

Proceedings from the “Innovation, Education, and the Maker Movement” Workshop



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Background of Maker Faire Movement

Maker Faire is a two-day, family-friendly event that celebrates the Do-It-Yourself (DIY) movement. For Makers, and those who are learning from this movement, the process is as important as the product, and experimentation and participation are the principal motivators. This broad-based community encompasses scientists, engineers, students, welders, software developers, hackers, circuit benders, musicians and crafters of all stripes: individuals and communities of people drawn together by a common delight in the magic of tinkering, hacking, creating and reusing materials and technology. With an international reach and a deliberately local feel, Maker Faires celebrate the best of human imagination and creativity, where Makers share their process and product, including arts, crafts, electronics, artisanal and traditional foods, urban farming, woodworking and music.

The Maker community has evolved into a growing movement of individuals who, in the words of Dale Dougherty, general manager of the Maker Media division of O'Reilly Media and founder of the Maker Faire festivals, “look at things a little differently and who just might spark the next generation of scientists, engineers and Makers.” Through Maker Faires, these individuals have organized into thriving communities to create things that are personally motivating and socially engaging. Maker spaces are springing up in cities large and small throughout the country in which people can drop in and learn from other community members about using 21st century tools such as computer-controlled table saws, laser cutters, and 3-D printers to prototype and fabricate physical products. Similarly, informal hacker groups are collaborating to create innovative software and interactive devices, many of which are freely shared through open source license agreements. According to Thomas Kalil, deputy director of the White House’s Office of Science and Technology Policy, the Maker Movement really “begins with the Makers themselves — who find making, tinkering, inventing, problem-solving, discovering and sharing intrinsically rewarding.”

Maker Faires, currently in their fifth year, began in the Bay Area at the San Mateo Fairgrounds. In 2010 the two-day San Mateo Faire attracted more than 80,000 people and featured 1,000 makers. In 2010 two new venues were added to the Maker Faire roster with events held at The Henry Ford Museum in Detroit and at the New York Hall of Science (NYSCI) in New York City. In New York, the event was dubbed World Maker Faire, in recognition of the diversity of Makers and audience who participated. The name also harkened back to NYSCI’s founding during the 1964–65 World’s Fair. A dazzling array of 530 Maker projects, with teams totaling 1,500 Makers descended on NYSCI.

Visitors of all ages explored a multitude of activities, such as learning how to pick a lock, learning how to solder, taking a ride on a rocket-propelled “jet pony,” screen printing a T-shirt, learning how to design a window hydroponics garden, and marveling at a large scale kinetic sculpture inspired by the classic board game Mouse Trap, complete with a bowling ball “marble” that starts a chain reaction that ends with a two-ton safe smashing a New York City taxicab.





Innovative solutions to a range of interesting problems were also presented by Makers, including cell phone-based sensors for detecting carbon dioxide and ambient noise, a **chemist** working to create some of the capabilities of a \$10,000 Scanning Tunneling Microscope for a few hundred dollars, or the engineer who used reverse geo-caching to design a wedding present — a **puzzle box** that only opens on one spot on the planet.

As Tom Kalil described: “It’s work done in many different mediums, including electronics, open source hardware, metal working, **DNA**, medieval weapons, wood, arts and crafts, robots, rockets, **quadropters**, Diet Coke and Mentos, fire and other dangerous things.”

In addition to Makers who shared their craft with others, there were well-attended and high-spirited demonstrations and discussions with titles as diverse as: *Sustainable Hacker and Maker Spaces Blending Craft and Technology at High-Low Tech*, and *Wired* magazine’s Chris Anderson’s talk on the *Next Industrial Revolution*. Sprinkled throughout were interactive events and performances such as the Rock-It Science Cabaret, a battle of the science bands, and ArcAttack, a performance group that uses two custom built **Singing Tesla Coils**, which have been modified so that a specially equipped keyboard or guitar can play the coils by modulating their spark output.

Innovation, Education, and the Maker Movement Workshop at the New York Hall of Science: Attendees and Goals, and Guiding Questions

Recognizing that the Maker movement embodies aspects of science, technology, engineering, and mathematics (STEM) learning that are the hallmarks of effective education — deep engagement with content, critical thinking, problem solving, collaboration, learning to learn, and more — NYSCI, in collaboration with Dale Dougherty and Tom Kalil, approached the National Science Foundation to sponsor a two-day workshop. Over 80 leaders in education, science, technology and the arts came together at NYSCI to consider how the Maker movement can help stimulate innovation in formal and informal education. Participants included leaders from foundations, federal agencies, respected educators and developers from schools of engineering, architecture, computer science, and multimedia design, entrepreneurs whose life work has focused on “Making” in different sectors, innovators in the fields of formal and informal science education, research scientists in teaching and learning, and directors of leading science centers, museums and arts institutions (see page 20 for Attendees).

