MAKING SENS: SCIENCE EDUCATION NETWORKS OF SENSORS
Omron Sponsored Workshop of the Media X Program (http://mediax.stanford.edu/flash/home.html)
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Report available from: Media X (http://mediax.stanford.edu/flash/home.html) and SCIL websites (http://makingsens.stanford.edu)

A small group of leaders from research, industry, and education convened in a one-day workshop at Stanford's Center for Innovations in Learning (SCIL) to brainstorm on the use of data probes, sensors, and communication technologies in the development of innovative science education curricula. This report documents the results of a morning brainstorm and afternoon group exercises developing educational scenarios for which sensor networks would be powerful in enhancing learning content and promoting engagement in middle school, high school and college science. We are grateful to all of the creative contributors for the their efforts to explore these new frontiers and encourage readers of this report to join in making the visions that excite them in this report real. We would like to thank David Sibbet, President of Grove Consultants (http://grove.com/) for his superb rapid visualization of emerging concepts, trends, relationships and other diagrams throughout the day. These images, captured in real time during the group's work, populate the pages along with gently edited conversational contributions from the workshop's participants.

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WORKSHOP GOALS

Including Stanford faculty and leaders in the field, a design workshop was held on the prospective educational needs of environmental sensor networks that could be used for learning and educational purposes at the pre-college and college levels. The aim was to survey and advance the collective of work going on using sensors and probes in science education at multiple educational levels, in universities, not-for-profit research organizations and in industry. The workshop set the stage for establishing next steps toward defining projects for collaborative work under the Media X Network arrangements with Stanford faculty and in other co-development projects to be defined with Stanford faculty and partners in other organizations. But the report is also open for broad distribution, in hope that other innovators and researchers may be inspired by the visions expressed in these pages.

There is considerable interest in considering the types of sensors described by Omron as possible directions for this effort in sensor networks, including cameras and vision sensing, seismic, NO_2, CO_2, pollen count, water quality, suspended particles, habitat monitoring, microclimates, and contaminant flow. Our workshop included brainstorming and scenario development concerning best practices in the field of using sensors and probes in science education. We also considered other sensors than light, touch and temperature that could be used in a programmable sensors/smart bricks kind of approach like that developed by Resnick and Martin (MIT) and Eisenberg (U. Colorado).

The brainstorm and educational scenarios were designed to shed light on:

* meeting significant learning needs (important national and state learning standards in K-12), not simply "supplemental activities";
* being tremendously engaging in tapping issues and concerns that learners at these age ranges care about, and where sensor networks could serve important public concerns (e.g., biodiversity, habitat preservation, safety from pollutants in the home or school, water quality, air quality, ozone depletion);
* novel uses of sensors or probes in education or have dramatic prospects for reductions in cost, usability, and other factors;
* ideas for promising NSF or other grants to study their use in testbeds of schools and assess teacher needs and learning outcomes.

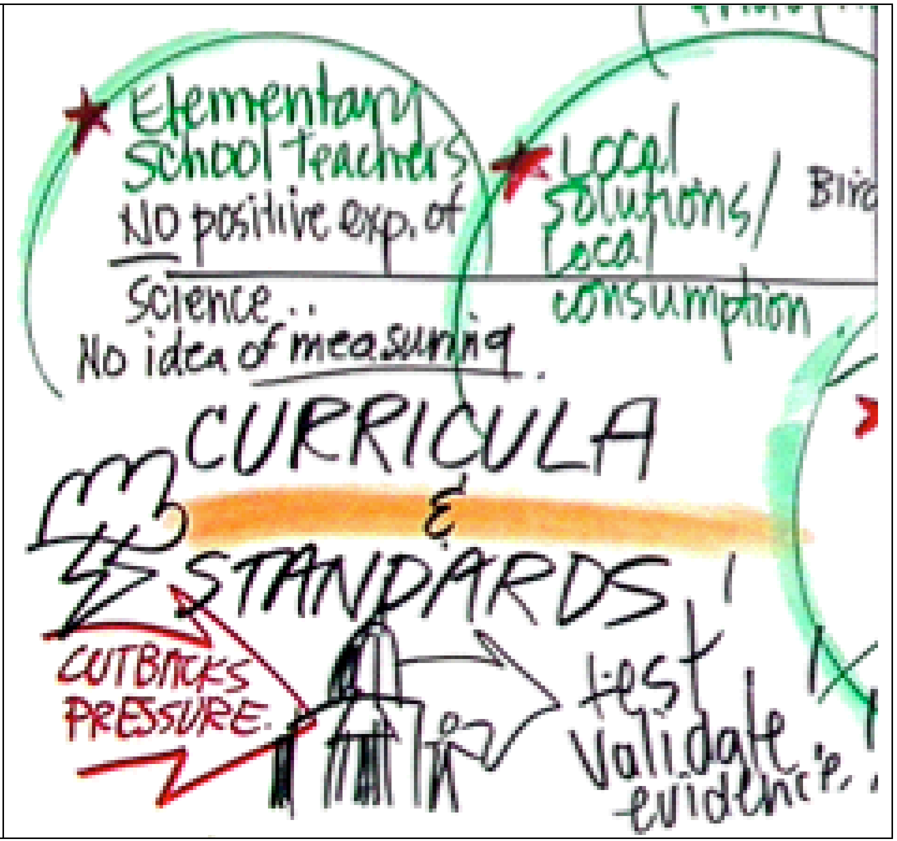
How the workshop relates to a larger program of research
Following this workshop, we would aim to identify as a group the most productive directions for continued Stanford-Omron collaborations in terms of prototype system development and "testbed" work with learners at various levels and in partnership with schools and other institutions. We can foresee substantial concept, scenario, prototype and product development for the sensors and sensor networks viewed as most productive for the science educational applications.

Workshop website
Additional information about the goals of the workshop as well as a database of resources concerning sensor networks in k-12 education as applied to diverse subject areas can be found at: http://makingsens.stanford.edu.

PART 1. Highlights from the morning brainstorm

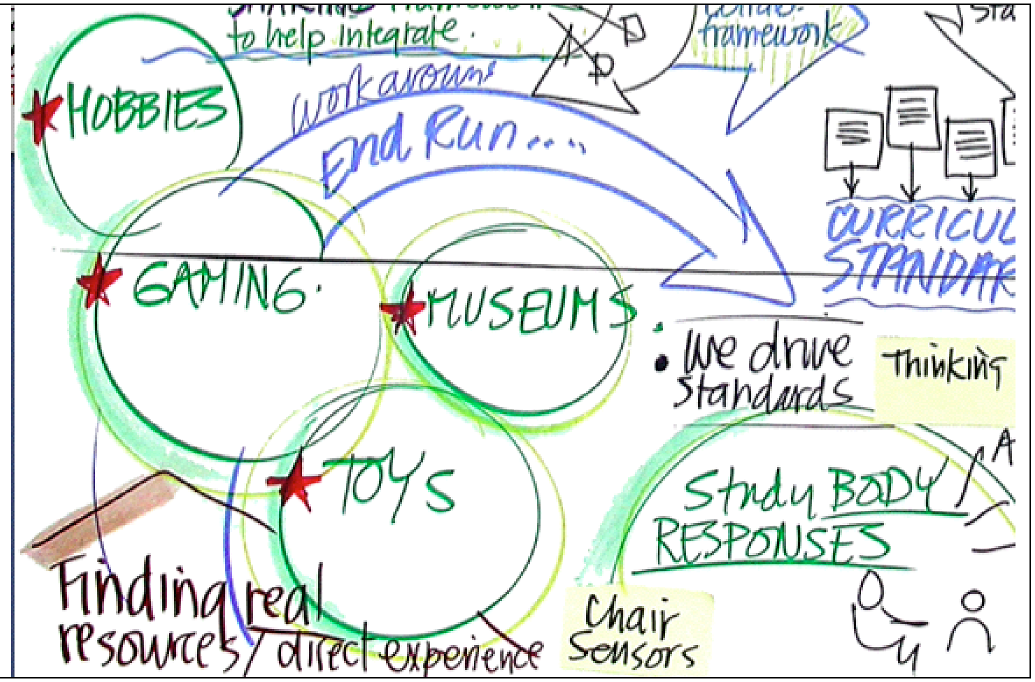
The challenge of curriculum and standards.
A major challenge for the integration of sensing networks into education is the tremendous pressure from the federal government for testing and assessment. Hence, to truly exploit the potential of sensing networks in education, we are faced with the need to build enormous infrastructure for evaluation as programs are being built. Programs without such standards will not be adopted. How can one prove that sensing networks actually produce measurable learning?

One approach to the issue is to ask how we can drive standards by showing that kids can do amazing things with a new kind of curriculum in which sensing networks play an important role. This would redefine the problem to one of assessment, not standards.



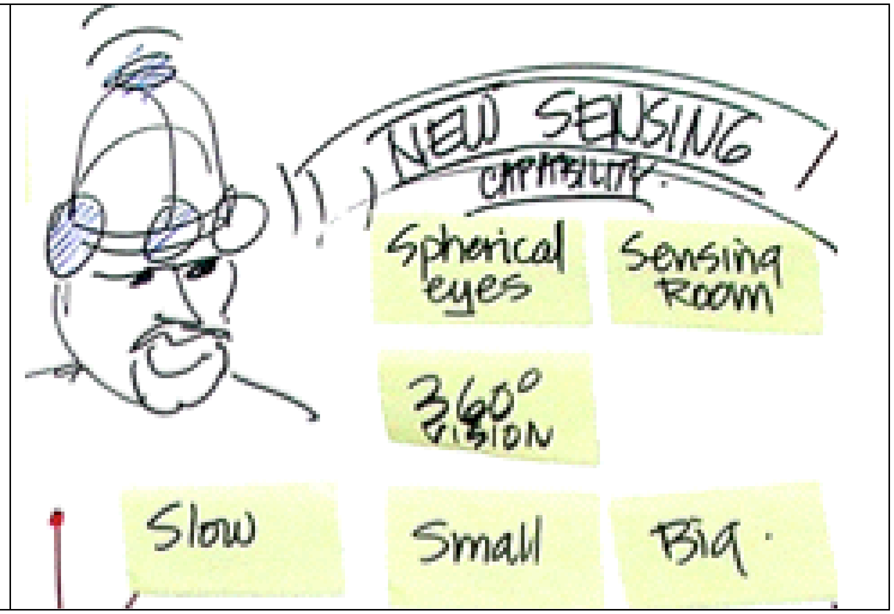
The role of informal learning

Another approach to dealing with the seemingly insurmountable problem of standards and the formal curriculum is to develop programs of informal learning. For example, develop toys, games, museum exhibits, and activities for kids in which sensors and networks play a role.



New uses of sensors for simulating visceral experiences

An exciting educational application for sensing technology allows kids to have new kinds of visceral experiences. For example, spherical lenses could be used to simulate what it would be like to have 360-degree panoramic eyes--to see the totality of a room or vista. They can also manipulate space and time scales; for example, example, being able to shift perspectives from being very big to very small or to experience phenomena that change very slowly or quickly.

