FABLEARN

Meaningful MAKING 2

PROJECTS AND INSPIRATIONS FOR FAB LABS AND MAKERSPACES

EDITED BY

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Meaningful Making:

Projects and Inspirations for Fab Labs + Makerspaces

volume 2

Edited by Paulo Blikstein, Sylvia Libow Martinez, Heather Allen Pang, and Kevin Jarrett

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About the FabLearn Fellows Initiative

The FabLearn Fellows program was created and housed at Paulo Blikstein's Transformative Learning Technologies Laboratory (TLTL), an academic research group within Stanford University's Graduate School of Education from 2008 to 2018. It is now housed at Teachers College, Columbia University.

The Fellows program brings together experienced educators from all over the world to contribute to research about constructionist learning, maker education, and digital fabrication in schools to create an open-source library of curricula and best practices. To date, there have been two cohorts of FabLearn Fellows, a diverse group of thirty-eight educators and makers. Many Fellows from the first cohort have continued to contribute to the FabLearn program as Senior FabLearn Fellows. Together the Fellows represent sixteen countries, including fourteen states in the United States, and work with students from a wide variety of demographics at public and independent schools, community organizations, museums, and nonprofits.

The FabLearn Fellows program was created as part of a larger project sponsored by the National Science Foundation entitled "Infusing Learning Sciences Research into Digital Fabrication in Education and the Makers' Movement" (NSF Award 1349163, Division of Information & Intelligent Systems). Some Fellows have been supported by the Lemann Foundation (Brazil) and the Suksapattana Foundation (Thailand).

FabLearn Fellow Goals

Despite the recent popularity of the maker movement and fabrication labs in education, most teachers work in isolation, cut off from other practitioners doing similar projects and disconnected from learning sciences researchers. One of the main objectives of the FabLearn Fellows program is to bring researchers and practitioners together to help bridge these gaps, learn from each other's experiences, share these lessons with their local community, and together create educational materials for the rest of the teaching community.

Through this project, we hope to answer four major questions:

- How can we scale up maker education without losing its transformative power?
- How can we generate an open-source set of constructionist curricular materials well adapted for makerspaces and fabrication labs in educational settings?
- How are teachers adapting their own curriculum in the face of these new "making" technologies, and how can they be better supported? What challenges do teachers face when trying to adopt project-based, constructionist, digital fabrication activities in their classrooms and after-school programs?
- How are schools approaching teacher development, parental/community involvement, and issues around traditional assessment?

About the FabLearn Labs

FabLearn Labs (formerly known as FabLab@School labs) are physical makerspaces in K–12 schools developed by TLTL and managed in collaboration with US and international partners. While today there are a growing number of fabrication labs in school settings, in 2009 FabLab@School was the first such program designed from the ground up specifically to serve grades 6–12.

There are currently FabLearn Lab installations on the Columbia University campus (US), and in East Palo Alto (US), Palo Alto (US), Moscow (Russia), Bangkok (Thailand), Barcelona (Spain), Melbourne (Australia), Sobral (Brazil), and Espoo (Finland), with partner labs in many other cities.

The intellectual roots of FabLearn extend back to the work of Seymour Papert, a pioneer in the field of educational technologies, and his collaborators at the MIT Media Lab. Papert and his colleagues developed Logo, a programming language designed for children and the first systems for educational robotics. Papert's constructionist perspective (a belief that children learn most effectively when they build artifacts and share with peers) is at the heart of the FabLearn program. A second important component is the work of Paulo Freire, a Brazilian scholar who was a pioneer in highlighting the importance of culture, equity, and social justice in education.

The original Fab Lab was conceived in the early 2000s in the Media Lab at MIT by Neil Gershenfeld (in collaboration with Bakhtiar Mitkak) as a creative space for university students. Within five years the concept had been transplanted successfully to community centers and entrepreneurial centers around the globe under the banner of the Fab Foundation. In this book, the spaces that are affiliated with the Fab Foundation are called Fab Labs, while those not associated are called fab labs, fablabs, makerspaces, or their own unique name based on the preference of the organization and author.

Paulo Blikstein was a student at the MIT Media Lab when the very first Fab Labs were being created. He began researching digital fabrication in education in 2004 as part of his doctoral work, created the FabLearn Lab concept when he joined the Stanford faculty in 2008, and designed the first-ever digital fabrication lab at a school of education. Blikstein is currently an associate professor of Communication, Media & Learning Technologies & Design at Teachers College, Columbia University.

About this book

This book is a compilation of some of the work of the FabLearn Fellows and Senior FabLearn Fellows. Included are articles about making and fabrication in many different learning spaces, ideas for projects, reflections, curriculum integration strategies, and much more. Many of the articles and projects include resources for additional reading and exploration, and every Fab-Learn Fellow has a page on the FabLearn website (fablearn.org) where more projects, details, and contact information can be found.

Acknowledgements

Contributing FabLearn Fellow Authors:
Josh Ajima, Sarah Alfonso Emerson, Anne Bown-Crawford, Justin Brown, Reina Sofia Cabezas, Jaymes Dec, Koffi Dodji Honou, Cassia Fernandez, Christa Flores, Alphonse Habyarimana, David Hann, Nico Janik, Kevin Jarrett, Wojciech Karcz, Susan Klimczak, Per-Ivar Kloen, Angela Sofia Lombardo, Angie O'Malley, Heather Allen Pang, Mario Parade, Sam Phillips, Erin Riley, Daniel Schermele, Mark Schreiber, Nalin Tutiyaphuengprasert, Aaron Vanderwerff, Juliet Wanyiri, and Mathias Wunderlich

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Transformative Learning Technologies Laboratory
The Transformative Learning Technologies Laboratory (TLTL) is a multidisciplinary research group creating and investigating new technologies for project-based STEM education. Within the realm of digital fabrication in schools, the TLTL conducts research and disseminates findings through four main programs: FabLearn Labs (educational makerspaces in K–12 schools developed in collaboration with US and international partners, formerly known as the FabLab@School project), FabLearn conferences, FabLearn training classes, and the FabLearn Fellows program.

Constructing Modern Knowledge Press
Constructing Modern Knowledge (CMK) Press is a publishing company dedicated to producing books supporting modern learner-centered approaches to education.

Caution

Some of these projects call for tools and materials that can be dangerous if used improperly. Always follow manufacturer's guidelines and safety rules, and use common sense.

Meet the Contributing FabLearn Fellows

Josh Ajima

Josh Ajima is the instructional facilitator for Technology and Makerspace at the Academies of Loudoun in Loudoun County, Virginia, United States. He was awarded the VSTE Innovative Educator of the Year award in 2017 for his work integrating maker education into the content area. He has a passion for digital fabrication and has won the FormLabs 3D Design Awards for Top Educational Model and served as a reviewer for *Make:* magazine. Ajima shares his work on making in the classroom on his blog (designmaketeach.com) and YouTube channel (youtube.com/designmaketeach). He holds a bachelor's degree in chemistry from the University of Virginia.

Sarah Alfonso Emerson

Sarah Alfonso Emerson is a cofounder of the iSTEAM Lab at Bing Wong Elementary School, a public school in San Bernardino, California, United States. The iSTEAM Lab was founded to inspire students to imagine, innovate, and engage in building hope for their futures. Emerson is the school's STEAM program facilitator, primarily teaching mechanical engineering, manufacturing, product innovation, entrepreneurship, and animatronics to students in kindergarten through sixth grade. She also collaborates with her colleagues at the elementary level as well as the secondary and postsecondary levels and community partners to design and implement cross-curricular units in which students explore careers in various STEAM industries. Emerson is currently a certification writer for Linked Learning at the elementary level. She holds a bachelor's degree in Chicano studies, a master's degree in education, and a GATE certificate from the University of California, Riverside.

Anne Bown-Crawford

Anne Bown-Crawford is the executive director of the California Arts Council. With nearly forty years as a teacher at the secondary level, she is a champion for arts education in California, United States, serving as administrator for numerous exemplary arts programs. Bown-Crawford is the founding director of the Arcata Arts Institute and the Innovation Design Institute, programs within Northern Humboldt Union High School District, as well as the former Fine Arts department chair at Arcata High School. She is a founder of the Create CA Leadership Council, a statewide organization with a mission to rethink and create an educational environment for all California students featuring arts education as a central part of the solution to the crisis in our schools. Bown-Crawford is a new media studio artist, a freelance graphic designer, and an Adobe Education Leader. Bown-Crawford holds a master of arts in education from UC Berkeley, a bachelor of fine arts in design from Northern Illinois University, and was an MFA Design candidate at the California College of Arts. Bown-Crawford is a member of the National Art Education Association and the California Art Education Association.

Justin Brown

Justin Brown graduated from TCU with degrees in music, political science, and psychology as well as his teaching degree from Chaminade University in Honolulu, Hawaii, United States. Coming from six generations of educators, he has planned to work in education policy since the age of ten. Before entering the classroom full-time, Mr. Brown worked as a jazz and classical bassist with many internationally acclaimed artists. He currently serves as the CTE coordinator and lead advisor to 20+ STEM and citizenship-based programs at Kealakehe High School in Kailua-Kona. Under his direction, the Kealakehe Robotics/STEM program has grown into one of the most prestigious and comprehensive programs in the state, winning over one hundred awards and over a dozen international qualifications. He has worked extensively with the West Hawaii Complex and State Curriculum office on expanding educational robotics as well as the design thinking model. He is a HI Hope Street Group Fellow, ASCD Emerging Leader, and coordinator of the Kealakehe STEM Academy.

Jaymes Dec

Jaymes Dec is the Fab Lab coordinator at the Marymount School of New York in New York City, United States, an all-girls independent school serving students in pre-K through high school. Dec, who has taught makers of all grade levels from kindergarten to graduate school, currently works primarily with middle school students. In addition to his compulsory technology course, which covers programming, design, and fabrication, he supports teachers in other grades who are integrating design elements into their curriculum. The Marymount School program is a member of MIT's Fab Lab network. In 2013, Dec, concerned that Fab Labs and makerspaces were disproportionately the domain of wealthy schools, cofounded the NYC Makery, a public makerspace for children and families. Dec is the president of the Nerdy Derby, a "no rules" model-car building and racing competition. He is a graduate of the Interactive Telecommunications Program at New York University. He recently joined the faculty at Columbia University's Teachers College.

Reina Sofia Cabezas

Reina Sofia Cabezas came to the San Francisco Bay Area, California, United States from Nicaragua as a political refugee like many of her current students and their families. Sharing that experience of struggle and resistance and designing learning opportunities that help them shape their own counternarratives is in itself an act of resistance. As a sixth-grade maker educator at Epic Charter Academy in the heart of Oakland's Fruitvale district, Cabezas feels lucky to be part of a Design and Engineering department that values honoring those past and present legacies: explicitly making ethnic studies a pillar through which we create curriculum. She is a mother of two beautifully creative teenage men, and she pours her heart, mind, and spirit into teaching and learning toward an empathetic and compassionate world, and helping them reclaim their space and duty to defend land and life.

Koffi Dodji Honou

Fab Lab manager at Defko Ak Niep Lab (Dakar, Senegal), Honou is passionate about ICT, digital fabrication, and the maker movement. He developed valuable knowledge in Fab Lab implementation, management, and optimization in West Africa. Winner of several international awards with WoeLab, the very first Fab Lab implemented in Togo, Dodji Honou is now specializing in a Fab Lab's pedagogical potential in teaching and learning subjects such as physics, engineering, robotics, art, mechanics, and electronics. Dodji Honou believes that the international and African maker movements can greatly contribute to reshaping and improving the teaching and learning experience in African education systems through the promotion of "learning-by-doing" or "hands-on-learning" methods and philosophy.

Cassia Fernandez

Cassia Fernandez is a researcher and educator interested in exploring meaningful and experimental ways of teaching coding, electronics, and science for children. She holds a bachelor's degree in physics and completed a master's degree in electrical engineering, designing physical computing activities based on a tinkering approach to foster students' creative thinking and creative confidence. Currently she works as a project coordinator for the FabLearn Program in Brazil, focusing on science curriculum design and teacher professional development, and at the Interdisciplinary Center for Interactive Technologies at the University of São Paulo. She has experience in teaching coding to elementary and middle school students and created a low-cost physical computing tool kit that has been used in Brazilian schools and in her academic research.

Alphonse Habyarimana

Alphonse Habyarimana is the manager and developer of Kepler Tech Lab, a social innovation center and STEM Laboratory based in Kigali, Rwanda, with the aim of improving and providing hands-on learning experiences to middle school and high school students and accelerating innovation through human-centered design, workshops, outreaches, and advising. Habyarimana holds a bachelor of arts in management and associate of arts in general studies, both with a business concentration, from Southern New Hampshire University. He is also a member of International Development Innovation Network, a program led by Massachusetts Institute of Technology's D-Lab, which empowers a diverse, global network of innovators to design, develop, and disseminate technologies to improve the lives of people living in poverty.

Christa Flores

Christa Flores began her career as a science educator for grades K–8 in 2001. Inspired by the maker movement in education in the spring of 2012, she cofounded the Hillbrook School iLab, a classroom designed for material and digital making in Los Gatos, California, United States. Flores is currently the STEMlab manager for the Asheville Museum of Science in North Carolina, where she designs experiences that foster STEM literacy with an emphasis on material science, design thinking, working in collaborative teams, sharing work, and entrepreneurialism. Flores graduated from the University of California, San Diego, with a degree in biological anthropology; spent time doing research through the New York Consortium of Evolutionary Primatology; and obtained a master's degree in secondary science education from Teachers College, Columbia University. Flores is the author of the book *Making Science: Reimagining STEM Education in Middle School and Beyond* and has published various articles on the subject of making in science.

David Hann

David Hann teaches eighth-grade math and six-/seventh-/eighth-grade design and technology at Donview Middle Health & Wellness Academy, a public school in Toronto, Canada. He was the first teacher to pilot a 3D printing program in a Toronto middle school, complementing his existing Design & Technology program in a wood/metal shop. In 2014 and 2015, Hann and several colleagues collaborated to have eighth-grade students build pinball machines using Makey Makey and Scratch for a cross-curricular final project (covering math, English, science, history, and geography). He has presented this project at conferences and Maker Faires, including the 2015 World Maker Faire in New York. Hann is one of the cofounders of the MakerEdTO group, which organizes a summer maker conference for Toronto/Ontario teachers and facilitates the development of educators' maker skills and professional network. He holds two bachelor's degrees from the University of Toronto, one in education, the other in history and philosophy, and has additional qualifications as a design and technology specialist teacher.

Nico Janik

Nico Janik is the Makerspace/Engineering coordinator for the Ravenswood City School District (RCSD), a public school district with seven campuses serving low-income students of color from transitional kindergarten through eighth grade, in East Palo Alto and eastern Menlo Park, California, United States. A team of dedicated STEM-oriented people have been working since 2013 to build the makerspace program at RCSD from one pilot program in an empty classroom, to having equipped and staffed makerspaces at all of its seven school sites. Janik's work includes helping a team of site tinkerers (makerspace staff), tinker teachers, and classroom teachers bring making to their students. She is also lucky to still be able to occasionally make thing with kids! Before becoming a classroom teacher, she worked professionally as a mechanical engineer, most notably at IDEO Product Development, OddzOn Products, and Hasbro Toys. She holds a multiple-subject teaching credential. She also holds bachelor's degrees in both mechanical engineering and environmental studies from the University of California at Santa Barbara, and a master's degree in engineering/product design from Stanford University.

Kevin Jarrett

Kevin Jarrett is a teacher educator, author, speaker, and STEM/maker education consultant in New Jersey, United States. Jarrett is grounded in the belief that giving students the opportunity to imagine and create original solutions to real-world problems helps them develop the skills, dispositions, and adaptable mindset needed to survive and thrive in an uncertain future. Jarrett spent fourteen years in public education before transitioning into a consulting role, where he now devotes 100 percent of his time to helping schools embrace maker-centered educational programs that support hands-on, minds-on learning experiences. In addition to his experiences with making education and professional development, Jarrett is a Google Certified Innovator and Trainer, and a cofounder of the Edcamp movement. He has a master's and bachelor's degrees in business administration.

Wojciech Karcz

Wojciech Karcz has a background in materials science and engineering from Warsaw University of Technology in Poland. He works as a local FabLearn program coordinator in Copernicus Science Centre in Warsaw. Besides building the first educational Fab Lab in Warsaw, he also develops a whole range of maker activities and hands-on workshops for students. Karcz is an active member of the maker movement in Poland. He organizes a variety of different events like Arduino/Genuino Day, Maker Show, and hackathons/make-a-thons in order to encourage others to make and tinker. In his spare time, he makes things, teaches art students how to use new technologies, and brews craft beer at home.

Susan Klimczak

Susan Klimczak is an education organizer at the South End Technology Center @ Tent City's Learn 2 Teach, Teach 2 Learn program in Boston, Massachusetts, United States. Each year, the institution's three-dozen teenage teachers learn, build, and teach six different technology modules. Together they reach more than eight hundred children at more than twenty-five Boston community organizations through a series of summer camps. Fab Lab 001, the first Fab Lab outside of the MIT Center for Bits and Atoms, is located at the Center. Klimczak has also done academic research for the Ford Foundation, National Science Foundation, and the MIT Media Lab, among others. She is a research affiliate with the MIT Media Lab Lifelong Kindergarten Group. She holds a master's degree in education from Harvard University, a master's in environmental education from Lesley University, and a bachelor of science in electrical engineering from University of Maryland College Park.

Per-Ivar Kloen

Per-Ivar Kloen has been trained as a biology/science teacher. He teaches at High School De Populier in The Hague, The Netherlands. Inspired by an early issue of the magazine *Make:*, Kloen and his colleagues started to organize monthly maker evenings for teachers and friends. After a few of those events, he realized that this kind of making had much potential in schools. They explored the endless possibilities of the maker movement in a wide variety of projects, inside and outside formal schools. Kloen was appointed as Educational Pioneer of 2014 in The Netherlands. The flagship project is an after-school program in which the students have the freedom to make whatever they want to make in a great makerspace. The students love this way of working, and they are creating amazing things. Kloen is also an active member of the National Platform Maker Education, working to get making back into Dutch schools by organizing working sessions, delivering speeches all over The Netherlands, and hosting workshops.

Angela Sofia Lombardo

Angela Sofia Lombardo is a constructivist psychologist (Italian Constructivist Society (SCI)) and project manager of the educational area for Fab Lab Bologna in Italy. Fab Lab Bologna is one of the most prolific Fab Labs in Italy, working in prototyping, peer mentoring, codesigning school makerspaces and maker education curricula with schools of every level, and also running after-school tech labs in more than ten schools in the Bologna area. Lombardo is cofounder and president of ProgrammaBol, a nonprofit organization with the aim to spread in Bologna the message that everyone can be active and creative with digital technologies. One of the most important actions of ProgrammaBol is to organize "CoderDojo Bologna." CoderDojo is a worldwide movement of free, volunteer-led, community-based programming clubs helping kids from eight to eighteen to express their creativity through digital technologies.

Angie O'Malley

Angie O'Malley is a STEAM specialist at Brighton School, a preschool through eighth-grade private school in Mountlake Terrace, Washington, United States. She began as a technology instructor and worked to develop a comprehensive, integrated STEAM program for elementary and middle school students. O'Malley helped plan and design the school's new STEAM lab, where she holds weekly classes, before-school programs, and summer camps. She received an undergraduate degree from Linfield College and a master's of arts in teaching from Seattle Pacific University.

Heather Allen Pang

Heather Allen Pang teaches history to eighth graders at Castilleja School, a grade 6–12 private school in Palo Alto, California, United States. She herself is a graduate of the all-girls school (class of 1984) and also serves as the school archivist. Castilleja's Bourn Idea Lab is very closely associated with Stanford University's Transformative Learning Technology Lab. Before joining the faculty at Castilleja, Pang taught at the University of California, Davis; Santa Rosa Junior College; and American River College. She holds a bachelor's degree in European history from Wesleyan University; a master of arts in teaching in European and American history from University of California, Davis; and a doctorate in American history from University of California, Davis.

Mario Parade

Mario Parade is the founder of Fab Lab Potsdam and Science Shop Potsdam in Germany and has been the Fab Lab manager since 2012. Mario's specialties are citizen science and repair cafés. He runs workshops with students and young people at the Fab Lab and nearby schools.

Samuel Phillips

Sam Phillips is the manager and lead instructor at MetaMedia, a digital media lab and hangout space open exclusively to middle-school youth at the McGaw YMCA in Evanston, Illinois, United States. At MetaMedia, he oversees curriculum development across multiple modes of making, including audio and video production, video games, papercraft, circuitry, and digital fabrication. Prior to MetaMedia, Phillips was a video and animation teaching artist at Street-Level Youth Media and Marwen in Chicago, and taught sixth-grade writing and technology at Nashville Prep Charter School. Phillips holds a bachelor's degree in cinema studies from Oberlin College.

Erin Riley

Erin Riley is the Mr. and Mrs. Alexander Jackson Director of the Engineering and Design Lab at Greenwich Academy in Connecticut, United States, where she teaches classes and facilitates projects with faculty at the intersection of art, design, and engineering. Additionally, she teaches a studio course in creative technologies at Columbia Teachers College in the Department of Art and Art Education. During the summer, Riley works with middle school–aged students on integrated art and science projects at REACHPrep, an educational access organization for underserved students. She holds a master of fine arts from Maryland Institute College of Art.

Daniel Schermele

Daniel Schermele is a maker teaching artist at DreamYard Project, a nonprofit serving the Bronx community in New York City, New York, United States. He piloted and now teaches maker classes at DreamYard Prep High School and at the DreamYard Art Center. His classes integrate a combination of constructivist learning, and social emotional and social justice pedagogy, focusing on projects that foster students' maker identities, build empathy, and encourage collaboration. Schermele's curriculum integrates art and music while also drawing connections to scientific, historical, and political concepts. He enjoys collaboration with other teachers and customizing his curriculum to meet individual learning needs. Schermele holds a master's in social work from Columbia University with a focus on social entrepreneurship and program design.

Mark Schreiber

Mark Schreiber is a consultant working with schools on integrating maker education with existing curriculum based on twenty years of experience teaching design and engineering. Formerly the director of innovation and design at the American School in Tokyo, Japan, he focused on integrating making into all subjects and training staff in design and fabrication. He holds a bachelor of arts in technology education and industrial technology, and a master's in construction, technology, and engineering education from Colorado State University. He is a member of MIT's international Fab Lab network. In addition to his work in education, he is the owner of DesignCase Consulting where he helps corporations embed more innovation into their company culture. Mark currently lives in Fort Collins, Colorado, United States.

Nalin Tutiyaphuengprasert

Nalin Tutiyaphuengprasert is cofounder and senior vice provost of Darunsikkhalai School for Innovative Learning (DSIL) in Bangkok, Thailand. She has been involved in the application of constructionism in Thailand both in formal and informal education since 2001 as a teacher in project-based learning and a school administrator responsible for academic and international affairs. Tutiyaphuengprasert was a cofounder of DSIL, the first Fab Lab and the first FabLearn Lab in Thailand. She is currently working as an interaction designer, a trainer for teachers, and director of the upcoming social enterprise project to scale up constructionism and digital fabrication for learning in Thailand. Tutiyaphuengprasert has a bachelor's in cinematography and master's degree in business administration. She also received a master's degree from Stanford Graduate School of Education in learning, design, and technology.

Aaron Vanderwerff

As the director of learning of MakerEd, Vanderwerff is responsible for content development and delivery to educators and trainers. He manages the design and content behind MakerEd's work, including resources, workshops, and programs. Throughout his sixteen years as a public educator, Vanderwerff has been passionate about making and inquiry, believing that learner-centered, hands-on education can revolutionize our educational system. Prior to working at MakerEd he was the director of the Lighthouse Creativity Lab in Oakland, California, United States, where he collaborated with teachers to turn learning over to students throughout the school day. Vanderwerff started the Creativity Lab program in 2010, growing it from a high school elective to the K–12 program it is today. He also supports educators through Designing Making Experiences workshops, the AbD Oakland Fellowship, and teaching a course on designing equitable groupwork in the Stanford Teacher Education Program. He taught high school science and robotics in the San Francisco Bay Area for over ten years. Vanderwerff lives in Oakland with his wife and daughter, who love to make things.

Juliet Wanyiri

Juliet Wanyiri is the founder of Foondi Workshops in Nairobi, Kenya, which runs collaborative design workshops. She is an electrical engineer and is an organizer and alumna of the International Development Design Summit (IDDS), an annual design and innovation summit organized by MIT's design lab. Wanyiri is a member of the 2016 IDIN Workshop Fellowship program. Prior to this, she was the director of Gearbox makerspace. She was also part of the engineering team behind BRCK.

Mathias Wunderlich

Mathias Wunderlich is a teacher at the Freie Aktive Schule Wuelfrath (FASW) in Germany near Düsseldorf. This is a private school with deep roots in the pedagogy of Maria Montessori as well as Rebeca and Mauricio Wild. The school offers students the opportunity to work, invent, and tinker whenever they want. It gives students maximum freedom of choice for what they want to learn, when, with which classmates, and in which chronology. Wunderlich runs a dedicated makerspace there, with all kind of tools and material for crafting, making, electronics, and more. He initiated the first repair café in a German school, which takes place once each month and is open to the public. With different groups of students, the school periodically takes part in Maker Faires, science nights, and competitions.

FOREWORD
Beyond Mindsets, Cultures, Brands, and Clichés: A Possible Future for Equitable Maker Education

Paulo Blikstein, Associate Professor, Columbia University

Evolutionary biologists agree that the capacity to learn highly complex new skills is what allowed our species to build civilizations in just a few thousand years. Sophisticated learning is what enabled our survival in ever-changing natural environments, so we did not have to wait a few million years for evolution to rewire our brains. This process is so powerful that in just two years a baby can learn how to walk, use tools, speak at least one language, and create refined theories about the world.

Still, for our civilizations to develop further, learning had to be somehow organized and regimented. We have gone through many models and settled for the one inspired by the industrial revolution, based on direct instruction, mass production, uniformization, and obsessive technocratic control.

Admittedly, this model had its merits: it made education possible at scale, and it brought basic literacy to hundreds of millions of people. However, it was based on theories of human cognition that were mostly incorrect or incomplete and was thus incompatible with how our brains evolved to learn. As soon as we needed children to learn more complex skills and content, this "instructionist" model showed its inefficiencies, requiring extrinsic motivation, tireless repetition, and copious amounts of time to learn even basic content. Scholars such as Dewey, Papert, Piaget, Vygotsky, and Freire began to give us components of a new (socio-) constructivist model, whereby learning is:

- social and contextualized;
- more about reconstruction than direct transmission of information, so students will never get a copy of what is in the teacher's brain;
- highly dependent on previous knowledge and preexisting mental models/schemata;
- tightly connected to our sensory experience of reality; and
- related to the symbols and media we use to represent and make sense of these realities, so the quality and affordances of those media matter.

While the previous theories were relatively intuitive to grasp, the new ones were fuzzy, complex, and in constant evolution. There were no easy analogies or shortcuts—just like quantum mechanics is harder to explain than Newtonian physics. This complexity created problems for the translation of research findings into school settings and their implementation in large systems. While the "instructionist" model was straightforward for policy makers to understand with easy metaphors (such as knowledge traveling from person to person just like bits flow between computers, or information being "broadcast" by teachers and "absorbed" by students), the idea of construction of knowledge was not as simple.

This new constructivist model—which was sometimes also called *progressive, experiential, active, or hands-on learning*—was initially a very hard sell. The theory was complex and had lots of gaps (and flaws), the research was laborious, implementations were expensive, and the educational methods stemming from it were ahead of their time. But despite all that, a heroic generation of researchers insisted on building new foundations for a different approach to learning and education.

Constructionism

The theoretical foundations of the FabLearn community are based on those new theories of learning, and one in particular: *constructionism*. It is the legacy of Seymour Papert and his many collaborators, who gave us a twist on the constructivist model. Papert wrote in 1991 an excellent definition of constructionism that the "maker movement" would revisit in the 2000s: "Constructionism shares constructivism's connotation of learning as building knowledge structures. It then adds the idea that this happens especially felicitously in a context where the learner is engaged in constructing a public entity."

The primary theoretical foundation of the FabLearn community is Seymour Papert's theory of learning, CONSTRUCTIONISM.

In the best tradition of Dewey, Piaget, and Freire, constructionism has, at its heart, a desire not to revise but to invert traditional instruction. One of the main avenues to accomplish that is to change how we approach construction in schools, which is usually a second-rate activity merely complementing the "real learning" that happens in theoretical lectures. Constructionists see the making of those public objects, programs, and inventions as first-rate activities that should be an integral part of the school day. But they also advocate that meaningful making cannot happen without a coordinated effort of minds and hands: there can't be making without sensemaking.

Fast forward to the first decade of the 21st century. The world's once-industrial economy had evolved into a multifaceted, globalized, complex network of products and services for which the labor demands are radically different. But the changes went deeper than just the labor market. As the world became more diverse, we realized we need to learn how to deal with it. The need for social and educational equity became crucial. We came to accept that all voices needed to be heard and respected, especially those of traditionally excluded groups. Deep changes to civic participation and human relationships all pointed to the need for new skills and competencies, many of which more recently received the designation of "21st-century skills." Interestingly, this new designation became very popular and gained many supporters. It was as if ministers of education and policy makers suddenly "got it"—though many could not grasp the concept of progressive education, most understood why children needed to learn different things in the 21st century.

And they soon realized that those skills were *not* learnable in the old drill-and-kill ways, so they turned to progressive educators for inspiration—constructivists and constructionists in particular. The results are everywhere: there are thousands of makerspaces in schools around the world; computer science, engineering, and design are becoming part of national standards; there is a growing popularity of project-based learning, and a renewed interest in Papert, Freire, Dewey, and Piaget. In this sense, progressive education—and especially constructionism—have won the battle of the minds.