Workshop participants were asked to attend the Sunday Maker Faire to experience the event in all its excitement and complexity and to interact with Makers. Using flip cameras and other devices, participants were welcome to document their experiences of the Faire. On the following day, all participants gathered at NYSCI to consider important ways in which the Maker movement can be leveraged to invigorate teaching and learning and to attract and inspire young people to engage in STEM fields. Through a combination of panel discussions and small group working sessions, the workshop focused on the following questions:

- How can the creativity and ingenuity that is core to the Maker/DIY movement inform and improve learning, particularly in STEM fields, in K–12 and career technical education?
- What kinds of collaborations might be developed with the Maker/DIY movement that could inspire innovation in STEM learning in formal and informal sectors?
- Where do opportunities exist for facilitating connections between the Maker community and participants’ areas of expertise and interest?

Why Making Now?

I want us all to think about new and creative ways to engage young people in science and engineering, whether it’s science festivals, robotics competitions, fairs that encourage young people to create and build and invent — to be makers of things, not just consumers of things.
—President Barack Obama at the National Academies of Science (April 27, 2009)

According to the National Academies Report, *Rising Above the Gathering Storm Revisited* (2007), our nation’s outlook in terms of innovation and human capital has worsened. In 2009, 51 percent of United States patents were awarded to non-U.S. companies. In 2000, the number of foreign students in the U.S. graduate physics and engineering schools surpassed the number of U.S. students for the *first time*. In the meantime, there have been little signs of improvement in mathematics and science education where our students rank 21st out of 30 countries on the Program for International Student Assessment (PISA) in scientific literacy (Bybee, 2009).

Acknowledging that the key to future economic development and job creation is dependent on our ability to innovate, President Obama has launched the “Educate to Innovate” campaign to improve the participation and performance of America’s students in STEM (<http://www.whitehouse.gov/issues/education/educate-innovate>). This campaign is a call-to-action to include efforts, not only from the federal government, but also from leading companies, foundations, non-profits, and science and engineering societies to enable young people across America to excel in science and math. The recently released President’s Council of Advisors on Science and Technology Report (PCAST, 2010) states that “the problem is not just a lack of *proficiency* among American students; there is also a lack of *interest* in STEM fields among many students.” PCAST acknowledges that STEM education is most successful when students and teachers develop personal connections with the ideas and excitement of STEM fields. In many respects, the Maker movement exemplifies the kind of passion and personal motivation that inspires innovation. The workshop was convened to explore the concrete ways in which this creative community of Makers might engage young people and educators in STEM learning.

What are the Qualities of Making and the Maker Movement?

To begin the discussion of “Making” in all of its forms, participants were asked to share a word or phrase that captured their experience of Maker Faire. The wide variety of descriptors reveal the power and potential of this movement to inspire the human



- What are the projects and initiatives that the Maker and STEM communities should be co-designing and co-creating?
- What are the big ideas, compelling goals and concrete “next steps” that would inspire individuals, companies, foundations, educators, museums, non-profits and government agencies to work together?
- What would teams of students build with access to a 3-D printer, a Tech Shop, powerful but easy to use CAD tools, and an experienced mentor?
- What foundational knowledge and practical skills would they acquire along the way — and what real-world problems could they solve?
- What are the biggest barriers to bringing Makers and their tools into the classroom and informal learning environments, and what experiments should we launch to overcome or route around these barriers?
- How do we make a special effort to engage women and under-represented minorities?
- What would career and technical education look like after a Maker make-over?



Connecting the Maker Community

According to Dale Dougherty, general manager of the Maker Media division of O'Reilly and chief architect of Maker Faires, once you are a part of Maker Faire things begin to happen. It is a place to make community connections and bring together eclectic groups of people who may be living in the same community and working on synergistic activities, but are not aware that others exist. Once you are at Maker Faire, no explanation is needed for why these different people are all there. Makers have the ability to deconstruct and reconstruct things in tangible ways, from Diet Coke and Mentos sprinklers, to mathematical Making through command lines of code (i.e., coding as performance art). Maker Faire is not just for kids, but also for families who are looking for entry points for themselves and their children into areas that are ordinarily out of reach.

