

---

# Computer/ Information Science

*Scholars representing the field of computer/information science were asked to identify what they considered to be the most exciting and imaginative work currently being done in their field, as well as how that work might change our understanding. The scholars included Ken Birman, Jennifer Rexford, Tim Roughgarden, Margo Seltzer, Jim Spohrer, and Erik Stolterman. Scholars representing educational technology were asked to reflect upon implications for our field. They included Greg Kearsley, Tiffany Koszalka, and Ton de Jong.*

---

## Ken Birman

In the areas of computing that I focus on, the “new thing” is cloud computing: the trend to displace all sorts of computing solutions from privately owned infrastructures to big data centers, accessed remotely over the Internet, and shared with many other users. The sharing offers chances to reduce costs, often dramatically, and with a rent-what-you-need model (and rent it when you need to use it), one only pays for cloud resources that the system is actually using. This offers a kind of elasticity that allows small companies to become large overnight without making huge fixed investments in equipment and staffing to run the systems.

As you probably know, the cloud emerged from the huge interest around “apps” for the iPhone and Android phone and Microsoft Web-enabled mobile phone, and most existing cloud infrastructures reflect their origins. The cloud is ideal for Google search and maps, Amazon, Twitter, Facebook, etc.; those companies are simply renting out the extra capacity. But this also means that the technical characteristics of the cloud are closely matched to the properties required by these owners. Amazon’s cloud sharing and cloud security models are precisely the ones it needs for the *Amazon.com* shopping site and other Amazon use-cases.

The reason this matters is that as we displace socially critical computing functions into the cloud (such as operation of the power grid, monitoring home-care medical patients, operating Google’s self-driving cars, etc.) we are suddenly becoming dependent upon the cloud (indeed, on many cloud systems operated by many vendors) and on the Internet in ways that, in the past, we wouldn’t have seen. We’re entering a new world in which the power grid for the whole country

might be down if the cloud infrastructure supporting it were to fail. We’re not there yet, but this is coming within a decade or so.

Moreover, as we move individually private, sensitive information into the cloud, it turns out to be far more exposed to the public than one could have guessed. Tiger Woods found this out when his phone records became “interesting” after his wife threw him out one night. General Petraeus learned this lesson too. The cloud is making our lives very public. Soon everything we do—e-mail, phone calls, texting, important documents, financial records—all of them will be in the cloud and dependent on these cloud “models” of assurance that were created to support Google search and Amazon’s book sales unit.

So my view is that we are on a collision course with reality here: we’re committed to moving these things to the cloud, and we are really embracing the cloud with an enthusiasm rare in the history of technology. But the actual properties of the target setting aren’t what many people might expect. And if we plan to survive this experience intact, we had better wake up and do something about the limitations!

Regarding how this work might change our understanding, my research is concerned with inventing a new form of high-assurance cloud computing: an option that might address issues such as security, privacy, fault-tolerance, rapid response, and many other kinds of guarantees, all in an easily packaged form that our students can use without getting PhDs in cloud computing first, and that could be adopted by the critical infrastructure communities.

This is a hard problem: Amazon, Microsoft, IBM, Google, and others have invested literally billions and employed tens if not hundreds of thousands of experts to create the cloud as we know it today. Overcoming the limitations of the cloud is technically hard, and doing it with a fraction of the resources is seemingly impossible. In fact our approach is to use the cloud to build a better cloud: we’re creating a layer to run inside the cloud that offers stronger guarantees but employs the same building blocks that have become standard. But, even so, the problem is extremely hard.

We also make a lot of use of formal methods, and of very stringent kinds of software testing. Our hope is to make our tools public and see them widely adopted someday, as a kind of layer that can strengthen the cloud at a relatively modest incremental cost.

## Greg Kearsley

We certainly need better security mechanisms for cloud-based databases. We see students and faculty starting to use them extensively for their class work but without any consideration for privacy or confidentiality issues. I am unaware of any malicious use of such materials, but I could imagine the potential for large-scale havoc.

## Tiffany Koszalka

As an instructional designer, I approach these wondrous possibilities from multiple perspectives: from the perspectives of (1) *technology integration*, defined as those technologies that are integrated into the activities that directly engage learners in the processes of learning; (2) *technology enhancement*, defined as the use of technologies to help the educator, teacher, and facilitator present lessons, instruction, directions, etc.; and (3) *learning environment*, defined as those technologies that are present in and support learning, like Web resources and tools that provide information, instruction, or learning engagement within the learning environment or create a learning environment such as a course/learning management systems for online or distance education environments. Also, I think about the *foci of instruction* that are influenced by new and emerging technologies—instruction (or curriculum) that supports the further development and use of new and emerging technologies (*building the technology professions*) and the competencies required by *users of the technologies* (educators who use the technologies effectively) inside, or to create the learning environment.