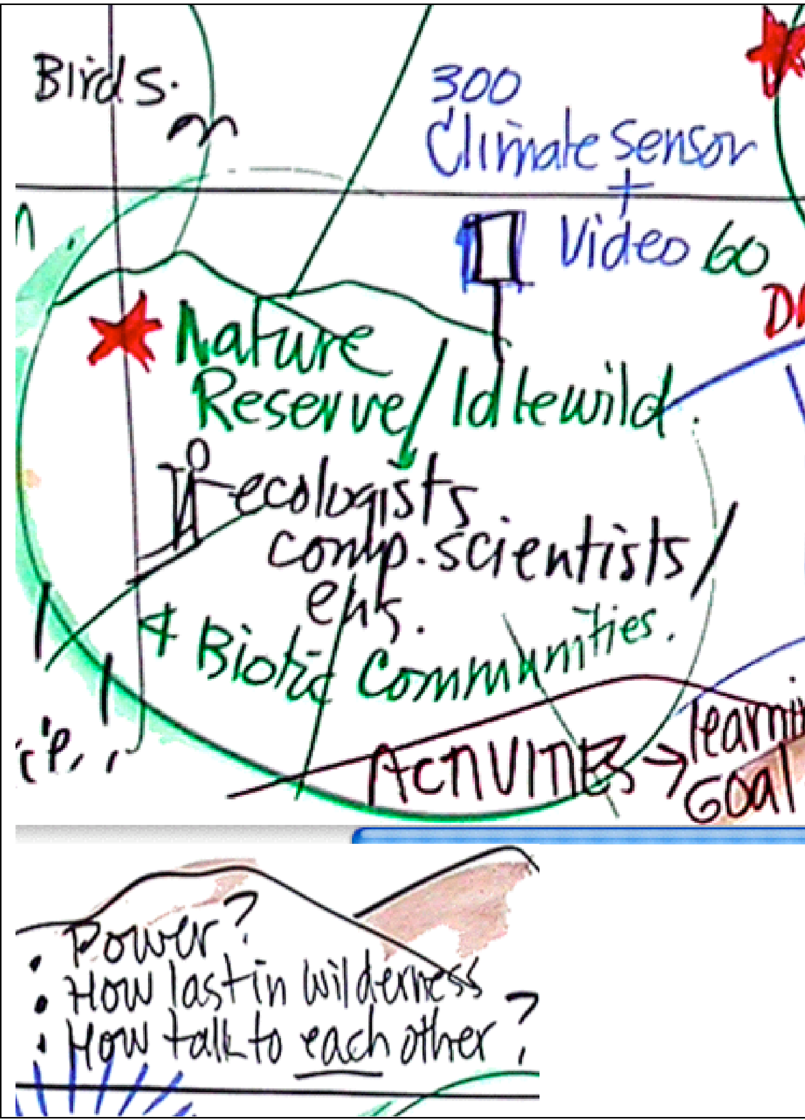


How to help teachers understand the educational potential of sensors?

There are science standards in elementary school, but a tremendous lack of trained science teachers. How can sensors help provide them with a positive experience in teaching science? Right now many teachers do not think of science as measuring anything. When we think of affecting change in the system, it's important to know whom we are trying to change. The belief is that, when given the right technologies and curriculum, kids can do great things with science.

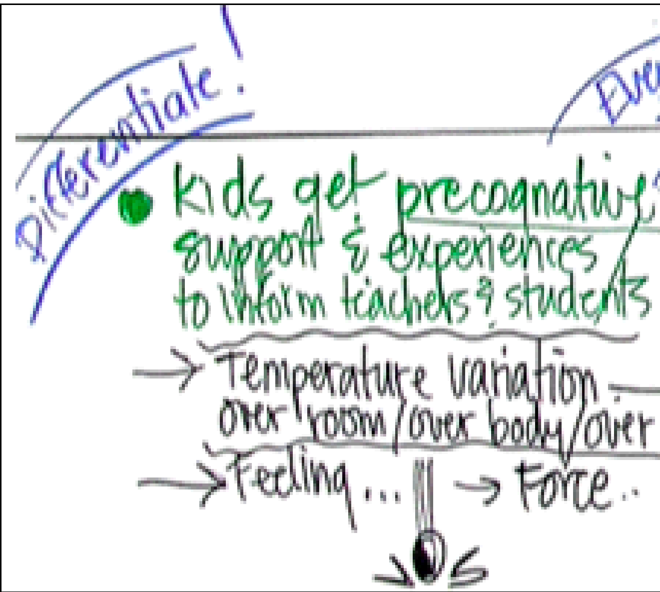
Networking sensor communities and power issues
An example of a project in progress today is CENS, an NSF Science & Technology Center based at UCLA. CENS is developing embedded networked sensing systems and applying this technology to critical scientific and social applications. The project aims to understand how these large-scale, distributed systems, composed of smart sensors and actuators embedded in the physical world, will eventually infuse the entire world at a physical — versus virtual — level. CENS systems will form a critical infrastructure resource for society — they will monitor and collect information on such diverse subjects as plankton colonies, endangered species, soil and air contaminants, medical patients, buildings, bridges and other man-made structures. Across this wide range of applications, embedded networked sensing systems promise to reveal previously unobservable phenomena. http://cens.ucla.edu/

Technical issues raised by the project include the problem of power supply, i.e., how to let sensors last in the wilderness as well as how to enable communication among the participants gathering the data.



The potential of sensor networks for pre-cognitive science

It could be that the most important use of sensing technology is not to teach young kids formal scientific concepts theories but *precognitive schemas*. This would entail using sensing technology to help kids understand in a visceral way some of the patterns that occur in the world. An example would be the notion that temperature can vary over the room or over your body. Another example would be dropping a ball and getting a visually sense of force and acceleration. A student doesn't get this kind of visceral understanding from just "being in the world" because these are undifferentiated experiences. Educational sensing networks would allow a more targeted experience of the underlying concepts.



Sensing networks and informal learning
How can we create informal programs to harness sensors and networks? For example, how can kids use sensor data to improve the local environment? These types of activities do not have to be lodged in the formal curriculum.

Sensing plus control
We should also be thinking about the technologies for controlling sensing. A simple example is the ability to control lights or a thermostat through a handclap. Other examples in the real world include Napa Valley vineyards that detect cold or hot spots and turn on fans to maintain stable temperatures. The question is how to get teachers to use this stuff in their science teaching. See NASA VINTAGE project at:
http://www.vestra.com/nasavintage/background.htm

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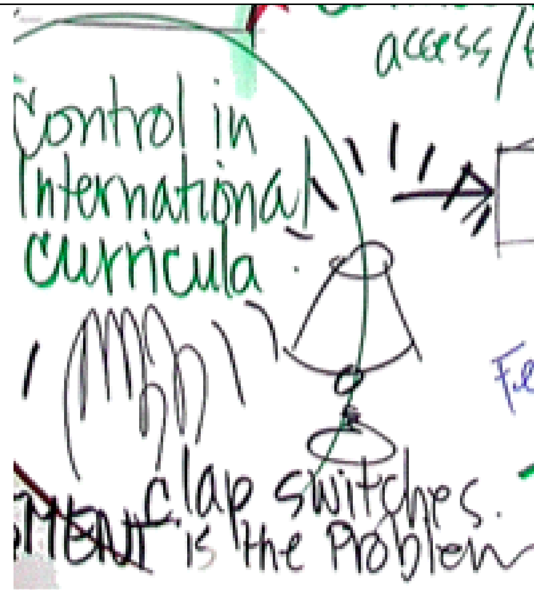
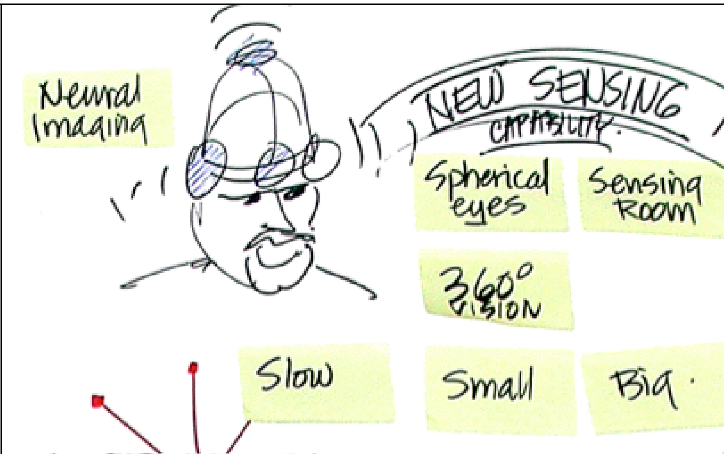
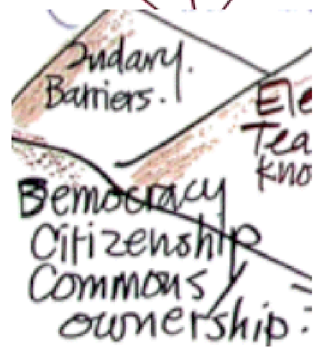
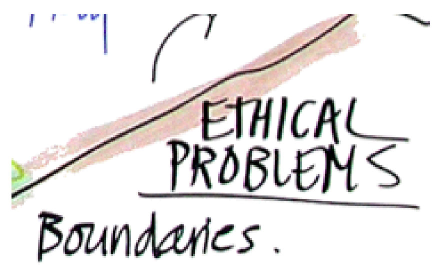


Sensing network, scientific communities and ethics

How about neuro-imaging — little thinking caps that can map activity of your brain during meetings? This kind of technology gets us thinking about new forms of democracy and citizenship. For example, in a world where your sense data are shared, there is the question of common intellectual property, an *intellectual commons*. At the limit we can ask, Are your physiological states even owned by you? There are new ethical problems raised by the possibility of recording and sharing sense data obtained from group meetings.