But we are still in the thick of our everyday, down-to-earth battles in our schools, districts, and cities. The revolution is far from over, and there are many areas that still require our attention.

Coexisting with the existing system to create sustainability

Some education reformers believe that we need to get rid of school and replace it with something very different. Incremental change will get us nowhere, they say. But given the sheer scale of the educational system, with millions of students and teachers, we need to think about both radical change and what teachers will do next week (or as Papert said, both the "Someday" and the "Monday").

The tools we have today offer the possibility of creating quite different learning environments even within the current system. Makerspaces are perhaps the best example. Twenty years ago, the most radical space you could build in a school was a computer lab. Granted, you could do wonderful Logo work there, but it was just one type of tool. Compare that to what you can do today in a makerspace (in addition to programming)—there is so much more that can be achieved, and there are multiple ways to tie in with the school curriculum, in STEM, Arts, and Humanities. It is also much easier to convince parents, principals, and teachers of the need to redesign curricula and have many types of learning experiences during the school day.

Thus, working "within" the system is not as terrible as it used to be, and we have the opportunity to improve the lives of many children right now—not in 30 years. The path to sustainability includes finding creative, ambitious ways to coexist within the current system while always pushing for more audacious changes.

Making the terminology more precise

Nomenclature sounds trivial, but it is not. We have far too many names for similar things: *project-based learning*, *maker education*, *student-centered education*, *discovery learning*, *hands-on learning*, *STE(A)M education*, etc. This is very confusing for everyone and makes it impossible to distinguish the pedagogical principles behind each approach. I believe that ***constructionist learning*** is an appropriate designation of theory of learning that underlies the maker movement. First, constructionism has a formal definition, and it has a clear historical link to constructivism—so we know its basic ideas, theoretical commitments, and principles. However, learning theory is not the same as classroom practice. The problem with a term like *hands-on learning* is that it can have so many interpretations that it is barely useful. Not everyone has to use the same words to describe what happens in classrooms or other learning spaces. But we should be able to distinguish and discuss choices in how people decide to teach based on what we believe about learning. This nomenclature work is a task for the whole community. We need to find spaces and places to have honest, nontrivial exchanges and even debate. The more precision in our descriptions of maker activities, the more we can talk about and improve them. But without precise language, we will end up in an educational Babel in which no progress can be made.

Rethink our use of the term *making*

I used to be an enthusiast for the term *maker* because it seemed to unify our community. But recently I realized that it is hurting the community in other ways. For instance, Leah Buechley's epic FabLearn 2013 keynote pointed out that *Make:* magazine covers overwhelmingly portray a maker movement dominated by affluent white males. This is the problem: *"maker" was invented as a brand, not as an educational concept*. It was invented by very well-meaning publishers to describe a conference and a magazine in the Silicon Valley, but it was not meant to be a pedagogy, an educational project, or a theory of learning. The term *make* is culturally insensitive because many populations associate "making your own stuff" (food, household object) with poverty and exploitation. It is only in affluent parts of the world that making your own cheese, soap, or furniture is associated with emancipation and liberation. In most places, to "make" those things is a painful and undesirable chore. It is also a gendered term. Many years ago, I remember a female high school student who told me that she felt offended by the term *maker* because she saw herself as a person who was first and foremost interested in helping people through making things but not as a "maker" who just creates physical things for their own sake. She felt that being seen as a "maker" was uncomfortable.

The term *make* is also generating an excessive number of useless conference panels about what "making" actually is (Is coding part of making? What is the difference between a fab lab and a makerspace? Does a makerspace need a 3D printer?). There are just too many books, manifestos, and definitions, as if we were trying to decipher an obscure and complex term created by a philosopher in ancient Greece—when in reality it was just invented 10 years ago. This is self-inflicted pain.

"Make" is not a pedagogy, a mindset, a way of thinking, or a revolution—it is a brand. It is useful in that it helps us communicate with the external world, but it should not be the way we think about ourselves. We need to move beyond the clichés, such as the trivial discussion of mindset, the superficial treatment of social-emotional competencies, the overly simplistic celebration of "making mistakes" without debugging, or demanding "grit" without students having personal ownership of their

MAKE is not a pedagogy or a mindset—it is a BRAND.

work. The so-called "maker culture," as we know it, is a collage of often US-centric, gendered, and culturally insensitive practices with no theoretical cohesion and often contradictory ideas. Of course, those discussions were a crucial start, and we need to be appreciative of all the amazing work that was done and the fearless leaders that dared to create a new movement. It was a great and bold start, but we need to move beyond these initial definitions and keep revisiting them as complex, evolving intellectual constructs and not as brands or clichés.

The so-called "MAKER CULTURE," as we know it, is a collage of often US-centric, gendered, and culturally insensitive practices with no theoretical cohesion and often contradictory ideas.

Thus, we should go back to the learning theories we care about and start placing maker education in there instead of reinventing wheels. If we accept that constructionist learning is the learning theory to base a future on, we must now get to work on what that means for classroom practice.

Transformative learning is up to us

In the famous "Gears of My Childhood" preface to *Mindstorms: Children, Computers, and Powerful Ideas*, Papert states what he has always considered "the fundamental fact about learning: anything is easy if you can assimilate it to your collection of models. If you can't, anything can be painfully difficult." Education needs a collection of models demonstrating the impact of implementing constructionist ideas in school. Maybe then they will not anymore be painfully hard to implement but a lot easier. This book is a collection of such models, written by visionary educators who took on the job of bringing constructionism to their schools; building labs; and creating activities, toolkits, and curricula. They understand that we are at a crossroads, where yet again two different philosophies of education battle: on one hand, the proponents of mass-produced instructionism now powered by internet tools, and on the other, the advocates of the highly personal forms of learning that come from making, building, and creating one's own theories.

At first, it seems like a lost fight. What can a few innovative teachers do against the power of the status quo, multinational publishing companies, and overhyped entrepreneurs? But I remember the early days of makerspaces and fab labs in schools, just a few years ago. People would look down on constructionist educators and on the maker education community as a bunch of absent-minded idealists who did not know how the real world worked. I should have gotten a cent for each person who said, "Logo did not work; this will not either," "It will not scale," and "Teachers cannot do it." But the community kept working hard, being creative, and creating alternative views of what education could be. And this made me believe that this time there is a way to survive and thrive. We might have to put aside our own idealized views of how things work and understand that overnight changes in education are hard—and that even Papert was a bit too optimistic (and sometimes mistaken) about it. A more productive path might be, indeed, to create multiple models of implementation, assessment, and curriculum construction; document inspiring narratives of success or failure; and do rigorous research on the learning that happens. With enough of these models and proofs of existence, it will be increasingly attractive for new teachers to join, new districts to embrace the ideas, and ultimately whole school systems to try to incorporate making and constructionism into their curriculum.

Maybe, after all, the revolution will not happen overnight but one school at a time. But until then it is our job to build those models, tell these stories, do the research, document the work, and tell the world about the incredible things students can do when they are empowered to build, think, and create.

After all, as Freire said, transforming the world is our "ontological vocation," it is the call to be the most fully human; it is what being *Homo sapiens* is all about. Schools have denied this to children for too long. What a time to be alive—it is objectively within our reach to change that.

Learning

The first section of this book is a collection of articles about how Seymour Papert's theory of learning, constructionism, combines with the modern tools and technologies of the maker movement to create new opportunities for learning. The FabLearn Fellows offer their views on various topics from the nature of learning to creating environments for children that foster deeper understandings and connections with powerful ideas. By placing these big ideas in real contexts of classrooms and other learning spaces, theory comes alive and vision becomes action.

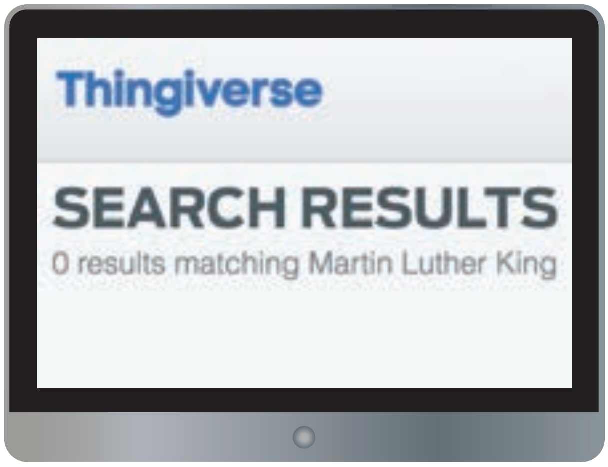
Find Your **Zero Things**: Diversity, Opportunity, and 3D Printing

by Josh Ajima

Zero Things is a call to action for students, educators, and makers to design and share 3D models that celebrate diversity, social justice, and equality. Even with over two million things, searches of popular 3D printing repository Thingiverse often find **zero** relevant models for topics related to identity, heritage, and culture. Each empty search is an opportunity for students to make a difference in the world.

Three things about me that might give you some context for this project are that I'm a high school technology resource teacher, which means I help teachers integrate technology into the classroom. I'm a 3D printing fanatic—I love 3D printing. I identify as *hapa*, which means "half" in Hawaiian—I'm half Japanese and half Caucasian.

In 2014 I was walking by the library in my high school, and there was a glass cabinet with a Martin Luther King Jr. display, and I thought, "Hey! I should 3D print something for that display cabinet—it looks a little sparse. I'm going to find something and 3D print it."



Zero results for Martin Luther King? Is this possible?

So, I went onto a 3D printing repository called Thingiverse to search for something to download and 3D print. I searched for "Martin Luther King," and I found **zero things**. And of course I searched for different permutations—"Martin Luther King Jr" and "MLK"—and I didn't find anything. Hmmm . . . it seemed like a great opportunity for me to post some designs. So I found a

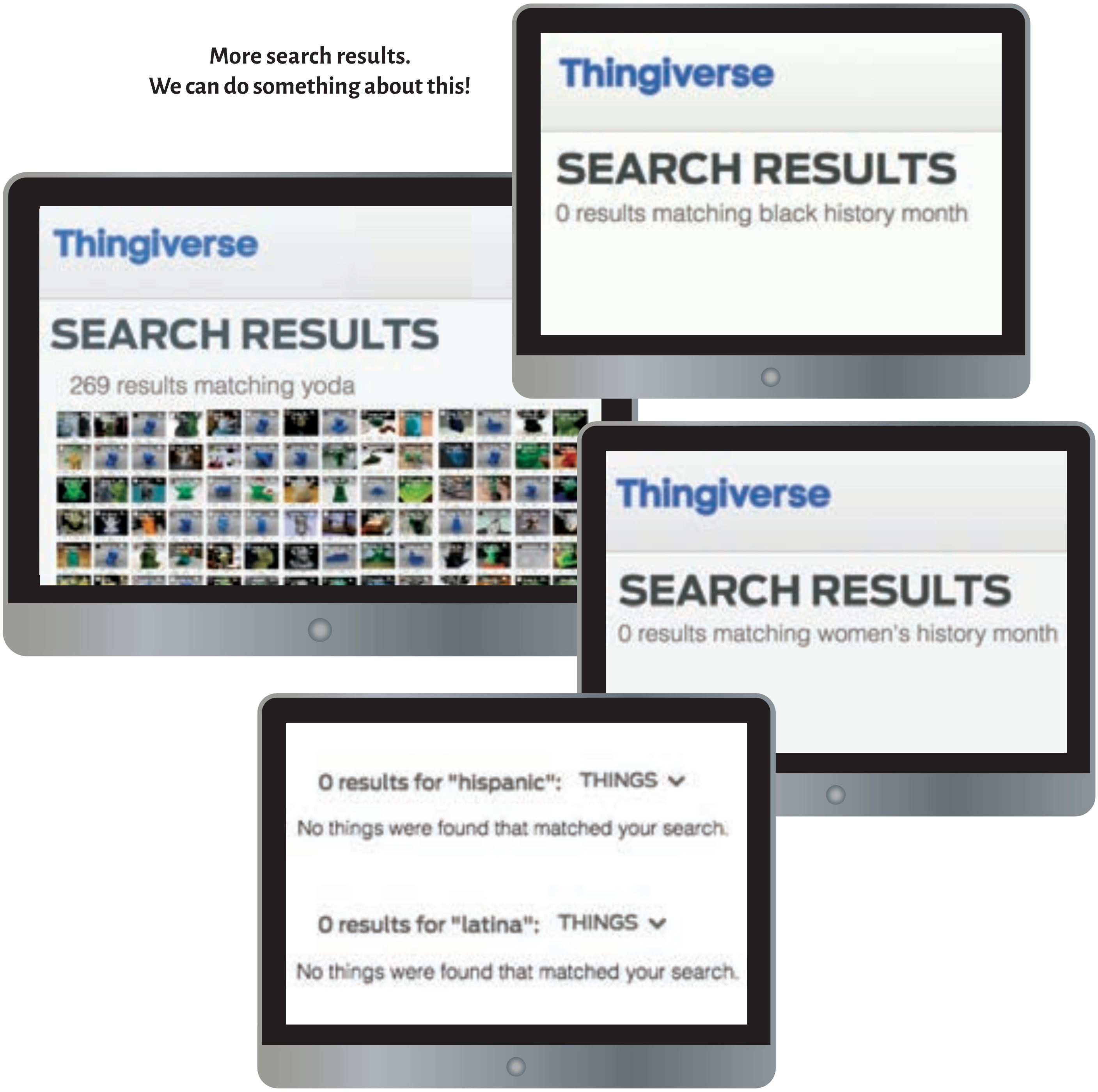
Lithophane 3D-printed MLK. Now there is one thing.

public-domain image of Martin Luther King Jr. I went to a Thingiverse Customizer and turned it into a *lithophane*, which is an object that reveals a picture when you shine a light through it. I went to the Google SketchUp Warehouse, and I found a low-poly model, converted that to an STL file for 3D printing, and uploaded both of those models to Thingiverse.

The next month was Black History Month, so I wanted to 3D print something. I did a search, and I found **zero things**. I searched for "black history," "African American history"—a lot of different keywords—but wasn't able to find anything. Hmmm . . . this seemed odd. I thought maybe the search function on Thingiverse was broken. I searched for "Yoda" and found 269 results. **Zero things** for black history; 269 results for 3D-printable Yodas.

The next month was Women's History Month, and again I searched—for "women's history"—and I found **zero things**. [Just a word of warning: If you search for "women" or "females" on some 3D printing repositories, you're going to find a lot of things that are not suitable for working with children.]

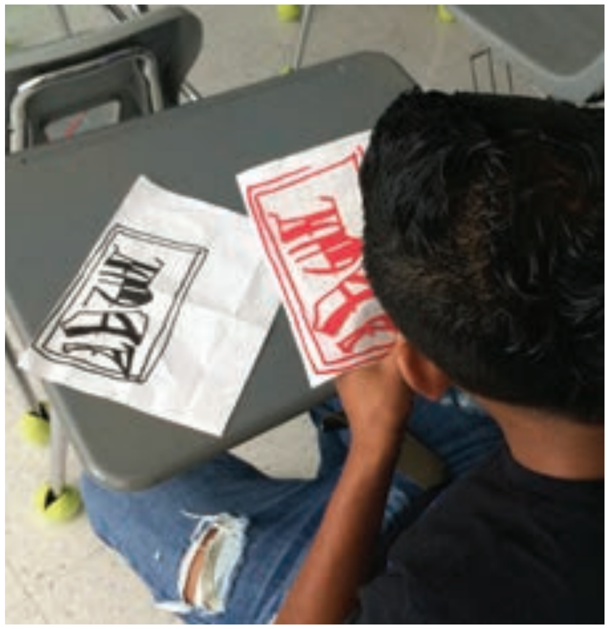
**More search results.
We can do something about this!**



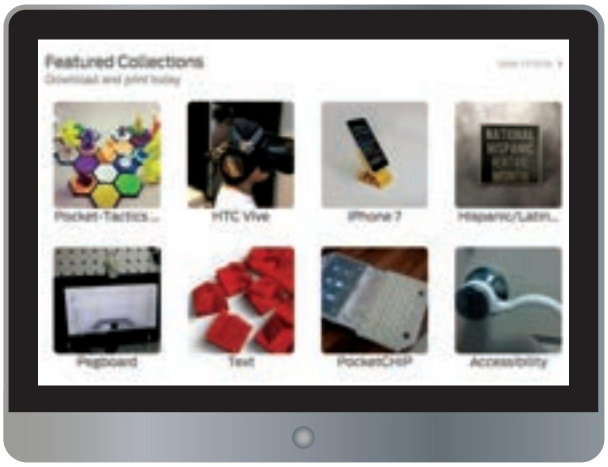
Imagine telling kids, "Hey! We have these new 3D printers! They are super exciting! You should go and find something to download and 3D print," and for a student to find **zero things** that represent their interests, their identity, their heritage or culture . . . ? It feels like they will be unable to find anything relevant to them.

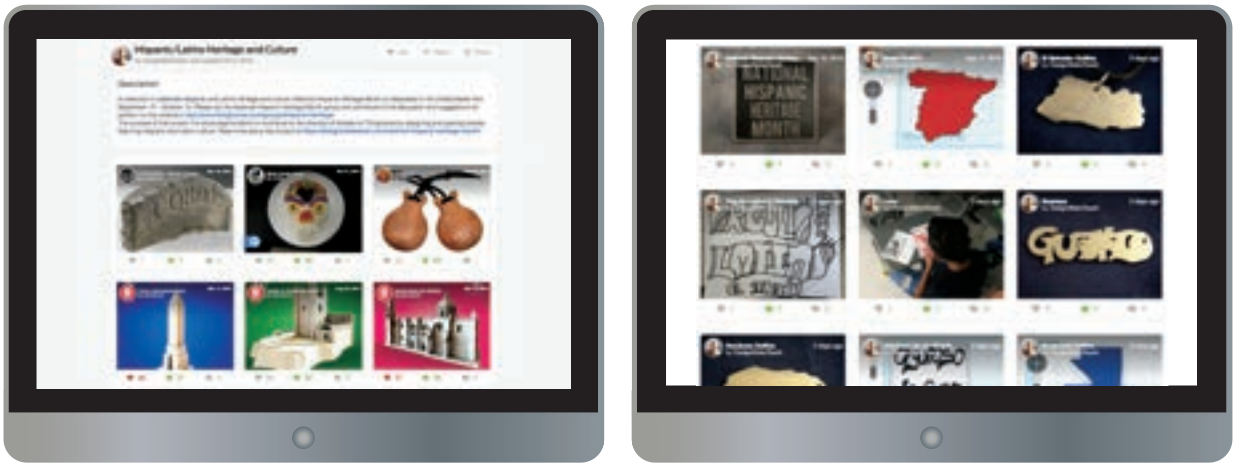
In my school we have a lot of English language learner (ELL) students from El Salvador, Honduras, and Guatemala, so when National Hispanic Heritage Month came around, I searched for "Hispanic" and "Latina" and "Latino," and I found **zero things** to 3D print. I worked with the ELL teachers, and we took this as an opportunity for students to take a Sharpie and just draw some designs on paper. We digitized them and put them in Thingiverse and then 3D printed them. In one case, the design says *Guanaco,* which is a nickname for Salvadorans, and this student wrote, "I am proud to be Salvadoran." We didn't do this with just one kid; we did this with a lot of the designs from this ELL class. Not all of them were able to be digitized in a format that you could 3D print, but we were able to upload a number of those designs and publish them on Thingiverse.

Student Designs



Not only did we publish the student designs, we found that there were a lot of designs that were just hard to find searching for “Hispanic” and “Latino,” so we curated a Hispanic and Latino Heritage and Culture collection. We searched. We did some research and found a number of these models and assembled them into a collection. Thingiverse found out about this, and they put this collection on the front page of Thingiverse—which I’m told is the only collection curated by someone who is not a Thingiverse employee to appear on the front page of Thingiverse.





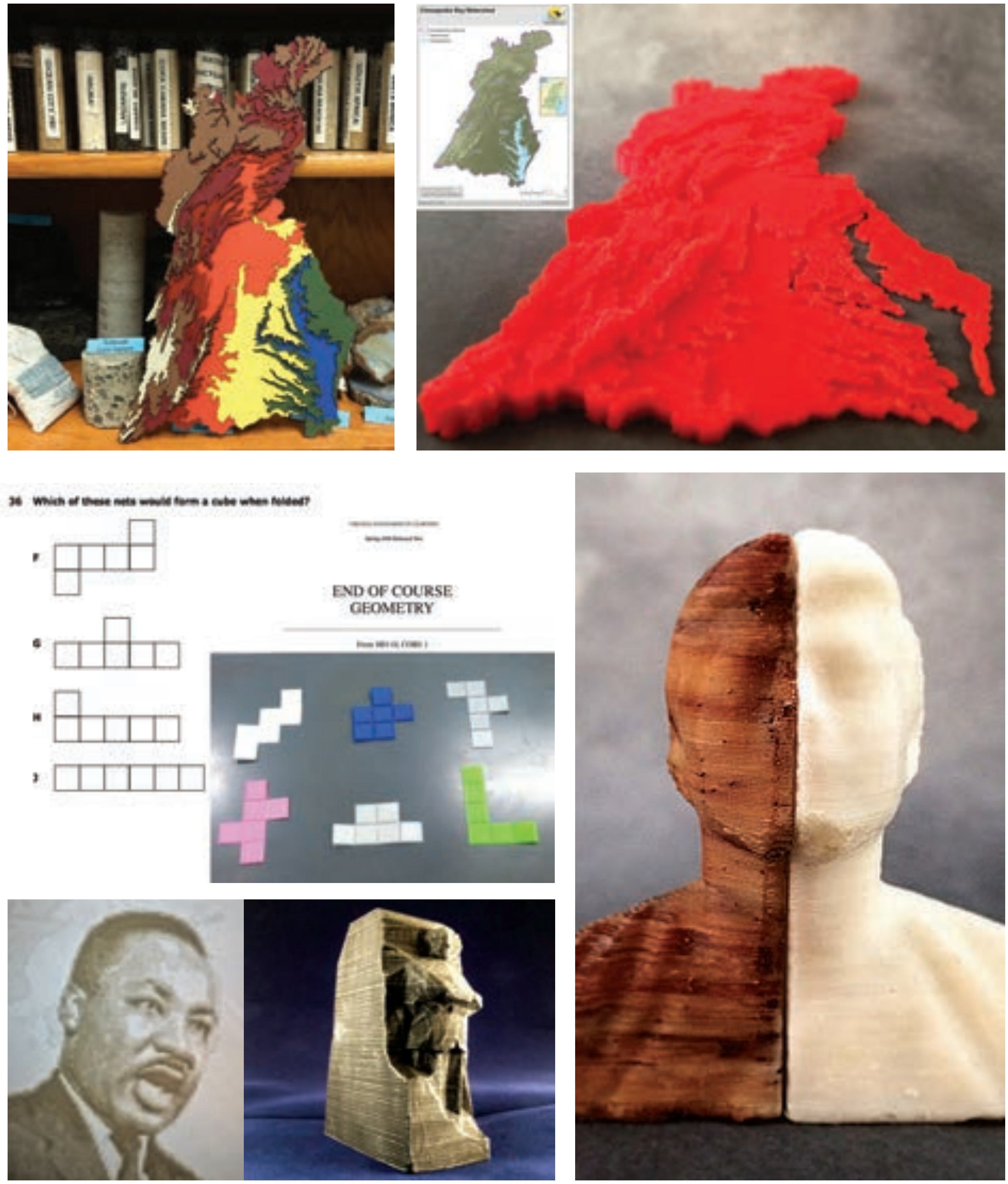
Hispanic and Latino Heritage and Culture collection on Thingiverse

It’s such a big deal to have a collection or model featured. When the *Hidden Figures* model first came out, there were tens or hundreds of views and then, after it was featured on the front page, it went up to thousands of views, and then when it came off the front page, that number of views just dropped off the face of the Earth.

Hidden Figures tribute lithophane space capsule design viewership soars after being on the front page of Thingaverse

Maybe your **zero things** result has nothing to do with identity, heritage, and culture. Maybe your **zero things** is something like the Chesapeake Bay watershed. I helped develop a model for an Earth science teacher who wanted students to understand why water from New York ends up in the Chesapeake Bay watershed. Maybe you are a geometry teacher and your **zero things** has to do with nets of a cube. The Virginia Standards of Learning had questions about which of these nets of a cube actually fold up to form a cube shape. We developed and designed 3D models where some of them folded up into the correct shape and some of them didn't.

Find your own Zero Things

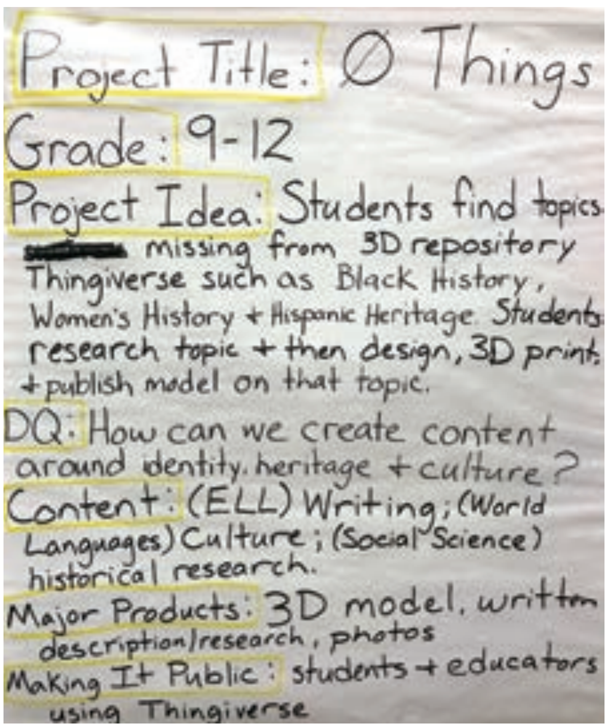


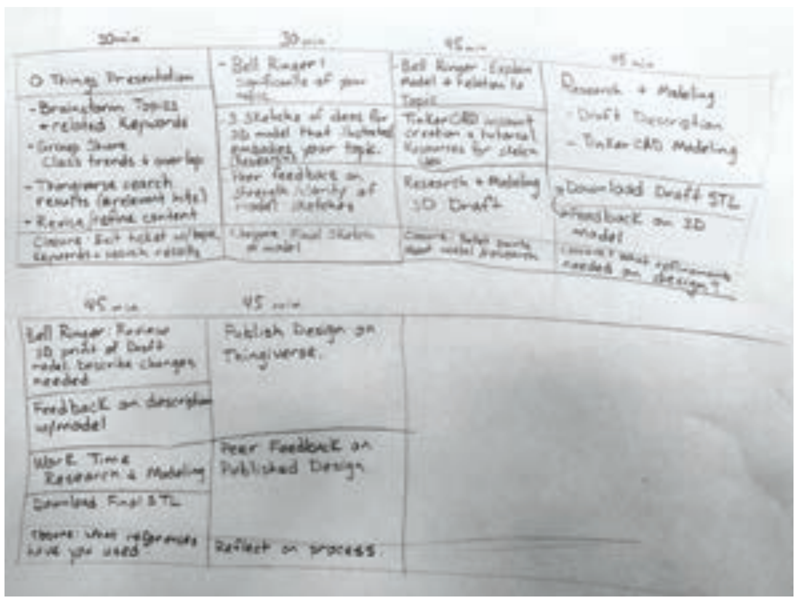
It is not just about creating these models or designs—it's about making it so that people can actually find them. It's about making sure they have the correct keywords. It's about all these modern digital information skills. It's about publishing research to give people some context about the model and what it represents.

Share your **zero things** with the world

So, what I learned from this project and this work is that **zero things** can become one thing, and one thing can become many things, and that students can have an opportunity to add knowledge to the world with digital designs.

For all of this I wish for you and your students the excitement and frustration, the joy and the despair, but most of all the opportunity of finding *your* **zero things**.





Digital citizens adding knowledge to the world

Real Tools, Real Life, Real Learning

by David Hann

Don't run with scissors

There is a lot of discussion in the FabLearn community about tools—not only new tools like 3D printers and CNC machines but also about finding great hand and power tools for children. As I have been pondering tool use in the classroom, I have come to several conclusions:

- Tools need to be sized appropriately for children.
- Tools need to be of good quality to do the actual work one might expect them to do.
- Children need to have access to tools when they are ready to use them.
- Different children are ready for different tools at different ages.
- Teachers need to recognize children's needs and skills and match them to the right tool at the right time with the right safety protocols.

We do a disservice to children who say "I'm ready for real tools" when adults feel the need to chide them saying "No, you're not." This mindset needs to change—to a response that sounds like "Okay. How can we make that happen safely?"

There are, of course, inherent risks involved with any tool use ("Don't run with scissors" is a common refrain in the classroom after all), but **instead of avoiding risk altogether, we should teach children to manage the risks safely**, and by doing so allow children to enjoy rich, meaningful making experiences.

Skills training for safety

My three-year-old daughter is in a Montessori-based program that lives this philosophy. She recently learned how to iron clothes using a real iron. In the program, learning to iron happens after a child has demonstrated mastery of "how to make toast." This is a complex and meaningful task for a young child that we adults easily take for granted. This task works as a prerequisite for ironing since it also has safety considerations. The iron is smaller than a standard iron, so it's not too heavy for a child's smaller body frame, and the heat setting is restricted to lower temperatures to avoid serious burns. However, it is still an iron; it will make creases in the clothes that the children iron, and it can still cause burns.