With these perspectives in mind, one idea that Birman's comments imply would involve *preparing and educating technology specialists* (database experts, programmers software testers, infrastructure designers, tech security experts) and *new technology entrepreneurs* (inventing apps for a variety of contexts and working with technical specialists) *working in the areas of cloud computing*. It would be prudent to design a unique curriculum for these groups that engages them in cloud computing as they learn more about how to create 'it' in a way that addresses the IT issues raised and gives them foundations in identifying needs that can be resolved by cloud technologies and associated 'apps.' This could help specialists and entrepreneurs design and develop future or next-generation cloud technologies to enhance the capabilities of mobile technologies (personal, such as phones and mobile computer devices, or attached to other devices like cars and industrial assembly line equipment) to capture, store, and share rich information among users to fulfill information needs and support problem solving.

It will most likely also be important for the technology specialists and entrepreneurs to design more effective ways to keep information 'safe' and perhaps weed out the possibility of sharing 'bad' or 'inappropriate' information—perhaps instruction on ethics. This type of curriculum might also be better provided in portals of informal informational, instructional, and learning materials within 'cloud connected hubs.' The resources in this hub might be for those who are technically sophisticated and looking for advice on a specific idea, answers to problems they are experi-

encing in their own work as professionals, explanations about an existing cloud feature, ideas and groups to test new applications in different types of cloud environments, or for entrepreneurs looking for fundamentals that can help as they take a new idea and transform it into a product design and then seek technical help for a social aspect of the hub to develop the product. The 'instructional hub' might become a repository of short tutorials (two minutes), learning objects (see Wiley, 2000), concept visualizations of cloud computer infrastructures, or FAQs about cloud computing, created and maintained by these groups of 'cloud computing designers and developers.' We are seeing this idea of *microlearning* starting to evolve in communities of professionals who are connecting with others to 'learn' from each other rather than seek workshops or formal instruction. This idea may grow to support and become part of cloud computer hubs.

From the perspective of how *cloud computing technologies influence traditional education today and in the future*, schools are already taking advantage of the multitude of apps and resources that exist. Many have been developed for specific school subject areas to engage students in learning subject matter and to help teachers and administrators communicate with parents, assess student learning, manage curriculum, etc. Older technologies have allowed educators to push content during instruction to multiple computers; with these *cloud computing technologies*, the network can be expanded to share multiple types of resources to students in any location: in a computer lab on school computers, from classrooms to a variety of handheld or laptop devices, or on a field trip through mobile technologies. Information can be made more on-demand as well as distributed and automatically updated. The learners themselves become the information capturers, interpreters, and educators to each other by transmitting images, sounds, and text resources from instructional exercises through the clouds to each other, thus providing multiple perspectives and an easily accessible database of information to review at a later time, together with the facilitation of an educator. This transforms the instructional environment from one of teacher-facilitated to student-controlled, as they determine what they need, share, ask, seek, interpret, etc.

These types of new technologies and the ability to 'grab' information from multiple places will further the need to enhance critical thinking skills in our youth. Educators and curriculum specialists will need to balance the idea of critical thinking and accessing/interpreting multiple forms of information (on demand) made available from these new tools. Learners will need to develop the fundamental and critically important higher-order thinking skills necessary to seek information and analyze multiple forms of information from multiple perspectives. This suggests modifications

to curriculum and the types of activities used with learners, especially those activities that engage learners in debriefs of what they have learned and how they support their learning with evidence. It may also suggest that assessment of learning will be much different, as there will be so many different *things* that learners will have the potential to learn. If instruction and assessment are not modified, learners will receive and not necessarily effectively assess the information, more likely leading them to confusion and potentially inhibiting learning.

### **Ton de Jong**

One of the mechanisms we know that, under the right circumstances, can really enhance learning quality is collaboration between students. The cloud enlarges students' abilities to communicate but also to share, evaluate, and re-use products of other students. In a recent project (SCY—Science Created by You) we made a learning environment in which students learn by engineering. They create a design (e.g., a climate-friendly house) and, on their way to the final design, all kinds of different "objects" (e.g., models, concept maps, data sets, artifacts, etc.). These objects are saved in the cloud and can be retrieved by other students, commented upon, tagged, and re-used in new designs. Students can distribute the design task, also, and partial solutions from different students can be compiled into one grand design. The intermediate objects and the final design can also be placed in an online portfolio, and teachers can grade the results of students. Having all these objects in the cloud provides us with a basis for whole new types of student interactions and support of new ways of learning.

### **Erik Stolterman**

Maybe, at the end of the day, the question of where data and computation actually happens does not matter. To me what is happening is a shift from computation and data to interaction and interfaces. With cloud computing we can "interface" with everything digital (and physical) via an interface. The interface will probably expand into (what I have developed elsewhere) "faceless interactions," that is, interaction with the world through things themselves and without a specific interface that demands directed attention. To me it seems fairly easy to imagine computational and data cloud solutions, but radically more difficult to imagine new potential forms of interaction.

---

### **Jennifer Rexford**

Shyam Gollakota, a recent PhD graduate of MIT, has done some fascinating research in network coding in his PhD thesis on "Embracing interference in wireless systems." This includes his work on non-invasive

security for implanted medical devices (Gollakota, Hassanieh, Ransford, Katabi, & Fu, 2011) and his work on Zig-Zag coding (Gollakota & Katabi, 2008).

