Building Modern Internet Sites for Science Education: Insights from Science, Technology, and Education

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This paper condenses insights gained during a three-day workshop of 30 experts and opinion leaders from diverse fields – including neuroscience, cognitive science, network theory, knowledge management, science education, and technology convergence.[3] The quick insights are a useful laundry list for anyone creating a modern Internet site on science education, while the deeper insights give a sense of what is on the minds of people leading the effort to use the Internet to connect people in real-time communities of common interest.

Quick Insights

Processing Science The process of science involves asking questions and solving problems. By simulating techniques and working with experimental data, students may gain insight into how scientists structure questions and solve problems. ◆ Many scientific problems can be reduced to simpler terms or systems that are easier to study under controlled conditions. Model systems may aid students in grasping key concepts in the same way they help researchers**.** ◆ Scientific problems are attacked on multiple levels of inquiry. Different approaches appeal to different kinds of learners and draw different audiences.

Involving Scientists Cultivate partnerships with professional societies, information technology organizations, universities, and funding agencies. ◆ Provide opportunities for communication between students, teachers and scientists. ◆ Emphasize sharing meaningful and useful health information. ◆ Educational outreach is encouraged or required by some federal grant programs; and educational contributions are increasingly considered in tenure decisions.

Knowing your Audience Use frequent online surveys to gain a quick picture of what your audience is thinking or to test design and navigation. ◆ Augment forced-choice questions and structured interviews with "think-alouds" that capture what a user is thinking when they interact with your Internet site. ◆ Use ethnographic research to "shadow" students and teachers – at home and at school – to understand their information needs and how your Internet site can best fit into their daily schedule of tasks.

Organizing a Network of Ideas Focus on concepts rather than details. Too many details obscure connections and diminish understanding. ◆ Use simple maps and features like zoom, pan, and filter to help students make sense of complex networks. ◆ Encourage students and teachers to tag and reuse items or to restructure the network according to their own needs. ◆ While three-dimensional views of a network may be compelling, they may not be useful navigational tools. ◆ A top-down, authoritative hierarchy organizes data and helps users see connections between ideas. Bottom-up, user-generated tagging involves users and adds value to ideas. Attempt to support both types of interaction. ◆ Make items searchable within the site and on the larger Internet. This may require strategies to make embedded or video content accessible to indexing engines.

Supporting teachers Clearly state learning objectives. ◆ Align and tag content according to national and state standards. ◆ Create "lenses" that sort content by standards and curricula, so that students and teachers can quickly find the most relevant information. ◆ Provide incomplete concept maps as scaffolds for class discussion or student projects. ◆ Provide consistent lesson plans, supporting materials, and pointers that help teachers to use content in their classes. ◆ Help teachers overcome the "fear factor" by providing professional development on how to effectively integrate multimedia tools into their instruction.

Supporting students Include ideas that appeal to both genders. ◆ Create a compelling experience by focusing on real-world problems and using multiple delivery channels. ◆ Use lists to focus attention on engaging content – such as top ten, featured, and highest-rated items. ◆ Challenge students to examine discrepant data and to confront naïve assumptions. ◆ Engage students in open-ended problems, simulations, and collaborative projects. Involve studentsby creating incentives and rewards for completing tasks

Fostering community and collaboration Value and elicit feedback. ◆ Create online discussion forums. ◆ Involve users in the creation and maintenance of evolvable items, such as lesson plans. ◆ Create collaborative environments where distant students and teachers can work together on projects.

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[1]Dolan DNA Learning Center, Cold Spring Harbor Laboratory. [2]Center for Children and Technology, Educational Development Corporation. [3]*New Horizons in Internet Development*, October 22-25, 2006, Banbury Center, Cold Spring Harbor Laboratory; supported by grants from the William and Flora Hewlett Foundation and The Dana Foundation.

Deeper Insights

I. Insights from Neuroscience Research Talks by neuroscientists stressed the process of analyzing cognition on different levels of resolution – from genes to biochemicals to cells to physiology to cognition to the environment.

Flies R US Revisited: The Case for Molecular Cognition, Tim Tully, St. Giles Foundation Professor of Neuroscience, Cold Spring Harbor Laboratory and Founder, Helicon Therapeutics

"Vertical integration of gene function" describes how gene expression initiates a series of biochemical, cellular, and physiological changes that ultimately culminate in an observable behavior. This is exactly the premise of the *Genes to Cognition* research program and Internet site. The CREB gene produces biochemical changes that facilitate the development of synaptic connections, which ultimately contribute to the formation of long-term memories. Some mutations in CREB extinguish its activity and lead to impaired memory formation, while other mutations to CREB dramatically improve long-term memory. Research on the CREB gene emphasizes the reductionist approach, in which elements of the complex phenomenon of memory formation are reduced to mutations in a single gene and studied in a simple model system, the fruit fly *Drosophila*.