Many people would insist the iron be locked away for fear of children hurting themselves. Instead, in this program when the teacher determines that a child is ready, the child is taught how to use this tool safely and properly—in a matter-of-fact, no-nonsense way, the same way as when learning how to use a pair of scissors. My daughter came home one day and described the process of ironing to me. She noted specifically how one hand went on the iron and the other hand went behind her back. She explained that this was so you don't burn yourself. She talked about how you couldn't leave the iron lying down and how the cord needed to be out of the way to prevent tripping. I was obviously intensely proud!

Built to last, built for real work

My sons are both older and have gone through the same program as my daughter: ironing, cleaning glass cups, cutting fruit for a snack with properly sharp knives, etc. This past summer they wanted their backyard playground renewed, so I ordered two yards of cedar mulch and we watched excitedly as the dump truck came and deposited a pile on our driveway. I informed the boys they needed to help me do the work since it was too much for me to do by myself and it was their project, so they eagerly pitched in. They watched me grab an adult-sized rake, shovel, broom, and wheelbarrow. They mimicked my preparations, getting out their mini-wheelbarrow and their child-sized tools: rakes, shovels, and brooms.

As I watched my sons working, I got to thinking about the tools they were using. So many plastic toys are given to children so they can "imagine" doing the real work of an adult. While imagination is wonderful and important, developing children who will engage in meaningful work is crucial as well. Yet while my boys were doing this real work of moving two yards of mulch 50 feet into our backyard, their tools were failing them. The plastic shovel broke in half, the metal shovel blade came off the shaft, and the tines on the metal rake started to bend. While these tools were designed to *look* real—and they were certainly appropriately sized for my children—they apparently weren't designed to fully handle real work.

Trust me

I've been working to renovate my basement. One day while I was working, I looked over and saw that one of my then-four-year-old sons had put on his (real) goggles, hard hat, and ear protectors and was running extra drywall screws into the wall with my impact driver. My easily distractible little guy was completely absorbed with his work, screwing them in along the line I had drawn earlier. Although he struggled a bit with the weight of the tool—the impact driver is pretty heavy, not a child-appropriate size and weight like the iron mentioned earlier—he worked with diligence and care. With his actions, he was saying "Trust me, Dad."

We need to trust our students when they embark on activities that may push us past our own comfort zones. Anyone would express concern to a child about to try something risky, but if the child's response is "Trust me—I can do this," then we should do the right thing and get out of the way (that is, after we double-check their safety equipment).

Not only do we need to trust children, we need to trust teachers who know their students and who work with each of them individually. I'm reminded of my visit with Gever Tulley at Brightworks, a school in San Francisco, California, where I was very impressed to learn that they use the chop saw with children as young as grade 1—with one-on-one supervision. It's no surprise that an article titled "The Most Innovative Schools in America" described Brightworks as "the school that teaches dangerously."[1]

Here is a brilliant excerpt from the Brightworks blog on the subject of tool use with young children: "Real, 'grown-up' tools empower kids, and expand their boundaries of what's possible. At the heart of our shop are power drills—an 'additive' tool—and our chop saw–a 'subtractive' tool. It's a simple, powerful combination that will allow your kids to build bigger, bolder, better projects."[2]

There is a thirteen-year-old student at my middle school who knows more about small engines then I do. Yet when he comes to school, we give him and all his classmates textbook pen-and-paper assignments and occasionally projects involving "jinx wood" (1 × 1 cm) and a glue gun. He told me that he thinks the challenge projects we typically give are kind of ridiculous. He is looking for meaningful real-world experience. Playing with syringes, tubes, and bits of wood is not relevant to him; he'd rather dismantle the engine of his riding lawn mower because the gear shifter isn't working, or build an oil-change stand for his motor bike. Coincidentally, where did he learn to embrace tinkering and hands-on learning? Not from school but from his father, a tradesperson. Thankfully we have a fab lab in my school that I oversee, so he does get some opportunities for things he finds meaningful. However, the overall school system's inflexibility and lack of trust in him and his abilities sends an implicit message that we don't value the things he does. Sadly this is doing more to chase students like him away from school at a time when we should be drawing them in.

It's not the kids—it's us: Adjusting our attitudes as educators

Many activities often considered unsafe are not actually beyond children's physical or mental capabilities; they are unsafe because we don't have enough adults and enough time to properly supervise and train children who are ready for them. By extension, it's actually unsafe because we don't set our expectations high enough. It comes down to our preexisting mindset. It's like I tell my students in my fab lab: "The MOST dangerous tool is actually the one you think is SAFE!" If we start with the premise that children are developmentally unable to work with tools, then we limit their opportunities for no reason other than the ease of blanket prohibitions. Instead of facilitating the taking of calculated risks, we don't trust teachers' judgment, and we are guided solely by fear of liability.

Unfortunately the other key piece here beyond adjusting attitudes is staffing and funding. In his fascinating book on the history and trajectory of manual work and hands-on education, Matthew Crawford argues in *Shop Class as Soulcraft* that what school boards wanted in the 1990s and 2000s was *fewer* adults in the room. As a result, shop classes were closed since the class sizes were much smaller, and students were put in front of computers in labs that could hold much larger classes.

What results in classrooms more often than not are projects that many students do not find challenging and see no value in doing. Children get very good at reading our implicit messages and the message we often send around tools:

- "We don't trust you."
- "You're not here to learn; you are just here to be supervised."

Granted, some amazing and forward-thinking teachers in Ontario and all over are getting started with hand tools and real materials in kindergarten and grade 1. The problem is that by the time these students reach the end of middle school, they may have been using the same tools for eight years, and by then many of them are long past ready to move on to greater challenges.

No wonder some of our students are discouraged, disengaged, and acting out.

The solution in my mind is simple (though admittedly the implementation would be complex): get rid of age-based "batching" (as Sir Ken Robinson calls it) and move to a more personalized skills-based focus. For students who are ready, bring out the real tools and let them get to work. For those who are not, provide different, "scaffolded" projects (perhaps using predetermined kits) to allow them to develop skills and learn at their own pace.

I'm not saying that *any* child should use *any* tool but that we must remain open to facilitating all kinds of authentic learning experiences using all sorts of real tools in appropriate circumstances. I'm grateful that students in my school have the opportunity to use a variety of real tools, but this option should be open to children at every school, and not just at select schools.

Notes

1. thisisinsider.com/the-most-innovative-schools-in-america-2016-4#brightworks-school-san-francisco-ca-the-school-that-teaches-dangerously-2
2. sfbrightworks.org/2013/12/how-to-use-a-chop-saw-with-five-year-olds

Makerspace of My Childhood

by Jaymes Dec

Note: This article is a reflection on Seymour Papert's classic introduction to Mindstorms, "Gears of My Childhood"

Even at the age of seven, I had a makerspace. The cellar of our family home in suburban New Jersey was dark in corners, and the cement floor was cold year-round. But the combination of semi-discarded machines, random material selection, and my father's heavy tools turned this underground cavern into my own proto–fab lab, a place where I was free to imagine and explore by making things, where I could tinker and create, a place where I could learn at my own pace and study in my own way.

My workshop was huge, encompassing the entire footprint of the largest house in the neighborhood. A generic wooden staircase descended into the middle of the room, splitting it into four main sections. The left side of the wall facing the base of the stairs was lined with the hot water tank and furnace that warmed the water for our house. Mysterious noises would emanate from this area of the basement. Sometimes my brothers would cruelly turn off the switch at the top of the stairs, and the only light in the room would be the flickering blue glow of the furnace reflecting on the shiny concrete floor.

Turning right to face the front of the house, one long windowless wall was lined floor to ceiling with steel shelves. These muscle rack units were stacked with junk and treasures packed into boxes and old luggage. There did not seem to be any order to what was in each container. It was up to me and my brothers to find out. The lower shelves were filled with boxes of our old toys and broken sports equipment. This discarded bric-a-brac became raw materials for make-believe and fantasy. The upper shelves seemed to contain older items, foreign detritus from our parents' childhoods. Reaching these archaic items was dangerous. The shelves were freestanding, and we had to climb them to reach the upper levels. More than once, a whole shelving unit tipped over on a small child, spilling ancient report cards and faded sepia photographs all over the concrete.

One entire shelving unit, closest to the staircase, was filled with my father's tools. This was my favorite of all the shelves. I knew I was not supposed to play with these adult toys, but there was something magnetic about them—their heft and their power. On the lower shelves was one large box of nails and one large box of screws. I loved to bang those nails with a hammer into scrap two-by-fours at wild angles, bending them haphazardly. Then I would use the pry bar on the hammer to slowly remove the nails. I loved the squeaking sound that would make. Some of the longer nails were harder to pry out. I remember discovering that a small block of material between the claw and the wood would help pull out those more difficult nails—one of my first discoveries of a simple machine.

On one of those shelves just above my head, my dad kept a few huge 12-volt batteries. I have no idea what they were for, but I'll never forget when one fell on my big toe while I was trying to climb up and pull it down off its perch. I lost my toenail soon afterwards. I used to love those batteries. They were so different from the wimpy batteries that powered my toys and remote controls. They had conical springs for power and ground. I remember playing with those giants and how I discovered that placing a nail across the two metal springs would produce sparks. My early experiments with electricity were fueled by a dangerous level of unbridled curiosity. I would connect my toys to those big boxy batteries and observe the effects. Sometimes my poor toys would make crazy sped-up noises, or popping sounds and smoke. I was circuit bending from a young age. Often the toys would stop working afterwards.

I lost interest in those batteries once I discovered the power of alternating current. In fact, my favorite toy growing up was an old electrical power cord that had been pulled out of a lamp. I don't remember where I found it—maybe in one of those boxes on the shelves, or more likely I cut it off a lamp myself. I used to run tests where I'd send 120 volts of alternating current through various materials and observe the results. My favorite objects to observe were metal bolts; they would get white hot. I could pick them up with pliers and burn hexagonal holes in paper or plastic. Now that I know a bit more about electricity, I realize my experiments could have caused some serious accidents. But I learned more about the principles of nature by getting electrocuted through that damn lamp cord than I ever could have in a classroom.

In fact, I learned plenty of real lessons in that basement that I never could have learned in school. In school the counselors and psychologists were saying that I had an attention deficit—that I had a hard time paying attention to the task at hand. In classes where we had to sit row by row for forty-five minutes at a time listening to a teacher talk about science or math, I was dreaming of doing science and math in the basement. And as soon as I got home, I would forget about that two-page worksheet that I was supposed to fill out for homework and get right to work on blueprints for my latest creation. In school I felt like a failure, but in the basement I was a designer, an engineer, and an inventor. In the basement, I would take stuff apart and put stuff back together. I was always trying to figure out how things worked. I would make things and often break things.

When Dad brought home a brand-new Sony Trinitron TV, everyone in the family was excited about the huge curved glass and those giant red, blue, and green pixels. But I was more excited about the prospect of disassembling the old TV, an ancient black-and-white box. I was convinced that if I could take the television apart, I could figure out how to source all the individual parts, but smaller, and build my own handheld television set. Of course, once I took that box apart, I saw how complex the system inside really was. I kept breaking that TV down into smaller and smaller parts until every single screw was removed and the giant glass cathode ray tube stood menacing but alone. It was not until years later, in graduate school, when I learned that the capacitors inside a television set hold enough current to kill an adult.

Not all of my explorations in the basement were as dangerous as the electricity experiments. Most of my time in this makerspace was spent playing and inventing with safer materials. One winter, I decided to build a snow bike. In the basement I had all of the supplies and tools that I needed. The bicycle that I learned how to ride on was small but heavy—my sister's old pink-and-white trainer with tassels on the handlebars. I studded the solid rubber back tire with screws spaced around the entire circumference. I attached a short child-sized ski with C-clamps cuffed around the bindings and the rim of the front tire. I'll never forget the satisfaction that I felt as I rode that pink bike around the snow-covered streets of the neighborhood. It might have been the first time I made a real working prototype of one of my inventions.

When I was twelve years old, my family moved to another town, another house—a house without a basement. Into my teens I continued to fail classes at school. My parents sent me away to a very traditional boarding school. My love of doing math and science in the basement faded. I was forced to fill out vocabulary worksheets and study for mathematics quizzes.

It wasn't until years later, after college, when Alan Alda appeared on PBS touring around the MIT Fab Lab, that I recalled the joys of making in that basement. The fantastic machines that I saw in that lab at MIT were way more advanced than any hammer, battery, or lamp cord, but I recognized a playfulness and creativity that had disappeared from my life as I left childhood.

In search of that feeling, I went back to school, and I learned how to use those fancy digital fabrication tools that I had recently seen on TV. I learned how to program a computer and build machines that sense and respond to the physical world. I learned more in two years of graduate school than I learned in all of my years of primary schooling combined. I rediscovered learning by making.

In New York City, where I live now, most kids don't have basements or garages, so I've been teaching in fab labs and starting makerspaces for kids. I've become obsessed with the idea that school should be more like my childhood basement, a place where students are allowed to explore and experiment, to tinker, to make, and to discover principles of nature all on their own.

Where Art Education Meets Maker Education

by Erin Riley

Making knows no boundary between discrete disciplines in education. As innovation programs facilitate skill sharing and as makerspaces and fab labs become more common in schools, art programs can access exciting new tools for self-expression and design.

At the recent National Art Education Association (NAEA) Conference in Chicago, the volume of STEAM and makerspace sessions was a testament to the growing knowledge base and enthusiasm for new technologies and materials available to young artists through digital fabrication and making. This is no surprise; there are many parallels between the characteristics of making and art education.

Student centered

Maker education and choice-based art studios put students in charge of their ideas and creative process. Learning environments rooted in Teaching for Artistic Behavior (TAB)[1] and constructionism are hubs for student-centered work.

Meaningful

Students enjoy being engaged in processes that have an impact outside of themselves and that have personal meaning. Design challenges that look outside the individual to solve problems encourage the development of empathy. Art making engages students to self-reflect and bring meaning through creation of an expressive object.

Sharing culture

The culture of makerspaces and fab labs promotes sharing in the interest of advancing ideas. Designs from websites Thingiverse and Instructables are modified and reshared like an appropriated remix for others to build on.

Student art with electronics

Design is a common thread

Design weaves through fields of art, design, and engineering. The elements and principles of design,[2] design thinking,[3] and engineering design process[4] are frameworks used by artists, designers, and engineers to inform their practice.

Making and building use materials that employ the hands, and it is inherently STEAM

Manipulating materials is spatial (math), understanding materials is science, and making with materials brings the physical language of STEM into the world to communicate an idea.

Failure is a necessary part of the process

Turning "mistakes into art" or working through an iterative cycle to improve an idea are necessary and provide opportunities for learning.

Celebrate the commonalities and let your makerspace/fab lab add to your art program

If you are fortunate enough to have a makerspace/ fab lab at your school, allow it to introduce new possibilities for your art program.

2D/3D design and digital fabrication

Students using 2D vector-design programs in the studio can fabricate their designs in the fab lab using the laser cutter, CNC router, or vinyl cutter. The list of objects for art that can be generated includes printmaking plates, screen-printing stencils, CNC-milled flat pieces for sculpture, and laser-cut paper designs. The possibilities are endless.

Row 1: Vinyl-cut stencils, laser-cut wood and paper prints.
Row 2: Scanned drawings fabricated on the laser cutter.
Row 3: Laser-cut cars.

Likewise, possibilities for 3D design and fabrication include 3D CAD and scanning for the 3D printer and building 3D models from laser-cut flat material or generating 3D positives for mold making.[3]

Row 1: 3D model and print in sections.
Row 2: 3D model and cardboard slice model, animal box with living hinge.
Row 3: Scan and 3D prints.
Row 4: Mold making with metal.

Electronics

Simple electronics can add beauty and meaning to a work of art. Paper circuits and e-textiles bring together technology and craft.

Deconstructed book with LED stickers

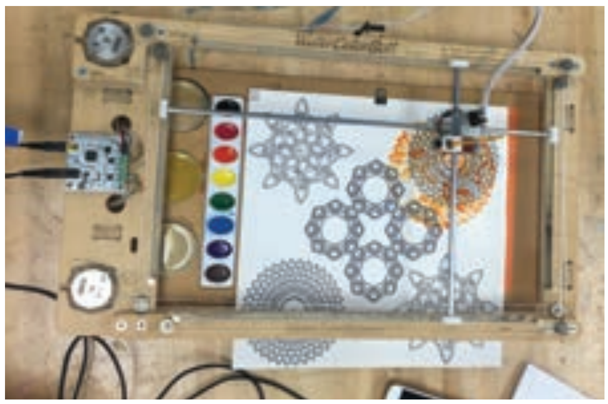
Circuit within book

Hand-enameled card with paper circuit

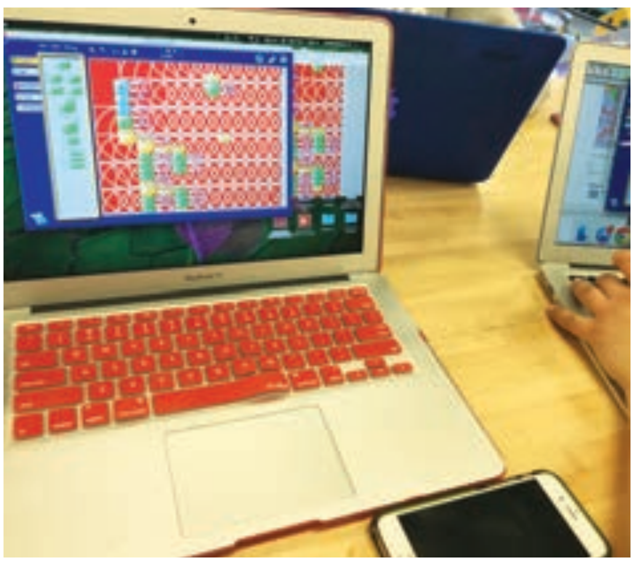
3D-deconstructed book with LED stickers

Programming and microcontrollers

Using programs like TurtleArt and Processing can empower students to use creative computation to generate 2D designs. Likewise, 3D forms can be animated, and interactive art can be produced through the use of simple electronics and controller boards in artwork.



Radial designs on a WaterColorBot



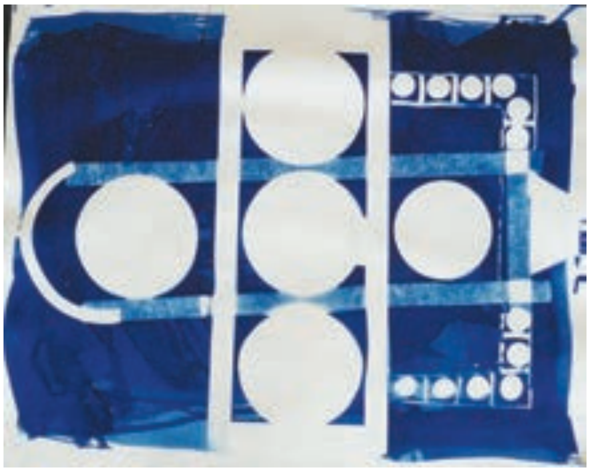
TurtleArt designs

Laser-cut gingerbread

Alternative photography

Bringing together the wonder of electronics with long-exposure photography is magical. The traditional process of cyanotype can be modernized with stencils generated with the laser or vinyl cutter.

Long-exposure photo with LEDs



Cyanotype using vinyl-cut stencils

Art and design education meets maker education, and at the intersection are possibilities

The art studio is a rich place for student growth as students master the tools and language for art and design and craft objects that hold meaning. With the building of STEAM programs in schools, creative disciplines merge and art programs gain access to an even wider set of tools and materials, further expanding the options and creative potential for young artists.

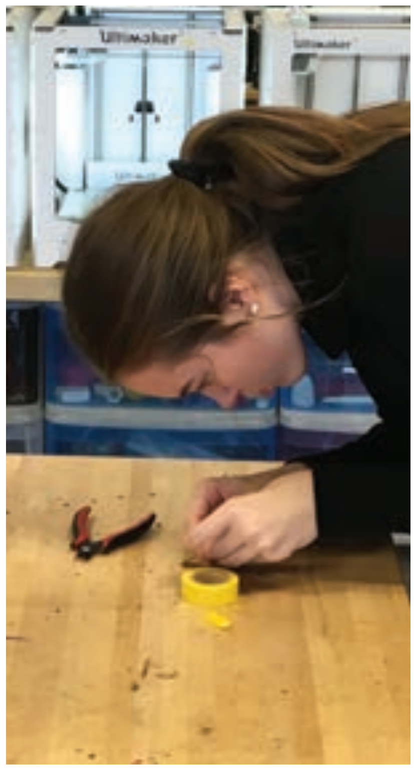
Notes

1. teachingforartisticbehavior.org
2. nwsa-2dart.blogspot.com/2012/08/elements-and-principles-of-design.html
3. ideo.com/post/design-thinking-for-educators
4. eie.org/overview/engineering-design-process

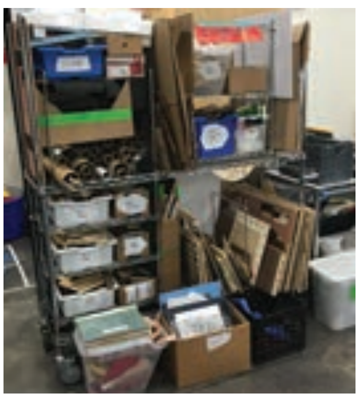
Artwork using low-tech materials

Recycle-pile leather sketchbook covers

Bookbinding



Student focusing on detail work



Recycle pile

Drawing in an upcycled sketchbook

Let's Not Make Making Too Complicated

by Mark Schreiber

My kids make stuff. They're not geeks, they're girls. Sure, they know how to make an LED light up, run a laser-cutter job, yep. Yet, even with all of this, their go-to material is still paper and tape—lots of tape.

I think we may be making *making* too complex.

For years I taught a middle school technology class, and I had my students memorize my preferred definition of *technology*: "a man-made object that solves a problem." Yes, a computer is technology. Yes, a 3D printer is an amazing piece of technology. However, a toothbrush is technology too. And so is tape. And paper, lots of paper. Our students' projects don't have to flash or be flashy all the time. They just need to solve a problem and get our kids learning by doing, by creating.

Now don't get me a wrong—it definitely is an exciting time if you are a self-proclaimed maker. I can now precisely laser cut with the click of a button; I can 3D print previously impossible-to-mill parts; I can code (formerly called programming) a new app and hook it back up to the physical world in ways I could only dream of when I was a kid. But the fact is that I did dream. I did create. I did build very unsafe tree house forts out of reclaimed wood and rusty nails—even before *reclaimed* was a hip term.

So let's not take the dreaming out of making. Let's not make making feel so complicated that our students feel that they aren't geeky enough to try it. Instead let's create.

Here are some projects that my kids have made. Most captions include what I think students learned in the process. So let's not be scared of complex makes—of failing. Instead let's get kids making. These are projects that my girls came up with using only their imagination and, yes, a lot of tape.

Paper bridges

Flying critters. The kids used a balloon and found the proper weight to make their critters fly. They also started to lighten the load over the days to keep the critter flying as the helium balloon started to lose lift.

More precision paper-sushi crafting skills

Sushi-go-'round. What can I say—they love sushi!

Pet City. Need houses for your plastic kitties? Come on over—we have a whole neighborhood!

Paper and tape. The basement makerspace needs a little bit of cleaning up, but it's all worth it to me!

It's not a box—it's a mindset!

Designing Learning Spaces for Constructionism and Learner Autonomy

by Christa Flores

Student learning how to drill safely

Every learner deserves a space to go every day that will expose them to the beauty of the world and the intrepid explorer that they truly are. How can learning spaces cultivate this goal while encouraging constructive autonomy in the youngest of learners? Two spaces that I have had the pleasure of visiting have shed some light on that question. The first stop was San Francisco, California's Brightworks and the second the Beam Center in Brooklyn, New York.

What is constructive autonomy?

The ability to work on passionate projects with very little adult or mentor guidance is a sweet spot in all creative pursuits. When working in a state of constructive autonomy, we get lost in the flow of joyful work. Time slips away effortlessly. We may even forget to eat or rest. Unfortunately, this kind of passionate flow is not cultivated in our current school system. While school schedules are regular, predictable, and easily managed (just the characteristics you would want in an industrial production line), when students seek out autonomy in this system, it can be perceived as a negative or behavioral issue. Thanks to the work being done in makerspaces now found in libraries, schools, urban enrichment programs, and museums, constructive autonomy is no longer the exception to the rule. In this article I will describe three components that allow for constructive autonomy for young learners when using a makerspace.

Trusting kids

A kid should lose autonomy only as a last resort, such as when they may inadvertently harm themselves. Let's face it, most of us have read *Lord of the Flies*, so constructive autonomy still has an adult in the room to monitor emotional and physical safety. Adults also have a need for autonomy but not at the expense of safety. Most of us choose to live in a society with law and law enforcement rather than none. Practicing constructionism in the school setting, therefore, is a balance of safety and responsibility that adults and children agree upon for the system to work. This builds an essential foundation of trust that must prevail over any excitement around any particular tool. I believe Gever Tulley, author of *Fifty Dangerous Things (You Should Let Your Children Do)*, is definitely onto something when he states that autonomy has to feel like *just the right amount of scary* to feel genuine.

My visits with Tulley at Brightworks in San Francisco taught me a lot about the "language" of trusting kids. Offering true autonomy to a student might sound a little like this: "Hey I see that you can handle this. I trust you. You are competent, and even if you make mistakes, I expect you to learn from them." The act of showing a child how to safely use a cordless power tool involves allowing children to experience the kinetic feedback of holding tools and manipulating materials. Sometimes it just means sitting with learners until the excitement of turning on a noisy or powerful tool dissipates to the point of boredom. Tool training can be followed by the adult turning their back to the new tool user as a sign of trust rather than disinterest. Turning your back shows the learner that they are now the master of their own work and safety. While the adult is still present in case of an emergency, the right and responsibility for bodily safety is ultimately in the hands of the tool user.

Note: Triggers on power tools can be hard work for small hands, and if using the trigger distracts young brains from their real work, then the tool may be too difficult or unsafe for their size. High-voltage plug-in power tools should always be monitored by an adult with younger users.

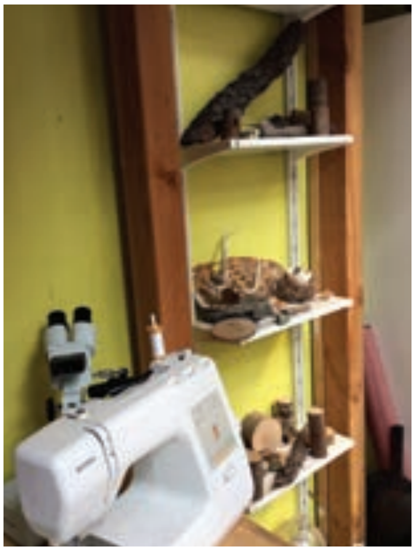
Access and inspiration

Designing spaces for constructionism and autonomy begins with allowing all users equal access to tools and materials. This is best accomplished by having clearly labeled areas for tools to be taken from and returned. I have seen lots of great versions of creating access for all learners that include providing building and scientific tools (microscopes, hand lenses, etc.) as well as computers, how-to books, and inspirational natural artifacts.

A makerspace should feel like a shared home away from home for learners. Something as simple as cleaning up and returning tools to their proper home can give a sense of ownership to a makerspace visitor. When visiting the Beam Center in Brooklyn, even brooms were on display as a sign of shared stewardship.

Design experiences

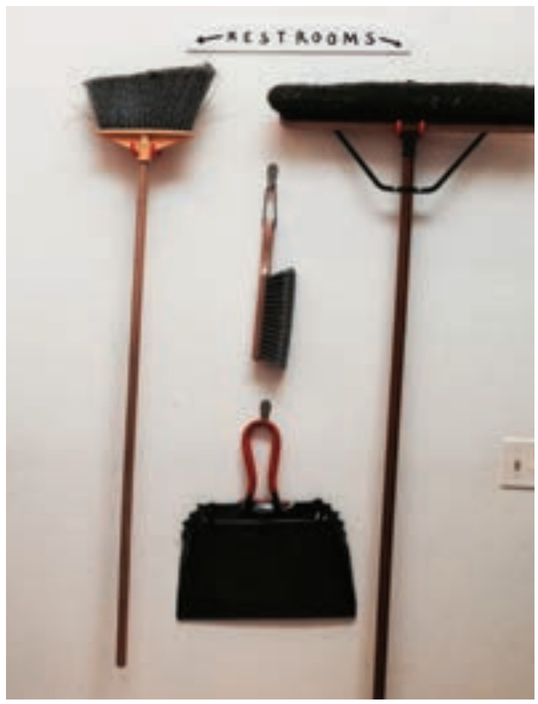
I was fortunate to visit the Beam Center in Brooklyn on a day when their week-long summer camp was just beginning a new session. The theme for



Tools and inspirational materials together

Hand-drawn labels let artists, makers, and inventors seek out and discover.

Tracing the shapes of tools à la Julia Child helps everyone return tools where they belong for the next user.



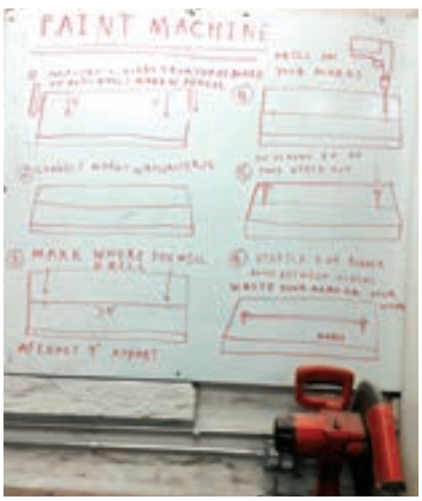
Make cleanup easy after a productive and messy day of making, with protocols and well-labeled tool storage using visual as well as text signage for nonreaders.

the week was color, a very fitting topic for learning about scientific principles, art techniques, and stewardship for a shared makerspace. Many of the Beam Center's summer workshops are targeted for a mixed age group of six to thirteen, allowing young mentors to work with younger or less-experienced learners, lending a sense of authority and helpfulness.