Michael Walfish at UT Austin has some exciting recent work (at the USENIX Security Symposium and a Cryptology ePrint) that makes past theoretical research on PCPs (probabilistically checkable proofs) many orders of magnitude faster, to the point these techniques can be used to perform computation securely on untrusted platforms, such as the cloud.

The OpenFlow and Software Defined Networking work at Stanford, Berkeley, and Nicira is turning the networking industry on its head, by moving the control of networks from closed, proprietary software that runs on individual network devices to logically-centralized software that uses open interfaces to the packet-processing features on the devices. Google now runs its private wide-area network using OpenFlow, and many campuses and data centers have deployed the new technology.

The network coding work challenges the prevailing wisdom that wireless interference is bad. The work shows how to extract information out of the seemingly jumbled mess that arises when multiple signals inadvertently interfere, or to intentionally use interference as a way to encrypt a signal.

The work on practical PCPs takes some highly theoretical work that didn't seem like it would ever be viable in practice, and shows how to make it work for real.

The OpenFlow/SDN work challenges the basic structure of the networking industry, and enables much greater innovation in networking—both in the research community and in industry—including several very successful start-up companies and a wealth of interesting research papers. The work is also drawing in researchers from other areas of computer science, such as formal methods and programming languages, to help put networking on a much stronger foundation.

### **Greg Kearsley**

There is no question we will continue to see interesting developments in networks, including personal networks that individuals can create to include people and devices of their own choosing (e.g., my friends, car, house appliances, etc.). I expect we'll see apps that allow people to create/configure their networks, which should unleash a lot of creativity.

### **Tiffany Koszalka**

With ideas of technology integration, technology enhancement, learning environments, and professional development and technology users in mind, one thing that the area of *wireless networking systems* implies is *preparing and educating technology specialists* (programmers, network specialists, network security

experts) and *new technology entrepreneurs*. Again, training individuals to work in and further develop this area may be an enterprise in itself. Most likely individuals working in these areas are already 'breaking' the rules in terms of networking systems and have fairly sophisticated technology skills. It may be that these types of specialists need better interpersonal competencies to work more collaboratively with those in other fields that take advantage of the networking technologies. This might include applications in medicine for implanted medical devices, or environmental engineering for nanotechnology sensors, or museum curation and librarianship to create context-sensitive sensors that provide visitors with information as they pass by exhibits or collections. Some of these applications already exist, at least in prototypes. The designs of these networking systems are most likely only limited by the applications in which they can be used and the technical and interpersonal skills of the specialists, entrepreneurs, and users. Training in ethics will also be important to those who will work with more advanced forms of open codes.

A second implication is *application in educational settings*. Imagine a network of sensors implanted into books, manipulatives, and other school resources related to a simple chemical reaction for a chemistry class, for example. The teacher shows a quick demonstration, pouring two clear liquids together, and they produce a green solid substance. The students then are directed to explain what happened from a chemical and physical perspective. They go off to a lab with all sorts of resources. In the lab a student stands in front of the shelf of books and hears a voice asking "What are you looking for?" On the other side of the room the students grab beakers (like those used during the demo) and go to a lab table. They put the beakers down and a voice tells them it recognizes the beakers and asks what they are trying to do. At another area of the lab students are standing near a cupboard of chemicals and again a voice recognizes them and asks what they are looking for. Through a conversation the voice helps them decide what they need for their activity and how much. There are a series of sensors in the areas of the room that engage students in describing what they are attempting to do. The sensors 'read' what they have and are doing and provide feedback. The sensors help guide the students and make sure they are interpreting correctly. It is the combination of the sensors, networking, and questioning that becomes a guide for prompting critical thinking and deep learning. Thus, the design of the inquiry and feedback systems becomes the prompts that support students' learning. The educator observes and guides; the learners think, process, act, and learn. The environment adds to the facilitation process. The learning is different from the "repeat the steps that are written as a lab activities" that we see in traditional

science instruction. It evolves to a more engaging exchange in response to learner activities and questions, in this case based on demonstration, seeking information, thinking, performing, testing, observing, and responding.

### **Ton de Jong**

Guided discovery, or inquiry, is known to be a very powerful learning mechanism. Simulations, but also virtual laboratories of all kinds, may form the basis for inquiry learning. Students who learn in these virtual laboratories often outperform students in real laboratories, and one of the reasons for this is that in virtual laboratories reality can be "augmented," for example, light beams and electric currents that are invisible in reality can be shown. One could even show the non-showable, for example, have students "feel" interaction between molecules. Physical laboratories still have advantages of which the most prominent ones are that students encounter measurement errors and learn how to deal with those and learn how to operate physical equipment. Virtual laboratories have the advantage that students' actions can be captured in log-files, and guidance can be made adaptive to the actions of students. The sensors mentioned above will enable us to have the guidance that is possible in virtual environments also available in the physical ones, and if the physical environment can also be augmented as we can currently do in a virtual one, we finally end up with a "best-of-both-worlds" situation.