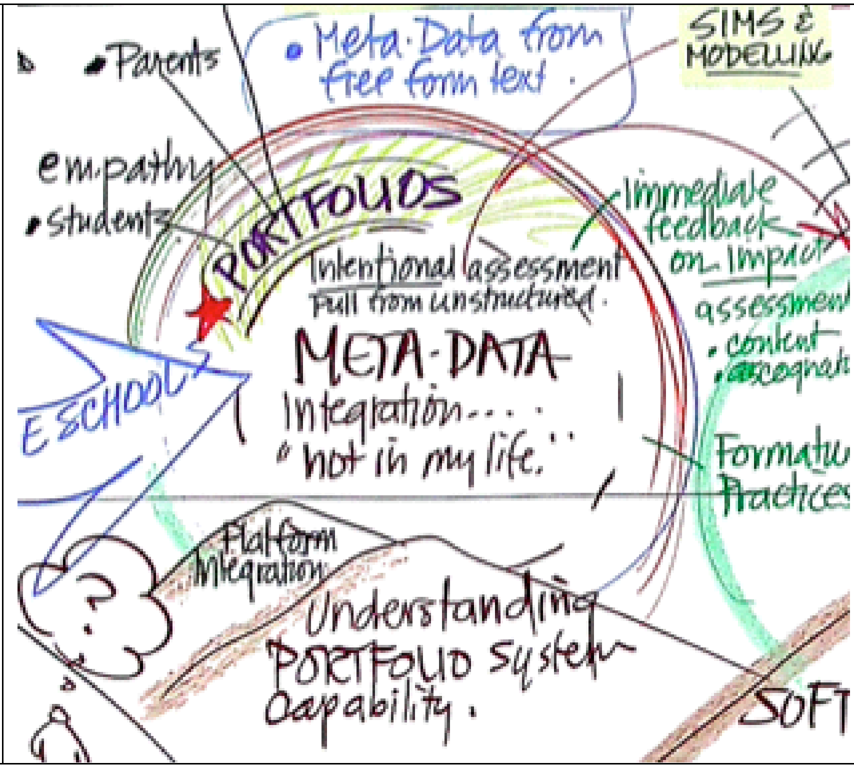


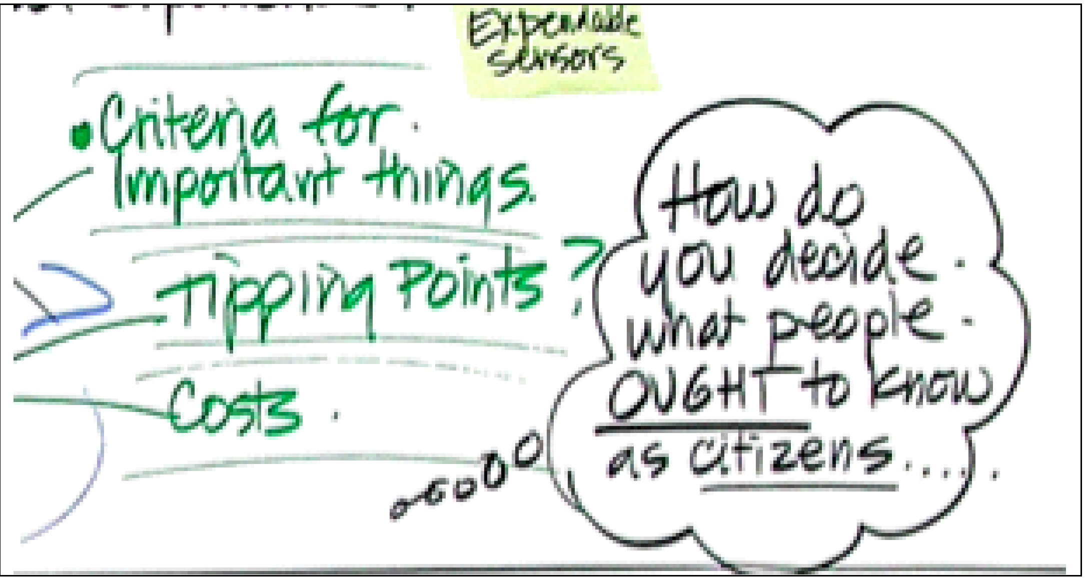


Portfolios as a "wedge"
Portfolios hold great promise as a mechanism for integrating sensing technologies in the school system. The basic idea is that an individual student would have a personal digital portfolio — in the form of some kind of electronic database — that would contain a record of projects, courses, grades, etc. A portfolio could "travel" with the student from class to class and over his/her academic career. Also, a student's portfolio can be part of a community portfolio or even a world portfolio that aggregates data from the individual portfolios. A critical feature of portfolios that make use of sensing data is that it contains not just results and data, but evidence of the student's *reasoning* process. Why did a student obtain a particular result? Or do a specific kind of measurement? Are there scientific sketches or drawings? A big opportunity is to map the reasoning to curriculum standards and assessment.

Tools for extracting meta data

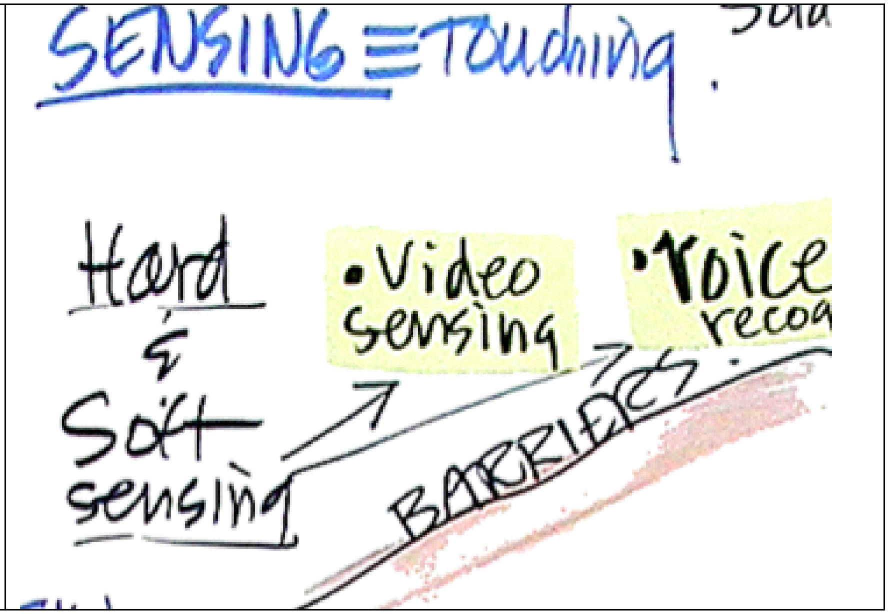
The portfolio vision cannot happen if there are no tools for processing the data that are contained in portfolios. And it is not sufficient to have an all-encompassing metadata scheme for portfolios: the artifacts are too idiosyncratic as are the points of view and the values of all involved. The development of looks that extract metadata from unstructured data and text would be key in developing a national portfolio system.



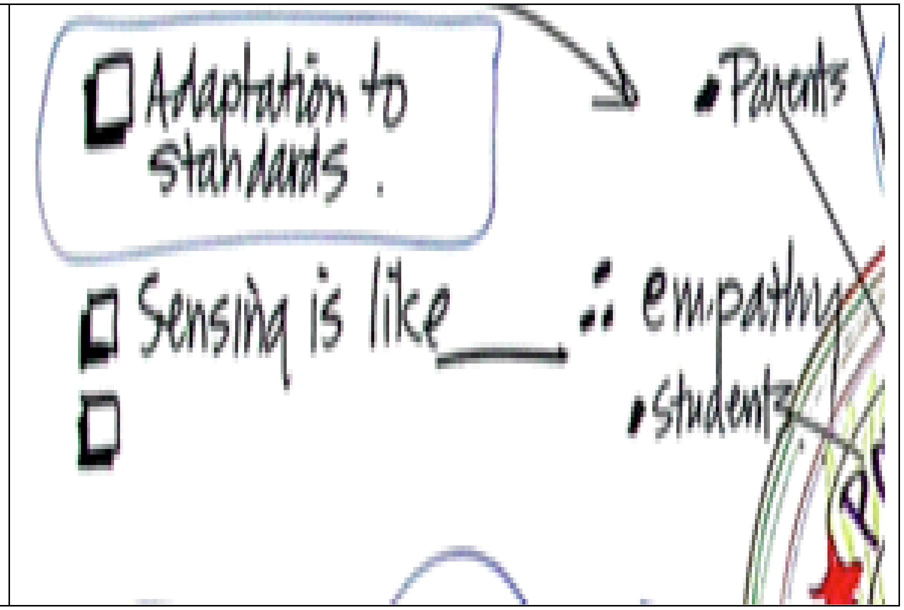
The importance of arguments A centrally important idea is that curricula and standards are a means to an end. And that end should be to test the ability of a student to persuade somebody of something. In other words to make a scientific argument or to perform other actions using evidence as warrants for supporting beliefs, in science or social science or in policy. This ability undergirds professional societies, etc. This should be reflected in Educational Testing Service exams.	

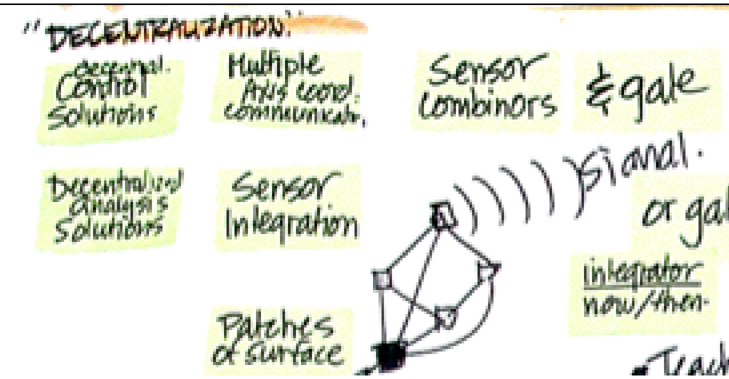
Hard versus soft sensing

Hard sensing often refers to sensors that touch something in the environment, e.g., sensing heat, light, moisture, etc. Soft sensors use algorithms to detect objects in the environment, e.g., video sensors that could be trained to track particular kinds of animals in a preserve.



Empathetic sensing and the curriculum challenge
There may be a systemic challenge with the use of sensors for "empathetic" sensing. How can we relate these experiences to a set of goals for general education, not just science? There is also a filtering process that needs to occur with teams establishing a finite set of goals or standards; we need a common vocabulary to talk about sensing in order to establish common goals.

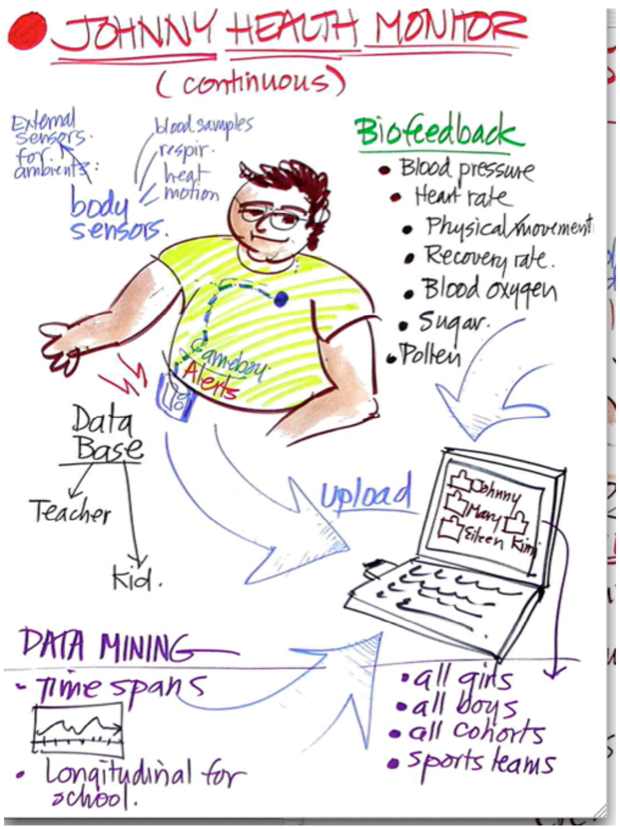


Sensing multiplexers and combiners On the technology side, one key thing that is missing is a decentralized control of sources of sense data. This involves multiplexed networks that can integrate sense data. Other aspects that are missing are what one might call *sensor combiners,* which detect signals and perform operations such as AND and OR. There are also integrator sensors. A few of these little combiners and how they combine naturally could move logic out into the edges of the sensing networks themselves. For example, you could build sensors for light *and* sound, but not sensing *both* light and sound. Also, you could imagine little surface patches consisting of sensors which could combine in a natural spatial way — for example patching together pieces of an image together using algorithms — to form a large sensor integrating information from different image sources.	