The workshop I witnessed was designed by artist and all-around Beam Center superstar Tim Fite. The project of the day was to make a painting machine from a plank of wood, two screws, and a rubber band. The rubber band works as a surface to apply paint. When pulled and released with differing force or direction, the vibration smacks and splatters paint onto a piece of paper, creating unique prints worthy of a modern art museum exhibit. The design of the machine was simple enough for any age level to construct and challenged summer schoolers to learn a range of tool use and makerspace protocol, setting norms for activity in the workshop the remainder of the week.

What I loved about this workshop is how summer campers were exposed to the world of making tools for the purpose of making art, a message about being a maker, artist, and scientist that is very empowering. Tools used during this project included measurement tools, cordless drills, screws, and rubber bands. Once made, the paint machines were an open-ended tool for little makers to use over and over at home. Using only four materials—a wood plank, two screws, a rubber band, and art paper—you can create the conditions for creativity, focus, and individualized learning.

"Mr. Tim" begins his introduction on screen printing with an informal discussion with learners about what happens when you mix color.



(left)
Getting to know your tool takes patience and practice. This one tool helps learners as young as six practice focus and iteration, and self-reflect on process.

(right)
Step-by-step instructions for making the paint machine

Giving as a Core Value in Makerspaces

by Josh Ajima

Whenever I go to a conference or a maker event, I bring gifts—a small topo map of Virginia for the FabLearn conference, makerspace starter kits and business card flashlights for education conferences, or personalized gifts for fellow makers at Maker Faire. I'm lucky to have access to a maker-space filled with shiny tools. The purpose of all these tools is to make things that fill a need for other people.

Educational makerspaces are for learning. Giving is a powerful framework for maker education, teaching students to be producers instead of consumers, makers instead of takers.

It is no mistake that the Stanford d.school uses gift giving as one of its Design Project Zero activity themes.[1] It is no accident that the most popular makerspace stories are makers gifting 3D-printed prosthetics.[2]

In my school, part of our mission is to help students live a life of significance. When I help my advisory students with goal setting, the most difficult one is always the service goal. What can you do to help other people? Students struggle with this question. Making gifts is one way to help students develop an answer.

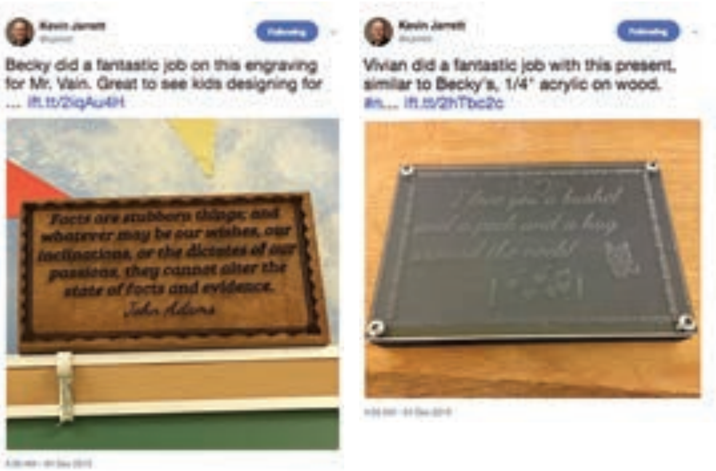
Service learning entwined with the concepts of empathy and giving can be seen in Manchester, Massachusetts' Brookwood School's 3D Design Problem Bank Project.[3]

Educational makerspaces also provide gifts to students:

- Gift of access
- Gift of making
- Gift of empowerment
- Gift of knowledge
- Gift of confidence
- Gift of self-discovery

Giving and making go together in many ways.

Student-made gifts during Maker Club



Kevin Jarrett had some nice examples in his Twitter feed.

Notes

1. dschool.stanford.edu/use-our-methods/design-project-zero-a-90-minute-experience
2. enablingthefuture.org
3. designproblembank.weebly.com

Design Reviews: Constructionism Conversations about Public Entities

by Susan Klimczak

> "Learning . . . happens especially felicitously in a context where the learner is consciously engaged in constructing a public entity." —Seymour Papert (1991)

> "Papert is interested in how learners engage in a conversation with [their own or other people's] artifacts, and how these conversations boost self-directed learning, and ultimately facilitate the construction of new knowledge." —Edith Ackermann (2001)

When people ask me to explain Seymour Papert's constructionism, I say that constructionism is "learning by making." However, much learning by making is unexpected and often unique to the learner; it can't always be predicted by a syllabus.

For the most learning to happen, makers must have many opportunities to discover and name what they are learning. As educators, we can provide youth with thoughtfully structured opportunities to **engage in conversation** about their projects during the making process in order to:

- Explain why and what they are making
- Develop skills at giving and receiving feedback
- Increase their creative confidence
- Discuss their process including research, successes, and challenges along the way
- Generate ideas about how to make the project better

Whether for a simple short—or an elaborately long—maker project, our Learn 2 Teach, Teach 2 Learn (L2TT2L) community has found that **design reviews** are one way to provide these opportunities. Carefully facilitated and strategically timed design reviews can dramatically improve youths' learning as well as the quality and success of projects. Our experience is that they harness the collective imagination, the collective knowledge, and the collective skills of our youth (and community).

Over the past fifteen years of thinking together, teenage youth teachers and college mentors have developed five different kinds of design reviews:

1. Project design review for generating simple project ideas
2. Group design review to evaluate initial ideas for bigger projects
3. Peer review of rapid prototypes
4. Formal community design review for proof-of-concept prototypes
5. Final community design review of full-model prototypes: Project Expo

Project design review for generating simple project ideas

You are planning a short, simple activity that takes only a couple of hours, such as building a paper circuit, laser cutting a backpack tag, creating a Makey Makey game controller, or coding a simple Scratch animation. Even for relatively short and simple project activities, conversations help youth explore ideas.

At L2TT2L, youth **sketch their ideas** with pencil and paper and present those ideas to their peers. Drawing and verbally explaining their ideas, then presenting them to peers for even **short feedback**, helps young people develop creative confidence

Feedback helps youth make ideas more concrete.

and a clearer direction that can dramatically improve the quality of the projects.

Starting to move ideas out of the brain to the physical act of putting pencil to paper (even if it is just words and scribbles) helps youth make their ideas more concrete. Our evidence comes from experience, but there must be some neuroscience explanation. Sharing their ideas with peers and talking about them—even briefly—helps to identify challenges and opportunities for simplifying or adding to their designs.

Group design review to evaluate initial ideas for bigger projects

When small groups design and build bigger projects that are to be worked on for several weeks, conversations about how the project demonstrates the characteristics of past successful projects can be inspiring.

It's empowering to have the youth themselves think about and generate metrics for great projects. We had a group of youth and mentors research and name the characteristics of ten years of the most successful and satisfying L2TT2L projects. The youth turned those characteristics into a poster of "project metrics."

Students generated this poster of metrics by which to evaluate projects.

Mentors meet with each group to have a conversation about how the group's project idea could be improved to demonstrate more of the great project characteristics from the best youth projects in the past.

Prototypes: Breaking up bigger projects

At Learn 2 Teach, Teach 2 Learn, we use a series of **prototypes** for long-term projects that might be built over a span of three to six weeks. Prototypes are a way to test ideas in the physical world. A great resource for learning about prototypes and how they are used in business innovation settings is a set of slides developed by the UK Nesta Foundation.[1] Here is an adapted version of the Foundation's definition:

> Prototyping is an approach to developing, testing, and improving ideas at an early stage. . . . It is a way of project and team working that allows you to experiment, evaluate, learn, refine, and adapt . . .

Prototyping:

- Involves relevant people at an early stage
- Develops ideas with the people who will help you find the answers
- Makes ideas tangible and tests them
- Refines those ideas
- Informs and improves any [plan] for change

The only thing I would add is that prototyping activities should be designed to engage a real sense of playfulness that fosters "falling in love." As Sherry Turkle said at a recent symposium on Seymour Papert,[2] falling in love with learning, ideas, materials, and projects are the most important gauges for the success of maker activities.

At L2TT2L, we structure design review conversations for bigger projects around three kinds of prototypes: rapid prototype, proof-of-concept prototype, and a full-model prototype. A **rapid prototype** is a quick (thirty-minute) building exercise using craft materials that communicates the idea for a project. A **proof-of-concept prototype** is a partial model built (typically over several days) to demonstrate that the big mechanical and electronic ideas that will be used in the model are doable. A **full-model prototype** is a working model of the project (typically created over many weeks).

The next three design reviews involve these three kinds of prototypes.

Peer review of rapid prototypes

We find it helpful to give the young people an opportunity to "think with their hands" and make a rapid prototype for bigger project ideas. I like these thoughts about rapid prototypes and their relationship to creativity from Tom and David Kelley's book *Creative Confidence: Unleashing the Creative Potential within Us All:*

> The reason for [rapid] prototyping is experimentation—the act of creating forces you to ask questions and make choices. It also gives you something you can show to and talk about with other people. . . . [A] prototype is just an embodiment of your idea. . . .
>
> Some failure is unavoidable. . . . The best kinds of failures are quick, cheap, and early, leaving you plenty of time and resources to learn from the experiment and iterate your ideas. . . . Creativity requires cycling lots of ideas.

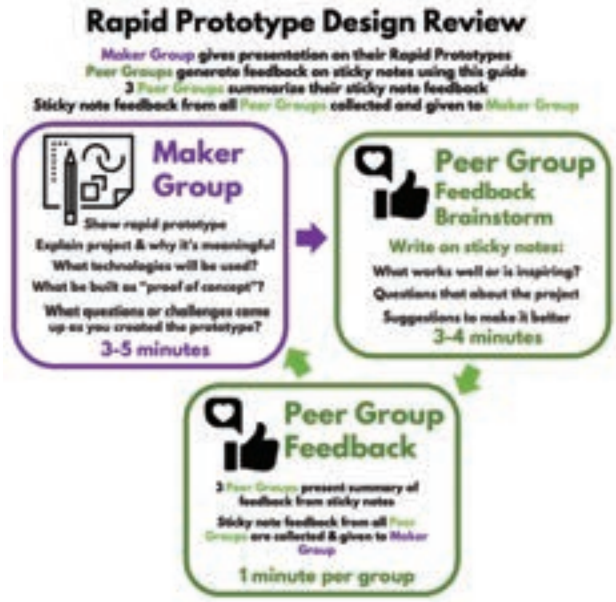
Guidelines for rapid prototyping

After rapid prototyping, we have an **informal peer design** review with facilitated questions to answer, as summarized in the guide.

We typically have thirty-six teen youth who are working in small maker groups on seven or eight projects, so this design review needs to be carefully facilitated to be effective and timely. Each small maker group presents its project for three to five minutes. Then the other peer groups have three to four minutes to come up with feedback that they record on sticky notes. Several of the groups summarize their feedback orally. However, the written sticky notes from all the groups are collected and given to the maker group. In this way, we can get through the design review in sixty to eighty minutes.

A facilitator (at L2TT2L this is a college mentor) makes the process run smoothly by:

- Introducing each maker group
- Being sure maker groups answer all questions and pass prototype around room
- Facilitating sticky note peer group feedback brainstorm
- Facilitating sticky note peer group feedback from three groups
- Giving all the peer group sticky notes to each maker group
- Having a timekeeper and someone to collect the peer group feedback sticky notes is also helpful in keeping the design review running smoothly.



The rapid prototype design review process

After the design review, give the maker groups time to have further conversation to discuss and document the feedback that they have received. Questions that might guide such conversations include *What different kinds of feedback did the rapid prototype receive? What changes to the project might be considered based on the feedback?*

At L2TT2L, we have youth document their entire engineering design process on a project blog that they keep. This is also where they post the insights from their feedback and conversations. This approach to feedback helps youth to develop competence in analyzing and critiquing projects. It also gives each maker group interesting guidance and ideas that will help the group improve its project during the next steps of the engineering design process.

Formal community design review for proof-of-concept prototypes

After rapid prototyping of larger projects, maker groups spend one or two days creating the next-level proof-of-concept prototype. A proof-of-concept prototype is a partial prototype that is constructed to test and demonstrate that the most important parts of the electronics, coding, and mechanical systems in the design are practical and doable.

Characteristics of proof-of-concept prototypes

Typically youth use prototyping kits such as littleBits (a kit with magnetized electronic components that snap together) or Grove kits (a shield that fits on top of a microcontroller development board that allows components like servo motors and LCD screens to be "plugged in" and coded without the complication of wiring) to create a simplified model of the electronics and coding.

Laser cutters and cardboard are typically used for prototyping mechanical parts of the proposed project to prove that they are buildable.

These proof-of-concept prototypes are presented at a more formal design review where representatives from the community serve on a panel that offers feedback.

Maker groups design Kickstarter-style presentations for the formal design review. To prepare youth, we introduce the idea of crowdfunding and show examples of inspiring Kickstarter sites (for instance, we often show youth the Makey Makey Kickstarter because they use Makey Makeys).

The idea of Kickstarter-style campaigns is evocative because crowdfunded inventions—and, we hope, the projects that our youth design and build—are created for real people and are designed to be used in the real world. The high-energy, quick presentation format and questions that Kickstarter videos ask seem to be exactly right for our youth: "Tell us who you are. Tell us the story behind your project. Where'd you get the idea? What stage is it at now? How are you feeling about it?"

A design guide is provided for maker group presentations. Maker groups are encouraged to incorporate slides or posters as visual aids.

Project presentation requirements

For the formal design review session, we gather a diverse panel of community members from outside the L2TT2L program. By *diverse* we mean that they vary in their work fields and also by gender and culture. For instance, we may recruit an engineering professional and a university professor but also seek out people with no engineering or technology backgrounds. We have invited community organizers, businesspeople, local teachers, trade union workers, and politicians. The diverse perspectives from the panel offer a wonderful variety of ideas, suggestions, and questions that are useful for the youth as they improve their final design plans, technical tools, approaches, and potential uses of the projects.

We set up a table for our design review panel with paper tents with their names and roles, paper and pencils for notes, and even some water to give the design review a professional and formal touch. We also provide them with some suggestions for the kind of feedback that would be useful for the maker groups.

Suggestions to guide panelists when providing feedback to student designers

The formal design review is structured with a facilitator for the agenda, timekeeper for presentation and panel feedback, and recorder to collect panelist notes and record verbal and written feedback on a Google Doc.

Reviewers are asked to provide feedback around the following considerations:

- What did you notice about presenting style, project, proof-of-concept prototype?
- How did presenters show they were serious, prepared, and capable of doing a good job?
- What puzzled you or surprised you about the project?
- What questions do you have for the group?
- What suggestions do you have for the project?
- Do you know of any resources (people, guides, etc.) that could help in their making journey?

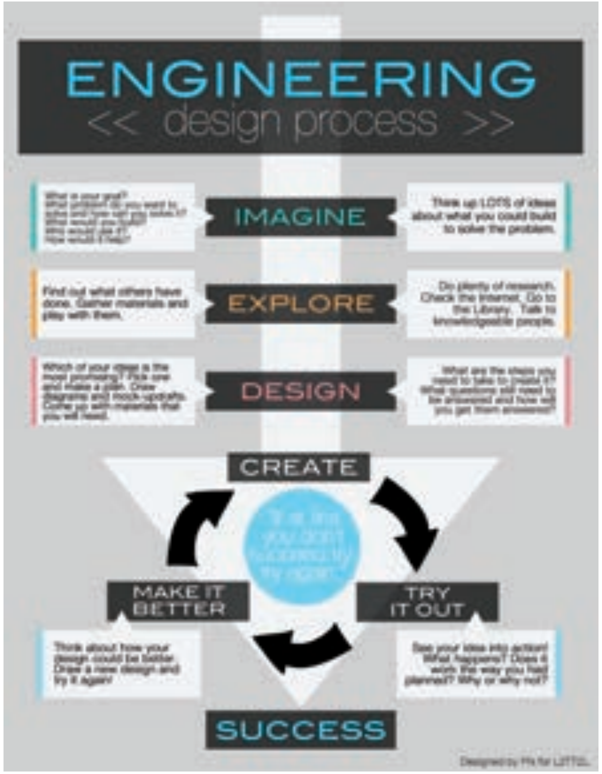
Formal design review process

Again, it is important to provide time for maker groups to discuss the feedback from the formal design review. These are some questions that they could discuss: What types of feedback about the social, technical, and artistic aspects of the project were given? How should the project be changed to respond to the feedback? Our maker groups document these conversations and plans for project changes on their project blog.

Final community design review of full-model prototypes: Project Expo

Each year, we hold a Community Project Expo at which maker groups display their full-model prototype projects. We have a potluck lunch and invite family and friends as well as local community folks—including technology and engineering professionals, educators, and businesspeople. There is also a sort of final design review embedded in our Project Expo each year.

Each maker group sets up a "booth" with its project and a poster that guides the viewer through the engineering design process, using our youth-generated engineering design process infographic as a guide. The maker group posters are very much modeled after conference posters but much more modest, of course.



The L2TT2L engineering design process

The maker groups receive serious feedback by using a more informal design review process. We ask community members, friends, and family to sit with the maker groups, their project posters, and projects and give them meaningful feedback and evaluation of their projects.

Maker group posters resemble their academic conference counterparts.

We find that a very large percentage of the youth's learning comes on this day when they have to explain their process and project twenty to thirty times to different folks. By the time the Project Expo is over, youth are really articulate about what they have learned and accomplished.

Youth are often so busy trying to finish their projects and poster before the Project Expo that their project documentation blog entries grow quite thin in the last week of project building. To address this problem, L2TT2L will add a documentation and discussion day after the Project Expo so that learning can be better documented.

Some concluding thoughts about Papert's public entities, Ackermann's making conversation, and design reviews

Seymour Papert's constructionism pedagogy is the most powerful approach to maker education that I (and so many others) have used. His insistence that maker projects become "public entities" is often quoted. Edith Ackermann (2001) says that one way to construct public entities is to focus on providing opportunities for meaningful conversation that help youth construct new knowledge. These conversations allow makers to create more robust internal mental models of how technology, engineering, and coding work in the world.

Yet even as a maker educator and experiential educator for over 30 years, I still find myself longing for more writing and focus on those concrete practices that help makers construct their projects as "public entities" and that suggest forms of conversation that move makers forward in constructing new knowledge. This article suggests the practice of design reviews as just one such strategy.

Acknowledgements

What is Learn 2 Teach, Teach 2 Learn? L2TT2L is a program at the South End Technology Center @ Tent City in Boston, Massachusetts.[3] Each year, we hire thirty-six teen youth teachers who represent Boston's diversity in genders, family cultures, schools, neighborhoods, and spectrum of thriving in schooling. Our goal is to create a critical mass of Boston youth engaged in the creative possibilities of technology and engineering. Each April to August, youth teachers learn six different technology and engineering modules and build projects that solve a community issue. Then they go out and teach what they have learned to more than six hundred Boston elementary and middle school youth in twenty-five community organizations in the neighborhoods most in need of education resources.

To **The Noun Project**[4] for its collection of very cool and useful icons. The icons used for the diagrams in this article were created by Daniela Baptista, Gregor Cresnar, Philippo Gianesi, Delwar Hossain, Gregor Cresnar, Jaap Knevel, Ghan Knoon Lay, Michael Rojas Olivia Stoian, and Unlimiticon.

To **Dr. Brian Gravel** of Tufts University for invaluable feedback and suggestions.

To **Eva Kerr**, longtime South End Technology Center @ Tent City volunteer, for her faithful eagle-eye editing.

Notes

1. nesta.org.uk/sites/default/files/prototyping_framework.pdf
2. media.mit.edu/videos/seymour-2017-01-26
3. fablabs.io/labs/southendtechnologycenter
4. thenounproject.com

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Making inside the Magic Circle

by Sam Phillips

> "I like to think of play as the art of world-making, and that play is about inventing invented realities. It is about creating a world, physical or virtual, inhabiting that world, and then eventually becoming inhabited by it." —Edith Ackermann

Setting the Scene

We're sitting at a kindergarten lunch table, munching on snack crackers and carrot sticks—when all of a sudden Kumbalayo, the evil sorcerer with fat warts on his nose, bursts into the laboratory and we all transform into Pusheen kittens in an attempt to escape. In the real world, we're small and struggle with things like peeling clementines, but in Kumbalayo's laboratory, we can have any power we want—the ability to shape-shift, to hypnotize, to sneak around like a ninja—and "there's always a way to escape" (as Dustin reminds us often). In the real world, I am the only adult—everyone else is five or six years old—but today in the game world, I am a Pusheen kitten and I am hiding behind a rack of jelly donuts. Sometimes I am the storyteller, but today I am waiting for Lilah the Donut Princess to save me. A bell rings and we all turn back to humans. The laboratory fades away and we start packing up our lunches and wiping down tables.

"Can we continue after school?" Lilah asks.

"Of course," I say. "Bring your wand."

Role-playing games as petri dish for whimsical tinkering

Every time you play a game, you enter a *magic circle*, "a temporary world inside the ordinary world dedicated to the performance of playing" according to Wikipedia. The circle is both a concrete boundary—a playground, a card table, a basketball court, a computer screen—and a state of mind that leads players to deep immersion, increased motivation to overcome challenges, and a willingness to adopt new rules and roles. I think about the *magic circle* often in my teaching practice, which from the outside may barely resemble "teaching" at all. Since becoming a FabLearn Fellow, I have worked in two non-traditional learning spaces: (1) MetaMedia, a free, drop-in digital media lab designed for middle-school students in Evanston, Illinois, and (2) Brightworks, a K–12 private school in San Francisco, California, where kids learn by making projects based on thematic units (called *arcs*). In both environments, I have spent a portion of my work time playing games with kids (an enormous privilege) and observing how their play sessions influence their project work. I've noticed that role-playing games help establish a whimsical, child-generated narrative context in which physical, social, and digital tinkering emerge and flourish. Because these tinkering experiences are embedded within a dramatic narrative story, they have the power to create indelible emotional memories for children.

A culture of choosing your own adventure

At Brightworks, children are afforded a lot of choice in how they navigate their school day. They co-construct classroom curricula with their teachers (called *collaborators*). They choose the format and focus of their capstone projects. They are given *independent design time* each day to dig into personal areas of interest. Brightworks students enjoy role-playing games, which tend to involve character creation and open-world exploration. This year at Brightworks, there are two primary cohorts of children who play collaborative role-playing games during school:

1. **LARPers (live-action role-players)** primarily consist of older middle school and high school students who schedule outdoor play sessions during the all-school recess block. One high school student is the "game master" and is responsible for planning the narrative, codifying the rules, and directing the game each session. The "game master" establishes a scenario (e.g., "The players are on a ship sailing to a nearby town and are attacked by orc-pirates"), which the players then physically act out using costumes and props. Characters and narratives are developed over multiple play sessions.
2. **Text Adventurers** primarily consist of younger students (five- to eight-year-olds) who initiate games during moments of down time (e.g., walking from school to the park, over lunch, after school). Games require one "storyteller" who guides players through a story and offers them choices along the way (e.g., "Kumbalayo bursts into the lab. Do you [Choice A] or [Choice B]?"). Characters and narratives rarely develop beyond single play sessions, although storytellers tend to remix each other's themes and scenarios.

A tangible game world

Physical tinkering: Toward a tangible game world

Sometimes during play sessions, children will make physical artifacts to enhance their storytelling. Sometimes the artifacts are two-dimensional representations such as character sketches, maps of the world, and diagrams. Other times the artifacts are three dimensional: props, costume pieces, or environmental spaces that mirror the game world.

A sidewalk chalk adventure in progress

During one outdoor play session, the Text Adventurers traced the outline of a boat in chalk on the blacktop to the (not-quite) scale of an actual boat. They could climb inside of it with their bodies and be rocked overboard during shipwreck. With just a line on the floor, they were all able to know how it felt to be squished into a tiny vessel and were naturally compelled to wonder, "What if we made our boat a little bit bigger?" During an indoor session, they used a set of color-changing LEDs to conjure the lighting of a lush forest, topped a couple of life-size Lincoln Logs with a green blanket for trees, and cued up Howard Shore's *The Lord of the Rings: The Fellowship of the Ring* score so that they too could walk barefoot around The Shire.

The LARPers also make physical artifacts: helmets, shields, and weapons—all from duct tape, foam, and other scraps. These props are more precious and permanent. The older kids take turns toting their cargo to the park each day in a giant barrel. They repair them when they get bruised. They develop regulations around how to care for them and become irritated when rules are broken. The LARPers store their artifacts in a public place, which allows them to become incorporated into the Text Adventurers play sessions as well.

Social tinkering: Rules, roles, rituals, and agreements

Role-playing games at Brightworks don't come from a box. There are no instructions to reference or online forums to consult for advice. The children's *habits of play* are as much a construction as the props and costumes that they physically build, and they constantly tweak these structures depending on the dynamics of each session.

Often before play, the Text Adventurers reset their group agreements: *How do we take turns playing? How long can a person's turn be? Can anything happen during a turn? Are we each in charge of our own character, or are some of us sharing characters? How many players can the storyteller handle today?* They tend to need the help of an adult to facilitate this conversation, resolve disagreements, and ensure that everyone's ideas are heard.

The LARPers, on the other hand, are entirely self-organized and document their systems in a binder carried around by the game master. They think deeply about how the game is perceived by others, how they share space on the playground, and how new players join their game. For many of the LARPers, the game is more than a pastime. It's an identity that they proudly adopt.

Digital tinkering: Computer as power-up

There are common limitations in both styles of role-playing games:

- Games can't be played in exactly the same way twice.
- Game progress can be easily forgotten or misremembered.
- Every component of the game has to be predetermined by the storyteller or game master, which means that nothing can happen by chance.

Interactive game designed in Twine

In some instances, LARPers and Text Adventurers use digital tools to overcome these barriers. For example, a LARPer, feeling constrained by the linearity of a notebook, charted his game's plot using Twine,[1] a free web-based tool for coding interactive fiction. Some Text Adventurers have adapted their games into sharable Scratch projects, creating animated avatars that they can control on the screen. During one play session, Text Adventurers programmed a micro:bit to become a random number generator, which determined the success of their move. Similarly, a LARPer has experimented with prototyping spells that can be cast from player to player using RFID tags embedded in cloth satchels.

This digital form of tinkering, unlike the previous two, typically happens outside of the play sessions. If I'm trying to nudge a Text Adventurer

Students using software to tell their stories

toward Scratch, I might suggest we try to adapt one of their role-playing game stories into a digital project. For some children, this is an excellent provocation and they slide into programming with gusto, but even in that ideal circumstance, their whole bodily approach changes. They go from standing to sitting, from being aware of the physical environment to staring at a screen, from creating in concert with others to working mostly alone, from rapidly erecting imaginary worlds to slowly crafting sprites, from authoring with their hands and mouths to feeling limited by the keyboard and mouse.

Student-created interactive games that blend physical and electronic components

Is there a way to prepare the environment so that this shift doesn't happen and children can engage in digital tinkering while maintaining their play?

Last week, I visited Dynamicland,[2] a community workspace in Oakland, California, that attempts to solve this problem by reimagining the computer interface. At Dynamicland, people create software together by "programming" on scraps of paper. The paper code is seen by a camera/sensor rig mounted in the ceiling, and then the program is projected live onto the tables, floors, and walls of the space. The setup encourages programmers to incorporate physical materials into their projects. During my visit, I play tested a game by Nicky Case called Frog Wars, where players flick origami frogs over projections of buzzing flies to score points. That same program was then transformed into a game called Tub Wars after Nicky brought new materials onto the table. The physical materials, which included a baking sheet filled with water and bathtubs made from plastic cups, inspired a whole new theme and style of play. There was no latency between playing the original game, imagining a way to remix the game, and playing the remix.

For the foreseeable future, the Dynamicland technology is only available to people who have access to its headquarters in Oakland, but it represents one potential solution for integrating digital tinkering into physical play. In the meantime, as we wait for the technology to catch up, it's important that we nurture playful makerspace environments so that children see tools as direct extensions of their imaginations and as vehicles to help tell stories, share visions, and make magic.