Maker Faire sparks ideas for others to organize. There has been a lot of ad hoc experimentation in making this kind of event happen on the local level. Organizers of Maker Faire are frequently contacted to help local communities figure out how to make mini Maker Faires in smaller locations. Some educators have begun experimenting with supporting Young Maker Faires instead of science fairs at their schools. There is an audience and a hunger for this kind of hands-on work that is often appealing to the very people who find or have found school especially unsatisfying. Families leave these fairs and want to find others in their communities to do this. The challenge is to figure out how to very lightly coordinate what people want to do by creating a space and a place for them to show what they are already doing. It requires finding out what young people are doing after school and supporting it. How can we listen to students and help them to follow their interests? As we try to move things ahead, we need to be cautious that we don't make “Making” tedious and boring. This is not about keeping kids busy, but about creating opportunities for young people to develop their own abilities to do things.

John Hagel and John Sealy Brown speak of a shift in the way we approach mobilizing resources and innovation as moving from “push to pull” (Hagel & Brown, 2005, 2010). For students, it seems that “STEM” is push, but “Make” is pull. Children want to do this. How do we not impose STEM learning on children but allow them to be drawn to it, engaged by their own interests, inspired through the art of Making?

Dougherty presented a structure built for disaster relief cut from plywood by a HotBot (all that is needed is the wood and the design tool). It can collapse into a 4-by-8 foot package and takes only a couple of hours to assemble. He challenged the audience to think: What if every school is shipped their own Maker Shed structure, which can serve as a platform for getting Maker spaces started in schools? How do we make a new shop class, garage, or Maker club possible in different settings?



The challenge is how to connect the Maker community together and create a smart grid for education. Informal education is creating great opportunities for alternative learning. How do children get more recognition for the Making that they do outside of school? A Stanford science professor revealed that he looks to see if prospective students participate in Maker Faire. More opportunities are needed for students to get this kind of recognition for Making.

In moving forward, the president and CEO of NYSCI, Dr. Margaret Honey, advised the group to consider how we go about creating broad invitation into the world of Making,

particularly for young people who are not connected to people who are involved in Making. Chris Anderson of *Wired* magazine gave a talk called *The Next Industrial Revolution*. He spoke about how his grandfather drew him into the world of Making by allowing him to mess around in his workshop with serious equipment. Not all children have grandfathers like Chris Anderson's, and the question of how we provide broad access to these new means of production and to people who can serve as conduits for engagement remains a critical issue. Honey believes this is one of the reasons why we need to embrace the opportunities that schools afford. At its best, formal education holds the potential to democratize learning and provide equitable access to opportunities and resources. In considering the potential of the Maker movement for education we need to build bridges across the informal and formal sectors as both environments are needed to bring the potential of the Maker Movement to all children.