PART 2. Making SENS Scenarios

Below are the scenarios developed during the afternoon breakout sessions.

1. Johnny Health Monitor

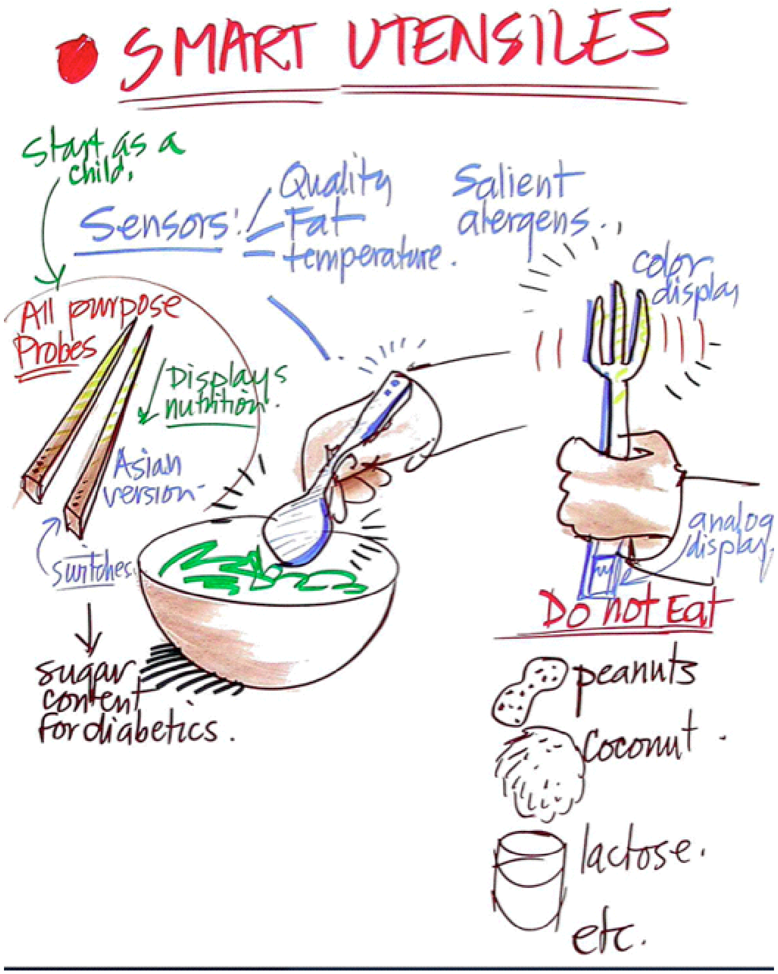


This scenario addresses the problem of how sensing devices could be used in school and informal settings to help control obesity in the country, not only for people with an obesity problem but for healthy people as well. The system could monitor blood pressure, glucose levels, and so on. It presents a *blue-sky* vision and does not focus on the technical details.

In this scenario, Johnny wears a health monitor that keeps a long-term record of his physical activity as well as certain properties of the environment in which he lives. In a school setting, lots of kids would be wearing these monitors. They would be Game Boy-like devices that would provide feedback. Each device would also upload the wearer's personal data to a classroom database so that individuals can compare themselves to their peers over time. One could also design specific activities where a student would measure his physiological states for a particular event (e.g., a race).

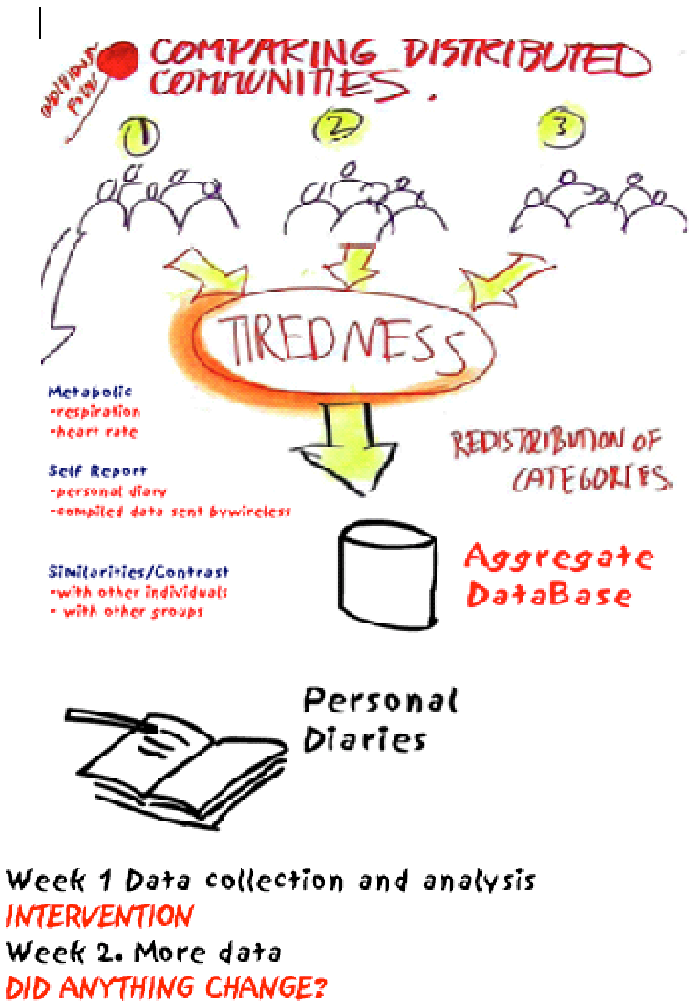
The health monitor could also be used in emergency situations to alert the school nurse or appropriate medical people that a child needs help. The system could also use kids' individual differences in physical exercise as a way to teach reasoning about data. For example, do sensors reveal differences in physiological responses for boys and girls under different conditions? Other uses include being able to quickly visualize the aggregate data to help kids think about the impact of what they eat. Finally, although there are mobile sensing devices that perform similar functions today (e.g., diabetes monitoring which control an insulin pump), they are not integrated with a network.

2. Smart Utensils



Related to the first scenario, this idea examines the role of embedded sensors to help kids understand nutrition and be aware of the consequences of their eating habits. For example, how could the sensors be used in the school cafeteria? A *smart spoon* could help someone identify how many calories are contained in what is about to be eaten: how much fat, how many calories due to fat, and so on. If the food is too hot, the utensil could change color to generate a "don't burn your mouth!" signal. These kinds of utensils could be culturally embracing (e.g., chopsticks). You could also have a *do not eat* utensil which, when inserted into food, could alert a kid to contents to which they are allergic (e.g., peanuts, coconuts, lactose intolerance). The idea is to bring nutrition and health to the forefront of consciousness by building utensils with embedded sensors.

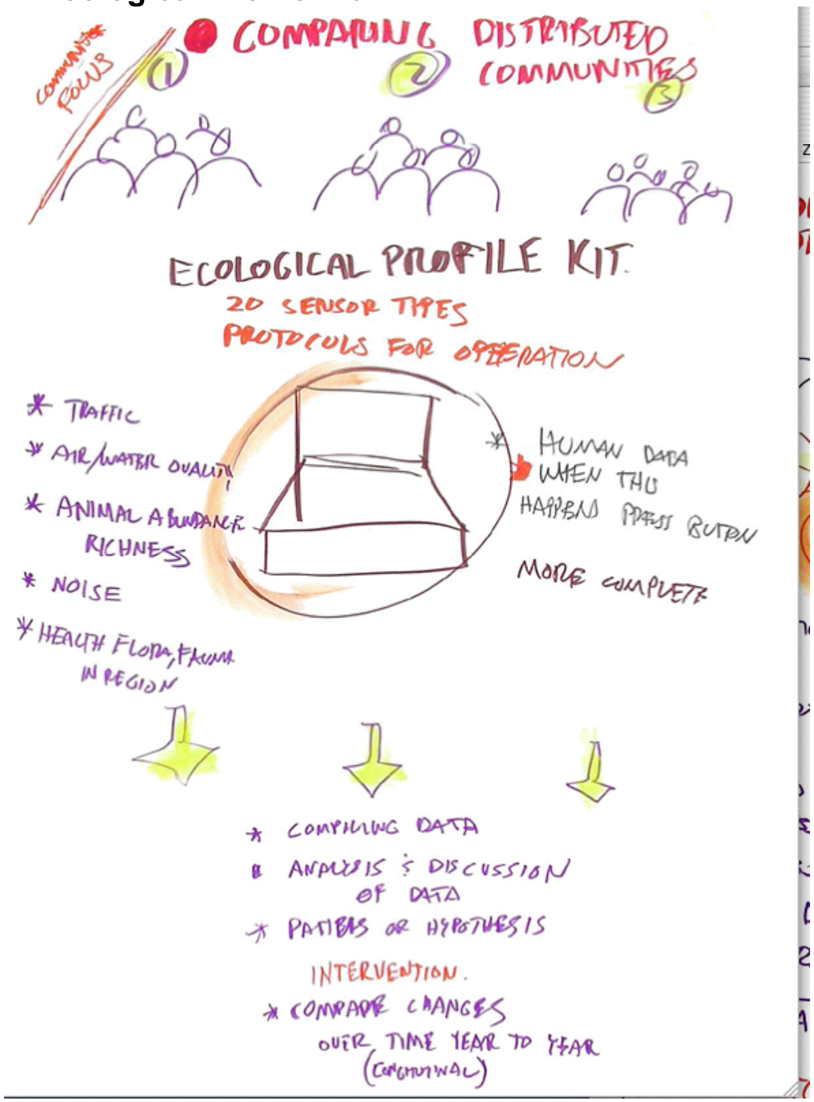
3. Comparing Distributed Communities



In this scenario three or more schools are working on common problems or games involving the community as a whole. Take the example of feeling "tired." Using a device like the Johnny Health Monitor described earlier, kids in different communities could be instrumented so that different properties could be sensed such as metabolic rate, respiration, etc. In addition to the quantitative sense data, the kids would have a means of recording qualitative or subjective data. For example, they would be able to press a button whenever they feel tired. Another possibility would to keep an electronic diary. The latter could be almost a blog that is a time-stamped self-report on how the kid is feeling. At the end of each collection period, say every one or two weeks, the data would be uploaded so that the aggregate data could be collated and visualized.

This opens up some interesting possibilities. For example, a screen could appear which compares the kid's subjective assessment with the quantitative data. "Here are the times you said you were tired, but the data say otherwise." The kids could also see visualizations of distributions of tiredness data within and between schools. This could trigger discussions across the network of the sources underlying the differences. The next phase would be coming to some consensual decisions about what to do about the tiredness issue. More nap days? More breaks? After the intervention, the students could then see if anything significant had changed over time in either the qualitative or quantitative data? Do they feel less tired as a group or individuals? Are we getting more tired as school this year as compared with last year? The system could afford inquiry for other psychological dimensions, e.g., anxiousness, loneliness.