Notes

1. twinery.org
2. dynamicland.org

Reference

Ackermann, E. (2010, April 30). Playful inventions and explorations: What's to be learned from kids? [Video file]. Retrieved from youtube.com/watch?v=l3jI19vR5bI

Making Art with Digital Technology

by Erin Riley

Learning through making

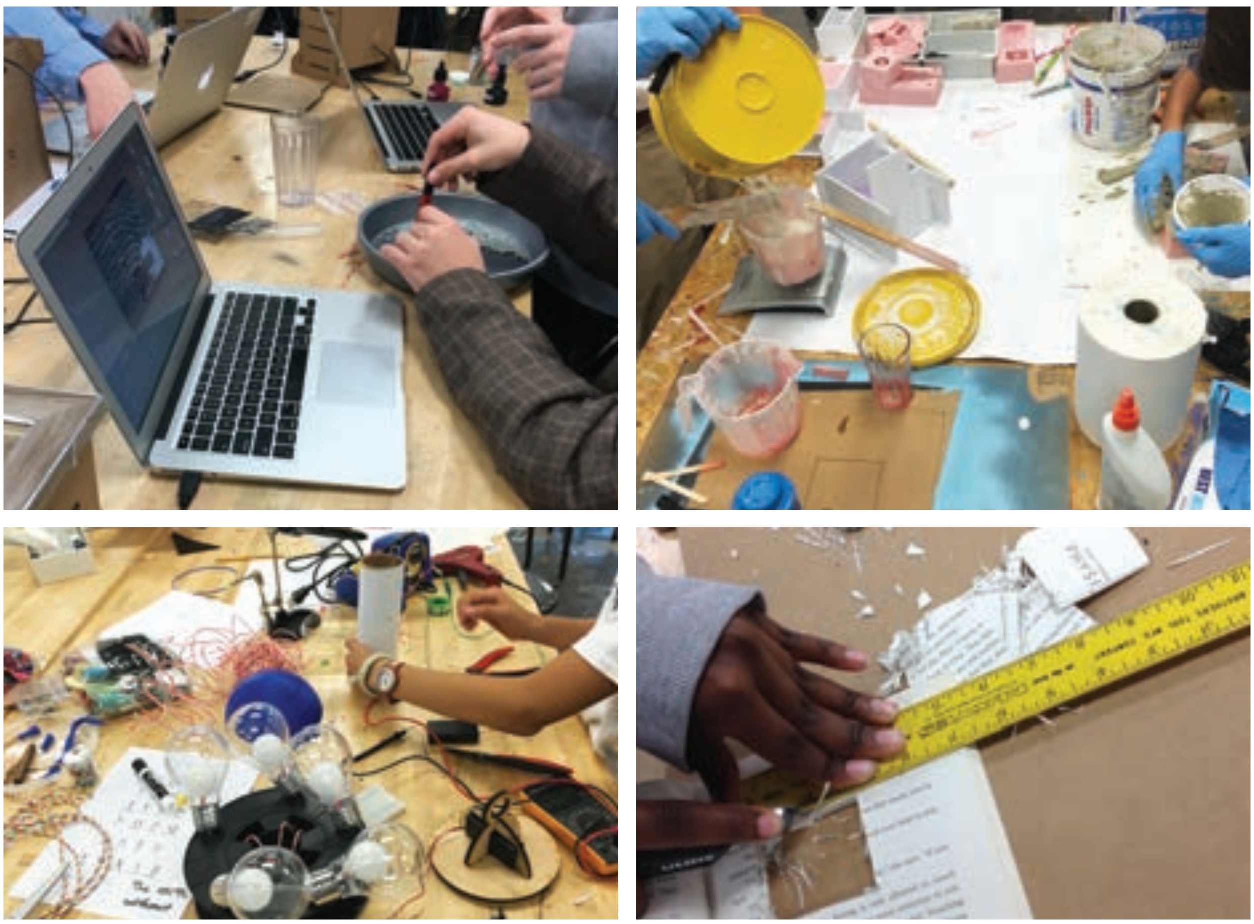
Learning by doing has been a cornerstone of progressive education with roots dating back to the eighteenth century. In the United States, the progressive education movement, through the work of John Dewey, as well as education philosophers like Jean Piaget, have advocated for learning by experience. Seymour Papert expanded this idea through learning theory of constructionism. People learn best through creating and sharing the things they make. Every time we make art, our material—whether it is clay, cardboard, or computer code—is used to form ideas and bring them into the world.

Art is the verb, the action, the making—our materials are physical, digital, or both

Digital materials for art

So what does a contemporary art studio look like today? How would progressive education advocates view the melding of digital tools with more traditional ones? With the enthusiasm around the maker movement and its growing influence on education, we have an exciting opportunity to push through the increasingly porous boundaries around traditionally siloed disciplines. Building on the principles of progressive education, it is time to equip students with a tool set that brings

Making projects with physical and digital materials



minds and resources together. Digital fabrication machines developed for engineering and commercial design have direct applications in art and design in a school setting. Educators can now fold the knowledge of tools and materials for art into the discourse and advancement of ideas in making.

Art + STEM + CS

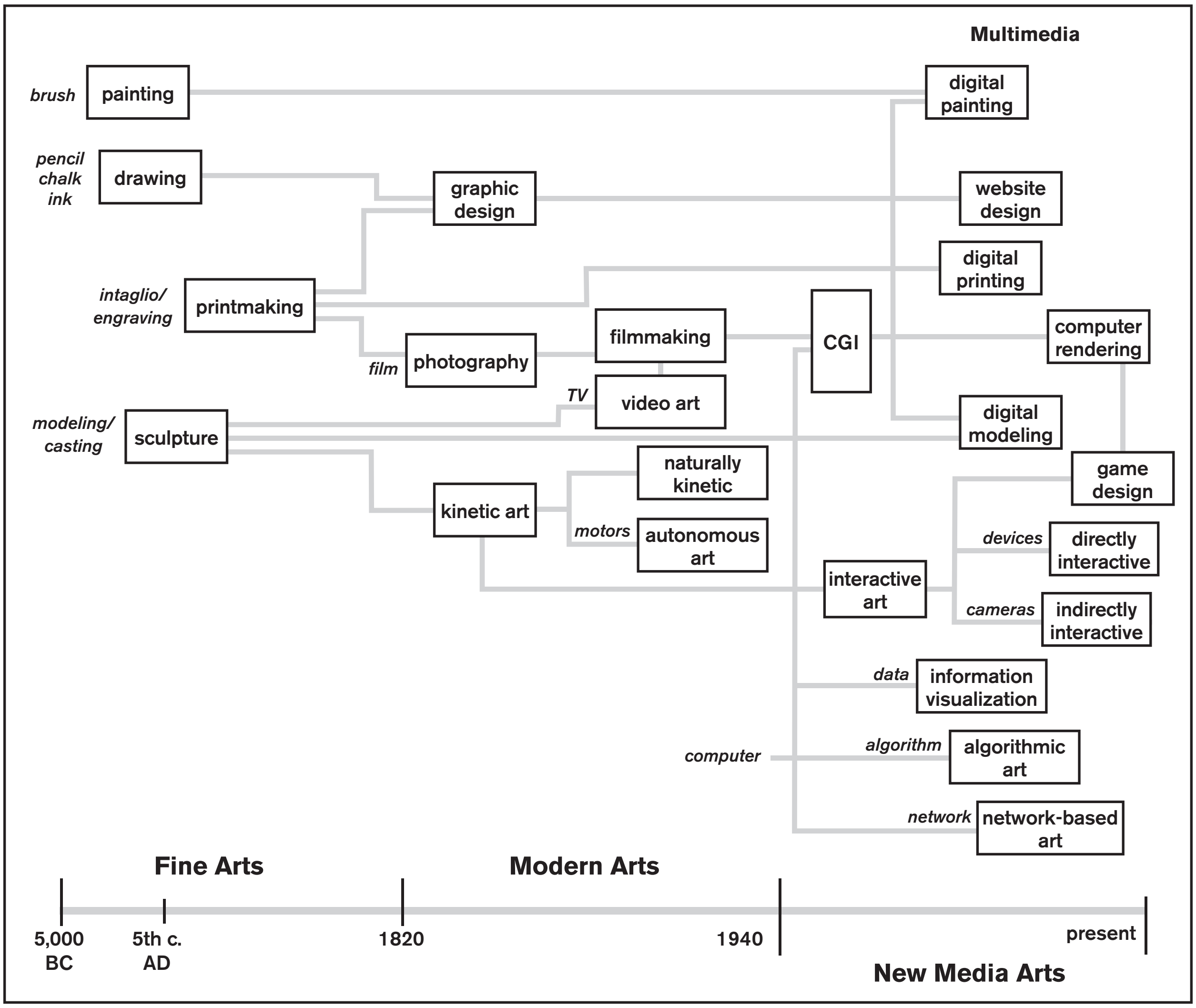
The artist, researcher, and teacher Rama Hoetzlein (2009) charted a lineage from fine arts to contemporary forms in new media art. This graphic makes clear that use of digital technology yields new tools for expressing ideas. If we were to expand this time line to include engineering, computer science, and, in general, STEM disciplines, we would see how cross-pollination has blurred the lines between discrete areas of study. STEAM (STEM + art) is of great interest to schools, and art programs can be engines of innovation.

True to art

Advances in technology have created a framework for interdisciplinary collaboration. With more support behind the idea of STEAM, art has a voice in the larger discourse surrounding maker education. While materials available for making art expand, it is important to keep firm roots in what makes art a rich place for material exploration, idea generation, divergent thinking, and expression.

Our role as teachers within STEAM initiatives, maker programs, and as interdisciplinary practitioners is not to decorate other's projects. Instead, we should continue to bring what is essential and powerful about art into the work students do. Art provides a place for youth to make personal things that they care about. Through artwork, students can assert their ideas and wishes, and feel proud of the skills they develop through the heart and hand. Artists, with their understanding of materials and keen aesthetic choices have much to contribute to making.

"What Is New Media Art?" from Hoetzlein (2009)



Design at the center

Regardless of how one identifies oneself as a creative maker, design is at the center of all forms in making. As students make, how do they understand what they are discovering? John Maeda, artist, technologist, designer, and educator, defines three types of design in his *Design in Tech Report 2016*. Classical design is the type of design most people are familiar with. These designers make objects and products. *Design thinking* puts humans at the center to drive innovation, and *computational design* uses computation to do design at a global scale. Similar to Hoetzlein's new media time line, Maeda's framework to understand design trends can help us understand where the material meets the digital in making practice.

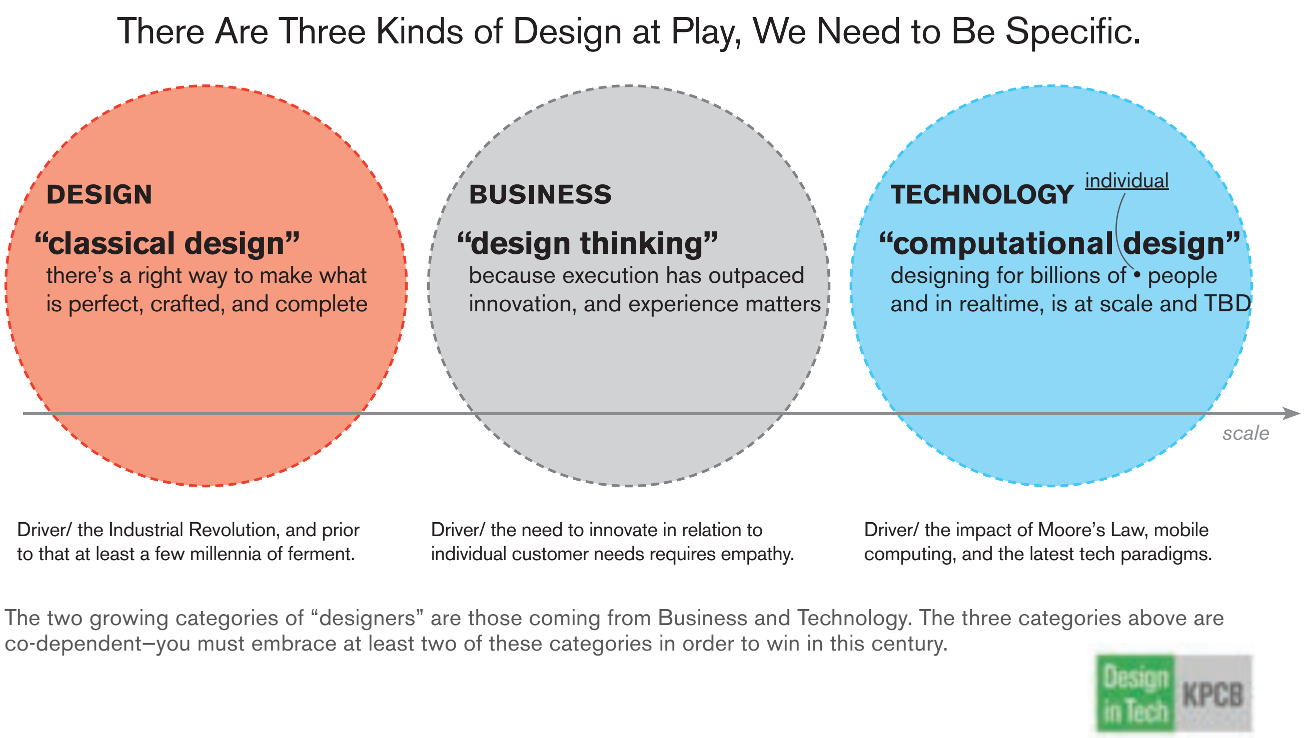
The principles and elements of design, a structure outlined by Maitland Graves in his 1941 book *The Art of Color and Design*, provides a framework for formal design decisions that art programs use today. These design rules branch into science and math. Color theory and optics guide decisions about which colors to juxtapose for a given effect. Viewers can be persuaded to see something new when their visual world is intentionally manipulated. In his geometric abstractions, Joseph Albers showed us how color is relative. Henri

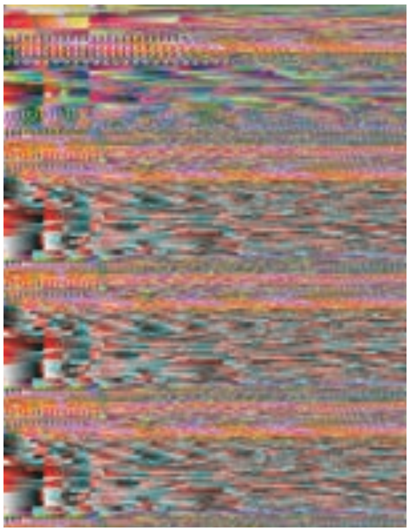
RYB color chart from Field (1841)

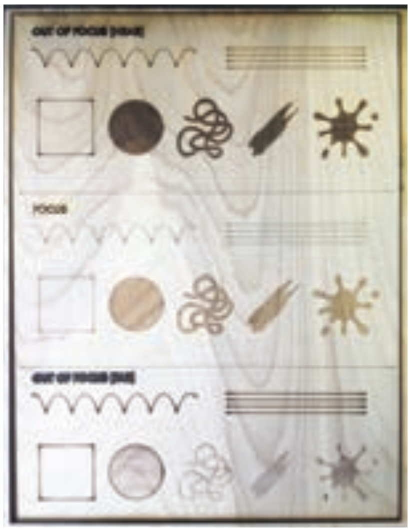
Matisse, in his bold replacement of color for value, demonstrated that color itself isn't the underlying fundamental; rather light and shade are the most important visual cues for form. Today game designers use procedural design to program color palettes in their virtual worlds.

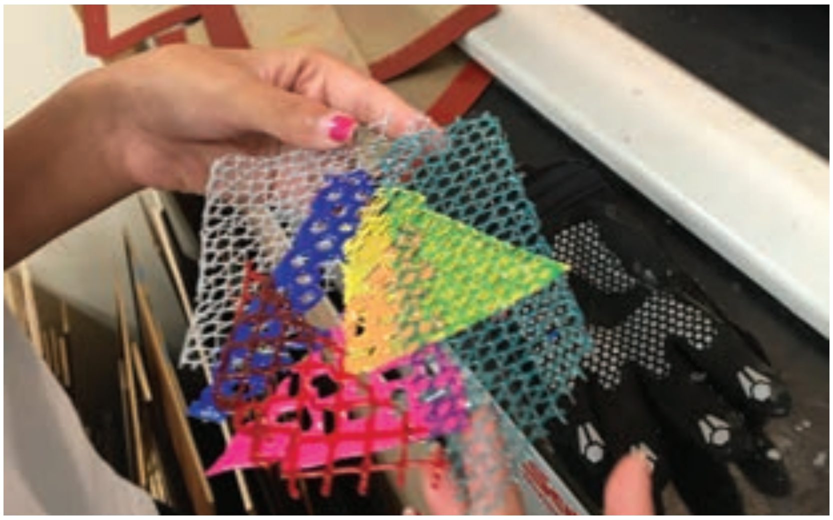
It is no surprise that art has historically been cross-pollinating with STEM disciplines. Much has been written about a Renaissance approach in support of STEAM initiatives, and as the field of art continues to expand, it seems fitting that artists look to the design processes used in engineering, architecture, and commercial design to inform their process.

The three kinds of design from Maeda (2016)









(*clockwise from top*)
Rosa Menkman's glitch art (2011); drawing with an out-of-focus laser; melting 3D-printed scraps

Design rules dictate how we use space in compositions. Entire worlds can be built using Cartesian coordinates, bringing a representation of three dimensions onto a flat surface or screen. Artist M. C. Escher used isometric projection to create illusions and spaces that appear to fold in upon each other using this mathematical gridding system. Impossible objects can be found in the digital world through puzzle games like Monument Valley.

Sometimes artists want less control in their process, choosing instead to see what unfolds, free from the pressure of a preconceived result. Serendipity plays a role as the designer engages in *misthetics*, pulling beauty out of mistakes or random actions. Artists have found ways to use technology as active partners in the design process through programming algorithms while letting the machine generate the art. The artist pulls out the best solution from what is generated. Similarly data bending by modifying image text creates corrupted information within digital files, giving rise to glitch art. Even high-tech approaches to making can introduce an element of chance much like automatism did for surrealist artists in the early 20th century.

Digital to form

Digital design mirrors physical design in many ways. Pixel painting in Photoshop can replicate many of the processes used in the studio addressing brush style, paint opacity, and layering. Digital information can mirror the push/pull responsiveness of physical material. Pixels are the painterly application of digital information, and on screens and in print artists are liberated to color outside the lines.

Designing for digital fabrication, however, is a different process altogether, which requires giving directions to machines and generating viable tool paths. Students have the opportunity to test their designs in the physical world through fabrication. Mistakes in measuring, scale, and transformations show up in the model that is output from the machine. Mistakes in set-up result in failed prints, machines cutting in the wrong place, or machines not working at all.

Pablo Picasso famously said, “Learn the rules like a pro, so you can break them like an artist.” Once artists learn the rules, and how to design for and control the machines, they can start looking for opportunities to use machines and materials in new and inventive ways. Artists can carry on the same research and exploration that is central to artist practice with a new set of tools.

Computer as an expressive tool

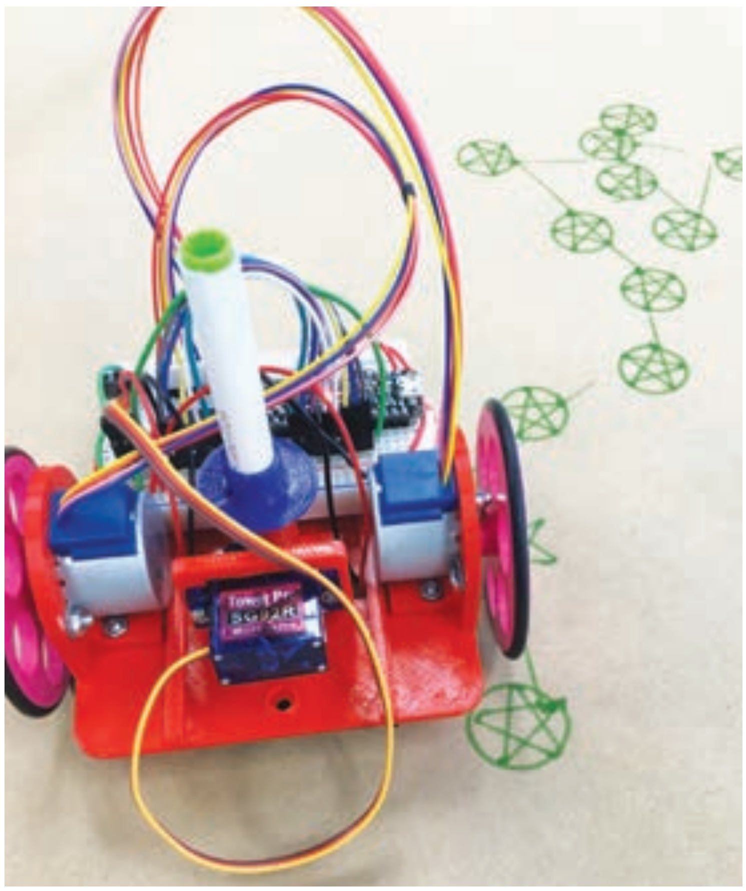
Since computers have come into existence, artists have been finding creative applications for their use. We can be inspired by exciting work in digital technology and build upon the pedagogies that put children at the center of their learning.

Logo, a programming language developed by Seymour Papert and Cynthia Soloman, brought design ideas to digital graphics or into the physical world through pen marks using the LogoTurtle drawing robot. Papert, in his vision for computers to unlock the curiosity and creative potential in our youth, paved the way for educators in art to adopt digital tools for creation, from artists working in a digital frontier like artist Vera Molnár, who brings digital to form through algorithmic design and plotter drawing, to artists who, like Papert, create tools for creative making. Casey Reas’s installations, prints, and software have inspired a new wave of creative technologists. Through the development of Processing, with cocreator Ben Fry, artists have a user-friendly environment for exploring new media art and visual design.

Just atoms, bits to atoms, just bits

Materials are beautiful. An art studio is a rich source of colors and textures and raw materials for projects. Concern around abandoning materiality for digital forms can deter some from adopting new technology. “Technology is anything that was invented after you were born,” said computer scientist Alan Kay. Digital materials add to a vast menu of options for bringing

Papert’s Logo turtle



Logo turtle from Josh Burker, Brian Silverman, and Erik Nauman impactful and personally meaningful objects and ideas into the world.

Neil Gershenfeld's Center for Bits and Atoms at MIT brought Fab Labs to the mainstream, and the FabLearn project out of Stanford University's Transformative Learning Technologies Laboratory supports K–12 schools around the world as they build digital fabrication labs. In addition to the learning that happens from design to object creation, I see a rich opportunity in art programs to wed the knowledge of art materials with digital process, and I encourage all art teachers who have access to technology to consider how they might bring it to their studios.

Art students who haven't been exposed to possibilities with technical tools can be introduced to artists, working in new forms that challenge and inspire them to think differently about art making. We can equip our students with a new language for speaking about technologies in relation to their work that is true to our fundamental methods of how we make and teach art.

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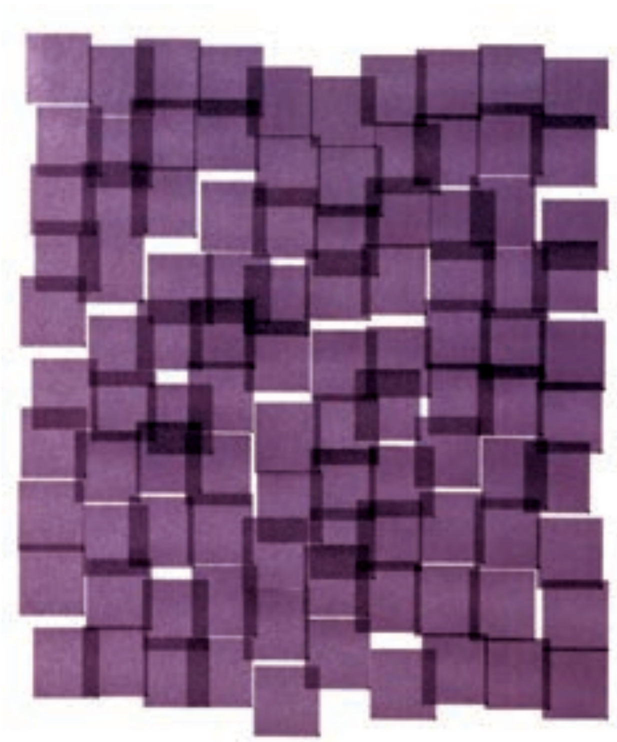
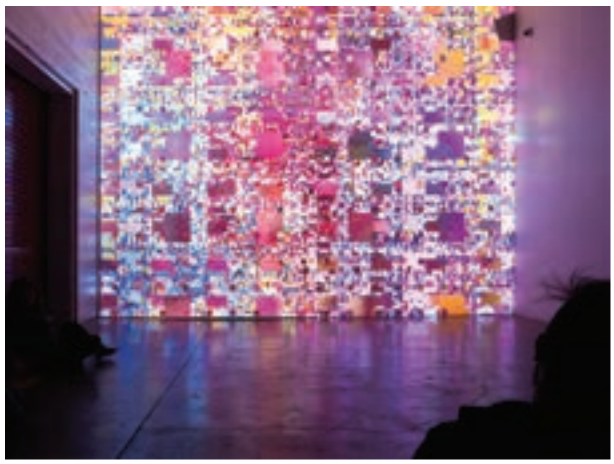


Vera Molnar's *Interstices*. Plotter drawing, ink on paper, 22 x 25 cm, 1986. With permission of the artist and DAM Gallery.



Casey Reas: KNBC, custom software, digital video, computer, projector, dimensions variable. Sound by Philip Rugo. With permission of the artist.

Strategies to Foster Creativity in Classrooms

by Cassia Fernandez

During the past years I've been deeply interested in creativity. In this article I condense some strategies aimed to stimulate children's creative expression in the classroom that I've tested in my physical programming classes and analyzed during my master's research. Most of the strategies presented here are not based merely on personal insights but rather grounded on theories suggested by researchers from the field, which I adapted to my own classes.

These strategies are divided into three main groups that refer to three relevant aspects connected to creativity expression:

- Fueling intrinsic motivation
- Setting a supportive climate for exploration
- Scaffolding the development of ideas

Of course, there are intersections of these three aspects; this division is only a way to try to organize them.

Fueling intrinsic motivation

Teresa Amabile, who studied creativity for many decades, found through her research that people are more creative when driven more by enjoyment, interest, and passion than by external pressures (also called extrinsic motivators) such as grades or money (Amabile and Fisher 2009). Below I suggest some strategies that could help to foster this important aspect of creativity.

Create ways to connect activities to students' personal interests

Involvement in explorations connected to personal interests is an important aspect to foster students' creativity since it heightens the levels of intrinsic motivation. Moreover, by connecting classroom activities to their passions, learning becomes a way to achieve personal goals, which makes it feel much more valuable and meaningful. However, if we want to offer opportunities for this kind of engagement to all students, it is important to consider broad and gender-neutral themes for the activities, which will enable each student to find their own point of intersection between the proposed theme and their own interests. For example, instead of asking all students to accomplish a strict goal or a narrow challenge, activities based on broader themes can be much more inviting and be connected to their interests. (Rusk and collaborators [2008] have condensed some of these strategies beautifully in "New Pathways into Robotics.") When implemented in my classes, such strategies are really effective in engaging students in learning in a very personal way. Some examples of themes that have created wide engagement in my physical programming classes are creating an interactive art project, a magical house story, a Rube Goldberg contraption, and a pinball machine game.

Encourage students to believe in their ideas

Throughout my teaching practice, especially in underserved communities, I have seen how relevant it can be for students if you show, as a teacher, that you believe that their ideas are valuable. Sometimes when I talk to students with very little confidence in themselves, words of encouragement and demonstrations of enthusiasm seem to be important supports to make them move on and keep challenging themselves, feeling confident to test their own ideas, and going beyond what they expected from themselves. Of course, it is not just about being superexcited about everything but rather looking for something you find really cool in their projects or discoveries and talking to them about it.

Creating a positive emotional climate and showing enthusiasm for students' ideas and discoveries throughout their learning processes encourages them to believe that they are capable of bringing their ideas to life—which, in turn, can positively influence motivation and creativity.

Create opportunities for cooperation instead of focusing on competition

Encouraging cooperation rather than competition can positively influence motivation and creativity (Amabile 1989) and expand participation of learners with diverse abilities and interests in technological-related activities (Rusk et al. 2008). Moreover, in classrooms with large numbers of students per teacher, peer collaboration can allow students to be less teacher dependent. Students who help others usually feel more confident, while the ones who need help don't have to wait for the teacher to move on. By collaborating and getting in contact with other project ideas through interacting with their colleagues, ideas can be shared and inspire the creative process in others.

Setting a supportive climate for exploration

Create a safe environment for initial explorations

Overly open and unstructured activities can generate frustration and lack of interest rather than engagement and autonomy. Conversely, activities based on very restricted challenges usually don't offer many possibilities of connection with personal interests and of creative development. By creating short initial activities from a limited number of materials (whether physical elements or programming blocks), students can develop some initial understanding that allows them to feel safe to explore possibilities without fear as they move onto longer projects.

Select appropriate materials for experiments

The materials offered for construction are directly related to the way students engage in the process of testing ideas. When materials allow quick changes in the design and immediate observation of its effect, students can perform small quick experiments, which can stimulate the development of new ideas since several ideas can be tested and refined.

In my classes, I have seen kids really obsessed with trying to build something with materials and tools that were not ideal for the situation or their goals. When inappropriate materials crossed the path of obstinate students, the result was that they spent long periods of time trying to build something that eventually led to frustration. Inadequate materials and long periods of frustration result in decreased intrinsic motivation.

Allow course changes throughout the process

Many teachers think that planning—the steps involved, the materials needed, and the outcomes expected—is as important as actually creating something. These planning skills can, of course, be very valuable in many circumstances through our lives. But if planning is always the entry condition (or barrier) for creating something, a lot of ideas won't have the chance to be explored, and kids won't have the wonderful experience of going with the flow in unpredictable learning experiments. If we want our kids to be creators, it's important to show them that it's okay to rethink our paths and change our ways.

By allowing (and creating conditions for) our students' ideas to evolve with time, their creative processes will certainly be much more fruitful. So, instead of always requiring them to make plans for the final product and then proceed to the construction, we can rather leave them somewhat free to explore new pathways when facing problems and as new ideas arise.

Provide adequate time for the development of projects

It is common among teachers to say that if there are no deadlines, students will work slowly and be unfocused. However, what I have learned over time is that if the task is sufficiently engaging for the students, they will work hard to find the answers to their questions, and even though they can take longer periods of time to create a "final" product, they will engage in a much more meaningful experience.

Encourage sharing in a safe environment

Providing space for students to share their ideas, questions, projects, and insights in collective moments are important aspects of classroom dynamics. However, it is important that the sharing climate is pleasant and stress-free so that students feel comfortable sharing unfinished creations and can emphasize the learning process instead of only their final creation.