Promises of Making in Education and in the Community

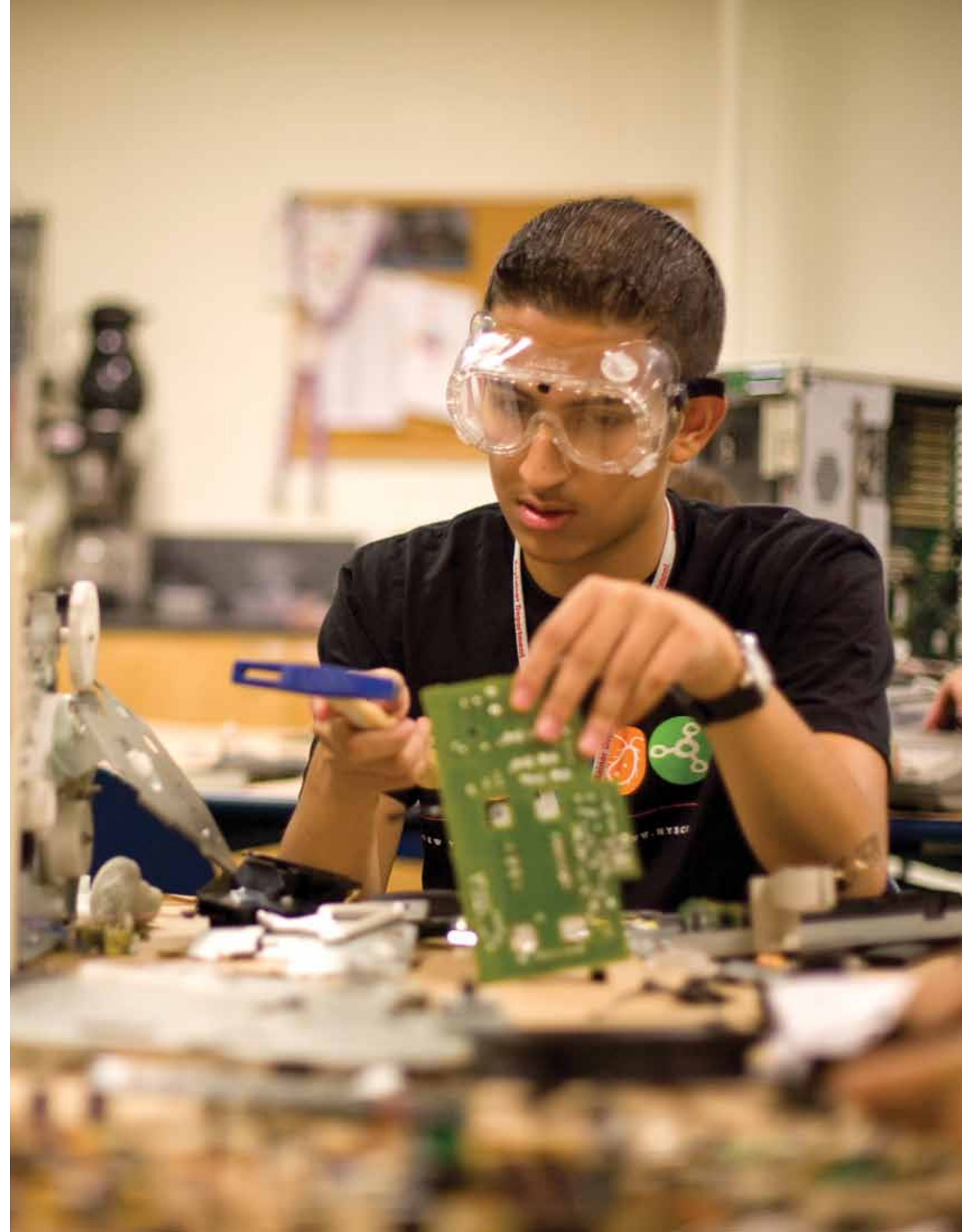
Making in education and the community is already underway in many different forms. Educators have found that students and people who have not developed confidence and identity in STEM subjects through traditional courses have a different relationship to STEM learning when embraced through the process of Making. Making encourages experimentation — students can make mistakes and still have confidence and a strong sense of identity to pursue their interests. To explore how to connect Making to education, four educators who have spent much of their professional lives thinking about how to support this kind of identity development discussed lessons learned across different settings:

- **Elliott Washor of Big Picture Learning** has devoted a lifetime to creating school environments in which Making is an integral part of “how young people figure out who they are in the world.”
- **Frank Wilson, neurologist and author of *The Hand: How Its Use Shapes the Brain, Language, and Human Culture*** has investigated how the act of Making with one's hands facilitates different types of STEM learning.
- **Mary Simon of RAFT** has thought about how to provide large numbers of teachers with the resources and support to make “Making” possible in the classroom.
- **Mike Petrich and Karen Wilkenson of the Exploratorium** considered how to design informal learning contexts to support meaningful Maker activity.

Students Becoming Makers: Big Picture Learning

“It feels so good when you can say ‘I made this’ when a week ago you never would have thought you could make it. This has shown me what I really do have talents in — and it's a lot.”

—Big Picture Learning Student on Making





Elliot Washor of Big Picture Learning runs a nonprofit organization of 140 schools devoted to focusing on one student at a time, particularly those who have been alienated by traditional schooling — the “drop-outs” or the “leavers.” A diverse group of students from these schools participated in the Maker Faire Detroit, including a Liberian student who is interested in clothing design and dressmaking, a boy who builds cars, and another boy with Aspergers who created exquisite chessboards. The philosophy of Big Picture Learning is to find a way to keep students in school to follow and develop their interests. Big Picture uses a methodology known as POPS — people, objects, places and situations (in and out of school) — as the central recipe for helping students to find their interests along with a process of *thinking* — engaging the hands and the mind. Making involves how to approach a problem with an unknown answer compared to more traditional schooling that involves rewarding a student for solving a problem or issue with a known answer. During the process of Making, students recognize that they do not need to be target-oriented to get the best results. The process is not linear; problems people solve move in circles. Practice for the students is not about efficiency and acceleration, but about improving things and making them better.