4. Ecological Profile Kit

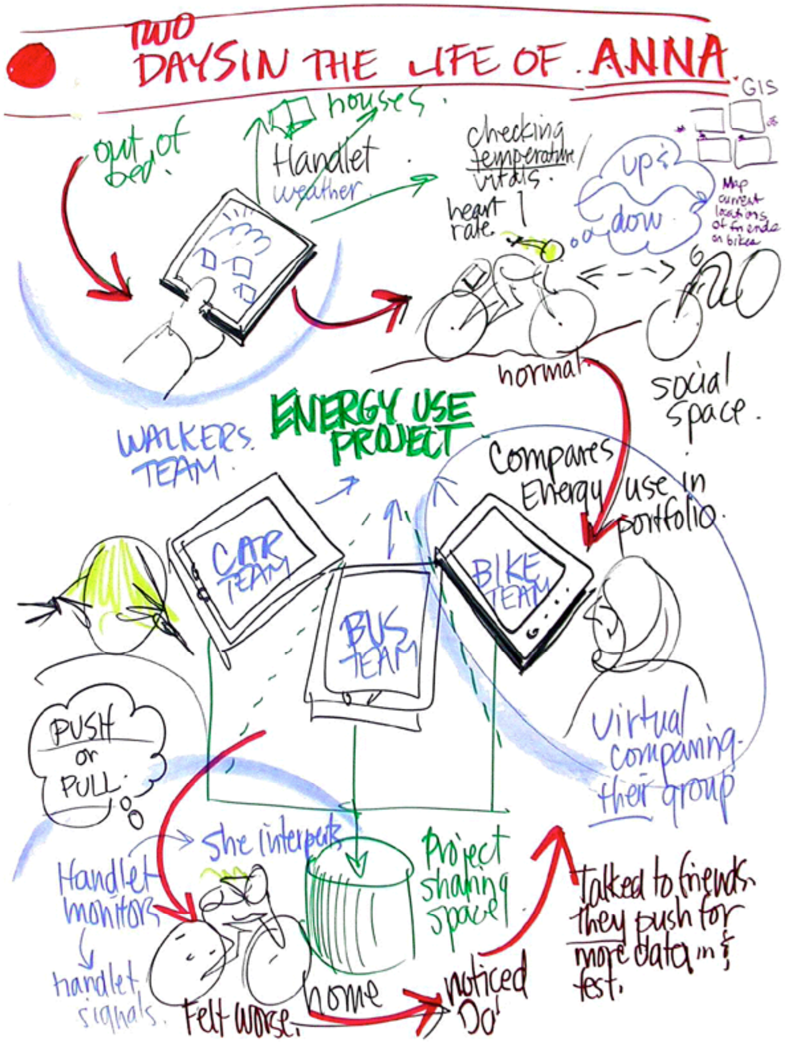


This scenario involves instrumenting communities with 20 or so sensor types that would measure air quality, water quality, traffic patterns, noise pollution levels, etc. Each school site would be responsible for creating an *ecological profile* for a 5-mile radius around the school based on the data gathered by the 20 different sensors. For example, a traffic monitoring system could be set up to count how many cars pass by a certain point every hour.

Once an ecological profile is obtained for a school, it can then be shared with other schools and used to provoke a discussion about similarities and differences.

One of the most powerful learning opportunities afforded by this technology would be the ability to compare data across communities and get feedback. This could also be used to track the effects of intervention. For example, if a new housing development is created, how would this affect the ecological profile overtime?

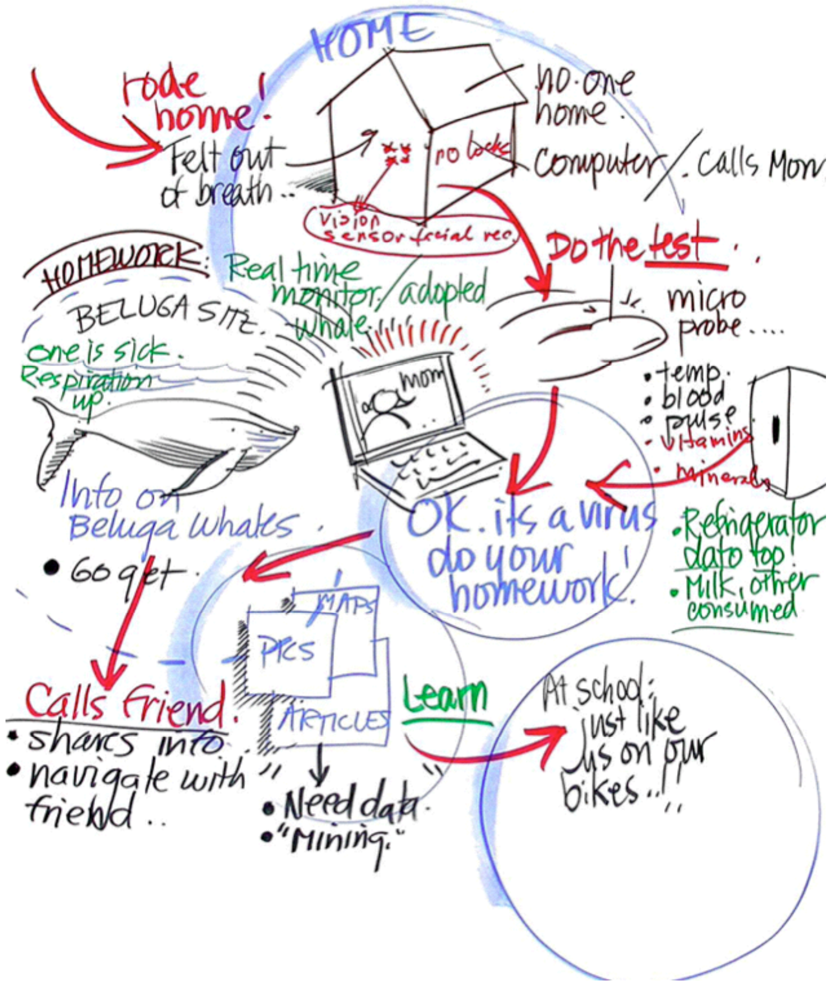
5. Two Days in the Life of Anna



This scenario would take place five years from now. The first thing to know about Anna is that she is equipped with a notebook tablet size device called a *handlet*. Handlets have some interesting properties. For example, it not only has a camera, but the camera can record different colors of the light spectrum -- red, green and blue wavelengths. The handlet also has a GPS system in it, so Anna knows exactly where she is.

Anna gets out of bed, and her handlet lets her know what time it is. And since it is part of a sensing network, the handlet can also tell her how cold it is or even how humid it is outside.

Anna is also part of a school group doing a project on energy use and transportation. She in the biking group so she really does want to know if it's going to rain later on in the day.

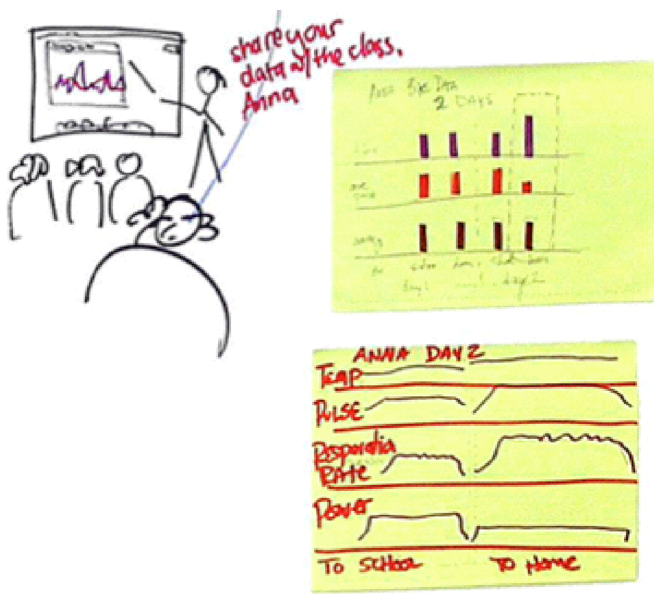


While Anna rides to school, her bike is collecting data on how much power she is exerting while pedaling and also using time to calculate her energy usage. As she pedals to school she has a *cool* bracelet version of the handlet which shows a map with the locations of her other friends on their bikes. When she gets to school she meet ups with her bike team to share their thoughts about the morning ride. Other teams are the car team and the bus team. Each team is gathering data that is all being saved in a *portfolio* system so that all the students can see and share each other's data.

Toward the end of the school day, Anna is not feeling well. She has the one-day flu. On her ride home, her heart rate is fast and she feels more tired than usual. When she gets home, she is out of breath and wants to talk to her mom, who is still at work. She can do this using her handlet that has voice and video over IP. Anna tells her that she is not up to doing any homework. Her mom tells her to stick her hand into the "doctor tester." The doctor tester uses a drop of blood to measure a number of parameters about what is going on inside her body. It also does an imaging spectral analysis of her pallor. Her mom can also see the results and determines that indeed Anna has a virus and that there's nothing to do about it but rest. But mom also insists that Anna does her homework.

Later on, Anna decides to check in on the Beluga whale project that she is a part of. The project is tracking a pod of baby whales and getting data about their physical and migratory states. She does some research on Beluga whales on the web and puts copies of relevant research in the appropriate place in her portfolio. Interestingly, this information isn't just stored locally but centrally so there is always a copy in case something happens to the handlet. This also enables her to share her research with other project members. Later that night she detects that there might be a problem with some baby whales. They used to come to the surface more often. The mother appears to be pushing the baby to the surface. She and her friends have an online discussion about the fact that both Anna and the baby whale felt sick on the some day.

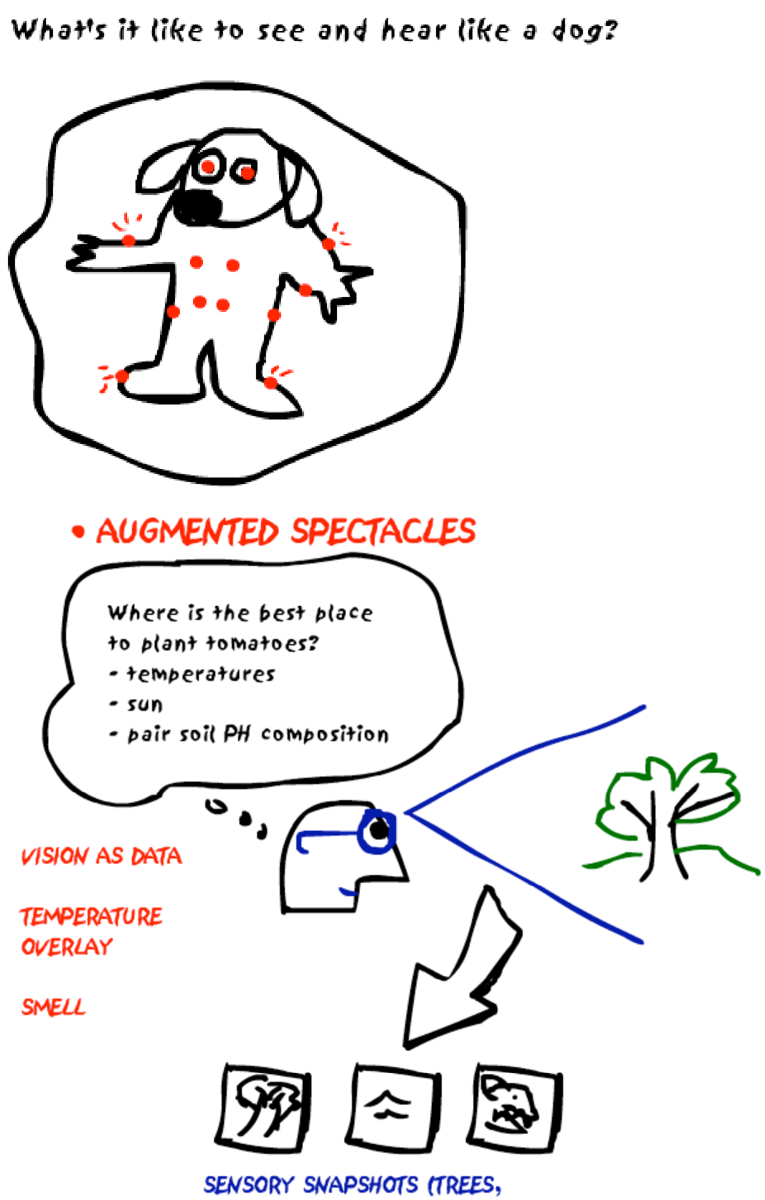
Anna goes to bed and her handlet keeps track of her sleep cycle, detecting intervals of REM and possibly bad dreams. She will be able to use this data to compare how her healthy sleep cycle compares with this particular night when she is not feeling well.