---

### **Tim Roughgarden**

"Big data" is one obvious trend in computing over the past 10 years. This trend has several aspects. One is richer data collection from transactions that were already occurring, for example, transactions at a Walmart. A second is explosion of interactions that have moved online over the past 10+ years (commercial ones like Amazon, social ones like Facebook). It is of course easy to collect a massive amount of data from such online interactions.

Driven by the availability of data, computing is changing to accommodate this. New systems have been developed (Map-Reduce, Hadoop, etc.) to process in parallel massive data sets. New algorithms have had to be invented for classical computational problems (sorting, etc.) that are tailored for these new hardware systems.

With so much data one must necessarily aggregate it. This has dovetailed with an increasing trend to think about data statistically, and statistical machine learning is much more prevalent now than 10 years ago.

Commercial applications have been driving these trends (e.g., Google wants to collect data to show users more relevant ads and increase click-throughs). But

hopefully important non-commercial applications are on the horizon. For example, I'm involved in online education (see <https://www.coursera.org/course/algo> and <https://www.coursera.org/course/algo2>) and there is an opportunity to collect rich data from students watching videos (e.g., where do they tend to pause/rewind/drop out forever?) and solve problems (e.g., which mistakes are the most common?) Needless to say, appropriate analysis of such data could lead to qualitative improvements in how we teach all kinds of subjects.

### Greg Kearsley

Yes, it's intriguing to think about data mining the student performance records of a college or university system to identify good/bad teaching practices, something that I don't think has ever been done. Certainly seems doable for MOOCs. However, most learning theory is aimed at individual achievement, not the kind of collaborative, group-based work now common in online learning, so there are questions about what to measure.

### Tiffany Koszalka

Certainly there is a tremendous amount of rich information and social connectedness available to those who access the Internet in searching activities, watching television, playing with technology based games, accessing social networking resources, etc. There is a lot of information that is valuable to a lot of people and a lot of information that is not valuable to many people at all. There is authoritatively provided information and opinion-oriented information and downright wrong information. There is a lot of 'safe' information and a lot of 'unsafe' information. The list goes on. One major problem is that users of this information are not always very well educated on how to identify information that is accurate and useful and information that is not. There are also a lot of misconceptions about how the Internet works and how searching works. These become serious concerns when we think about how best to use these 'big data' for educational and instructional purposes, in both formal and informal learning environments.

With these in mind, the *explosion in data and online interaction possibilities* continues to push the ideas of collaborative and cooperative learning models that include those inside and outside of the traditional classroom. With such rich data it is important that younger learners (and lesser users) get some subject matter help when identifying and analyzing large data sets of information. I am not necessarily talking about formal data sets of numeric data, but rather engaging learners in seeking examples, non-examples, definitions, influences, facts, history, etc., of the subject matter they are learning, then together seeking understanding by sharing their interpretation, and then testing their ideas with 'know' experts or specialists.

Imagine students working together in small groups in health class, studying how a disease can spread into an epidemic. Students could be promoted to gather information from health care information databases about the disease of interest, the conditions under which it is most likely to spread, factors that lead to spread, and how fast it has or can spread and to where. Then, they can access simulations where they can manipulate the situation and see the spread of a disease across the country or around the world.

Or, in a unit of meteorology, students can be directed to study different types of weather and how satellite data helps in the creation of weather models. Again, they can access simulations or visualization tools to help them 'see' how patterns are predicted from calculation-based applications. These types of databases and simulations already exist, as do many others that compute very complex calculations from large data sets.

In education, however, the thinking behind the models and calculations is hidden. It is a black box leading students to think that by pushing a button or clicking a box the answer appears. And, often the educators are not well prepared to describe what happens behind the scenes, and students are not prepared to interpret it.

Technical specialists, those who create behind the scenes, may benefit in the future from training that helps to de-mystify the calculations and helps users to develop an understanding of how to analyze and use the data in these 'big data sets'—what the results of these simulations and calculators are really telling the user.

More advanced uses of the logic behind these data set sorters, calculators, and interpreters might be combined with social networks and thus with those who can further explain 'solutions'—those who are trained to support K-12 students, higher education audiences (faculty/student), and the general public. Or, even more intriguing would be these big sets of data combined with some level of artificial intelligence or intelligent tutor that would support users in identifying information needed to answer a question or solve a problem, analyze the data, and interpret it. Both those who would design these technology solutions and those who use them (educators) would need competencies in inquiry and interpersonal skills to work collaboratively in designing.

Imagine combined multiple large data sets being used to create virtual environments in which students can engage in exploration of different subjects within school curricula or out of their own curiosity: the immersive environment provides the tools and easy access to explore, combine, re-combine, and subtract; visualizations help students 'see' patterns; and feedback systems model interpretation and respond to questions. Big data then becomes useable and, hopefully, the environment becomes motivational, prompts

curiosity, provides assessment of understanding, and supports all levels of learners.