The process of continuous improvement is core to Big Picture’s learning philosophy. Washor describes helping students to become skilled artisans — leading them from apprentice, to journeyman, to master. In practice, apprentice level involves deep immersion in what one wants to learn; journeyman is focused on gaining expertise and recognition for one’s craft; and master level is about giving back to other people what one knows and has accomplished.

Assessment, in the Big Picture context, focuses on helping students become nimble and creative problem solvers. These measures might include soft metrics that are becoming more commonplace in industrial design sectors such as a Hope Index, or measures of joy and engagement, critical self-assessment, and real world outcomes (e.g., college attendance rates, number of entrepreneurs developed, number of patents filed).

Through Making, Washor offers an alternative vision of how schools can facilitate learning: Most “schools ignore how we understand through the process of making things and choose breadth over depth, efficiency over exploration, and acceleration over patience and persistence. By bringing Making to the disciplines and the disciplines to Making, teachers and students will understand what key understandings and skills are absolutely essential in the traditional disciplines.”

Making and the Hand: The Power of Self-Assessment?

Frank Wilson tackled the issue of assessment and connected it with his own background as a neurologist who sees one patient at a time where the specific circumstance of the individual is primary. Wilson believes that as educators we need to focus less on collective outcomes (e.g., test scores) and more on individual teachers and students. Interested in how his daughter approached the study of music, Wilson would watch her hands move in a “blur,” and yet she knew exactly what she had missed in her piano recitals. He realized that there was a special nature to hand control and he was fascinated by how we use our

hands to communicate and understand the world. Through this experience, he realized that a critical aspect of hand learning involves assessment that is grounded in deep self-awareness. There is great difficulty in becoming an objective observer of your own performance. In mastering a craft, you have to know how to decide for yourself how well you have done.

Wilson suggested that the National Research Council’s Committee report on *Learning Science in Informal Environments* (Bell, Lewenstein, Shouse, & Feder, 2009) has identified key learning strands that are very relevant to “Making,” but needs to be reordered according to how such skills and understandings develop in children.

NRC Learning Strands in Science	Wilson’s Reordering
1. Experience excitement, interest and motivation to learn about phenomena in the natural and physical world.	1. Manipulate, test, explore, predict, question, observe and make sense of the natural world.
2. Come to generate, understand, remember and use concepts, explanations, arguments, models and facts related to science.	2. Experience excitement, interest and motivation to learn about phenomena in the natural and physical world.
3. Manipulate, test, explore, predict, question, observe and make sense of the natural world.	3. Participate in scientific activities and learning practices with others, using scientific language and tools.
4. Reflect on science as a way of knowing; on processes, concept and institutions of science; and on their own process of learning about phenomena.	4. Come to generate, understand, remember, and use concepts, explanations, arguments, models and facts related to science.
5. Participate in scientific activities and learning practices with others, using scientific language and tools.	5a. Reflect on science as a way of knowing; on processes, concepts and institutions of science; and on their own process of learning about phenomena.
6. Think about themselves as science learners and develop an identity as someone who knows about, uses and sometimes contributes to science.	5b. Think about themselves as science learners and develop an identity as someone who knows about, uses and sometimes contributes to science.

Wilson pointed out that scientific Maker-like experiences start where the child’s mind and body starts: reaching out, touching, grasping and evaluating, followed by excitement and the surprise of discovery as children react to the unexpected in a more focused and attentive way. This is followed by engaging in scientific activity with others, as social and cooperative aspects of learning are key, and then generating and understanding concepts and facts through a synergy of tools and models that help one flesh out ideas. This activity leads to the final learning strands identified by the National Research Council that have



to do with reflection and objective self-assessment of one's efforts, which contributes to one's sense of self as a learner and doer of science.

Supporting Teachers as Makers: RAFT (Resource Area for Teaching)

If we want to engage students in Making, we need to consider how to engage teachers. This is a central challenge faced in fostering connections between Making and the formal education arena. Founded in 1994, RAFT (Resource Area for Teaching) is a thriving non-profit organization with Learning Resource Centers in San Jose and Redwood City, Calif. as well as affiliates in Sacramento and Denver, Colo. RAFT's mission is to help educators transform the learning experience through "hands-on" education that inspires the joy and discovery of learning. The tenets of RAFT are based on three principles: collaborative hands-on activities, access to a vast array of low-cost materials and the training to use them in hands-on projects, and an emphasis on 21st century learning skills.