Anna feels better the next morning. Today her bike group is presenting their power usage data to the rest of the class. She shares her physiological data over the days the bike group has been keeping track of its energy expenditures. Looking at her charts, Anna’s teammates notice that her energy output level was much lower on the day when she was sick. The group then drills down to get more detail on what was wrong. They look at Anna's actual metabolic data. They see that her pulse, temperature, breathing were higher but her power usage was a lot less and it took a lot longer to get home.

The teacher's role is to provoke a culture of inquiry in the science class and she uses this instance to challenge the class to come up with some reasons that would explain this data. The students then embark on a project where they want to systematically experiment with the relationship between power usage and respiration rate, temperature and so on. The goal is to come up with general indicators of how healthy someone is. To probe this further, they need a larger pool of data. So they communicate and begin to convince other classes around the country to share their data so they can get a larger sample size for their study.

5. Sensor Augmented Costume

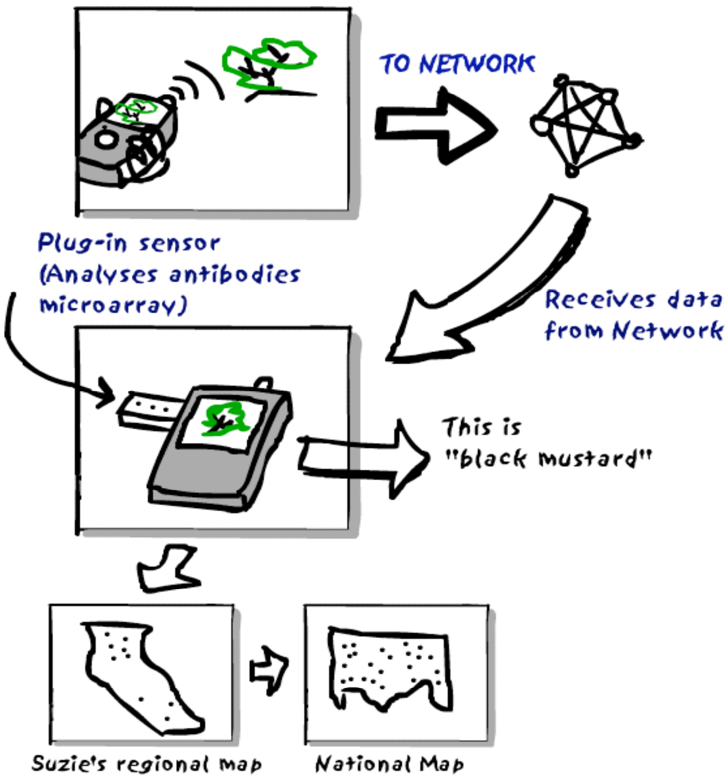


This is an idea for younger kids. Imagine a Halloween costume of a dog with sensors that allow you to see the world with the kinds of colors that a dog could see. Or with lenses that would allow you see as though you were looking through a compound eye.

It builds on the existing culture of kids liking to dressing up, but harnesses sensing technology to give kids a —sense of what it might feel like to be a particular kind of animal.

6. Artificial Nose

Imagine being able to recognize or sensemore in the world than you are currently able. It could also be thought of as a kind of *category recognizer*. Suppose you are walking along and see something you don't recognize for example a plant or a bird. You could take *sensory snapshot* of the thing that might involve images or even the object's chemical composition. You can go home and upload it to your desktop machine and get information about the particular kind of object you saw. But more importantly, you could use the desktop machine to make a custom sensor for the particular object. That is, ask the machine to "make me a sensor" for this plant or this bird or this sound. Maybe there's a kind of flash memory stick that can be inserted into the desktop machine that is a *programmable sensor*. Now you have a sensor that is for this category of object.



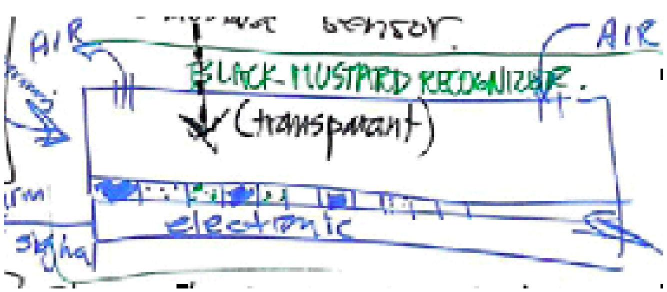
Suzie walks up the hill and sees a new plant. "What's this?" She takes a picture with her digital camera and images it.

Later in the day Suzie customizes the sensor to be a "black mustard" sensor by plugging in her analyzer stick -- a device that is able to take a chemical "fingerprint" of the plant.

She uploads her local data map on black mustard to the regional analysis and mapping center. She is connected via GPS while wandering around. Later Suzie's local data is integrated with a national data center and map on black mustard. She compares these.

You can collect or trade category sensors or give them away. Now as you walk along in your environment and you see the object, you can place the sensor beside it and down load the information to the desktop device — this is another instance of using the category to learn about objects that you are curious about. Once you are connected to the web there's all kinds of related information that could be gleaned — movies, facts and so on. There are a lot of ways the idea could play out including being able to compare the location or other properties of your particular object against information in larger databases generated by communities of data gatherers. This could play into kids' notions of scrapbooks. You could imagine having a scrapbook so that as you page through the scrapbook of actual leaves, the scrapbook might also contain a little chip that attaches to your sensor device that would provide more information about it.

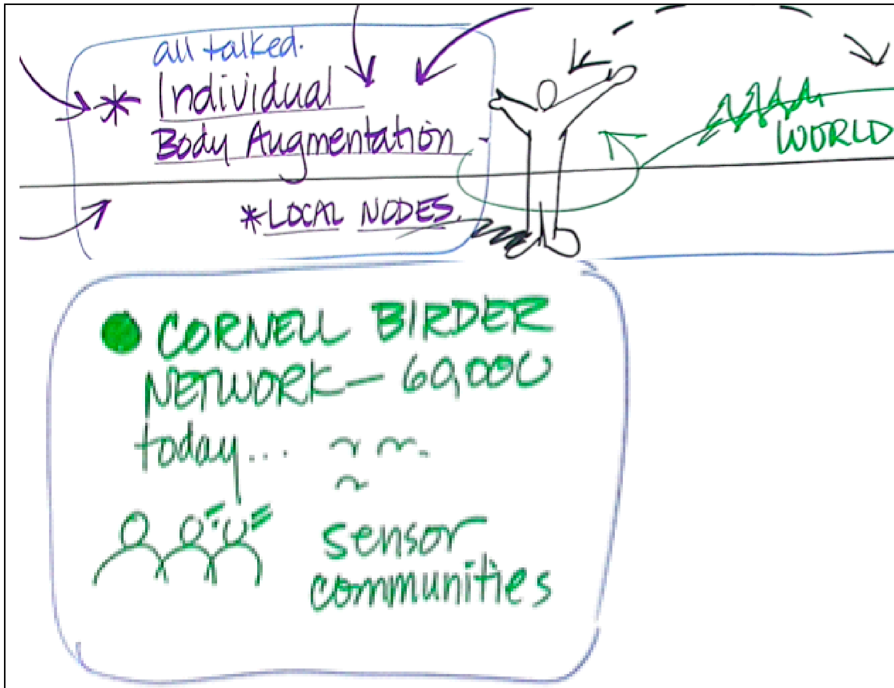
In general, the world is filled with things that you'd like to recognize. What sensors can do is expand your cognitive repertoire of things that you would like to know more about. Once you have programmed your custom sensor, it could be posted on the web so that others could download it and create a community of informal researchers interested in say, invasive plants of a particular domain or region. This would enable you could then get a map showing the distributed locations of a particularly noxious or invasive plant *right now*. You could also get a sense of a plant's local effects by capturing the stuff around it and map its effects on its environment overtime. For example, what are the other locations in a particular region that have this same *fingerprint?* You could also see temporal and visual overlays making visible how one plant prepares the way for the next one that moves into the region. With augmented reality glasses, you might even see a projection of how the local region you are looking at might change as you see the invasive plants marching across the hill or meadow. If there was a true sensing network, millions of people with their own sensors could build up a rich database of knowledge about the environment. A key idea here is how your own personal activities can be seamlessly connected to broader communities of social interest



A rough schematic of how this might work is to have a micro analytical array of antibodies with an electronic substrate that draws air through it and detects those places where molecules stuck to the antibodies. Then you could see how antibodies stuck to the electrical substrate and see changes in the responsiveness of the particular parts of the array. This would create a kind of *fingerprint* - an organic chemical sensor.
Finally, you could think of this as a kind of *deja vu* sensor packaging the sound, smell and sight of a particular object that could be recognized and re-experienced. A group at Cornell is working on this right now – their project has 60 thousand birders gathering and collecting information on the migration patterns of various species of birds. This demonstrates that one can build virtual communities of people with common interest by making each of them sensors for particular kinds of object. These scenarios create a future vision. But it is impossible to know when the ubiquitous sensing networks will exist, with the appropriate computation, to make these scenarios a reality.