One time, I told my students that they would share their final projects in an exhibition to the whole school. Then, I started to see some of the kids (especially those with lower self-esteem) changing their "crazy" (but supercool and complex) ideas to something much simpler—something they already knew how to make—just because they were afraid of not having something working for the "superimportant" moment. Since I was interested in fostering their creative potential, that made me rethink the way I deal with exhibitions.

Scaffolding the development of ideas

Provide learning resources that allow students to follow different paths

Providing good learning resources is essential to allowing deeper explorations and greater autonomy during the development of projects. An aspect that can be helpful in the design of such resources is the students having small blocks of information that can help in their initial steps and that can be connected among them for the development of more complex projects. The Scratch Cards are great examples of such learning resources: instead of giving step-by-step instructions on how to start a project, students can autonomously imagine their projects and look at the resources to achieve their goals, which can be especially important in classrooms with many students and open-ended projects.

Encourage students to get inspiration from the available materials

Materials can have deep impacts on the ways ideas are developed. Instead of asking students to come up with a project and then look for the materials they will use to build it, sometimes I encourage them to start by looking at the available resources and only then imagine the project they will create. In my classes we work mainly with everyday, low-cost, and recycled materials. When ideas emerge from the contact with the available resources, ideas evolve quickly and can go in unexpected ways.

Stimulate students to look at familiar resources in new contexts

This suggestion, based on the approach of Tinkering Studio, seemed to be very effective in my creativity research. In my classes, besides bringing recycled materials and what some people would call "trash," I also encourage kids to bring interesting materials from their homes to our classes. The materials they bring are not supposed to be used for their personal projects but instead to be a common resource for the whole group to use. In our talks, I saw that this was a really important strategy to encourage them to look at the things around them in a new and curious way, which made them feel more creative.

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Brainstorming: Makerspace AI

by Josh Ajima

Fellow FabLearn Fellow Jaymes Dec posed an interesting question: "What does an AI-augmented makerspace look, sound, or feel like?"

I started brainstorming about how artificial intelligence might support a makerspace that becomes safer and smarter as time goes on. Here are some of my thoughts.

The makerspace AI monitors the environmental conditions including airborne particulates, sound levels, and machines in operation and recommends or enforces use of personal protection equipment such as safety glasses, ear protection, or a respirator. IR temperature sensors detect soldering irons and hot glue guns left on, fire in a laser cutter, over/undertemperature in a 3D printer, and blade/bit overtemperature in cutting tools.

The makerspace AI communicates through audio, visual, and augmented reality (AR) embedded in safety glasses and ear protection (for example, Hologarage).[1]

The makerspace AI can project visual information on any surface in the makerspace, and project audio in focused areas through ceiling-mounted projectors and sound panels (for example, AR Sandbox from UC Davis; Audio Spotlight from Holosonics[1]).

The makerspace AI recognizes individual users and knows machines that users are qualified to use. The makerspace AI has individual control over every powered device in the makerspace including hand tools and can disable access to unqualified users (for example, using the Milwaukee One-Key app). The makerspace AI provides just-in-time training through audio, video, and AR on the specific machine a user needs with specific materials the user wants to use. The makerspace AI notifies a makerspace facilitator when a user is ready for a hands-on demonstration of skills. Safety usage is monitored and retraining required when necessary.

The makerspace AI recommends or enforces specific tool settings and bit/blade combinations for specific materials and applications, and recommends alternative materials or tools based on the database of available makerspace resources. The makerspace AI estimates and records ongoing project costs based on cost of material used, machine/tool use, and consumables (for example, Amazon Go). The makerspace facilitator is notified if assistance is needed changing a bit/blade or to authorize use/cost outside of approved parameters (for example, a project limit of $20 of materials).

The makerspace AI records, collects, and curates project information and files; assembles a project time line including video/audio of brainstorming among users, design iterations, and prototypes; and records project materials lists and project instructions (autogenerated Instructables and project documentaries).

The makerspace AI converts verbal descriptions, drawings, and physical prototypes into 3D models in AR. Users can modify designs using AR or traditional design tools. The makerspace AI can render the model in any material or construction method available in the makerspace. The makerspace AI can apply algorithmic design to create multiple variations of user design: "Show me ten variations of this design that can be created in the makerspace from plywood using the laser cutter." Designs can be optimized for strength, cost, material usage, or complexity. Users can create custom design algorithms.

The makerspace AI assists users in programming wireless electronics modules through natural language interface. "When I press this button, this LED turns on." "This LED's colors correspond to this temperature sensor." "When this pressure sensor is activated, this motor is triggered for three seconds." The makerspace AI shows code for program in block code and the appropriate programming language. The makerspace AI converts a project into a circuit design shown in AR space with other project design elements. The makerspace AI creates a CNC circuit board design that fits a user project. A user can cut a custom circuit board and then follow the makerspace AI's instructions to create a final version of their prototype design.

The makerspace AI assists with cleaning (Robot vacuums), maintenance (tracking servicing intervals, monitoring cutting/printing quality), and ordering (monitoring stock levels).

Note

1. youtube.com/watch?v=5HV3fcTvZk0

Teaching

Making in education is not about having the coolest, most expensive tools or the fanciest makerspace. Making is a way to empower people to solve their own problems and develop the skills and mindsets to do so.

At its core, the maker movement is about sharing ideas and access to solutions with the world, not for money or power, but to make the world a better place. It's about trusting other people—often people you don't know—to use these ideas for good.

Making in the classroom is also about power and trust, and perhaps in an even more important way, because it's about transferring power to the learner—young people who are the ones who will take over the world in the not-too-distant future. And in giving learners agency and responsibility over their own learning, they gain trust—not just the trust of the adults in the room, but trust in themselves as powerful problem solvers and agents of change. All of this takes preparation and work on the part of the teacher. The articles in this chapter show how it happens in the classroom to inspire readers to bring these ideas into their own teaching practice.

Rube Goldberg, YouTube, and the Archimedes Screw: Hidden Drivers of Pedagogic Transactions

by Sarah Alfonso Emerson

In Edith Ackermann's "Hidden Drivers of Pedagogic Transactions: Teachers as Clinicians and Designers" (2003), she shows that as teachers take on the role of clinicians (facilitating communication around a problem) and designers (imagining and creating a safe learning environment for exploration and negotiation of old and new thoughts), a pedagogic transaction takes place between the teacher and the learner in which both parties are shaped by and shape a problematic situation.

A learning experience that took place between a small group of my fifth- and sixth-grade students and me can serve as another example that shows what Ackermann stated: "that learning occurs because participants are jointly engaged in exploring, expressing, and negotiating ideas [on a topic that matters] because they create and use external forms as a means to mediate ideas and experience, and because they come at it from different angles" (2013).

It started with a small group of students whom I was coaching to prepare for the county Rube Goldberg competition. The team of eight students had broken up into smaller teams of two to build separate components of their Rube contraption, which had a Route 66 theme. Their machine was to follow a story centered around an imaginary family going on a road trip along Route 66, from Chicago to San Bernardino. Their project had already included various setups of inclined planes with cars traveling "cross country." However, I knew as well as the students that their project needed a wow factor—something to be engineered so creatively that viewers of their project would be highly impressed. We decided to look at the idea of simple machines from a different perspective, and where do eleven- and twelve-year-olds look for new ideas and inspiration other than YouTube?

Off to YouTube the children went, watching Rube Goldberg videos, looking for something different. At first the children were growing in excitement by seeing other ideas, but as I probed them to think deeper about what they were seeing (e.g., "Is that really a new idea?," "Is that a unique use of a simple machine?"), they realized they continued to see a lot of the same old thing—inclined planes with objects rolling down, pulleys being activated and releasing an item to the next location, wheels and axles rolling along. I went home that night and decided to do some of my own YouTube research. I came across a video in which cans rolled upward along an inclined plane.[1] Now, this was something quite different—it almost looked like magic. The next day, I showed them the video in slow motion, and we watched the cans rolling upward multiple times, analyzing the movement, attempting to figure out how it worked. The students came to the conclusion that some sort of magnet must be involved. Nevertheless, their challenge was set before them. They needed to include SOME way for SOMEthing to roll UPWARD.

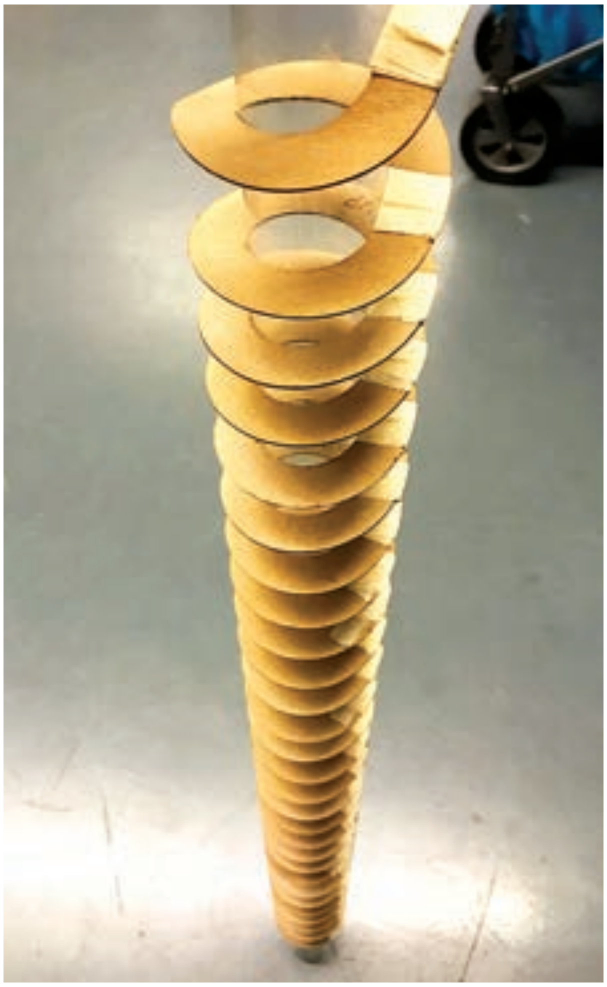
Back to YouTube they went. They wanted to find more examples. At this point, of the eight team members, three were assigned the task to figure out how to make something roll upward, so only three students YouTubed their way through their challenge. After about twenty minutes on YouTube, they came across an example of a cardboard Rube Goldberg project[2] in which a small marble was deposited at the bottom of an Archimedes screw and traveled upward along the screw to be deposited at the top of the machine, where it would then continue to travel downward along the typical Rube inclined plane setup. This was what the students wanted to accomplish.

So, they got to work. Student 1, whom I will call Monica, was the small team's artist. She began sketching the contraption they wanted to build. Student 2, whom I will call Moses, continued to analyze the video to try to figure out how the Archimedes screw worked. Student 3 ended up leaving the group to help other teams and never returned.

As a side note, I'd like to mention that none of the students ever read the description of the video, in which the term Archimedes screw was used. They went along for weeks not knowing that what they were attempting to build was called an Archimedes screw. It was really fun to have them later read about Archimedes and learn the history behind the design they had built.

Back to the story. After Monica and Moses were done sketching and analyzing, they searched the room for materials. They came to me with a clear plastic pipe that we had lying around the lab. I believe it is the type of plastic pipe that is used for encasing electric cords to keep them in place. It was just one of many random items I had purchased at Home Depot the month before, figuring it may be used for something or another over the course of building the Rube Goldberg machine. They wanted to use the plastic pipe as the center of their screw.

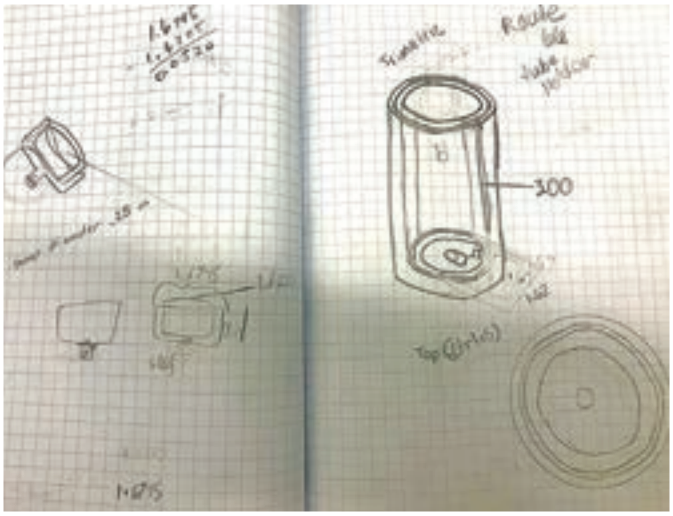
Next, they needed to add the rounded inclined planes (the threads) around the plastic pipe to make a screw. They thought of cutting cardboard into strips like in the YouTube video and came to me for advice. I probed them with a simple question, "Why struggle with scissors and thick cardboard such as this when we have thin sheets of cardboard that can easily be cut with our laser cutter?" Their eyes widened and they set to work. They retrieved our digital caliper to start measuring the diameter of the plastic pipe. Next they measured the diameter of the ball they wanted to use (a small 3D printed ball I had lying around the lab, similar in size to a ping-pong ball). Then they logged into CorelDraw (a graphic design software), and with a little reminder from me on how to set their lines to RGB red and Hairline, they sketched a circle to match the diameter of the pipe, and then another circle to match the diameter of the pipe plus the diameter of the ball. They included one straight line to connect the two circles that had the same center point, and they sent it to the printer. It was done in fifteen seconds. They tested it, and sure enough, it fit perfectly and snugly around the plastic pipe. They went back to CorelDraw to duplicate their drawing multiple times, enough to fit the sheets of cardboard we had, and printed multiple sheets of these circles.



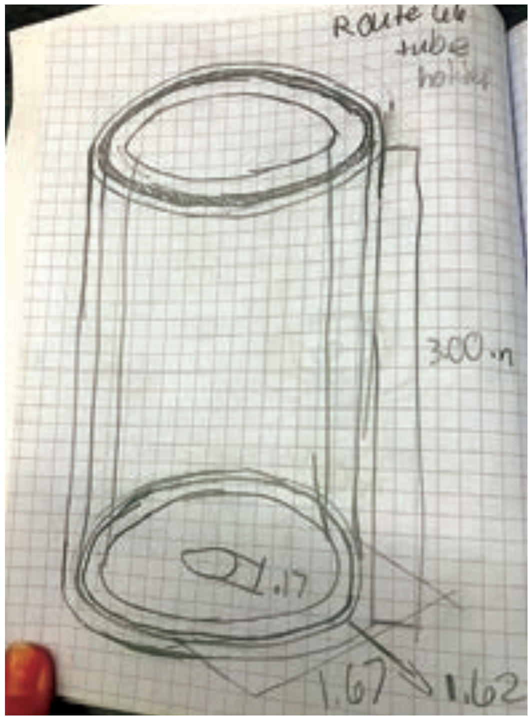
Laser-cut cardboard spirals will become the threads around a plastic pipe, making a screw

I'm going to fast-forward a bit here. Basically they were able to create a "screw" with their plastic pipe and many, many laser-cut cardboard "donuts." Their next hurdle was to make this pipe rotate. Luckily we had a few windshield-wiper motors in our lab leftover from last year's animatronics projects. I suggested to them that if they could find a way to mount their screw to the motor, the motor would rotate the screw for them. The problem was that their pipe was hollow; it had no bottom or top that could be attached to the motor. Coach Emerson to the rescue: “If you could find a way to solve your last problem by designing something to be laser cut, don’t you think you can find a way to solve this problem by designing a part we could print?”

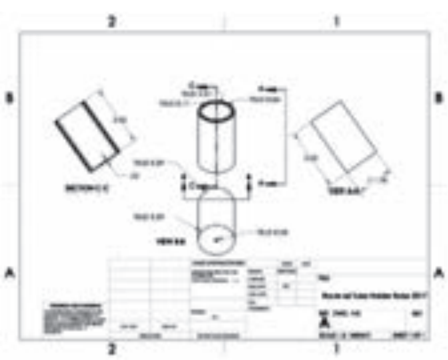
For this task, Monica and Moses needed a lot more of my help. With the last task, they were able to find the tools they needed mostly on their own and were able to design what they wanted in CorelDraw because they were both very familiar with the program (from previous classes they had with me in which I taught them CorelDraw). For this new problem, they would need to use SolidWorks (advanced CAD software, used primarily in the manufacturing industry), and neither Monica nor Moses had used SolidWorks in over a year. So we sat down together, each at our own computer with our notebook, the caliper, and the plastic pipe. We discussed together, with a lot of my probing (“What is it that you need to design?,” “How should it look?,” “What features does it need?,” “Is this what you expected it to be?”) and came up with a sketch of what we wanted. We took measurements of both the inner and outer diameter of the pipe and came up with a cup-like design, basically an extruded cylinder base with a hole in the middle to screw to the motor, and two more raised, hollowed cylinders to encase the sides of the pipe. The pipe would sit inside this cup-like design and be screwed to the motor.



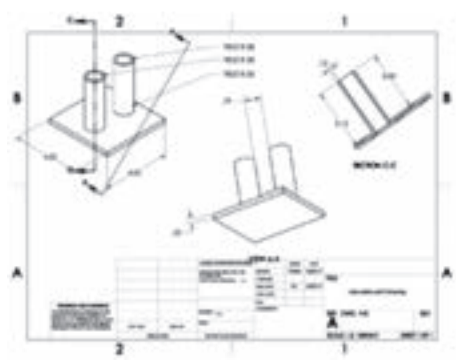
Initial sketches and calculations before designing in SolidWorks



Monica’s close-up sketch of the part to attach the screw to the motor



Drawing of 3D-printed pipe holder



Drawing of 3D-printed SolidWorks dowel holder

The 3D-printed part that was attached to the windshield-wiper motor

For the next step, they needed to learn how the motor actually worked. Monica and Moses had not participated in our school's animatronics project from the previous year, so they sought out another student whom I will call Bianca, who was known to be the electronics expert of the team. She had worked on a number of the motors during the animatronics project the year before and easily taught Monica how to set up the wires so the motor would run. They tested it and it worked! The motor successfully turned the screw; however, they immediately noticed a new problem. Because their screw was so tall, it swayed outward and did not stay directly upright while being moved by the motor. They decided to use two wooden dowels spaced purposefully at the exact distance from each other to hold the ball from falling off the edge of the screw. This idea they got from the YouTube video. This would keep it in place on one side, but it did not stop the screw from swaying outward. With the help of my colleague Richard, who probed them to think about securing the screw from the top just like they had on the bottom, they duplicated the part they had already printed to mount the screw from the bottom, added a top to the part that could spin inside a small hole, in a similar way to how a gear spins in place, and it was now secure! They tested everything, and it finally worked. They completed their challenge to have an object move upward, creating that unique almost "magical" effect that we knew their project needed.

In the end, they took their project to competition and placed second against other teams of mostly seventh and eighth graders. We were all very proud of their accomplishments, but what I know to be the most powerful aspects of this project are all of the "transactions" of learning that took place between these students and me. We designed solutions to problem after problem, using and manipulating technology and tools at our fingertips, and I was able to design, immediately and authentically, challenges that stretched my students' minds and allowed them to mediate and share new ideas with each other.

Notes

1. youtube.com/watch?v=rZyEunPgwwk
2. youtube.com/watch?v=TjDVTMYE2Yc

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Ackermann, E. (2003, August). Hidden drivers of pedagogic transactions: Teachers as clinicians and designers. In *Proceedings of Eurologo* (pp. 29–37). Retrieved from web.media.mit.edu/~edith/publications/2003-Hidden.drivers.pdf

Hey, Kids—Follow the Directions!

by Aaron Vanderwerff

Four years ago at a Young Makers meeting, a parent mentor told the group, "Following directions is not making." When I recently saw the same sentiment on a post or tweet, it made me think about our practice at the Lighthouse Creativity Lab in Oakland, California, and when following directions *is* making. We can place most making projects and activities on a spectrum from step-by-step to completely open ended (similar to a spectrum of inquiry), and we choose where the learning activity falls based on what we want students to learn and students' prior understanding and experience. My instinct is to always push toward open-ended, student-driven projects, but there are times when following directions can be powerful.

In that first year of our maker program, I knew that many of my student groups would be following directions from tutorials or magazines because they had never been asked to create a project of their own vision before. They had trouble even conceptualizing what was possible. When my daughter first started playing with LEGO bricks around age two, I purposefully didn't give her any directions. I wanted to hold off on directions so that she wouldn't come to rely on them, thinking that the more I could encourage her to free build, the more likely she would apply this mentality to the world around her. And, so far, the plan seems to be working. She builds towers, vehicles, spaceships, sculptures, and buildings all while telling intricate stories about what is happening (and using LEGO Minifig heads as structural components).

Once upon a time . . .

At about three-and-a-half she received a kit and wanted to build the mining truck on the front of the box. I tried to stay out of it, only helping her align what she was building to the picture in the instructions when she got stuck. What did she get out of this experience? First of all, pride. She was extremely proud to have built the mining truck just like the one in the picture. Second, watching her work through the directions, she was clearly developing her precision and spatial thinking.

How does this apply at the Lighthouse Creativity Lab? We try to make the project's place on the continuum from step-by-step to complete autonomy match its educational purpose.

Physics students constructing a wind turbine

Our physics students build wind turbines based on a specific design, meaning all students work from the same directions.[1] One of our goals is that five years from now students remember magnet, coil of wire, motion = electricity. Just building the turbine helps with that. But we also want them to experience a more open-ended, process-based aspect, so we ask them to make it better. But even if they are just building the

Students learning woodworking by making a chair

turbine itself, they are still learning core physics content, building skills, learning the importance of precision, and developing persistence.

In our high school making elective, students start the year with skill builders that involve following a lot of directions; they make a chair (woodworking), a pillow (sewing), and a circuit board (soldering), and play around with Arduino (programming and circuits). The core goal in all of these projects is to build student confidence and comfort in each of these areas so that when they undertake their independent project, they will venture outside of their initial comfort zone.

The circuit board is a step-by-step process students follow exactly, but after only a few class sessions, they are decent solderers and much more knowledgeable and comfortable with electronic components. Working with Arduino is a move away from this step-by-step. We ask students to move through the existing Arduino example code and tutorials so they learn how to find references. Then they engage in an Instructables Arduino[2] project to experience all the issues that come with following someone else's directions to do something new because it turns out that following directions is not always easy.

Ideally students should be able to move fluidly between referencing directions and moving forward with their own vision. Like in the Arduino projects, I want students to know how to find a tutorial, video, or other reference to get started and then take the project in their own direction.

So is following directions making? It can be. When students use directions to get started, they build confidence and learn perseverance and precision that will take them beyond the directions. When we find that students are afraid to leave the directions, it's our job to nudge them into their own creating.

Notes

1. re-energy.ca/wind-turbine
2. instructables.com/id/Persistence-of-Vision-Wand

Maker Teacher in the Classroom: What Should I Do (and Not Do) for Students?

by Heather Allen Pang

As a maker, one of the things I like to do is to spend a great deal of time on something, go deep, and feel that the result is really due to my hard work. I have taken up quilting recently because it lends itself to that kind of project. I need to learn new things and then do them. It makes me happy. As a teacher of eighth-grade US history, I love bringing in that maker mindset, but I also have a few other priorities that I need to balance with the idea that the maker (in this case the student) should figure it all out. Even when I am teaching in the makerspace, or a sewing elective, I still wonder about that perfect balance between what I should do to help and what I want the students to figure out for themselves.

One of the things I have started to do when I explain something to students (something fun like using the laser cutter, or something perhaps less fun like constructing proper footnotes using the Chicago style) is to remind them that even though I am telling them all the steps they need, and they have the steps in the instructions, I don't expect them to get it all the first time, and they should ask each other and me for help. I do want them to read the instructions and help each other. We are all still working on that.

But it always comes back to the same questions I have asked myself about instructions, kits, prepared sets of parts, and other methods to move things along a bit faster. How much is too much? How much is too little? In some ways this gets at the heart of the difference between my own personal making and my making with students in the classroom. The goals are different, and some of the methods are different too. So rather than thinking in terms of strict rules of making, I want to think in terms of questions to ask and ways to balance competing benefits. It is not a case of finding the one right answer (choosing between one good answer and one bad one) but rather, in any given situation, which of the two good arguments gets to win out a little even as I try to give some space for the opposite argument.

In some of my projects I have come to a pretty satisfactory balance. I have an annual project on the telegraph, where students work in pairs to construct a prototype of a working telegraph to start the unit on technological change in American society. The making activity brings the lesson to life, creating a tactile understanding and generating deep discussions. The students ask amazing questions and make thoughtful observations (questions that have never come up when we just read about the invention and use of the telegraph). But my goal is not to teach the science of electromagnets or current or wire stripping. In balancing this lesson, I want the focus to be on the history, so I give students instructions and prepare some of the parts they use.

It is not a bad thing that students sometimes ask questions about these things, and I invite them to explore the answers. If I were teaching a science class, I might reverse the order—give them few instructions and let them figure out what parts to use. Likewise, when students make display boards for National History Day, I don't make them discover that contact paper is the best thing to use for covering the cardboard (spray paint will warp the cardboard, and leaving it plain won't work since we recycle the boards) or that if you mount an iPad at the top of the board it will tip over. They could learn from trying, or breaking several iPads, but I have made the decision to start by telling them these things. Sometimes they don't listen, but that is a different story. I also use the large-format color printer to print their images for them—they don't have time or access to that particular printer; their other choice would be to pay a copy service, and that costs money some of them don't have.

There are other projects where I still go back and forth about how much I take away from their opportunity to learn when I tell them the answer. I guess I always will. I do think after almost two decades of teaching eighth graders I am getting better at asking these questions:

- What does the item I would be giving or doing for them have to do with the point of the lesson?
- How realistic is it that students can figure it out themselves or make the item themselves?
- Could I give some help but not do it for them?
- How much is time a factor?
- How much joy will they get out of doing it themselves?
- Can I do less for them to do more?
- Can I teach one member of the group and have her teach the rest?
- Can I use this lesson to teach students how to figure it out? Should I?

Part of the role of a maker teacher in the classroom seems to me to continue to ask questions like these, and to iterate my own teaching with each project and each class.

Students work from precut parts to construct a telegraph machine

Trendy, Educational, or Creative? Solve the Robotics Kit Dilemma!

by Angela Sofia Lombardo

In 2015 a local business association wanted to sponsor a robotics after-school lab for five different first-grade classes in the Bologna, Italy, area. I was named to the organizing committee, and one of our first tasks was to decide which robotics materials, kits, and software we would use.

Our committee had seen the MilkBot,[1] a little robot that combines the open-source Arduino microcontroller with scrap material, and wanted to offer a similar creative experience to the students involved in the project.

However, our students had no experience with Scratch nor with Arduino, so we started reflecting on choosing the most useful kit for our purpose.

Constructionism provides learning dimensions

Seymour Papert's constructionism was the model that we chose as inspiration to design the learning experience because we strongly believe that the educational power of a technology resides in the potential for creative expression that it offers.

We asked ourselves what learning dimensions an educational robotics kit should have to be effective for a constructionist learning experience in a school context.

Papert often used a metaphor of "low floor, high ceiling" to describe what useful technology looks like in a constructionist learning experience:

- ***Low floor***—To be effective, a technology has to be easy to use, even for a beginner.
- ***High ceiling***—The same technology has to offer the possibility of creating increasingly complex and sophisticated projects as the user becomes fluent and wants to experiment with new things.

Mitchel Resnick, the LEGO Papert Professor of Learning Research at the MIT Media Lab, adds another dimension, *wide walls*: To be effective, a technology has to allow multiple types of creations in order to enable the users to express themselves creatively regardless of their level of competence.

Practical considerations

Working in a school context with groups of twenty-five students at a time demanded that we consider other practical and logistical elements.

Cost. For a technology to have a significant impact on learning at school it should be available in sufficient quantity to let a class of twenty to twenty-five students work in groups of four members at the same time.

Adequacy. To be effective at school, components must be in line with learning and developmental goals already achieved by the final user (students) and, at the same time, must stimulate its progress gradually (scaffolding). For example, a technology must be adequate for the students' fine motor skills but also for their ability to take care and respect the tools and materials. The variety of components, from actuators to sensors, available in the kit must match the cognitive level achieved by the students and must provide adequate challenges to grow and enrich learning.

Every teacher/educator has the duty of assessing the adequacy of what's available in the kit based on the learning goals and the skills already acquired. This is the most delicate and challenging aspect of our job because it requires us to empathize with our students, to put ourselves in their shoes and imagine how they could interact with the robot and what they will learn through it while trying to go beyond our personal expectations.

Quality of the programming environment. An effective educational robotics kit must be supported by an online and offline programming environment.

It must be adequate and adaptable to the level of competence of the students. Just like the kit components, the programming language must also be adapted to the competences already reached by the students and must gradually stimulate their development. It could, for example, offer block programming and then gradually move on to text programming. Also, in this case, the level of adequacy (and the programming language offered) must be evaluated by the educator based on the skills of the specific class group (or at least for the expected targets for the age).

It must provide a good level of interaction between robot and computer. To satisfy interaction, we have two concerns. The first is about the communication between robot and computer: Do we have to use a cable? Do they connect via Bluetooth or use a wireless protocol? We observed that the kits that only use the cable communication limit students' creative possibilities, yet kits that communicate via Bluetooth tend to have connection problems (for example, the robots in the classroom connect to the wrong PC). The second concern is related to the possibility of making the robot interact with things happening on the screen. The traditional concept of robotics involves the use of computers only for compiling and uploading the code in the robot's brain; in a constructionist learning environment it would be useful to be able to do more.

Versatility. To be effective within a constructionist learning environment in a school context, the robotics must be adaptable and "neutral" enough to enhance imagining and ideating of all kinds. At the same time, it must be practical and light enough not to clutter up the students' creations.

