.

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 have dominated consumers' transition to digital media. Following the analogy, it is possible that schools will 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, content and quality 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 instructional 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 Learning Designs could make the critical difference – the difference between "old wine in new bottles" and transformative applications of the new capabilities of digital media to engage students in learning some new and some old 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 and the nature of the learning environment for the age of cyberlearning?***

There are legitimate questions as to whether NSF's mission should include the production of the core materials 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 can 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 Learning Designs 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 Learning Designs that support 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 Learning Designs, 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 Learning Designs 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 Learning Designs 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 the 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 common 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.

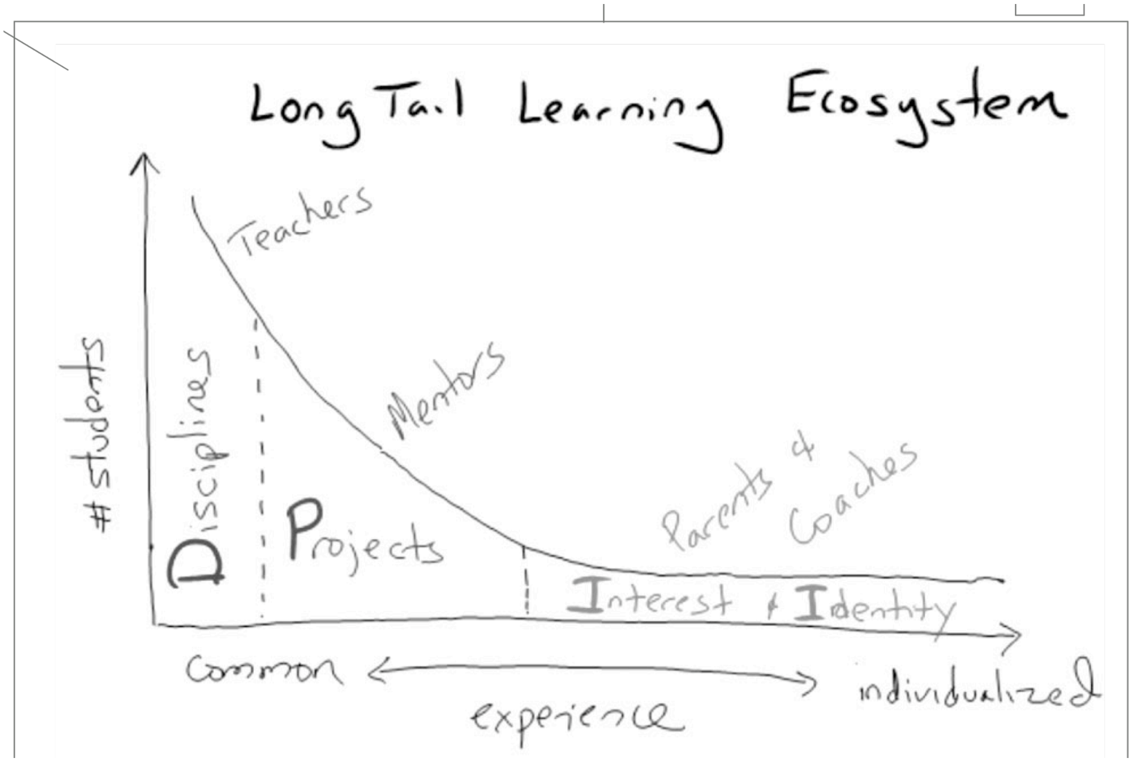

Figure 2: Long Tail Learning Ecosystem

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 Mathematics Advisory Panel, 2008; Schmidt, 2001). Although the best students might be able to learn from a bricolage of found materials, most students need to be guided through a very carefully planned and executed sequence to develop understanding and 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 curriculum. It will be more important to provide everyone with a sound curriculum (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 textbooks used currently in some high performing countries, such as those found in Singapore, Japan and Finland . 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 individuals with varying interests 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 own 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 (Neulight et al., 2007; Squire, 2007; Schaffer, 2005). It seems quite likely that the greatest learning benefit 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).

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 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 of the money placed on the tall end of the spectrum can now be more connected across the whole spectrum.

The ecosystem could be usefully organized around a "cultural commons" that aligns schools, museums (and like institutions) and homes as places of learning, while building on the unique attributes of each.

An emergent idea from the Blue Sky Workshop, articulated in the paper by Sherry Hsi (2010), describes a plan in which children's learning time is more thoughtfully balanced across school settings, after school and informal settings, and homes. The cultural commons concept challenges the community-based consortia to weave together their unique capacities to create more "seamless" learning opportunities across traditional boundaries. Cyberinfrastructure, of course, can be a key enabler for linking together activities in disparate places.

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 provide access to scientific data (highly personalized region). The result of these investments has been the community represented at the Blue Sky Workshops; an active learning sciences community with high quality research credentials that is also somewhat balkanized by the quirks of funding programs.

To date, the community has not had a mechanism to taken responsibility for their knowledge and activities as a continuum or spectrum that forms a coherent learning ecosystem.

A full spectrum, highly connected learning ecosystem perspective is 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 mathematics textbooks, but these are likely to be much like current paper textbooks but in digital form that allow for limited degrees of choice and personalization. Other companies will continue to produce highly successful games that attract a large following among youth. Nonprofit organizations will continue to sponsor engineering competitions and the like. But these efforts will not be part of 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 school teacher 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 the core content that schools are accountable for.