Some Current Trends in Cognitive Research, Howard Kurtzman, Chief, Cognitive Science Program, National Institute of Mental Health

It is important to realize that cognition spans a range of higher mental abilities including perception, attention, learning, memory, knowledge representation, decision-making, planning, and communication. Because cognition has consequences for emotional and social behavior, it is tempting to sensationalize the results of cognitive research. For example, brain imaging might make it appear that certain regions of the brain are responsible for altruism or schizophrenia. However, imaging studies highlight the physiological/anatomical outcomes of extremely complex processes and provide few answers about the biochemical and cellular roots of cognition. Multi-method approaches combining cellular imaging with biochemistry and genetics are can help to surmount this problem. Current research emphasizes the need to examine cognition at multiple (and interacting) levels of analysis and to approach research results with a healthy degree of skepticism

Levels of Analysis in Modeling Cognition, Richard M. Shiffrin, Luther Dana Waterman Professor of Psychology, Indiana University

Our perceptual systems have evolved to perform a variety of complex inferences about the world around us. For example, the brain uses visual information from the eyes to guess what things actually look like. To understand the complex process of inference making, scientists have had to reduce the problem down to the activities of individual elements of the perceptual system and its wiring to the brain. While useful, this reductionist approach has forced most scientists to operate within a single dimension of a very narrow sub-discipline. Thus, students must be aware of the paradox of reductionism – too much focus on details may make it difficult to conceptualize the whole. It becomes important to move between different levels of analysis – both gene-up and behavior-down – and to understand the technologies and methods that allow us to infer what is going on at each.

II. Insights from Mapping and Modeling Talks by web developers dealt with the problems of organizing and displaying large data sets and multimedia.

The Knowledge Web as a Dynamic Knowledge Repository, Patrick McKercher, University of California, Santa Cruz and Project Director, Knowledge Web

The *K-Web* is an interactive network to connect thousands of people, places, things, and events in a highly associative fashion. A network system can provide opportunities to combine information in different ways and to telescope in on key features. Innovation may more likely come from exploring weak links in the network, which may be lost in top-down display. The *Wikipedia* model of collaborative learning is *en vogue* now and may be especially appropriate for sharing lesson plans. By providing different levels of permission in content authoring, web designers may satisfy teachers' demand for vetted content and overcome reluctance to use community-edited content.

Evolutionary Wisdom and Anti-Intelligent Design, Mark Buchanan, author

A structure needs to be imposed upon a network that makes it navigable. The network organization can be supplied by content experts or by a mathematical algorithm – which provides a common set of definitions that relate content items. Another solution is self-organization in a person-to-person community. For example, users of *Flickr* provide their own labels (tags) for photographs they upload to the site. Over time a stable, shared nomenclature and network structure emerge as users organize and share photos. *Wikipedia* provides another mechanism to overcome conflicting vocabulary and to capture group knowledge. A hybrid system might initially create a “top-down” network based on expert knowledge or mapping techniques. Then control might be ceded to users, allowing the network to dynamically reconstruct from community input. As Web 2.0 develops, the power and intelligence of communities is becoming increasingly evident, and the perceived need for top-down control is diminishing.

Mapping the Structure and Evolution of Science Locally and Globally, Katy Börner, Associate Professor of Information Science & Cognitive Science, Indiana University.

A finite amount of information can be packed into the text of a page, and extracting this information is labor-intensive. Maps shift the mental load from slow reading to faster perceptual processes - such as pattern recognition – that better fit our cognitive abilities. Map technology is beautiful, functional and amenable to hands-on manipulation. A map’s conceptual linkages foster understanding by making concepts tangible. For example, a map of keywords from the most highly cited PNAS papers from 1982-2001 (below) conceptualizes the themes dominating modern science research. Features such as zoom, pan, and filter can make it easier to making it easy to access, navigate and manage detail at various levels. Physical maps can be overlain to track ideas through space and time.