### **Ton de Jong**

Data sets are a rich source for learning; think of information about river tides over the ages or observations from telescopes. The big challenge here is to think of new (3-D) visualizations that help students to see the data from different angles and to observe correlations and regularities. One could even imagine a student “stepping” into the data as an avatar walking the “data space” as Alice in Wonderland and being able to manipulate visualizations by grabbing, pushing, and turning.

---

### **Margo Seltzer**

There are two main thrusts in computer science research these days that most excite me. The first is in the broad area of self-organizing or bio-inspired systems. My colleague Radhika Nagpal is one of the leaders of this field, and when I first learned of her work almost 10 years ago now, I thought, “I have seen the future.” The basic idea is to observe how biological entities, from cells to organisms, collectively get things done, and then see if we can build computational agents that use the same techniques.

Biological systems are so much better than anything we have built at handling failure, being robust to changing conditions, and amassing enormous numbers of cooperating entities to accomplish a single task. I believe that the only hope we have of building truly robust distributed systems will emerge from this kind of work.

The second area is being undertaken by many, and it is the application of machine learning to large data *corpora* to discover facts or create new knowledge (i.e., the area of “big data”). One can view any large collection of data as a lot of noise with a signal buried in it. We now have new techniques to extract that signal, and I believe that this will open up vast new areas of knowledge. Many people work in this area, and Eric Horvitz of Microsoft Research and Carlos Guestrin of the University of Washington are among my favorites.

The work in bio-inspired engineering challenges our assumption that one must leverage complexity to achieve complex behavior. The beauty of some of these biological systems we study is that they are elegantly simple, and yet, in large numbers, accomplish the seemingly impossible—think of termites constructing enormous termite mounds or two cells ultimately forming a human being.

The machine learning/big data arena, I believe, challenges our notion of how to discover new knowledge—sometimes brute force wins out over human creativity!

### **Greg Kearsley**

I still believe that development of intelligent tutors/agents that can help people learn more effectively is something we will eventually achieve, although so far we haven’t made much progress (Elliot Soloway’s early work notwithstanding). Perhaps the study of biological systems will produce some breakthroughs on this.

### **Tiffany Koszalka**

Think about the ideas within the ‘big data,’ ‘networking,’ and ‘cloud computing’ sections; now add to these technology-supported learning resources and environments and elements of learner-organizing and self-adapting learning. Students determine how much information, support, and practice they need while ‘seeing’ their own learning progress (with respect to goals that are established both by the educator based on curriculum and by the learner through exercises of goal setting—metacognitive prompts) and while getting support on how to enhance their knowledge and connect it to other key areas of learning. This is not memorizing; rather, the technology becomes more context sensitive to the learning outcomes and progress of learning of the student.

Collaborative teams who design these types of environments for learning will need to also have strongly developed competencies in teamwork and collaboration so that they can bring their own talents to bear in ways that suggest understanding of the content and technology from multiple perspectives. Education, a combination of formal and informal, for such teams would certainly also involve developing some common understanding of learning, instruction, decision making, developmental psychology, feedback mechanisms, and assessment, among other topics related to the human condition and learning. Teachers and other educators would have to develop enhanced ways to support learners in their connecting of ideas, focusing on both expected learning outcomes and exploring their own interests, and certainly in the multifaceted perspectives of assessing learning.

In the formal learning environment such technologies will need to find their place among the uses of self-study, group-study, and collaborative and cooperative activities so that learners experience both personal and social growth.

---

### **Jim Spohrer**

Curriculum Redesign by Charles Fadel—dealing with the “what” that should be taught in the age of smart machines.

ISSIP by Jim Spohrer *et al.*—dealing with T-shaped service innovators with depth and breadth across disciplines, sectors, regions.

Andrew Ng, Coursera—MOOCs that allow large

numbers of students, and therefore rapid statistical learning, rapid improvement in learning.

Sebastian Thurn—good approaches to innovative project-based learning.

Regarding how this work challenges our assumptions:

- (1) Assumption: We are smartest entities on the Planet.
- (2) Assumption: Hyper-specialization is best.
- (3) Assumption: Learning systems and pedagogy improve slowly.
- (4) Assumption: Student projects are just toys.

### **Greg Kearsley**

In general, our present models and theories of learning don't embrace the potential of current/emerging technology. Project-based learning and games/simulations are a good example. We know these are highly effective learning methods, but they are uncommon in classrooms at any level. Why?

### **Tiffany Koszalka**

Perhaps what is emerging is a time when 'what should be taught' will become much more simplified—back to the basics of reading and arithmetic. Reading will become more complex with the advances of technology. We already have many more symbols beyond the alphabet that we use in our communications through everyday technologies (text, images, sounds, etc.), and we have calculators (all kinds) that can compute numbers and patterns among other forms of symbols (e.g., text, images, etc.). However, we still need to prompt learners to understand basic numeric functions, to identify patterns, and to understand calculating. Science, writing, language, social/cultural studies, etc., may be reduced to reading and arithmetic. The smart computers then become the tools upon which learners, with reading and arithmetic, can design their own curriculum based on explorations of existing careers, interests, curiosities, etc., and design their own careers based on developing understanding of problems within the global world. The learners shape their own knowledge; the technology provides a majority of the inputs, including information from published resources, and through social networks (ask-a-question type systems, conversation tools, etc.) and observation tools (windows to specific aspects of the world, work environments, etc.), as well as presents inquiry prompts to engage learners in explorations, connecting ideas, finding answers to their questions, developing patterns to their study habits, etc.