RAFT grew out of founder Mary Simon's own experience teaching mathematics and science in second and third grade and her use of hands-on materials in the classroom. She recognized that to be creative she needed an abundance of materials around her. RAFT was developed to take away the barriers teachers encounter in implementing hands-on experiences with their students. Materials accessible through RAFT are simple everyday objects that come in all different shapes, sizes and textures. They are recycled from the business community and offered at minimal cost to teachers. By using materials in this way, teachers are invited to see materials in a new light — what others might consider rubbish becomes useful for teaching and learning. RAFT is the ultimate "upcycling" center for teachers.

RAFT currently reaches 9,000 educators in classrooms, home-schooling situations, and after-school or community-based programs. Equally important as accessible materials, are opportunities for teachers to become part of the RAFT community. By attending an innovation institute, teachers graduate and become innovation fellows at RAFT who help novice teachers develop new practices that disrupt familiar teaching approaches through relevant, hands-on investigations.

Replication of RAFT is a slow process and the organization is looking at how digital technologies can help disseminate this novel approach to teacher development. Along with creating brick and mortar "Maker palaces" for teachers that are green and sustainable, there is even greater interest in figuring out how you move from "bricks to clicks" by making resources available to teachers that are not dependent on a physical site.

Making in the Informal Learning Environment

Science museums are often seen as a place to mess around and explore, but how do museums and other informal institutions support "Making" spaces? Created originally through the NSF-funded PIE (Play, Invent, Explore) network, the Exploratorium Tinkering Studios are an ongoing series of experiments on the exhibition floor designed by their Learning Studio staff and collaborating artists, scientists and educators. Envisioned as a





space for staff and visitors to work with one another on thought provoking, construction-based activities, the Tinkering Studio environment contains tools, materials and starting points for a variety of experiments. Recent Tinkering Studio topics have included Marble Machines, Wind Tubes, Cardboard Automata, and [Light Distractions](#).

Karen Wilkinson and Mike Petrich, co-founders of the Learning Studio, shared insights into the most important features of creating public making spaces. First and foremost, they spoke about how they built a community space through the creation of “Open Make” sessions where featured Makers talk about their work, and facilitators in the museum help to guide the Making of those who wander in. Very often, the adult is the novice in these situations and the child is the expert. Typically, hosts of these sessions contend with apprehension from adults who can often be found saying:

“I’m not a Maker.”

“Making is only for kids.”

“We can’t do that here.” (It’s too messy, chaotic, expensive, dangerous, noisy.)

“It looks like fun but what are they learning?”

Wilkinson and Petrich note that it is important to support initiative and autonomy among visiting “Makers” and to allow for cross-pollination to occur through intergenerational collaborations. Facilitation is key to making this happen for all types of learners who may or may not be drawn to making activities. Facilitation includes modeling what you hope to happen, inviting people in who may not feel welcome, and asking what-if questions. Facilitators need to help people see that they can do things (e.g., you might think you can’t draw but you can learn to draw). Equally important is having activities that build on visitors’ prior interests and knowledge and materials that invite inquiry. STEM itself serves as a means (i.e., as the process) that supports Making, not as the ultimate end goal.

In response to the presentations, workshop participants raised a number of issues when considering how to build connections between the Maker movement and education.

Supporting community-based collaboration. Mobilizing resources in a community to engage young people in Making requires the collaboration of multiple organizations, formal and informal. An example of funding designed to mobilize community resources is a collaboration between the MacArthur Foundation and the Institute of Museum and Library Services. They are working to create a competition for 30 new youth learning labs in libraries and museums across the country that help young people become Makers and creators of content, rather than just consumers. This is one example of the kind of collaborative activity and funding that needs to take place for the Maker movement to have any broad impact on youth.

Supporting creative teachers. As we transition from an information economy to a creative economy, we want teachers to be creative producers of engaging learning environments. In our current system, we do not put much emphasis on this. RAFT is a compelling example of an organization that is paving the way in this regard, but we need to broaden experimentation and investment in this area.

Importance of tools. There are newly accessible tools such as the 3-D printer that enable a level of creativity and Making that we have not been able to support before. Such tools democratize access to creativity. We need to consider how to leverage these tools in underserved communities and to examine what it takes to support them.

Thinking beyond STEM. A number of participants cautioned that “Making” should not just be framed around STEM. The Maker Movement is about innovation and that may require looking across STEM and non-STEM subject areas. The focus should be on creative thinkers, not STEM learners, if we are really concerned about educating to innovate.

Recognition for Making. The Intel Science Competition is well respected and gets great publicity for identifying talented students in science education. Similar efforts can be done for the Maker community. The dimensions students are judged on can vary from the usual (e.g., awarding students who do the most resourceful projects with the fewest resources, or a project with the best aesthetic).