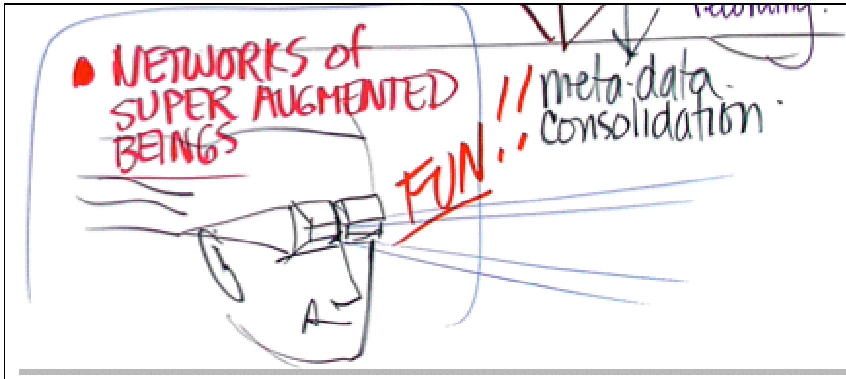
PART 3. Making SENS -- Emergent Ideas

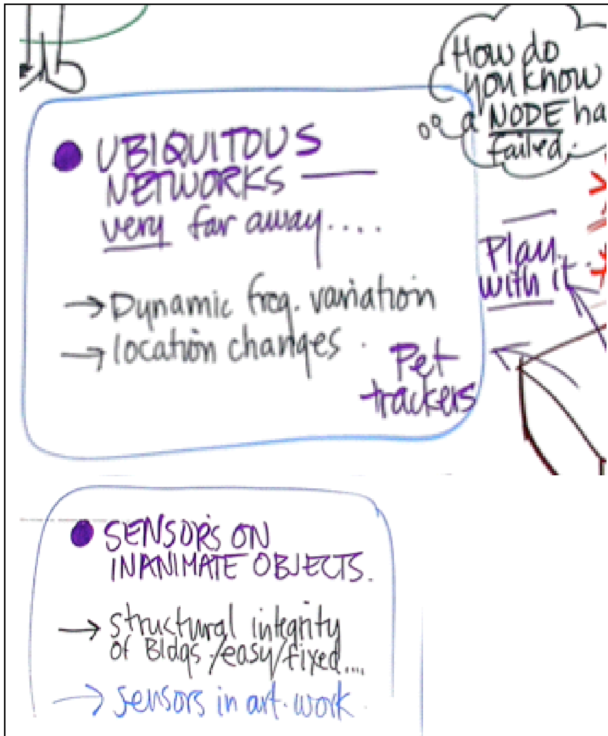
Here is a summary of key ideas that emerged from a synthesis of the morning Making SENS matrix exercises and the afternoon scenario sketches.



Integrating personal with networked communities

A key idea cutting across all the scenarios is the importance of not only instrumenting peoples' personal sensing possibilities, but also how to integrate their personal experiences with centralized, and possibly massive databases of containing information from other individuals. A nascent example is the Cornell project exploiting the data gathered by 60 thousand "birders".

	**Interconnected Cyber-beings** A vision emerges of networks of cyber-being; humans augmented with super sensing powers and the ability to consolidate this data via metadata schemes.



Technical issues in making ubiquitous networks a reality

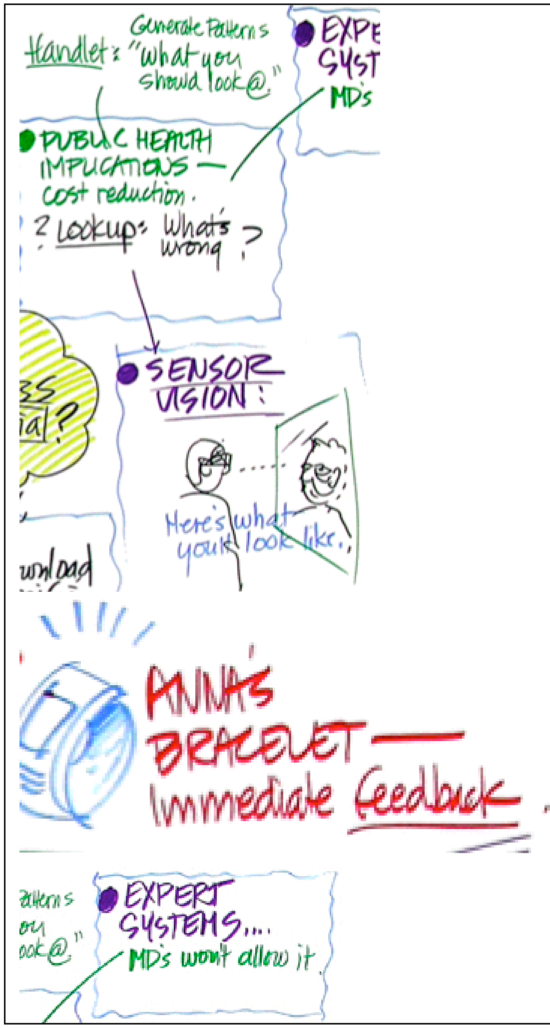
The reality of having ubiquitous networks enabling the integration of millions of sensing nodes is very far away. There remain many technical challenges. For example, it is easier to integrate information from sensing nodes that are fixed on buildings than from sensors on mobile objects.

Markets for sensing networks in education?
Is there a market for SENS networks in education? Rich in long term potential -- especially the customizability of personalizable sensing devices -- it is still an open issue as to how to develop such networks and products serving real needs and business models that are sustainable. Especially difficult is the challenge of gathering empirical evidence that such networks would afford real learning.

On the other hand, the compelling, engaging notion of a *handlet* sensing device may not be that far away.

There may be opportunities for making money through developing and selling pieces of the process that might drive innovation.

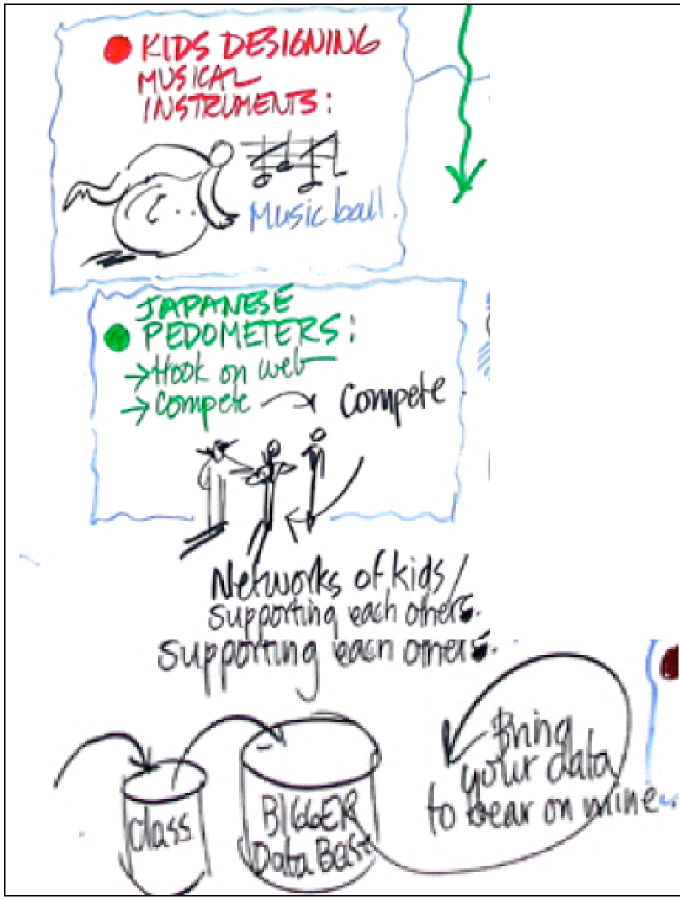
There are specific sensors out there for various properties, but the idea of *programmable recognizer* may be powerful, do-able and marketable. The idea could be a sweet spot for whole generation of sensors. Another important idea is having techniques for filtering for kinds of data someone could be interested in.



Public health as a fertile area for development

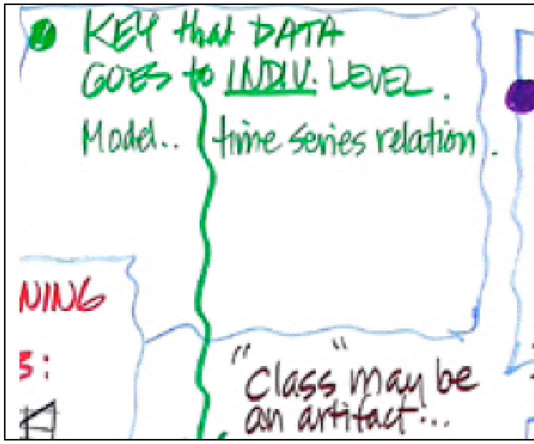
Public health is also a domain where cost reduction and improvements could drive sensing network innovation. On the psychological side, if you knew what you were doing to yourself (e.g., overeating) would it change your behavior? For example, sensor vision which would show you visually the effects of smoking in a mirror.

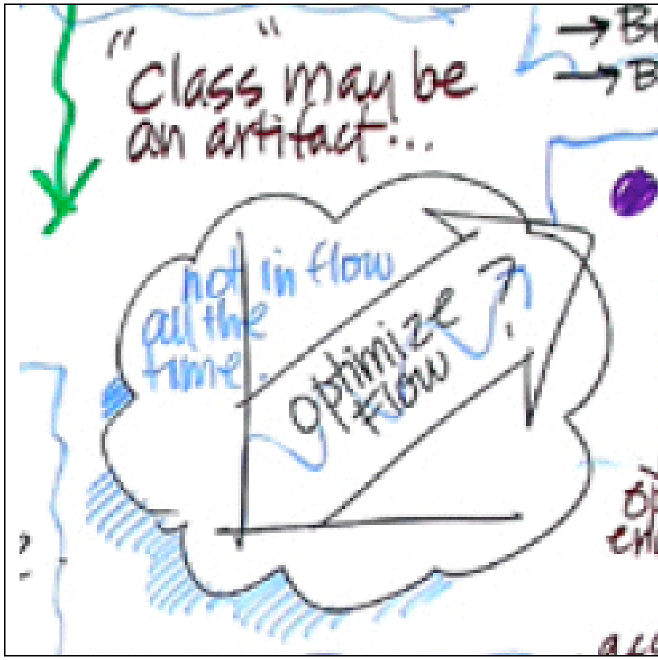
Anna's handlet could provide immediate feedback to parents or doctors about emerging patterns that might affect her health. But would a doctor really allow this?



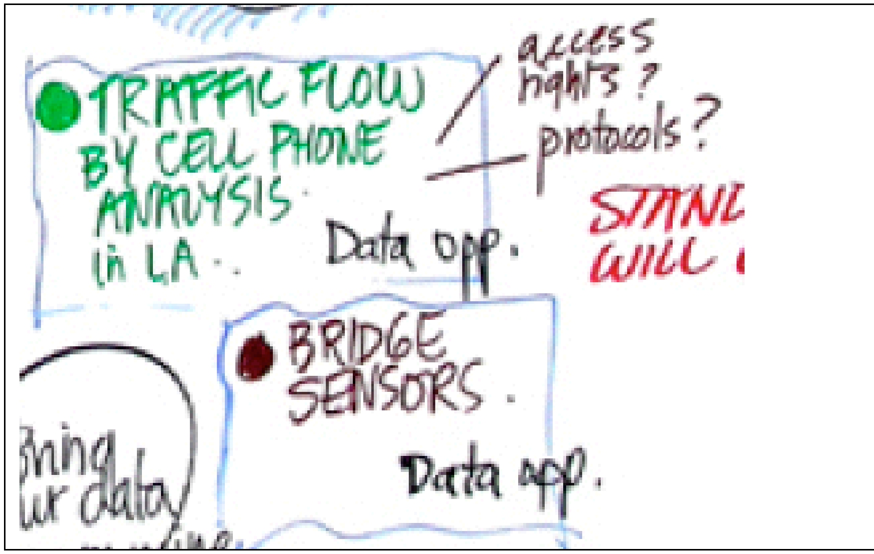
Designing new kinds of musical instruments
Maybe slightly less controversial yet marketable applications are tools for helping kids design new kinds of musical instruments that might respond to properties like one's body position or breathing rate.