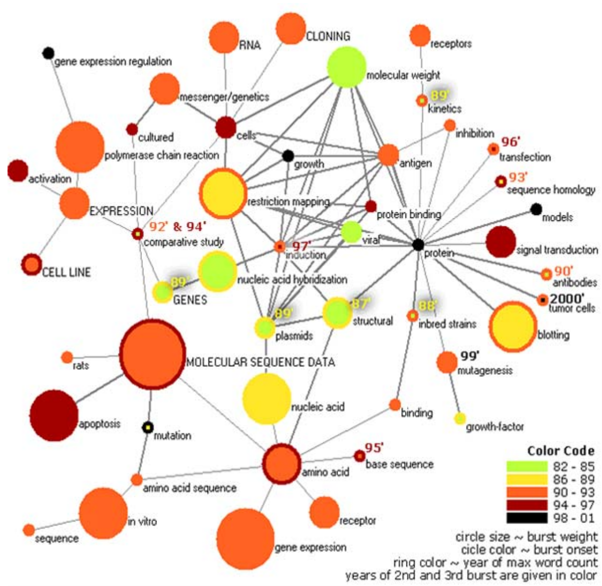

Figure 1, the most highly cited PNAS publications from 1982-2001, PNAS cover, April 6, 2004.

III. Insights from Knowledge Management

Organizations use knowledge management to identify, create, and distribute knowledge for effective reuse and learning.

The Business of Knowledge Management, John Beisty, Global Vice President of Knowledge Management, SAP AG

The goal of knowledge management is to create online resources that support effective knowledge sharing and transfer. Knowledge management support clears organizational objectives and specific outcomes – such as shared intelligence, improved performance, or competitive advantage. Knowledge managers blend sophisticated information architecture with content models/templates to create an interactive knowledge repository. By providing ready access to cross-disciplinary expertise, knowledge managers help to create formalized communities of practice. Effective knowledge management focuses on delivering useful content to the end user. Ethnographic research, which follows people through their daily work routines, is increasingly used to understand how knowledge resources can best serve the information needs of the target audience. From a design standpoint, it is critical to minimize potential roadblocks to finding the most appropriate data, such as overly embedded structure, hidden links, awkward navigation, and unnecessary mouse clicks.

A Knowledge Management Approach in Education, Lisa Petrides, President and Founder, Institute for the Study of Knowledge Management in Education

Knowledge management is organized around four interrelated concepts: data, information, knowledge, and action (DIKA). Data are specific facts or numbers, and information is data set in context that allows a person to make sense of it. Knowledge is context-specific patterns of information. Action is knowledge-seeking behavior or practice, which creates an iterative process of questioning, answering, and taking action. Information flow requires incentives to get people to openly share what they know. The use and reuse of open content may change the way people think about, and participate in, sharing high-quality educational resources.

IV. Insights from Medicine on the Web Developing forums for medical information for clinicians/researchers and the general public entails different but related problems.

Citizen Science and Patient Communities on the Web, Jason Bobe, Business Development, DNA Direct

Internet medicine and health information has evolved since WELL was founded in 1985 as an online community to provide patients articles, tips, and moral support. With the advent of dynamic page technology to generate customized information and personal profiles, patients are being empowered to take control of their disease, change their health practices, and even to identify clinical studies in which they may participate. Users can search the online community to communicate directly with other patients with rare disorders or those in the same disease stage or drug regimen. *DNA Direct* allows patients to learn about available genetic tests, to submit samples for testing, and to receive personalized test results – in conjunction with personal counseling.

Research Forums, Hakon Heimer, Editor, Schizophrenia Research Forum

The Schizophrenia Research Forum delivers high-quality scientific information and nurtures relationships among scientists by encouraging discussion of hot-button topics. Academic papers published in smaller journals – which scientists don't have time to locate and read even within their own specialty – can surface within this sort of research forum, fostering discussions that might not otherwise happen. The site also offers an interface between scientists and the public by, in effect, allowing laypersons to eavesdrop on an ongoing conversation among scientists.

V. Insights from Educational Internet Sites The construction of Internet sites for education poses numerous issues – including universal design principles, development of rich media, standard-aligned content, meaningful learning, collaboration within online environments, professional development for teachers, and sustainability.

Science Portals as Hubs for Hypermedia Discourse, Simon Buckingham Shum, Senior Lecturer, Knowledge Media Institute, Open University

Discourse-analysis and hypermedia-discourse tools can help people make sense of discussion that takes place in multiple perspectives about constantly changing subjects. These tools help uncover how meaning and comprehension come about and encourage people to collaborate to achieve mutual understanding. The tools provide an anthology of ideas in response to questions and lists of pros and cons about specific arguments. Dialogue maps act as "group memory" – capturing individual contributions to complex discussions, providing connections between ideas, increasing shared understanding about the problem at hand, and summarizing the rationale behind decisions that are made.