Looking Ahead: Recommendations for Next Steps in Connecting Making to Education

Workshop participants spent the afternoon deliberating these and other issues in breakout groups facilitated by NYSCI staff and selected guests. Each group was asked to consider how current Maker work could be grown, expanded, leveraged and supported. The goal was to generate a proposal for either building on an existing project or developing a new idea for bringing Maker-like activities into formal and informal education. The following proposals emerged that are connected to four larger policy areas: Maker Infrastructure, Making in Teaching and Schools, Making and Student Learning, and Making and Assessment.

Building the Maker Infrastructure

For Making to be infused into formal and informal learning environments, we need to support and invest in efforts that enable national “Maker” events to have a means of expanding into local communities. As Dale Dougherty urged: we need to “connect the Maker community together and create a smart grid for education.” A number of suggestions and proposals emerged in this area:

- **Grow the Capacity of Maker Faire to Support Locally Defined Efforts.** In the early days of Internet access for schools, it was important through the E-rate and other efforts to build the capacity and provide the resources for schools to support the use of technology in the classroom. Similarly, to enable the Maker movement to build alliances with education, we need to strengthen and stabilize the capabilities and resources both of the Maker Faire enterprise and its regional informal learning colleagues (NYSCI, Exploratorium, Henry Ford Museum, etc.), enabling Maker Faire and its partners to disseminate best practices and technical support to facilitate community-based activities in the spirit of the Maker movement. This could include developing web-based and other



“how-to” resources that can help communities to host their own mini-Maker Faires in smaller towns. Part of this capacity could also include developing “how-to” kits and resources for schools to run Young Maker Faires, similar to science fairs. Rather than a one-size-fits-all model, the objective is to build platforms and tools that enable communities to plan their own events that reflect community needs and ambitions. Other initiatives should be directed at widening the participation in the large-scale regional Maker Faires, so that the events see a consistent growth from year-to-year, both in terms of the number and diversity of Maker projects and also in the community outreach that will draw larger audiences (from greater distances) to experience Maker Faire with their families and neighbors. This is important because the “Maker community” is not just the Makers themselves, but the people they inspire and collaborate with in developing new projects.

- **Develop a “Make for America Maker Corps” of Volunteers to Help Schools and Communities.** To broaden the basis of support for Making in local communities, create a *Maker Corps* of master Makers with drive and passion who are available to work with groups in and out of schools. Investment will be needed to support these Makers to become mentors in schools and in other community contexts. Existing Maker Faires can be used to get the word out and after-school clubs and informal science institutions can serve as test beds for how a network of Makers can be grown and tapped in communities across the country. The Maker Corps can, in turn, inform how master Makers might work in schools.
- **Create Better Tools for Sharing Maker Activity.** There is a need for online tools and databases that make it easy to locate and share information about different Making projects and topics (e.g., easy access to all blogs on Making in different topic areas relevant to schools). Many online resources exist, but a platform that easily allows the user to structure and capture the ideas and iterations Makers go through would be valuable to educators and those trying to engage in Making outside of school.

Making and Teaching in Schools

A major challenge in schools today is the issue of student engagement, particularly in the STEM subject areas. Teachers and schools need support in the forms of strategies, materials and administrative policies that enable them to experiment with moving STEM from “pushing” what students need to know, to “pulling” them into innovative and engaging content that is personally relevant. A number of proposals were generated for thinking about how formal education can infuse Making into schools to meet these needs:

- **Create Teacher Professional Development That Promotes Innovation.** To promote innovation in teaching, we need to investigate how to engage and support teachers as Makers. Through the act of Making, the goal should be to help teachers develop the qualities identified as critical to innovators: enduring curiosity, empathy for understanding the problems of others, and leadership grounded in infectious enthusiasm. The best way to do this is to enable teachers to become Makers themselves, enabling them to innovate, experiment and learn from failure just as engineers do in their design work. We need to



create safe places for teachers to tinker in which failure can be expressed and analyzed and new ideas can be born. If there is no trust and appropriate permission for doing this kind of experimentation, Making will not authentically gain traction in schools.