One of the challenges in education (both for youth and adults) is in the capabilities of those who lead and those who are at the heart of facilitating learning (teachers), those who support learners (parents, spouses, etc.), as well as the learners themselves, to break the

old paradigms of teaching and learning, to try to incorporate technologies into these paradigms (see Stead, 2006), and to create new, flexible, purposive, contextualized, authentic, feedback/developmental-focused learning experiences—where learners use the technologies to help them learn, become more productive learners, and take responsibility for creating their own futures, and where 'teachers' truly become guides and 'instigators' of student learning.

It is also important that those in ed tech research collaborate more fully on interdisciplinary teams as leaders and practitioners to take ideas beyond individual research studies to large-scale implementation with these new cloud, networking, social networking communities, etc. The ability to go large-scale with implementation is greatly increasing. Unfortunately, it seems that the human condition (inability to agree on goals or techniques that will help learners) is generally a mechanism that slows progress and change.

### **Ton de Jong**

Using self-organizational principles most directly fits with learning in teams. If students collaborate on a certain task, a network analysis of their interaction behavior could be used to provide them with the most adequate and appropriate task at some point in time. Even without noticing that they are observed and guided, students will encounter just that information or challenge that fits the best in time and in relation to the work of other students, in this way ensuring an optimal learning space.

### **Jim Spohrer**

In the age of cognitive computing, more and more intelligence tests will be "passed" by intelligent machines like IBM's Watson, which is currently able to "read" six million pages a second, such as the latest findings in medical journals.

In the future, students will get two grades for a course: individual grade (testing depth of knowledge, which can never reach the level of smart machines) and team grade (testing breadth and ability to work in teams, competing for collaborators, to invest time and other resources to get things done).

These two grades for every course will be for depth and breadth.

The team projects will evolve as a result of *Kickstarter.com*, *Skild.com*, *Kaggle.com*, etc., into intellectual sport/challenge competitions that lead to making a job, not taking a job.

---

### **Erik Stolterman**

There are some basic ideas that are growing today that I see as inevitably becoming core topics and also important.

The first is a realization that the best way to understand technology is no longer to see it as manifested in distinct artifacts, devices, and systems. Instead, computing and computational support are being distributed into the surrounding environment. This realization has many aspects and consequences. For instance, almost all research approaches engaged with users, user behavior, and user experience need to be changed. Instead of seeing user behavior and experience as a consequence of a particular artifact, it has to be seen as a consequence of a 'device landscape.' For instance, when technology in the classroom is studied, it can no longer be done without seeing personal devices and technology that students bring to the classroom or have access to elsewhere as part of the environment. This notion also relates to what is right now among other things called the "Internet of things." So, a much stronger orientation towards systemic thinking and analysis is needed and is already growing. This will also further along strongly influence the design of technology and services.

Someone who is doing interesting work is Malcolm McCullough. Some people in ubiquitous computing also relate to this but not necessarily in a constructive sense.

Another aspect that I see growing and is more technical is the notion of interaction without an interface. Kinect is an example of new forms of interaction that will free people from having to interact with a surface or device. Interaction will become the same as being and doing. The shrinking of devices will push such a development, since size will not allow for the kind of interactions we need, so interaction without interface will become the next thing (and is already here to some extent). There are a lot of people doing this but mostly from a technical and innovative perspective, and much less with respect to intellectual and theoretical considerations.

A third development that I think we will see is a growing resentment at doing computational activities that require us to sit in front of a device. At the same time, this will not mean that people want to say no to the technology; rather, a new field will be how to design technology that provides the function and power that technology can, while at the same time making it possible to live without having to carry and be in immediate contact with technology. I think we will see more and more technology that can be described as following Albert Borgmann's idea of "focal things" instead of being commodities. This is, of course, only something that can be seen today with a careful investigation, but I am sure it will come.

Again, no one in particular is working on this, it is more an overall emergent gestalt that I can sense.

### **Greg Kearsley**

No question the future of technology is ubiquitous computing. For example, I went skiing in Colorado last winter, and the "lift ticket" is now an RIF chip in a card

you keep in your pocket. You get scanned when you get on the lift, providing complete details of your daily skiing activities online to you and the ski industry who can data-mine it. How about we do that for education?