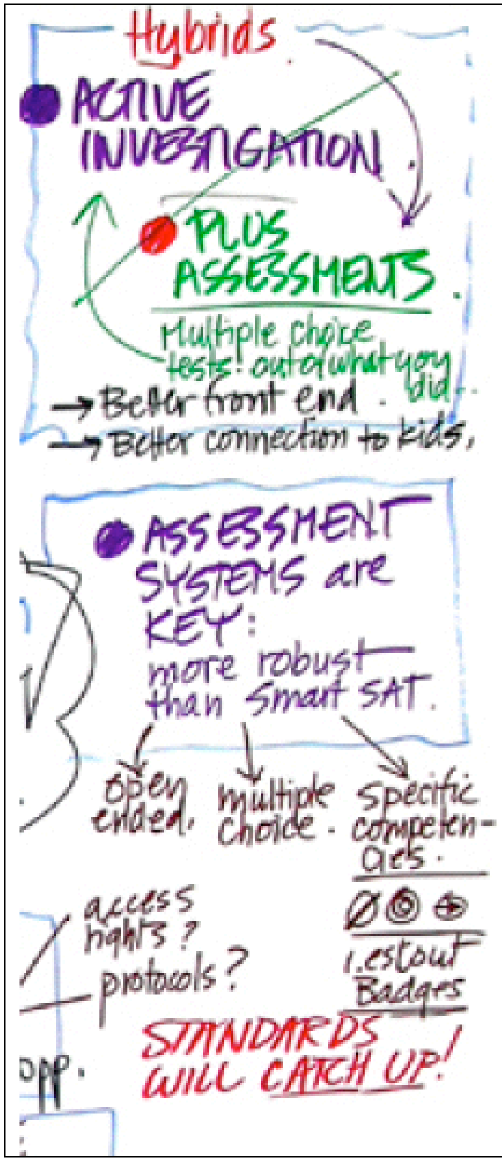
Competition may also be used to promote sensing technologies. In Japan, there are individuals (not kids) already competing with each other over networks that sense data captured by individual pedometers.

	**Understanding patterns of data overtime** A powerful idea is to link the individual to patterns of data changing overtime. This requires linking actions and outcomes for learning. One possibility is to use reminders and prompts as predictors as to what might happen if behavior continues in a certain direction.



How to exploit data from a classroom as a unit?
How could sensors be used to measure flow of the class as a whole throughout some interval of time? Could the *flow experience* (in which skill level and task challenge are matched so well that one develops new abilities in a "flow" with the environment) be optimized using sensors? Perhaps time-stamped portfolios are part of answer; metadata captured in portfolio activity overtime would reveal relationships among many kinds of data. The goal would be harnessing new analytical techniques to figure out what are the relevant relationships and attributes in looking at a million portfolios overtime. This approach diverges from traditional scientific method of hypothesis testing.

	**Existing sensing projects tracking flow** There are existing sets of data that could be exploited for learning. For example, Los Angeles transportation engineers are using cell phone data to map traffic patterns. They are also sensing bridge traffic. But kids have no access to the data gathered in these projects. How can we make these available to a kid for specific purposes? What are the access rights and issues?



Hybrid models of learning and assessment

How to make these visions happen pragmatically within the school systems over the next five years remains a daunting challenge. But there are interesting possibilities. For example, one step may be to develop a *hybrid* model of active investigation -- scaffolding multiple-choice items with active investigation based on some activity a student has just carried out. This would insure not only the ability to do active investigation, but also the ability to perform well on standardized tests. Data analysis tools in portfolios could still be a key enabler. The challenge is how to link traditional items in an assessment to what kids are actually doing. Think of a future on-line SAT that coordinates assessment with active investigation. One would still need evidence that these activities are working in the assessment scheme. How do we get beyond the constrained linear multiple-choice model to encourage critical thinking made possible by open-ended assessment? It could be that we should just proceed to innovate and that standards will catch up.

WORKSHOP PARTICIPANTS

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Stephen Bannasch, Director of Technology for the Concord Consortium, manages technical planning and development. He pioneered the technology used in educational applications of computer interfaces to laboratory experiments (microcomputer-based labs or MBL). Dr. Bannasch is currently working on the Data and Models project developing new physical and computer models for helping kids understand heat and temperature. He also works with the Exploratorium in San Francisco developing handheld computers and wireless communication to allow visitors to explore exhibits in greater depth. http://www.concord.org/~sbannasch/

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Michael Eisenberg leads the Craft Technology Group at CU Boulder. Craft technology refers to the interweaving of computation with craft materials both new and old. This blending can take many forms, including the application of specialized software to aid in the design and construction of traditional crafts such as quilting and origami and in the creation of craft objects with embedded intelligence. He is an Associate Professor in the Department of Computer Science, and an active member of the Institute of Cognitive Science and the Center for Lifelong Learning and Design (L3D). Professor Eisenberg's research interests include mathematics and science education, educational technology, end-user programming, and spatial cognition. He holds MS and PhD degrees from the Massachusetts Institute of Technology. http://www.cs.colorado.edu/~duck/

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Fred Martin is an Assistant Professor of Computer Science at UMass Lowell. As a research scientist at the MIT Media Laboratory, Dr. Martin developed a series of educational robotics materials that laid foundation for the LEGO Mindstorms Robotics Invention System. In 2000, he published *Robotic Explorations: A Hands-On Introduction to Engineering*

(Prentice-Hall), a textbook that supports college-level courses based on mobile robot design projects. Dr. Martin also co-founded Gleason Research with his wife Wanda Gleason, a robotics company that consults on educational projects. He is a founding engineer for Ipsil, Inc. a privately held start-up company in Cambridge, MA. http://www.cs.uml.edu/~fredm /

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Stanford Center for Innovations in Learning
Michael Mills is cognitive scientist with 17 years experience in interface, product design and user studies. He has a track record of innovation and accomplishment in real-world interface development, product design and teaching. While principal scientist at Apple Computer, he was instrumental in the development of QuickTime and QuickTimeVR. At IDEO product development, he was lead interaction designer for 3COM's Audrey information appliance. As tenured professor at NYU he developed The Active Eye interactive softwarefor teaching visual perception and has taught courses on computational media, computer graphics and research methods. He holds several interface design patents in digital video and has authored many articles on interface design. http://www.stanford.edu/~mmills

Charlie Patton, Ph.D.
SRI International, Center for Technology in Learning
Early in his career, Charlie Patton was struck with a compelling vision of how handheld devices could be designed to radically democratize access to the concepts of mathematics. In 1982, he took this vision to Hewlett-Packard Co., home of the first scientific calculator. Since that time, at HP, with Texas Instruments, through NSF grants, and now, at SRI, he has been fully engaged in researching, fostering, and inventing the future of handhelds in education, including the first symbolic handhelds, the HP-28C and successors, that changed forever the ground rules for the teaching of calculus and algebra. Dr. Patton has authored 4 books, numerous articles, and currently holds 13 final and pending patents in handheld software systems, wireless networking, and digital rights management, with several more in preparation. At CTL, Dr. Patton is helping build a technology bridge from research to practice, while fostering the uptake of learning science insights in a number of SRI's technology programs.

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UIUC/NCSA, Division Director, Cybercommunities
Grid computing technologies offer professional and research communities a revolutionary new mode of operation. The Cybercommunities Division of NCSA is leading the way by building and transforming these communities of practice and by applying and extending the Grid infrastructure. Any technology is hampered from the start if its implementation ignores

the human side of the human/technology interaction-not only on the individual level, but also within the dynamics of larger groups. By forming close partnerships with selected communities, Cybercommunities ensures they are served by an innovative and effective Grid-based environment, developed and implemented through an understanding not only of the newest technology, but also of the human processes related to collaboration, learning, and knowledge sharing. Tom directs this NCSA Division and the NEESgrid Project (http://www.neesgrid.org/) , a major grid computing initiative funded by the National Science Foundation, which is linking earthquake researchers across the U.S. with leading-edge computing resources and research equipment, allowing collaborative teams to plan, perform, and publish their experiments.

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Roy Pea is Professor of Education and the Learning Sciences at Stanford University, Co-Director of the Stanford Center for Innovations in Learning, and Director of a new PhD Program in Learning Sciences and Technology Design. Since 1981, Dr. Pea has been active in exploring, defining, and researching new issues in how information technologies can fundamentally support and advance learning and teaching, with particular focus on topics in science, mathematics, technology education. Particular areas of interest are computer-supported collaborative and on-line community learning, uses of digital video for learning research and teacher education, scientific visualization, and pervasive learning with wireless handheld computers. He has published over 110 chapters and articles on cognition, education, and learning technologies, and was co-author of the 2000 National Academy Press volume, How People Learn. With NAE President Bill Wulf, he has been chairing a joint National Academy of Sciences/National Academy of Engineering Committee on Improving Learning with Information Technology. Before coming to Stanford, Dr. Pea was director of the Center for Technology in Learning at SRI International. He also founded the Learning Sciences Ph.D. program at Northwestern University, and served as dean of the School of Education and Social Policy. http://www.stanford.edu/~roypea/

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Center for Embedded Network Sensing
Dr. Sandoval's research examines the following areas and how they relate to one other: (1) Children's ideas about how science is done and what scientific knowledge is, and how these ideas influence their efforts to learn science; (2) Teachers' ideas about how science is done and what scientific knowledge is, and how these ideas influence their science teaching; (3) The role technology can play in mediating science learning and teaching in classrooms, especially in supporting meaningful scientific inquiry; and (4) Understanding how innovative designs for education can help us develop

better theories of learning and better educational practice. He is collaboratively pursuing these issues using CENS's embedded networked ("in-situ") sensing technology for habitat monitoring and seismic sensing over the next several years, so that grade 7-12 students can, using Inquiry Modules, remotely observe complex systems in nature, by pursuing their questions through creation of new experiments that direct networked sensors to collect data in a way they have designed. Each Inquiry Module is developed by focused, collaborative teams including domain experts, grade-level teachers, educational researchers with experience developing and studying inquiry-based learning environments, and information scientists experienced in integrating complex data and interactive tools into curricula.
http://www.gseis.ucla.edu/faculty/sandoval/

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University of Michigan
Nancy Songer is an Associate Professor of Science Education and Educational Technology at the University of Michigan. Her current research focuses on in-depth investigations of the educational potential and realities of innovative technologies for reform-based science education. Recent awards include being named a 1995 Presidential Faculty Fellow by the National Science Foundation and the White House, and the 1995 Early Career Research Award by the National Association of Research in Science Teaching (NARST). Dr. Songer currently directs the Kids as Global Scientists project (www.onesky.umich.edu), a WWW-based curricular/software program currently implemented in 90 world-distributed middle school locations. http://www.soe.umich.edu/faculty/songer /

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Lori Takeuchi is a second-year doctoral student in the Learning Sciences and Technology Design (LSTD) program at Stanford. Lori has been involved in the WILD research projects and is currently the Program Advisor for Stanford's Learning, Design, & Technology (LDT) Masters Program. Before coming to Stanford, Lori produced middle-school science software for companies including BBN, Logal Software, and Riverdeep Interactive Learning. She received a master's degree in Technology in Education from Harvard, before which she worked in instructional television at Thirteen/WNET in New York.

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