- **Create 21st Century “Maker Schools.”** To reinvigorate STEM learning, we need to incorporate into both traditional academic high schools and vocational-career academy schools Maker programs where design and Making are core to the STEM disciplines. One strategy might be to create a design capstone course that everyone completes, which consists of a year-long “Make” project centered on a student’s interest. Assessment would be authentic and performance-based to capture what is learned in the context of such a course. Accomplishing this will require establishing test bed collaborations comprised of schools, informal institutions, higher education, and industry partners who are committed to educational reform, innovation, and future job preparation. Investment is needed to conduct design research to understand how to develop and support this kind of reform.
- **Support the Growth and Adoption of Personal Fabrication Technologies as Pedagogical Tools for STEM Learning.** Personal fabrication technologies like “makerbots” or 3D printers prevalent at Maker Faire are the “desktop manufacturing” of today and a key to future economic development. We need to gain further insight into the value of using these small-scale product design and manufacturing tools in the science and engineering classroom. Experimentation at the university and community level suggests that these technologies hold great potential for inspiring creative model building and problem solving. Additional research and development is needed to equip schools with the latest technologies and to investigate the benefits of fabrication design-based projects for STEM teaching and learning.



Making and Engaging Diverse Learners

Maker-like projects enable young people to discover what they are good at and to pursue further opportunities in STEM-related fields. To increase the diversity of young people who get involved in STEM and become innovators in this new economy, we need to invest in initiatives in which student interests are nurtured and grown through stimulating interactions with people, places, objects and situations that foster experimentation in STEM-related areas. Specific actions include:

- **Seed Young Maker Club Educational Initiatives.** Many existing outreach programs integrate different levels of Making into their work with young people. We need to build deliberate partnerships with informal and formal learning organizations that help schools and communities host “young Maker workshops” or “clubs” grounded in service oriented work (e.g., health-oriented, artistic, environmental, cultural). Students in urban environments may have different interests and community needs than young people in suburban or rural communities. These experiments should be conducted with an eye towards developing the kinds of resources, tools and strategies needed to support *student interest-driven* “Making” in different social contexts. Leveraging initiatives like National Lab Day (www.nationallabday.org) and the work of informal and

formal institutions (e.g., Cooper Hewitt Museum’s Design In Education programs and the Salvadori Center) can help further develop this work.

- **Create A Network of Maker Spaces to Introduce STEM to Diverse Learners.** Create Maker spaces to grow communities of practice around prototyping local ideas and products of interest to diverse groups of people that naturally draw on STEM and non-STEM disciplines. As an example, Lilypads Arduino is a set of tools that empower people to build soft, flexible, fabric-based computers and to blend textile craft, electrical engineering and programming in surprising ways. Research on Lilypads has shown that the blending of low-tech and high-tech strategies can create inviting environments where 7 to 80-year-olds bring new ideas to life. We need to acknowledge the serendipitous, interdisciplinary nature of Making and leverage that in such high-tech and low-tech settings. That means looking across the arts and sciences for intersections.



Making and Assessment

A key challenge in enabling the Maker movement to become integral to education is how to assess the learning that takes place. To move forward, we need policies that allow for alternative assessment measures to be adopted and used to document the kinds of outcomes that result from engaging students in Maker-like activities. A great deal of work has been conducted in engineering education and the arts that makes the case for why Making and design are valuable for student learning in STEM-related areas. The following directions for assessment were proposed:

- **Identify and Create Authentic Performance-Based Assessment Methods That Capture Important Aspects of Making.** There is ample research on doing and Making and the effects it has on the brain and learning (Bransford, Brown, & Cocking, 2000; Bruner, 1960; 1967; Caine & Caine, 1991; Gopnik, Meltzoff, & Kuhl, 1999; Dewey, 1925; Kyle, Bonnsetter, Gadsden, & Shymansky, 1988; Lowery, 1990; Piaget, 1986). We need to connect what Makers are doing to well-established bodies of learning research that already exist. To migrate the Maker movement into schools and to satisfy stakeholders that Making is a worthwhile area for investment, we need to employ an assessment process that documents the process of Making, not just the product. Performance-based assessments in engineering education or “crits” central to architecture and design education, where students present and critique each other’s work, are central to what Makers do at Maker Faires. In moving forward, research is needed to identify appropriate methods for assessing the learning that takes place in interdisciplinary “Make” projects.
- **Not the Same Old Metrics: Assessment of Affective Learning.** To address the engagement gap that we see in our educational system, we need to apply existing measures for assessing enjoyment, engagement and motivation to the Making process. The key is not to be pushed by STEM when it comes to assessment, but to find effective means for assessing the affective dimension of Making that distinguishes it from other hands-on approaches to teaching in the STEM disciplines. Identifying valid measures of affective learning is key to establishing the legitimacy of the domain for STEM engagement.

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