For example, in some cases the "brain" of the robot is very bulky and poses some very difficult design challenges for the students. Or sometimes the kit comes with very short connection cables (from board to sensors/actuators), limiting the size and aesthetics of the creations.

Moreover, some kits are sold in boxes containing images that invite students to build certain types of robots, which are very appealing to the eyes of a boy or a girl but can limit imagination and creativity, for example, kits that only show examples of rovers and cars. We have observed that students who experiment with a robotics kit by building and programming a car are less likely to imagine and create something far different from the car. Even if they only saw the image on the box, their ideas will converge in the direction of a car.

There is no perfect solution, but we did it anyway

There are many kits available on the market that support the three learning dimensions to one degree or another. Finding one that meets all three in a balance is the difficult part.

For our project we chose the mBot off-the-shelf robotics kit from MakeBlock company.

It had a low floor because components were easy to connect to the board; the mCore is an Arduino-core microcontroller built to facilitate plugging sensors and actuators thanks to its RJ25 wires, avoiding kids having to struggle with circuits, breadboards, and resistances.

It had a high ceiling because it provides a block-based programming language, very similar to Scratch, that translates block code into Arduino code just by pushing a button, so students can start to discover how an Arduino code looks and upload their code on the mCore.

Robot and computer communicate through cable or with a 2.4G wireless protocol so students can easily create sophisticated projects in which robot interacts with what happens on the computer screen.

The kit is very cheap compared to other robotics kits, and the number of components provided is wide enough to let kids experiment and learn about different kinds of sensors and actuators.

What we missed using this kit were wide walls and versatility. The kit is set up to build a car, providing chassis, tires, and short RJ25 wires that facilitate building compact objects. The box and instruction booklet show images of a car and how to build it, so kids' imaginations and creativity were limited.

After three years of using these kits we figured out how to design the learning experience and how to introduce students to the kit to solve the wide walls and versatility issues.

As an example, we use spray paint to cover all the images on the boxes, and we take the chassis and tires away from the box as well as the instruction booklet so as not to limit students' freedom in exploring and imagining what they can invent.

An alternate option is buying an Orion board (similar to the mCore but with more RJ25 ports) and buying each component separately instead of purchasing the off-the-shelf kit. This solution requires conscious budgeting to determine which components to buy (so it takes more time), but it offers the chance to go beyond wide walls and versatility issues and provide our middle school students with adequate building material and objects to think and tinker with.

Final reflections

Before buying an educational robotics kit, it is very important to have the chance to either experiment with it yourself or to talk with someone who already uses the kits. Visit fairs and events dedicated to educational robotics, participate in workshops, or observe laboratories (such as CoderDojo) where you can use robotics kits, join numerous online communities, or ask for feedback from colleagues in other schools, and make a decision that takes into consideration the pros and cons based on all the information you collect.

Every context, every class group, every educator is unique and special, and for this reason personal reflection and a careful evaluation of the characteristics that an educational technology must have are necessary in order to achieve the preestablished objectives.

Note

1. raspibo.org/wiki/index.php?title=Milkbot

Building Knowledge and Relationships through Building Toys for Others

by Erin Riley
with Nathan Holbert and Sawaros Thanapornsangsuth of Teachers College, Columbia University

GAMES, Greenwich Academy's Makers and Engineers in Greenwich, Connecticut, a program designed to engage students in the process of making for others, offers an environment for gaining new knowledge and skills in the school's makerspace. Fourth graders make toys for their "little sisters" as part of a special yearlong collaboration. This article shares observations and outcomes, focusing on the perspective of little sister "clients" and makers. The motivation behind making for others deepened the impact of this project while further developing their competencies in making.

All names in this article are pseudonyms.

Project description

A long-standing tradition at Greenwich Academy, the Big Sister/Little Sister program pairs fourth-grade "big sisters" with first-grade "little sisters" in activities throughout the year. In a partnership with the Snow Day Learning Lab at Teachers College, Columbia University in New York City, the GAMES program engaged fourth graders with designing "dream toys" for their first-grade little sisters. Rather than have students make toys or objects for themselves, the dream-toy activity is about building connections between the maker and her community. The expectation is that opportunities to create artifacts to "give back" or support one's community might provide learners with a broader perspective of the value of making and appeal to a more diverse audience.

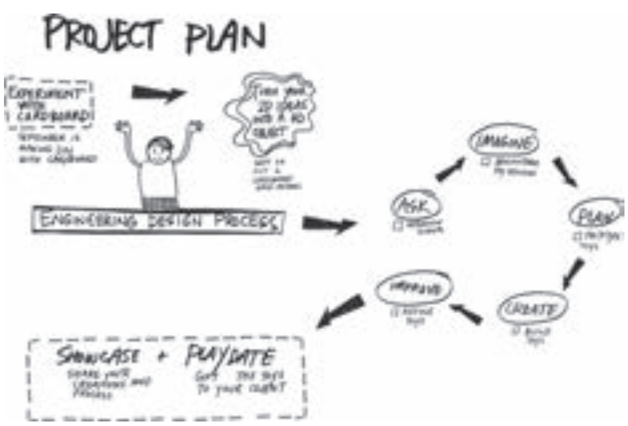
Sophia sharing progress on her toy design for Nancy

Cathy sharing her final toy design for Annie

The process

The overarching goal for the year was for students to engage in the engineering design process to create a dream toy for their little sisters. They met every two weeks for sixteen sessions. The activity sequence began with two days of making with cardboard to familiarize the girls with the lab and stimulate creativity for the year ahead. After the initial making sessions, girls interviewed their little sisters to gather the information needed and brainstormed within a small group. After three days of prototyping, they met with the first-grade girls, who offered feedback on their prototypes. The girls then had seven sessions in which to complete their final designs for their little sisters. The concluding event was a play date where the toy exchange took place and the girls could play together.

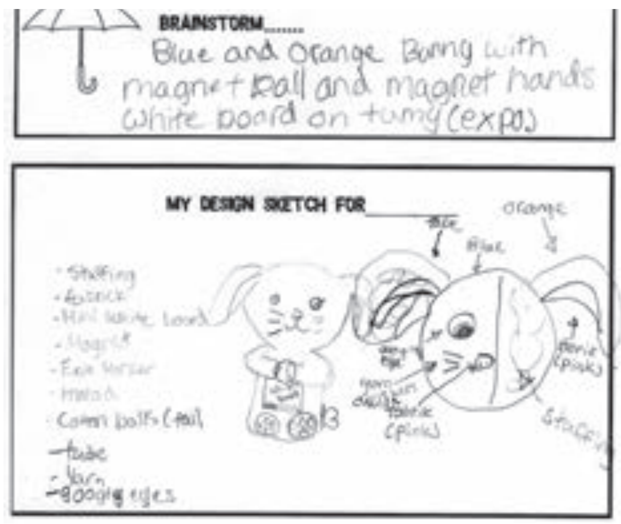
Activity	Number of Sessions
Make with cardboard	2
Interview little sisters	1
Brainstorm with small group	1
Prototype	3
Receive feedback	1
Make toys	7
Play date	1



Project plan using engineering design process

The engineering design process provided a framework for the girls to plan their design and overcome various challenges on their way to a complete toy. Despite the common task of designing a dream toy, a wide range of design ideas developed. Some fourth graders pulled out one or two ideas from the client interview to focus on, while others incorporated as many of the ideas presented as they could, to create complex and highly personalized toys.

For example, Chloe, a fourth grader, designed and made a plush dry-erase board for her little sister, Pam. From her little sister interview, Chloe learned that (1) Pam likes the colors orange and blue, (2) her favorite animals are bunnies, (3) she likes to draw, and (4) she likes to play with Magna Tiles and stuffed animals. This information helped her to form her first prototype using cardboard, markers, and magnets. Chloe's concept showed careful consideration for her client, as the prototype satisfied all of the criteria gathered from observations and information recorded in the interview. Presenting her prototype at the feedback session allowed Chloe to tailor the idea further to fit Pam's toy and play preferences. Chloe revised the final toy design to include magnets, which hold the eraser, into the paws.



Chloe's brainstorm and design sketch for Pam's toy

Chloe prototyping Pam's toy based on her interview

Building final toy

Chloe's final toy for Pam: magnet paws and dry-erase board for drawing

Aside from the natural constraints of time, materials, and size, students could envision whatever they wanted for their little sister's dream toys. This resulted in a diverse range of toy creations. While soft toys were the most requested toy types from the first-grade little sisters, their soft-toy creations were personal, unique, and highly creative.

Four examples of plush toys illustrate the variety of ideas that emerged from the design process: Ellie's plush snake for Gina, Kylie's light-up pillow for Willow, Betty's pillow with the golden thread (inspired by her favorite fairy tale) for Pam (Betty shares her sister with Chloe), and Amy's talking pillow for Emma.

Ellie's snake idea pushed the boundary of scale: her creation for Gina served a double function as a wearable piece. Kylie incorporated a light-up element and decorative trim, treating the surface of the pillow like an artist's canvas. Betty's golden thread pillow brought a magical touch to Pam's dollhouse. Amy's sunshine-yellow pillow gave Emma an equally cheerful message: with a squeeze, the pillow says, "Have a great day!"




(left to right, top down)
Ellie's large-scale plush snake for Gina; Kylie's light-up element for Willow's pillow; Betty's golden-thread pillow for Pam; Amy's talking pillow creation for Emma

The value of making for others

The little sister/big sister relationship, one that is meaningful for both grades, proved to be a strong motivating factor in the work the girls produced. In many of the toys we saw students making adjustments and putting their vision for the project aside to create something that matched the interests and toy preferences of their little sisters. This was particularly evident after the client feedback session.

One maker, Ruth, presented a talking pillow prototype to her first-grade little sister Stephanie at the feedback meeting. While Ruth expected the pillow with the "I love you, Stephanie" message to be embraced, Stephanie offered a new direction, requesting a "dollhouse with wheels and a bedroom." While initially disappointed, Ruth showed flexibility in her thinking and design, abandoning her initial idea and adapting to Stephanie's feedback. By the third session following the feedback, Ruth began making progress on a one-story dollhouse and on the second-to-last day was putting finishing touches on her creation. She said, "I am so proud of myself today!" When asked why, she said, "I worked so hard. I'm almost done!" Ruth demonstrated an ability to receive feedback and change course with her design idea. In the end she expressed how proud she felt of her efforts and completing the work on time.

Confidence with tools

We offered a variety of tools for students to work with over the course of the year to execute their toy construction. This included standard hand-building tools like saws, files, vices, and cutters for the workbench area as well as hot glue guns, a sewing machine, and power drills.

By providing the tools with some general safety guidelines, students had many opportunities to hone their skills. Tool "rollout" came in stages, with students trained in proper use and safety procedures. By the third session in making, the girls had all aforementioned tools available to them, and they were encouraged to support each other by lending a hand to fellow makers. A helping spirit emerged in the weeks that followed; experts in tool use willingly assumed a teaching role with their peers. This was especially true with the power drill and sewing machine, where Ellie helped Melodie with her pillow project.

Students were encouraged to use tools to develop creative solutions to design challenges. For example, Melanie came up with a creative solution for a functional axle for her little sister Allison's car. Searching through a container of various bolts and nuts Melanie stumbled upon some eyebolts. She marked and drilled pilot holes in the wood, matched her bolt size to her drill bit, and attached the bolt and nut. The eye functioned as a loop for the axle. Giving students the freedom to experiment with tools allows them to create new possibilities for making and solving the problems at hand.

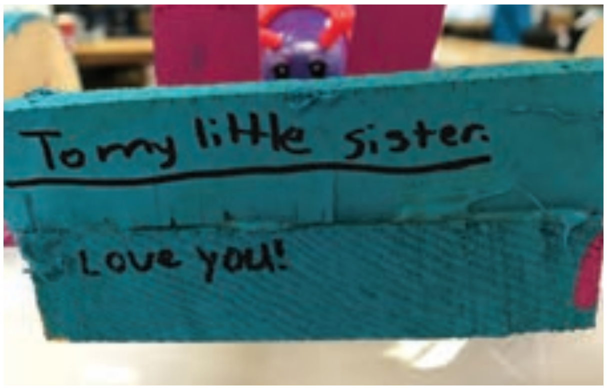
Melodie and Ellie working together at the sewing machine

Melanie's axle solution

Making connections and building community

As a school of many traditions, Greenwich Academy welcomes a new one into the mix—one that focuses on innovation, developing making skills, and building connections between the maker and her community.

At the final play date, where fourth-grade makers connected with their little sisters to exchange toys, it was clear this relationship between the girls was personally meaningful. The joy in making for others experienced by big sisters was equal to that of little sisters who received the handmade toys. With a hand in the design process, these girls are already looking forward to reaching fourth grade to start this process with their future little sisters. The fourth graders, now entering middle school, have established a strong tie to the Engineering and Design Lab and can confidently work in the space through integrated projects or courses.



Iris's message to Lilly

Makers playing together during the toy exchange and playdate

Sample of final toys for GAMES

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Postscript: A Farewell to Fours (2018)

Note: Erin Riley gave this graduation speech to the students who had just completed the Toy Building project and are moving on to middle school.

Parents, friends, and most especially members of the fourth-grade class,

I am so honored to be here to say a few words about our wonderful fourth-grade girls. This is an important day. While we say farewell to you as fours, I have the privilege of also saying welcome. Welcome to you as fives . . . and sixes . . . and sevens . . . and so on. While GAMES (Greenwich Academy Makers and Engineers) comes to a close, your time for making whatever your imagination brings is just beginning. This marks the closing of a remarkable year of creativity, problem-solving, collaboration, and most importantly of demonstrating YOUR character in our Engineering and Design Lab through the making of toys for your little sisters.

Group four, next year you will be off to middle school, and it gives me great pride in knowing that you will be taking tremendous superpowers with you to fifth grade and beyond. Since you are all makers, let's just call these *makerpowers*.

Maybe some of you are wondering what a makerpower is exactly.

Let me explain. A makerpower is a set of awesome abilities. You get these powers when you make things—when you take something from your imagination and bring it into the world.

Now you might think makerpowers might be sawing wood, sewing, or using a glue gun. These skills are awesome, for sure, but makerpowers are a little different. They are SUPERpowers. These powers allow you to do all sorts of things—more than cutting or gluing wood. This morning I want to point out some makerpowers that you have, that you can take with you to fifth grade and beyond.

Makerpower 1: Bravery

This power helps you choose bravery when faced with new tasks. You learned to hammer, drill, use machines and tools. You faced your fears and practiced the makerpower of bravery. I witnessed your strength and confidence in full force in the Engineering and Design Lab.

Makerpower 2: Hard-problem solver

This power makes you willing to solve hard problems, and after that, even harder problems. You can see how this would be a very handy superpower. Being able to put the thickest thread into the tiniest needle, or getting paint to stick to rubber, were truly challenging, but they have equipped you for new challenges to come.

Makerpower 3: Creative thinker
This power helps you think for yourself and see things a little bit differently. Each and every one of you made something unique. Now, in the middle school you will have even more choices in clubs and arts and performing—more opportunities to be uniquely you.

Makerpower 4: Self-believer
This power instills a can-do spirit. When things get hard, you push through. Two more classes of GAMES and two boards to saw, four holes to drill, one pillow to sew and to stuff, but no problem! It can be done! When you have the self-believer makerpower, you know you do not give up because you know how to make a plan and deep down that you can get the job done.

Makerpower 5: Team builder
This power helps you work well with others and negotiate. When you are a team builder, you help, you share, and you work together. When we work together, we can get more done and do great things.

Fourth-grade girls, you have done amazing things in lower school. You have learned, and now you lead. Think of these makerpowers—bravery, hard-problem solver, creative thinker, self-believer, team builder—as forces for good that you can put out in the world. Spend lots of time this summer exercising your creativity. Make lots of things, and see you next year in the lab!

Lesson Plan: MLK March on Washington Artifact

by Josh Ajima

Martin Luther King Jr. at March on Washington for Jobs and Freedom. By Rowland Scherman; restored by Adam Cuerden (US National Archives and Records Administration) [CC0 or Public Domain], via Wikimedia Commons.

The 1960s civil rights movement sought to end segregation and discrimination against African Americans. One of the largest political rallies of the civil rights movement was the March on Washington for Jobs and Freedom. A key moment of the march was the "I Have a Dream" speech delivered by Martin Luther King Jr. from the steps of the Lincoln Memorial to a crowd of two hundred thousand to three hundred thousand. The effects of the March on Washington include building momentum for the passage of the Civil Rights Act of 1964 and the Voting Rights Act of 1965.

Objectives

- Students will investigate and explore the legacy of Martin Luther King Jr. and the civil rights movement through a reproduction of a button from the 1963 March on Washington (shown being worn in photo above).
- Students will design, make, and share a historical artifact that illustrates a significant aspect of the civil rights movement.

Lesson plan and activity

Investigate: What is the significance of this button?

Teacher presents button to students and ask them to research and present why it is significant. (Teacher could tell students that a button has been donated to their history class and the students need to report on its historical significance. Or the students could be given the role of appraisers/experts and asked to explain the value of the piece. See *Antiques Roadshow* or *American Pickers* as examples.)

Button worn by participants of the March on Washington for Jobs and Freedom in 1963.[1]

Explore: Take action

Teacher provides students with copies of the button to wear. (All files for this project are posted on Thingiverse.[2]) Students are asked to plan/participate in an event/project/presentation to commemorate or recreate the march. Examples might include a march through the school or creating photos/videos of students marching. Students could also green screen themselves into photos/videos of the time period. Students might also take on the persona of people from the era and conduct historical interviews from the march.

Design/make/share: Civil rights era artifact

Authentic challenging problem: Create a historical artifact that represents the legacy of Martin Luther King Jr. or illustrates a significant aspect of the civil rights movement.

1. Research and then design the artifact in 3D modeling software such as Tinkercad or Morphi.
2. Make the artifact using a 3D printer. Iterate the design if necessary for printability. Take photos of finished design.
3. Share design on Thingiverse. Be sure to include a photo and key fields such as summary, category, and tags.

You may want your students to document the process with the Mini Maker Notebook—Thingiverse Edition.[3]

Notes

1. Multiple source images were used to create the vector image for this button design, with buttonmuseum.org/buttons/march-washington-jobs-and-freedom providing the primary visual source material.
2. thingiverse.com/thing:2018467
3. thingiverse.com/thing:93186

Constructionism for Science Literacy

by Christa Flores

Construct-a-what? One of the beautifully ironic traits of the pedagogical theories of constructivism and constructionism is that a deep understanding of either is impossible from just reading this, or any text. Nevertheless, try this metaphor.

If constructivism was a backpacking trip into the Alaskan wilderness on a shoestring budget armed with a "good plan," then traditional teacher-led models are more like an all-inclusive, family-friendly, low-risk Alaskan cruise: look but don't touch. Having that "Aha! I get constructivism!" moment is often visceral; you feel it before you can put it into words. Understanding constructivism authentically requires you, the learner, to experience learning in a self-directed environment. It requires time to get a good "feel" for the discovery versus consumption path to new knowledge. You must allow yourself to play, explore, and expand your own experiences while problem-solving or reaching a learning goal.

I hope to define the terms *constructivism* and *constructionism* through the lens of science literacy and the maker movement in education. This work has a deep and valuable history—tested, researched, and proven to be good for kids and society.

Constructivism is a term from the 1960s coined by Jean Piaget that means learning is constructed inside the head of the learner as new knowledge combines with existing experience.

Applying constructivist principles to education is a source of great joy and inspiration, but it is not the usual way schools operate. Why should schools adopt it? How do we know what students are learning? Growth in the accumulation of knowledge inside a person's head can be hard to measure. You have to rely very heavily on a learner's communication skills, such as speaking, drawing, and writing. The most highly prized form of evidence of learning we have in traditional settings is test scores despite tests being designed by teachers for efficiency from a teacher's perspective yet often badly designed from a learner's perspective.

Constructionism, a term coined in the 1980s by Seymour Papert, is accumulation and application of new knowledge through measuring, making, and using problem-solving techniques to make or create something. It builds on the idea of constructivism, but unlike constructivism it shows physical evidence of possessing and comprehending new knowledge. When a learner creates an artifact, they engage all the senses. The existence of the artifact—a line of code, a fat-free muffin, a photograph, a rubber-band gun— is evidence of learning and knowledge specific to the challenges that the student faced to make the individual artifact.

Not convinced? Try making something you have never made before without a recipe or kit. You will learn a lot through trial and error, or more quickly by seeking out reliable how-to videos to apply new skills to a unique situation. While making your object, you are learning through constructionism. The creation of the artifact will drive your learning using all of your senses and nearly every part of your brain. This is a concept that author David Perkins calls "making learning whole."

> The role of the teacher is to create the conditions for invention rather than provide ready-made knowledge. —Seymour Papert

Constructivism is the discovery approach to learning. If you provide learners with the tools they need to ask questions and to invent, they can and will drive their own learning. Helpful adult facilitators design the prompts and provocations, but the learner is allowed to discover new ideas independently through their tests and their creations.

Constructivist science

The idea that each individual should learn through direct experience rather than direct instruction is so obvious to real scientists that the Latin phrase *Nullius in verba*, which translates to "take nobody's word for it," was adopted in 1660 as the official motto of The Royal Society of London. The motto was adopted as "an expression of the determination of Fellows to withstand the domination of authority and to verify all statements by an appeal to facts determined by experiment." A scientist is a constructivist by nature and profession; for example, many scientists design and build their own tools for inquiry to make sure that they really are doing what is intended.

In the late 1700s and early 1800s an educational reformer was working with children right around the same time that "science" was being revolutionized in Victorian England by such icons as Faraday, the Herschel family, and Darwin. Having read Rousseau's *Émile* (1800), a book about education that looked at Christianity critically and was later burned publicly, Johann Heinrich Pestalozzi (1746–1827) affirmed "that teachers and parents never should teach children anything they could learn or experience naturally." In 1799, handed the care of war orphans, Pestalozzi created educational programs that focused on hands-on learning by making real-world objects, giving these children both education and a pathway out of poverty. Pestalozzi was an entrepreneur, constructivist, and a constructionist who would often say that learning should be by "head, hand and heart."

> I went gladly, for I hoped to offer these innocent little ones some compensation for the loss they had sustained, and to find in their wretchedness a basis for their gratitude. In my zeal to put my hands to the task which had been the great dream of my life, I should have been ready to begin even in the highest Alps and without fire and water, so to speak, had I only been allowed.
>
> —Johann Heinrich Pestalozzi

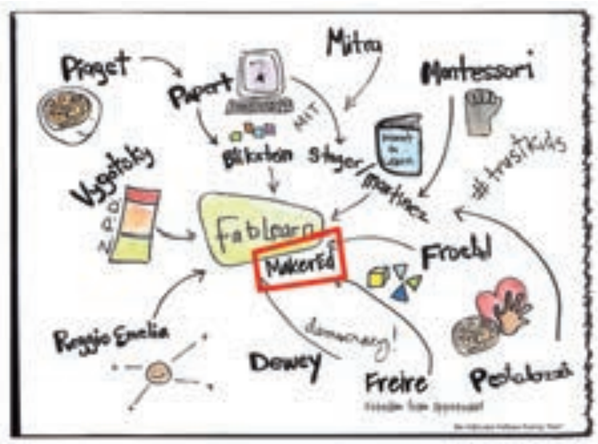
A sense of wonder in the creation of shared artifacts

Born in 1870, one of the first scientists to study how children develop cognitively was Italian physician and curriculum designer, Maria Montessori. As early as 1901 Dr. Montessori was advocating for the use of the scientific method to inform curriculum design. Dr. Montessori began her groundbreaking work in the 1910s on what is now known as the Montessori method, or one of our first modern models of self-directed learning, or constructivism.

Despite their successful models, Montessori and Pestalozzi were not mainstream. Education by now had been designed for standardization during the industrial era. Nevertheless, new ways of thinking about learning were appearing in areas as disparate as the Bauhaus school of art and architecture (1919–1933), the arts and crafts movement, and the work of American philosopher and educational reformer John Dewey.

Influenced by Rousseau and Plato, Dewey would advocate for the role of education in protecting democracy in such works as *Democracy and Education* (1916). Even though they were describing the idea of constructivism, the term would not be coined until Swiss psychologist Jean Piaget (1896–1980) would study young children, beginning with his own.

Piaget noticed that children construct an understanding of their world via sensorimotor interactions with their environment. Piaget was highly influenced by Dr. Montessori as well as the Montessori method, which modeled a learner-centered and effective model for constructivism. Piaget used the terms *assimilation* and *accommodation* to explain the twin processes of constructing new knowledge or understanding. Assimilation happens when the input children take in from their environment becomes part of their schema, or toolbox of knowledge.



The FabLearn Fellows family tree

As facilitators of making in science, we have the opportunity to witness learners practice Piaget's accommodation and assimilation in the act of making, fixing, and deconstructing artifacts. When given the time and materials to explore and test without overt adult instruction, the learner is practicing "constructive autonomy," the sweet spot where you can answer some of your own questions. Learning is about going beyond yourself, stretching and gaining new knowledge, and that happens only as a result of getting stuck, or what some term "failing."

Even a self-directed learner may get stuck and need a mentor. Thankfully Lev Vygotsky's theory of "social constructivism" as well as "zone of proximal development" offers a new mode for assessing and encouraging constructivism (1987).

When using a constructivist approach to learning, students are in a constant state of "it reminds me of" while they make sense of the world. This allows new knowledge to "rest" on a fertile foundation of some kind. Piaget called this fertile ground for new learning a person's schema. If a new idea is incorporated into a learner's schema, this is called *cognitive development*, or learning. For anyone to learn complex models and abstract ideas in science, there must first be fertile foundations to latch onto these new models. If fertile ground is absent, the new idea may be ignored or rejected outright. Science and technology that cannot be assimilated would have the effect of being "magic" to a person not ready to assimilate new ideas. Take for instance how popular science fiction is a temporary break from our boring old schemas.

Constructionism, a learning theory and a model for science literacy through maker education

Standing on a foundation of Pestalozzi, Montessori, Dewey, and Piaget, we begin now in the 1960s in Brazil, where another revolutionary thinker named Paulo Freire was frustrated not only by the poverty but also by the lack of success of solutions imposed on the poor. Freire showed through experimentation that literacy was the key to achieving freedom and self-actualization. He coined a new learning model called *critical pedagogy*, where education was a tool to question any system of oppression, including economic and educational systems. Friere was laying the groundwork for what we now call the *maker mindset* before the term existed, a sentiment that would resonate in Piaget's work as well.

Piaget was not only a learning theorist, he was also an early advocate for the mindsets we now cherish in the current maker movement such as agency and inventiveness. Piaget advocated that learners be allowed to employ a bottom-up, or user-generated, learning model that would challenge traditional schooling, which was passively receiving canonized ideas from teachers. Piaget saw school as a venue for raising innovative thinkers instead of well-trained consumers much in the same way Freire saw education as a tool to enlighten not oppress.

While working at the University of Geneva (1958–1963), Piaget hired a young mathematician, Seymour Papert, to help understand how children learn mathematics. This experience would be reflected in Seymour Papert's seminal work entitled *Mindstorms: Children, Computers, and Powerful Ideas* (1980), which states that children should use computers as powerful tools to create their own educational experience. His theory of constructionism, is a combination of constructivism as well as the word construction.

Papert's constructionism builds on the power of constructing one's own knowledge but adds the idea of making things. Papert was struck by the power of the computer and how this power could be used by children in a creative way. He and others invented the Logo programming language as a way to make that happen. Papert successfully predicted that the use of technology as seen in the current maker movement, and increased use of programming in science labs to collect and analyze data, would allow young learners to construct their knowledge of various subjects through personal inquiry and creativity. The Scratch programming language is a descendent of Logo, and its various outlets for exploration are a fine example of this reality.

When we expand constructionism to include paper, tape, wood, fabric, sound, light, etc., in addition to programming, we not only unveil the "maker movement," we see a concrete mode for identifying a learner's personal schema—not to mention tangible documentation of growth in new knowledge.

When actively creating our own education from first-hand experiences through play, testing, and exploring, we learn by doing in a constructivist way—behaviors we expect to see in the next great scientists and inventors, and simply the behaviors of someone who is learning through constructivism.

When we make and build models of ideas or tools for inquiry, or invent something, this is constructionism. Most proponents of progressive education then and now would deem the effective use of both constructivism and constructionism in school as necessary. Constructionism assumes not only Piaget's constructivism, but thanks to the maker movement, it can also reflect Friere's ideas on self-determination and Papert's prediction about the role of technology to foster a more innovative and truly democratic society. It's perhaps the perfect storm of puzzle pieces for real change in education.

The last pieces of the puzzle are now in our hands. Learning through the making of things is constructionism in action. This is what happens everyday in a makerspace; therefore, makerspaces are learning "ecologies" designed for constructionism. If you are working with learners in a makerspace, you are a facilitator of constructionism. Welcome to the club. Lets stand on the shoulders of so many giants, learn from critical pedagogy and constructionism, then dare to cultivate a society of inventive, empathic skeptics. *Nullius in verba*!

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Engineering Starting from Scratch

by Alphonse Habyarimana

Kepler Tech Lab middle school and high school students in class

The Kepler Tech Lab (now I4Fab) in Kigali, Rwanda,[1] offers after-school engineering classes and workshops to middle school and high school students. Creating and facilitating these classes was an extraordinary experience as we helped young students with zero knowledge of engineering or tinkering get started with experimenting and testing what technology has to offer.

For the first time, we enrolled and taught middle school and high school students in a two-month experience, and it was amazing to see how they were excited to build their own things, play around with Arduino kits, and try the concepts of electricity using Squishy Circuits. Without the Kepler Tech Lab, these students would have had no exposure to these concepts. I also gained a better understanding of interactive learning through the experience of creating these workshops.