### **Tiffany Koszalka**

The technologies today are everywhere, even in the poorest corners of the world. It is curious how so many are physically hungry for food, yet have cell phones or handheld computing devices. It is also scary to see so many who are so focused on technology that they seem to forget how to socialize in-person; they communicate in bytes that do not necessarily represent depth of understanding but rather quick, shallow bleeps of info. Our youth seem to have such short attention spans that they have lost problem-solving abilities and seem to quickly lose patience in learning activities. I fear the uses of technology are not improving the condition of humans, but rather reducing it to bytes, and the education system pre-K though professional development is reducing learning to narrow and shallow, abbreviated responses that lack critical thought, higher-order thinking, and evidence-based solutions. No doubt that these tools are opening up advantages to those who were marginalized in education before, including those who have preferences and styles that excel through technologies, and helping the world of resources become more accessible, helping learners take more control of their learning, and helping educators and learners become more productive. However, many do not have the skills to find and assess the information they seek and retrieve, to effectively use the technologies as tools to help during learning, to understand how to reach depth of understanding and use that new understanding to problem-solve and develop competence, to become more productive in work and learning, to understand when the technologies help or hinder learning or life, or to understand the ethical issues of free access to information.

The technologies are emerging and evolving fast, and there are few who are actually looking at these new applications in terms of their capabilities to support and enhance learning. Perhaps in the next few decades we might really begin to understand how the simple computers of today can consistently support learning. Of course, by then computers will not be like they are today. But education may still look the same, that is, we are already decades behind the times.

Perhaps the question is how do we better prepare educators (pre-service and in-service) in how to adapt to the valuable aspects of new technologies? And then, of course, not just the educators, but the education system, families, social institutes where learning occurs (museums, libraries, etc.), and places where learning could occur (amusement parks, malls, playgrounds, social centers, etc.).



## Ton de Jong

The most direct way of interacting with devices and interfaces would be directly from the brain. There are already brain-computer interfaces, but they need a quite extensive set-up. Imagine that this can be done via wireless, and we could steer the application just by thinking!

---

## Other Comments

### Greg Kearsley

Gordon Rowland asked us to stretch our imaginations at little, so here are a few “wild” thoughts. I would anticipate that trends in mobile/ubiquitous computing continue to the point where most artifacts (clothing, buildings, appliances, cars) have networked intelligence and can interact with us, creating a truly distributed knowledge environment. (I wonder what security/privacy implications of that would be?)

I don't see much role for traditional educational institutions (i.e., schools, colleges) in this future, since learning will be completely on-demand, user-determined, and virtual. As for interfaces, at some point we ought to be able to read brain waves directly, so we can dispense with typing, talking, and gestures and have technology-mediated telepathy. That should present some interesting data processing challenges!

### Tiffany Koszalka

These new, up-and-coming, technologies are wonderful and challenging. The thinkers who designed and created them were most likely not thinking about education applications. Computers and cell phones were NOT designed for education.

However, creative thinkers in education domains saw some value and convinced society of their value, thus the billions of dollars invested in technologies that rarely show large-scale impact on learning, at least as defined by school systems. There is something going on, however.

These technologies and their uses are growing. You cannot turn on the television, take a walk down the street or in the mall, go camping in the wilderness, or even go to a restaurant without seeing technology in use by people of all ages, in use by the workers around you, in use by kids, adults, and even some animals.

There is something that draws a vast majority to humans to these ‘things,’ provides resources beyond our imagination only a few years ago, and keeps our attention more than anything else in history. As members of the academy, our challenge is to be the observers, thinkers, data-gatherers, listeners, and problem-solvers who collaborate with the technolo-

gists, educators, learners, assessors, and others to determine how to prepare the next generations of creators and users who can really benefit from and further develop technologies to enhance the human condition. Perhaps it is not the emerging technology that should be the focus; rather, the purposes and mechanisms of education that need to emerge before we think about how technology can become a ubiquitous and valuable part of formal and informal learning environments.

### Ken Birman

It seems to me that we've all agreed on the importance and promise of the trends in this space but are also agreeing that the biggest challenge centers on helping students get proper experience with cutting-edge computational projects and tools.

In my comments above, I singled out cloud computing as an especially promising trend, and talked about my own interests in high-assurance cloud computing. But one of the biggest barriers turns out to be that without working at a cloud computing technology company, it can be very hard to do credible experiments or even to gain experience with the key technologies.

There has been a big push to improve resources for these kinds of experiments, but for me, it continues to feel like a vicious circle: we academics seem to gain access to very slimmed down cloud platforms, and often to ones that aren't state of the art anymore, even as the industry jumps on the next really big trend. Even when we do get full access, the learning curves are terribly steep. And physically owning clouds here in the University is a very costly and unrealistic prospect. So we end up in a situation where the kinds of work we and our students can do in a credible way is very circumscribed.

This said, the frantic pace of change seems to be slowing, and I'm actually encouraged. I think the next few years will be a period of tremendous educational innovation as we all figure out how to teach the most important new technologies, and how our students can gain hands-on experience, but I genuinely believe those are both challenges we can overcome. And this puts us in a position to really start having meaningful impact on the cloud computing space.