The Use of Cmap Tools to Facilitate Meaningful Learning, Joe Novak, Professor Emeritus, Cornell University and Senior Research Scientist, Institute for Human and Machine Cognition in Pensacola

A meaningful learning experience challenges the person to question their pre-existing knowledge and to connect pre-existing knowledge with new information. Concept maps were conceived as a means to build meaningful learning by helping students explore the relationship between concepts. *Cmap Tools* provides and environment in which students can construct concept maps, then augment their maps with graphic or tabular data, to create personal knowledge portfolios. Maps can be stored and made public to allow students to work collaboratively on projects – both synchronously or asynchronously. Cmaps provide opportunities for enhanced instruction and assessment. Teachers can monitor how student maps "grow" and change over the course of instruction or provide "skeleton" maps as starting points for further elaboration by students.

Creative Commons: Connecting Collaborators, Cooperating Communities, Crossing Chasms, and Celebrating Communities, John Jungck, Mead Chair of the Sciences and Professor of Biology, Beloit College; and co-founder of BioQUEST Curriculum Consortium

The process of science involves three key practices: problem posing, problem solving, and peer persuasion. BioQUEST simulates these practices online, encouraging students to probe scientific data and to seek answers to their questions. Open-ended and problem-solving simulations provide learning paths into extracted real-time data sets. Making best use of simulations and data sets requires professional development for teachers and partnerships with professional societies, universities, and funding agencies.

Exploragraphic: Learning Designed for Today's Tech-savvy Students, Louisa Stark, Director, Genetic Science Learning Center, University of Utah

Classroom teachers are critical to the process of creating effective and engaging learning activities. Teachers are an integral part of the *Exploragraphic* design team, helping to: clarify learning objectives, review scientific topics, develop assessment tools for student understanding, and field-test instructional materials. In this system, content is organized around clearly stated curricular priorities, with "big ideas" surrounded by foundational concepts and skills. Information is presented at several levels of complexity, allowing students to seek one that suits their information needs and to gain successively deeper understanding.

Building an Internet Site for Teachers, Christine Dietlin, Senior Producer, Educational Productions Department and Teachers' Domain, WGBH

Teachers' Domain (www.teachersdomain.org) is a free and expanding online service that presents more than 1,000 media resources selected and produced specifically for K-12 educators to augment their existing lesson plans. Content is organized by commonly taught topics in engineering, and life, physical, and earth/space sciences, and aligned with both national and state-level curriculum standards. Each media asset is contextualized with a background essay and discussion questions for teachers to implement in the course of their lesson. Teachers are recruited to manually correlate content to standards by assigning keywords from a lexicon for each standard.

What the "Participation Culture" Offers (Science) Education, John Kruper, Chief Learning Officer, Cardean Learning Group

To foster a conversational paradigm among experts, mentors, novices, and apprentices, it is critical to design online resources around a socially based view of knowledge, as opposed to an information-processing view. Rather than merely delivering content, e-Learning should cultivate a self-driven community of practice that is sustained by high-level engagement and motivation among its participants. In this context, problem-based learning and community work with authentic data support students' intellectual and social development. A formalized usability process, which may include ethnographic approaches and controlled environments, should be employed to iteratively improve e-learning courses.

Designing Games for Learning, Kay Howell, Vice President for Information Technologies, Federation of American Scientists

There is growing interest in figuring out how to tap into the relationship between children and games to provide opportunities for improved learning. Games offer insight about how to engage and motivate students, and how to help them sort through information needed to perform well on specific activities. Students can customize their learning experience by choosing and modifying the behavior of game objects. Group play and quick availability of context-sensitive answers to questions can reduce frustration and help students get over difficulties that might cause them to abandon the game. However, educators need help in identifying appropriate educational games, assessing their accuracy, and developing effective strategies for using them in the classroom.

VI. Insights from Technical Development of the Internet

How can the Internet of the future become more secure, dynamic, trusted and transparent, accessible and affordable, flexible and robust?

Internet Evolution: Technology Opportunities and Institutional Constraints, Walter Baer, Senior Fellow, Annenberg Center for Communication, University of Southern California, RAND Corporation

Although the Internet remains a loosely interconnected network of networks, it holds incredible potential as a public infrastructure. At a system level, the technology needed to support the Internet's continued evolution is developing quickly – including optical bandwidth, data storage, network and user equipment, broadband wireless, grid computing, and embedded sensor networks. At a network intelligence level, Version 6 of the Internet Protocol (IPv6) provides opportunities to build a common platform for media, communication, information, computation, and sensing applications. Ipv6 has the capability to provide information about the header of a packet as well as its content, presenting potential security and privacy concerns if these include personal information. At the software application level, there is a trend towards using the web as a platform to merge data and applications and deliver them as web services. Mash-ups and social networking sites enable users to collaborate online and add value to the available resources as they share content and data. As we continue to move into this Web 2.0 world, a balance must be struck between the structured environments that companies and perhaps educators may want to build and the loose, free-form environments that students like to inhabit.