This community has the latent 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 funding is only available for infrastructure and does not allow cross-fertilization of the experts working on Blue Sky Learning Designs (including details of the tangible learning environment, the content, the instructional routines, the assessments, etc.). The nation needs a new generation of learning designs that coherently bridges across the cyberlearning spectrum of experiences to draw youth into STEM trajectories and foster accelerated growth in their skills and knowledge.

Some examples of research questions that a Blue Sky community, once suitably focused on the continuum of learning designs, might address include:

1. What is the nature and structure of digital STEM materials that support greater coherence in core disciplinary learning as well as in less formal, interest-driven activities?
2. How can cyberinfrastructure enable us to track (and measure) 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.

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 need to increase the capacity of all citizens to participate in an advanced scientific civilization, the Blue Sky community should seek support for structuring the content of the learning ecosystem to coherently and comprehensively support 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 standards-based 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 think innovatively about the future of STEM education. Of course, the features and structure of today's emerging cyberlearning ecosystem was not envisioned 15-25 years ago. 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 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, a Blue Sky Learning Design community could make a deliberate move to the rapid growth part of the learning curve, focused on a continuum of STEM learning experiences. 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 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 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.

The seeds of this new "steep learning curve" Blue Sky community can be found in prior NSF work: NSF has funded 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. Many suitable focus areas emerged during the Blue Sky workshops. For example, community building could focus on "thinking with data" as a broad organizing theme or "computational thinking" as another possible theme. Deep dives into particularly important learning challenges or the need to evolve tools and techniques for advanced digital textbooks could be another motivator for community building. What this latent community needs to catalyze its growth is a new ambitiously funded interdisciplinary program with enough resources and longevity to catalyze connections among different perspectives and focus on the questions of how to structure Blue Sky STEM Learning Designs 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 designs 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 common 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 already invested in the talent and knowledge base necessary to assemble the interdisciplinary communities that could take on the challenge of Blue Sky STEM Learning Designs and create groundbreaking examples that make it real. These examples are badly needed to prevent a de facto shift to digital curriculum that is simply a repackaging of paper curriculum into digital form, without 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. The nacent Blue Sky STEM Learning Designs community should organize itself to seek the funding it needs for the rapid acceleration along its learning curve that is now possible. A large, timely, ambitious investment is required. Many federal agencies might rise to this challenge, and certainly NSF - with its history in STEM learning, its desire to move to the steep part of the learning curve, and it's central mission of enhancing STEM learning – can contribute. If a suitable funding program can be obtained, the nacent Blue Sky Learning Designs community could rapidly build a powerful set of examples, research, and dissemination pieces 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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Appendix:
Workshop Participants

First Workshop (December 2009):

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Dave Campbell	NSF
John Cherniavsky	NSF
Marta Civil	University of Arizona
Doug Clark	Vanderbilt
Jere Confrey	North Carolina State University
Alphonse DeSena	NSF
Andy diSessa	University of California-Berkeley
Janice Earle	NSF
Joan Ferrini-Mundy	NSF
Jim Fey	NSF
Bill Finzer	Key Curriculum Press
Gordon Freedman	Blackboard, Inc.
Paul Goldenberg	EDC
Mike Haney	NSF
David Hanych	NSF
Margaret Honey	New York Hall of Science
Sherry Hsi	Exploratorium
Gladis Kersaint	University of South Florida
Glenda Lappan	Michigan State University
Kim Lightle	Ohio State University
Julio Lopez-Ferrao	NSF
Sharon Lynch	NSF
June Mark	EDC
Catherine McEver	Consultant/Documentor
Jim Minstrel	FACET Innovations, LLC
Bill Neufeld	NSF
Barbara Reys	University of Missouri
Chris Rogers	Tufts University
Jeremy Roschelle	SRI International
Susan Jo Russell	TERC
Gerhard Salinger	NSF
Kusum Singh	NSF
Brian Smith	Penn State University
Laurie Smith	Project Tomorrow
Elizabeth Stage	Lawrence Hall of Science
Kate Taylor	WGBH Television
Adam Tobin	Exploratorium
Peter Turner	Clarkson University
Eric Wiebe	North Carolina State University

Second Workshop (May 2010):

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Dave Campbell	NSF
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Jere Confrey	North Carolina State University
Andy diSessa	University of California-Berkeley
Chad Dorsey	Concord Consortium
Janice Earle	NSF
A.J. Edson	Western Michigan University
Joan Ferrini-Mundy	NSF
Jim Fey	NSF
Brad Findell	Ohio Department of Education
Bill Finzer	Key Curriculum Press
Paul Goldenberg	EDC
Mike Haney	NSF
David Hanych	NSF
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Gladis Kersaint	University of South Florida
Joe Krajcik	University of Michigan
Michael Lach	U.S. Department of Education
Glenda Lappan	Michigan State University
Kim Lightle	Ohio State University
Sharon Lynch	NSF
Alan Maloney	North Carolina State University
Jim Minstrel	FACET Innovations, LLC
Bill Neufeld	NSF
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Robert Reys	University of Missouri
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Amanda Thomas	University of Missouri
Adam Tobin	Exploratorium
Peter Turner	Clarkson University
Zalman Usiskin	University of Chicago
Elizabeth Vanderputten	NSF
Iris Weiss	Horizon Research
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