### Jim Spohrer

Reflecting on all these ideas, what I see primarily is the short-term being shaped by MOOCs in educational technology, and the long-term being shaped by Smart Machines passing certification exams, and the need for T-shape graduates with depth and breadth (educational technology platforms like *Kickstarter.com*, *Skild.com*, *Kaggle.com*—where students work in teams to do real-world projects). □

---

## References

- Gollakota, S., Hassanieh, H., Ransford, B., Katabi, D., & Fu, K. (2011). They can hear your heartbeats: Non-invasive security for implanted medical devices. ACM SIGCOMM, 2011; <http://homes.cs.washington.edu/~gshyam/Papers/IMDShield.pdf>.
- Gollakota, S., & Katabi, D. (2008). ZigZag decoding: Combating hidden terminals in wireless networks. ACM SIGCOMM, 2008; <http://homes.cs.washington.edu/~gshyam/Papers/ZigZag.pdf>.
- Stead, G. (2006). Mobile technologies: Transforming the future of learning. In A. Pinder (Ed.), *Emerging technologies for learning* (pp. 6–15). Coventry, UK: BECTA ICT Research.
- Wiley, D. (Ed.). (2000). *The instructional use of learning objects*. Bloomington, IN: Agency for Instructional Technology and Association for Educational Communications and Technology; online version available at <http://www.reusability.org/read/>.

---

## About the Authors

**Ken Birman** is the N. Rama Rao Professor of Computer Science at Cornell University (e-mail: [ken@cs.cornell.edu](mailto:ken@cs.cornell.edu)).

**Jennifer Rexford** is the Gordon Y. S. Wu Professor in Engineering in the Department of Computer Science at Princeton University (e-mail: [jrex@cs.princeton.edu](mailto:jrex@cs.princeton.edu)).

**Tim Roughgarden** is Associate Professor in the Computer Science and Management Science and Engineering Departments at Stanford University (e-mail: [tim@cs.stanford.edu](mailto:tim@cs.stanford.edu)).

**Margo Seltzer** is the Herchel Smith Professor of Computer Science and a Harvard College Professor in the School of Engineering and Applied Sciences at Harvard University (e-mail: [margo@seas.harvard.edu](mailto:margo@seas.harvard.edu)).

**Jim Spohrer** is the Director of IBM Global University Programs at IBM's Almaden Research Center in San Jose, CA (e-mail: [spohrer@us.ibm.com](mailto:spohrer@us.ibm.com)).

**Erik Stolterman** is Professor and Chair of Informatics in the School of Informatics and Computing, as well as Professor of Cognitive Science, at Indiana University–Bloomington (e-mail: [estolter@indiana.edu](mailto:estolter@indiana.edu)).

**Greg Kearsley**, a Contributing Editor and independent consultant, served recently as the Graduate Program Director for the University of New England's online education programs (e-mail: [gkearsley@earthlink.net](mailto:gkearsley@earthlink.net)).

**Tiffany Koszalka** is Professor and Chair of the Department of Instructional Design, Development, and Evaluation in the School of Education at Syracuse University (e-mail: [takoszal@syr.edu](mailto:takoszal@syr.edu)).

**Ton de Jong**, is Professor of Educational Psychology and Head of the Department of Instructional Technology at the University of Twente, the Netherlands (e-mail: [A.J.M.deJong@utwente.nl](mailto:A.J.M.deJong@utwente.nl)).

---

# Design

*Scholars representing the field of design were asked to identify what they considered to be the most exciting and imaginative work currently being done in their field, as well as how that work might change our understanding. The scholars included **Richard Buchanan, Nigel Cross, David Durling, Harold Nelson, Charles Owen, and Anna Valtonen**. Scholars representing educational technology were asked to reflect upon implications for our field. They included **Elizabeth Boling, Andrew Gibbons, and Irene Visscher-Voerman**.*

---

## Richard Buchanan

1. One of the most interesting and promising developments in design today is the emergence of what is called “public sector” design. This is the application of design ideas and methods to problems of organizations involved in social action. Notably, it refers to the uses of design to improve the work of governmental agencies, the formation of policies, and strategies to bring citizens into the operations and services of such organizations. Participation is a central theme of this work, and the design process itself moves from the traditional disciplines of design in creating artifacts and communications—disciplines that have taken shape around the arts of grammar and logic—into new uses of rhetoric and dialectic, where the voices of those to be served are brought together with the voices of intent in policy. Whether on the small scale of local government or the larger and more complex areas of national and even international action, this emergent practice opens the door for many new relationships in designing. I have argued that this new practice is a move from first and second order design—the work of graphic designers and industrial designers—into what I call the third and fourth orders of design—the design of actions, interactions, services, and processes and, then, into the design of the organizations that provide the surrounding environments for such actions and services.

There are many players in the new forms of design that I have described, but they are not yet widely known. I think of the work of MindLab in Denmark, guided by Christian Besson, and the work of the Helsinki Design Lab, guided by Brian Boyer and his colleagues. But there are other efforts in many countries in Europe, North and South America, Australia, and Asia, including work in China. I would also note some emergent work in the United Nations and its agencies.

2. “Public sector” design is a form of interaction