Lindy Hatten says, "Interactive learning is a hands-on approach to help students become more engaged and retain more material" and that "with or without a form of technology, interactive learning helps students strengthen [problem-solving] and critical-thinking skills." We felt that interactive learning was the key to helping students acquaint themselves with new concepts, and there is nothing more interactive then being able to program your own stories.

As part of our workshops, we introduced Scratch to our students and wondered if learners with little to no knowledge about using computers for programming can do something meaningful. In some ways, we were late to start because Scratch can be used by much younger children. It requires only critical thinking and drag-and-drop graphics without much typing.

As always, our students were interested in doing many things at once, trying to catch up with what they had missed during their early years. The lab staff only needed to provide a little support and steer them toward our goals for them to get the most out of the software.

Sample game of guessing numbers to show to students

Students' written stories in brief

How did we get started? First, we realized that we should not wait until our students are fluent in using computers. We helped them to navigate through the graphical user interface of Scratch to get them to understand how to pick a sprite, customize the sprite, change its style, make it move, add a message, and add sound, just to list a few. Isn't that enough for beginners? And that was just day one. On day two, after understanding more about what they can do with Scratch, I gave them homework to write stories of their choice so that they can start day three (we had three sessions in a week with these students) with making stories in Scratch. Do not try to read the first one from the right unless you can understand Kinyarwanda. (Hint: It's a love story.)

Day three was not only about teaching the students how to make animations of their written stories in Scratch but also for the students to present to the whole class what they had made to help develop their technical communication skills.

We still have a lot to do with Scratch, and students' smiling faces confirm that they are enjoying and learning a lot from Kepler Tech Lab.

Note

1. keplertechlab.wordpress.com

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Learning Scratch programming

Middle School Sewing Elective, Version 2

by Heather Allen Pang

I coteach a sewing elective for middle school students. This article is about the second version; the first ended in some frustration, so we stopped offering it for a while, and I went on to be part of other electives. Recently we resurrected the idea, and I am coteaching with a colleague (great fun and so much calmer).

The first time I taught the elective I ran into one big problem: I was the only one there who could fix the sewing machines, and they broke all the time. Beginning sewing students often have trouble with the machines, and things get tangled and messy pretty quickly. In particular, the "heavy duty" Singer machines we have are not, in fact, heavy duty, and they seem to have chronic bobbin alignment problems. These problems are made worse when students just keep sewing rather than stop as soon as they hear or see a problem.

So with ten students and five machines, I spent most of my time untangling machines, and very little time was left to help with actual sewing projects. The new model does not completely remove that problem, but it does offer a model that is more sustainable and allows students to move forward even if I can't get to the machine quickly.

We now offer hand and machine sewing together to about twelve students. Half of them start out on the machines (we still have five—usually four work at any one time). The other half start out with my coteacher on hand sewing. When they have completed their first project, they move to the other group.

All the sewing machine students start out making a tote bag from a pattern I have put together,[1] and all of the hand sewers start out making a small felt stuffed animal from a silhouette they find online. We then have a variety of more advanced sewing projects for them to move on to once they have completed the two basic ones. The most popular advanced machine sewing project has been a zippered pencil case bag. Getting a zipper in correctly feels a bit like magic, and they show off their new bags to everyone. We have offered the option of finding their own patterns or using some of the ones I have brought in, but so far we don't have any takers for the task of learning to use commercial patterns. They are much more likely to go online and find video instructions.

Machine sewing project—tote bag

Hand sewing project—stuffed toy

Although with the new model I still have to fix machines and there is some frustration, we can spend more of our time working on sewing. If all the machines break at the same time, we can do hand sewing projects while I fix them. A few students have taken the elective for a second time, and they are starting to learn how to fix the machines themselves. They watch me clean out the loose threads from the bobbin case and rethread the machine each time, and they realize they can do that too. We now run this elective twice a year (each one runs eight to nine sessions), and version 2 appears to be a success.

Note

1. Tote bag instructions: bit.ly/totebag_pang

Why I Teach SolidWorks CAD to Young Children

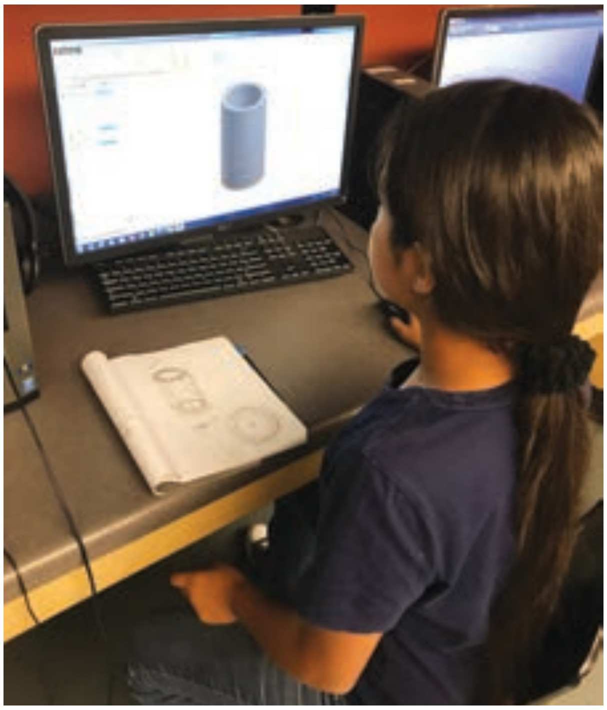
by Sarah Alfonso Emerson

SolidWorks is a CAD program, stated to be the world's most popular, used widely in the manufacturing industry—and it's a program I teach to kindergarteners. You might be wondering why teach SolidWorks to young children at all when free programs such as Tinkercad exist. Well, initially I had a very specific purpose for teaching SolidWorks, and it can be summed up with the following: LCFF → LCAP → Community Engagement Plan → Linked Learning → Career Pathways → Career Exploration.

Let me explain.

The lab out of which I teach, our elementary school makerspace, which we call the iSTEAM Lab, was envisioned and built with a certain end in mind. The iSTEAM Lab was built to fulfill a need that our school district became aware of through the state of California's Local Control Funding Formula (LCFF). The LCFF is a state policy/funding law that affects how school districts spend money. According to the LCFF, each California school district must have a Local Control and Accountability Plan (LCAP) that incorporates all stakeholders including parents, community members, and students. The LCAP must state how the school district plans to meet goals and address state and local priorities. In my school district, the San Bernardino City Unified School District, we designed a Community Engagement Plan to meet LCAP requirements.

Our Community Engagement Plan includes nine strategies that are designed to meet the following goals: each student developing and pursuing an academic and career plan based on their interests and talents; each student demonstrating independent initiative, civic responsibility, and community pride; each student developing creativity through mastery of fundamental



A fifth-grade student using SolidWorks to design a part for her independent project

knowledge and applied skills; and each student enjoying learning throughout life by learning how to learn. Of the nine strategies, which include titles such as Applied Learning, Learning beyond the Boundaries, and Network of Alliances, strategy six is titled College and Careers. Detailed in this strategy is our district's plan to transform high schools and the student experience by implementing a district-wide system of Linked Learning pathways built upon K–8 experiences that ensure college and career readiness upon graduation; establish a system of communication so that community, district, and school site strategy leaders are actively engaged in the work and can articulate the district's vision; create an infrastructure that supports development, quality, and sustainability of college and career pathways; have 100 percent of district students participating in high-quality pathways that focus instruction on academic and industry standards as well as twenty-first-century demands and are equitably accessible to any interested student; and assess progress and revise plans using processes and systems that support a culture of continuous improvement for district, college, and career pathways.

Clearly stated in our Community Engagement Plan is our commitment to career pathways through what's called Linked Learning. The Linked Learning Alliance website states the following:

> Linked Learning is a successful approach to education based on the idea that students work harder and dream bigger if their education is relevant to them. The Linked Learning approach integrates rigorous academics that meet college-ready standards with sequenced, high-quality career-technical education, work-based learning, and supports to help students stay on track. For Linked Learning students, education is organized around industry-sector themes. The industry theme is woven into lessons taught by teachers who collaborate across subject areas with input from working professionals, and reinforced by work-based learning with real employers. This makes learning more like the real world of work, and helps students answer the question, "Why do I need to know this?"

In order for this strategy to work at an elementary school, our school, Bing Wong Elementary School in San Bernardino, California, has begun a flagship Career Exploration program. The iSTEAM Lab was built to pave the way for the rest of our school's Career Exploration focus. The lab allows students the opportunity to explore careers in the manufacturing industry, which is a dominant industry in our region of California. Our school district has identified it as such, thus creating a manufacturing pathway at our local feeder secondary schools, Curtis Middle School and Indian Springs High School. My program in the iSTEAM Lab is designed in alignment with the curriculum of the manufacturing pathway that is being taught at Curtis Middle School and Indian Springs High School. All of this leads to why I am teaching SolidWorks to children as young as kindergarten. SolidWorks is the industry-standard 3D modeling software in the manufacturing industry and the program my colleagues at the secondary level are teaching their students.

Fourth-grade students used SolidWorks to design a coin cell battery and LED holder.

SolidWorks is complex but powerful

Now that I've explained why I teach SolidWorks to young children, I'd like to share why I continue to be passionate about teaching SolidWorks to students and why I would want to teach it to young children regardless of any LCFF; LCAP; Linked Learning; or other district, state, or organizational reason to do so.

I have no background in engineering. I have never taken any engineering classes. I have never been formally taught SolidWorks. Most of what I have learned about using SolidWorks, I have learned through personal trial and error, from watching YouTube videos, and from mini lessons from friends and colleagues who know more than I do. When I was first introduced to SolidWorks and struggled through completing a simple tutorial (when I say struggled, I mean STRUGGLED—like wanting-to-throw-my-computer-across-the-room kind of struggled), I left the experience thinking "Why would I ever want to put young children through what I just went through? I could make this on Tinkercad so much easier . . . probably . . . I think . . ."

As it turns out, I could *not* make it more easily on Tinkercad. Tinkercad does not have the precise sketching and dimensioning tools that SolidWorks has. It doesn't offer the ability to first sketch on one plane and then sketch on a different plane at a different angle and still have everything align well together. It doesn't allow for sketching separate parts and then putting them together in an assembly to see if they would actually fit together (which turns out to be so helpful when designing 2D pieces that will be laser cut and then pieced together into a 3D object). I couldn't transfer all of my sketches over to a

Fifth- and sixth-grade students designed these parts in SolidWorks, then laser cut them, and finally assembled them into a shadow box.

drawing/blueprint so students could deconstruct my work. I couldn't have my students slice their part and analyze its interior structure. I definitely wouldn't have been able to run the sustainability simulation as I taught students about the impact mass-producing their product would have on our environment.

Now, I may be wrong. Like I said, I'm no expert in engineering nor 3D design, nor have I had a heck of a lot of time using Tinkercad or SolidWorks or any other CAD modeling programs. But as I spend more and more time with both Tinkercad and SolidWorks, the more I am convinced that Tinkercad is a nice place for my young students to get an introduction to 3D modeling but SolidWorks is where I want to be spending most of my time teaching 3D design. The students are beginning to organically love studying and sketching blueprints. They make math connections more quickly by using their blueprints. They feel more authentically like the engineers I am always telling them they are. They genuinely feel more like the artists I am always telling they are.

Some examples of SolidWorks projects I have done or are working on with my young students include the following:

- Designing tetrahedronal kite connectors and then 3D printing them to build kites with straws and tissue paper (third-grade project)
- Designing coin cell battery and LED light holders and then 3D printing them (fourth-grade project)
- Sketching birdhouse pieces as separate parts, then creating an assembly to piece them together, and finally laser cutting the parts out of wood to build the birdhouses (kindergarten project)
- Sketching shadow box pieces as separate parts, then creating an assembly to piece the shadow box together, and finally laser cutting the parts out of wood to build the shadow boxes (fifth-/sixth-grade project)
- Designing parts to make a hydraulic scissor lift kit and analyzing environmental impact of manufacturing the kits (fifth-/sixth-grade project)

If you are teaching 3D design or 3D printing, attempt to get funding to purchase some educational licenses of SolidWorks. It is a powerful program that allows for powerful teaching moments, even with young children.

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Mystery Artifact Lesson

by Josh Ajima

Walking into school one day, I started chatting with a teacher about our plans for a joint maker challenge with our two advisory groups. I told her about the Martin Luther King Jr. design challenge some of the students were working on.[1] We started brainstorming how we could incorporate this idea into her current unit and use the school makerspace. Shortly thereafter I brought in one of the MLK artifacts, a replica of the key to the jail cell where he wrote the famous "Letter from Birmingham Jail" and presented the teacher with the broad outline of this lesson. The idea is to present students with a challenge that cannot be easily found on the internet and that rewards depth of research.

Students might need some hints. For this particular MLK artifact we could tell students that the owner lived in the South. Or that the key was owned by someone in law enforcement. Students research their ideas about what the artifact is and the historical connections. They present their appraisals, and then we compare them to the documentation of the original creator of the object.

Student instructions

"You are a professional appraiser brought in as an expert by a show such as *Antiques Roadshow*, *American Pickers*, or *Pawn Stars* to determine the value of an unknown artifact. Your job is to research the object and give a three-minute appraisal of its historical significance and value. The value of the object increases with the number of verifiable historical connections and associations you can make with the artifact."

Possible connections and associations

It's a key.

A key to a jail cell.

A jail cell in Birmingham, Alabama.

A cell where Dr. Martin Luther King Jr. was incarcerated.

A cell in which he wrote the Letter from Birmingham Jail.

A letter which defends the strategy of non-violent opposition to racism.

A strategy which became a pivotal part of the American civil rights movement of the 1960s.

A movement that helped to end segregation in America.

Questions to answer: What is this object? What does it do? What is its historical significance and value?

Replica of the key ready for 3D printing

Follow-up assignment

The next phase is to challenge students to research and design their own mystery artifact related to the unit they are currently studying. They need to provide information such as photographs or documents that support the accuracy of their design. They also need to create a video or document presenting the "correct answer" in the appraisal format.

Any number of objects related to presidents (or any historical subject that fits with your class) can be used as the mystery artifact. The object needs to be something that can be digitally fabricated using a 3D printer, laser cutter, CNC mill, 2D printer/button maker, or vinyl cutter.

You can download a replica of the MLK Birmingham Jail Key on Thingiverse for 3D printing.[2]

Notes

1. designmaketeach.com/2017/01/05/design-challenge-mlk-2017
2. thingiverse.com/thing:2027104

Reference

King, M. L. Jr. (1963, April 16). Letter from Birmingham Jail. Retrieved from en.wikipedia.org/wiki/Letter_from_Birmingham_Jail

Engaging Classroom Teachers in Making

by Angie O'Malley

Perhaps one of the biggest challenges for me, as a STEAM specialist, has been keeping making alive when my students leave the lab. I make a very intentional effort to collaborate with teachers, learn what students are doing in their regular elementary classrooms, and integrate this into lessons and projects in the lab. However, often this relationship is not reciprocal. In an effort to get more teachers incorporating making into their lessons, I've tried a few strategies this year that seem to be helping. Yet without having a specialized coach whose time is dedicated to going to individual classrooms and meeting with teachers, this process can be difficult; I am always looking for new ways to share the *making mentality* throughout my school.

Here are a few ideas I've tried this year:

After-school making party

Getting teachers to attend an after-hours event sometimes means meeting your audience. My audience happens to be one drawn to Pinterest, so we had a Pinterest Party. There were several projects inspired from Pinterest with materials for them to create. One of the projects purposely required the use of a Cameo vinyl cutter because none of the teachers knew what it was or how to use it prior to the party. In the end, teachers left feeling engaged, learned where materials were in the lab and what different machines do, and seemed curious about how they could bring more making projects to their own students. I plan to slowly incorporate more "lessons" into these events. Perhaps next is a Valentine Card Making Party, with one option being paper circuits.

Lab tours

During a staff meeting we broke out into various sessions, and I held a lab tour. I showed practically every tool, briefly explained how it worked, and showed examples of student creations that used that tool or machine. I had the teachers open up every cupboard and drawer and peak into every shelf. I wanted them to see all the materials they and their students had access to. I encouraged them to use the space with or without me, depending on their comfort level.

Making cohort/book club

My school has a monthly staff meeting on a specific topic we proposed at the beginning of the year. Typically there are four or five groups/topics to select from. Teachers choose which topic they want to further investigate, and a cohort is formed for the year. I am leading a making group (and proudly—as more than half of the teachers are in this group). We are reading *Meaningful Making* volume 1 and discussing it as a traditional book club might do. Teachers are also creating their own making projects they want to use with their students, and I'm here to support them through the process.

Not the End: Reflections on a Year of History and Making

by Heather Allen Pang

The end is in sight. The grades are almost done. The classroom is closer to clean, and my checklist for the end of the year now fits on one page.

It is already the next page I am looking forward to. I am thinking about personal making projects I will work on this summer, things I want to try for myself, things I need to make to make my life easier, fun projects I have been putting off, and most of all, ideas I have for the classroom next year. I don't know which ones will work. I don't really know until I try them in the classroom, but I have ideas I will try myself, and then maybe with students. I have modifications I want to make to existing projects. What can make it better? How can it be more them and less me? What are the fundamental skills for research, history, and life that I can help my eighth-grade girls find next year?

I think about these changes and improvements, and I can see at least one way in which making in the classroom brings me to my best place as an educator. When we make together, or even alone, we revise, rethink, and revisit almost all the time, and we have to go back to the fundamental questions of what we are doing: Why does this work the way it does? What can we do to make it better? What do we know now that we did not know before we engaged in this process? I think more about lesson planning as making now, and it helps me do it more effectively. I also think more about assessment construction as a making process too. If this document exercise is something I am making for my students to bring out their skills and knowledge, to let them show themselves what they can do, then I can think through what I construct differently, and I hope they can get more out of it when they engage with the voices from the past and my instructions.

Eighth-grade US history Monument project

So what am I thinking about for next year? I have a long list, including a reimagined writing assignment to go with the innovation of the telegraph (we build the telegraph machines [see page 56], then imagine the historical experience), a different way to look at architecture (we will continue to explore 3D printing of eighteenth-century Williamsburg buildings, but we will also take a look at more modern architecture later in the year), and perhaps a more open-ended set of questions for the research project at the end of the year. I am also looking forward to the projects that have become part of the yearly fabric of my class: the monuments, the silhouettes, and National History Day (see *Meaningful Making* volume 1, pages 81, 84, and 125, respectively).

Maybe when I get to the start of the new school year, some new idea will occur to me or my students. I look forward to it.

The Kepler Tech Lab's Girls in STEM Initiative

by Alphonse Habyarimana

What would it take to bridge the gap between girls and boys in STEM fields? It is believed that anyone can create or build things out of their creativity, but how can someone actually do it? I think it requires that person to be interested and committed to face challenges and celebrate successes if the end results look great. How about stimulating someone's interests through introducing developmental concepts and establishing different ways to be exposed to the applications of those concepts?

The Kepler Tech Lab in Kigali, Rwanda, has established a strong partnership with Igire Rwanda Organization, a not-for-profit organization that empowers youth to use their talents, skills, and opportunities to create their own jobs. With Igire Rwanda, girls are provided with soft skills at the same time as technical skills through STEM education right in the lab.

The lab is offering engineering enrichment programs in computer programming and electronics recycling to girls who recently graduated from high school or dropped out in the middle of their studies. Students are in the lab for three sessions a week, three hours per session, learning basic electronics, learning how to use electronic equipment, and practicing technical communications through a variety of presentations about their projects and experiments.

The goals of our initiative are not only to encourage equal participation of girls and boys in engineering fields but, more importantly, to facilitate them through independent long-term projects and become their mentors to turn the projects into high-tech business opportunities or careers in a variety of technical fields.

Kepler Tech Lab students testing a battery

A representative from Igire Rwanda Organization working with Kepler Tech Lab students

Students conferring on a project

Students working on an electronics project

Decolonizing STEMM: Reclaiming Indigenous Knowledge and Practices with Felt Monsters and Ceremonial Masks

by Reina Sofia Cabezas

In February 2009, on the heels of President Obama's victory, I had just started my first full-time fourth-grade teaching gig in East Oakland, California, a community highly impacted but resilient in the face of intergenerational trauma, poverty, and segregation. Fresh from a career transition as a crisis counselor, I inherited a classroom whose teacher had been released. I thought, "I did crisis counseling and case management with women and children survivors of domestic violence for ten years—I can definitely learn with kids *"all day, erryday."*

I quickly realized that I was supposed to dish out a lean diet of only English and math, *all day, erryday*. How can we expect students to find a connection with their education, their communities, and the world when we are complicit in serving anemic diets of decontextualized language and math?

As a K–12 student my education had been basic, rote, and boring. So, as a teacher, I was acutely aware of the many ingredients to a good education that had been missing for me as a student and were also missing for my own students. Ingredients like fun, engagement, inspiration, hands-on activities, and authenticity were still the exception instead of the rule.

So my students and I started experimenting with the little technology I could get my hands on. There was one computer lab on campus that no one used. We had it all to ourselves—to play math games, use Google Docs, and look up YouTube videos before districts knew to block them on the network That's when I started getting called the techy teacher, and before you knew it I was teaching a Digital Literacy class and my first middle school engineering class.

Even then, without knowing all the educational buzzwords I know now, I knew I had to figure out how to decolonize STEMM (science, technology, engineering, math, and making) in order to be a culturally responsive teacher. To understand what it meant to decolonize STEMM I needed to first understand colonized STEMM. *Colonization* is the elimination of indigenous peoples and their practices, knowledge, and beliefs by a conquering culture. Colonization of the Americas began in the fifteenth century and continues to be enforced by government, religion, poverty, and segregation. Adding insult to injury, the scientific knowledge and practices of indigenous peoples were appropriated by white practitioners and continue to live on in disguise as inventions of the white colonizer.

Leaning on my community of practice

This meant that to decolonize STEMM for my students I had to start by decolonizing my own mind. I started seeking out holders of knowledge willing to mentor me. I joined a local Xicana youth empowerment organization focused on third-world resistance and alliance building across international peoples' struggles. This organization gave me a pulse on local youth outside my own school. I also began attending and participating in professional development by and for educators of color, where we explicitly unpacked our own internalized oppression through readings, discussion, and actions. Lastly, I started a Women of Color STEMM (WoCSTEMM) educators group that has since evolved to include white STEM allies through a convergence with the Social Justice Math Educators of the East Bay (SJMEB).

The convergence of the WoCSTEMM and SJMEB groups eventually led to the creation of Radical STEMM Educators. We started in Oakland and have grown to include STEMM educators in San Francisco and Santa Rosa, California. I go to this group to work through curricular development issues and uncover how my colonized mind is creeping into my curriculum design. We use Critical Friends protocol to present projects that ensure educators and students are digesting well-balanced, nutritious STEMM through a critical pedagogical lens.

My path to a decolonized maker project

Decolonizing STEMM is a process of critical reflection on the colonizer—Western practices of education—untangling them from indigenous practices, and explicitly reclaiming them as indigenous practices for students. As I learned from Xicana Moratorium Day, I could not simply be an armchair revolutionary—I had to organize myself in active resistance to this parasitic diet of education.

By 2014 I was at Epic Middle School, and I had tailored out-of-the-box robotics and a 3D-modeling curriculum for students of color in East Oakland. The Design/Engineering department at Epic Middle School consisted of three teachers and offered me more space, more machines, and more open-ended design. This was when I officially caught my first wave in the maker education movement and meant I had to refine a process to develop maker projects grounded in critical pedagogy. Guided by the Ethnic Studies framework of the Oakland Unified School District (OUSD) and the critical friends protocol with members of the Radical STEMM Educators of the Bay Area, I set off on this journey, with many detours along the way.

The 2015–16 school year at Epic Middle School was a gutsy experiment for the design/engineering teachers and administrators. Before this, the Design/Engineering department was working in three isolated spaces. My sixth graders and I would spend an entire year in the engineering lab. The seventh graders and Sensei, their teacher, lived their whole year in the clean space, where they learned graphics software and Tinkercad. The woodshop was the domain of the eighth graders because they were supposed to be mature enough to handle a woodshop and all its amenities with Mr. Bell. Since we quickly realized that wasn't the case, we wondered if we rotated each grade through all three different spaces—the clean space, the woodshop, and the engineering lab—all three years, would students have more opportunities to build their skills in each move each school year?

The plan was for each grade and teacher to spend one trimester in each space each year. This gave teachers and students a much clearer timeline for project planning and deadlines. It also helped us spiral the safety procedures as well as curriculum related to each space, materials, and tools. I loved it as a teacher because I also got to learn new technical skills and strengthen those I had. We were also more of a team, able to meaningfully plan out the complete three-year experience for students.

The sixth graders and I started in the clean space, which was equipped with a whole lot of fun: a couple of sewing machines, a laser cutter, three paper cutters, a 3D scanner, and two heat presses. I just needed to figure out where to start. As the sixth-grade educator on the team I knew my role was to set the tone for students and basically make it a little easier for the seventh- and eighth-grade teachers. The mindset of our students for the next three years around the safety procedures and the spaces, materials, and tools potentially depended on how I framed them.

The students and I had fifty-five-minute periods in the makerspace four days a week for twelve weeks. I planned to start with two short projects that would introduce the students to the culture and tools in the clean space: writing algorithms and sketching basics. Writing algorithms was a fun way to have students learn about routines and procedures as well as safety for my classroom and the space. It was also a way to prime their thinking because I knew we'd be programming and building robots in the engineering lab by the third trimester. I planned a sketching project to introduce the Stanford d.school's design-thinking process. It was contextualized around an Epic Middle School uniform redesign. I love to use sketching in the brainstorming process and teach orthographic sketching at some point, so I wanted to preassess my new students' 2D sketching abilities. I learned that despite having actual sketching ability, most students didn't have sketching confidence. I decided to take a step back and not only teach how to use shapes to make realistic icons but also to introduce students to tracing. To my surprise some students even said they didn't know how to trace, so this mini project ended up being a great way for me to create peer tutoring pairs: one student with higher confidence in tracing supporting another with lower confidence. In turn, this helped me set expectations for communication and collaboration, and communicated that I was not the only expert in our classroom.

After this, we moved on to beginning sewing practice, along the way developing a process of checking materials in and out, reporting missing or damaged materials, and sharing materials.

These mini projects took most of the first half of the trimester but set the tone for the class. Plus, they gave students a lot of skills they could use in the second half of the trimester, which would be one major project: a felt monsters sewing project. The class would wrap up with a student-led conference for parents.

The Felt Monsters project was the bridge that helped me share my own maker narrative with students as well as share some of the values that shape my life and teaching philosophy. Students would design and make their own felt monster out of felt and thread. For inspiration, we explored ceremonial masks from around the world, their significance, and ways they were made.

To me this was a decolonized STEMM project because I not only shared my own maker narrative with students but also shared a piece indigenous peoples' maker narratives, developing a broader definition of a maker or engineer. Moreover, by giving students a concrete example of how people around the world make artifacts that are important expressions of their culture, students saw themselves reflected in the class, so they were all engaged and curious.

Detour 1: Developing my maker educator identity

As an educator my north star is codesigning *liberatory* learning experiences with colleagues and students in Oakland. There are other terms for this, like *culturally responsive*, *critical thinking*, and *twenty-first-century skills* that are all empowering for students of color to experience; however, getting to what we really mean as individual educators, let alone what the system means when we use such vocabulary, is not as straightforward. Many educators believe it is enough to teach students of color to read and do math really well and that is social justice. It is social justice, but I would add it is only the first layer of the social justice cake for me. *Liberatory* means that students can and will experience mainstream maker education—like typical high-tech to DIY projects—but will do so in the context of using their own maker experiences as a way to deconstruct how the mainstream maker movement can either disrupt or perpetuate systems of oppression. They build on their own maker backgrounds versus depending on some dominant culture to define what maker means for them.

I started with myself, tapping into my own background to build this definition. I studied Paulo Freire's popular education model of the 1930s long before I had heard of the design-thinking process. I knew the writing process and the scientific method long before I was aware that IBM's user-centered design from the mid-1980s interviewed consumers about their preferences. Empathy is not new. If students were to have liberatory maker experiences, I couldn't perpetuate the notion that designing with empathy, respect, and diligence is a newly invented ethic. I had to break stereotypes, not reinforce them: makers are nerds; makers are all white and male; makers only make high-tech, electrical things; makers create more waste. Most of all I had to break this notion that designers only exist in and for the mainstream world.

The mainstream, white-dominated maker world produces some insight into what maker education is. In the book *Maker-Centered Learning:*

Empowering Young People to Shape Their Worlds Harvard researchers synthesized four hallmark instructional strategies of maker educators (2016):

1. Students as Teachers—Facilitating Student Collaboration
2. Encouraging Coinspiration and Cocritique
3. Redirecting Authority
4. [Ethics of] Knowledge Sharing

While I appreciate this research, it is nonetheless, mainstream. It perpetuates the myth that maker education is a creation and invention of the mainstream, white-dominated culture. This perpetuates stereotypes that maker education is one thing, one way, from one origin, and everyone else is just learning about this way of teaching and learning. So while I appreciate and can learn from it, I needed different lenses to help me define *making*.

I found my answer close to home and decided to use the OUSD Ethnic Studies Framework as the pedagogical cornerstone of liberatory education. Ethnic studies was born out of the struggle of youth of color demanding that the education system remake itself in order to be worthy of their time.

Luckily I had help along the way. The OUSD happens to be a natural spring of talented ethnic studies educators who authored a framework tailored to Oakland students (bold added):

> ***OUSD's Ethnic Studies definition***
> *Ethnic Studies is a content and pedagogy that* ***humanizes and empowers*** *all people by* ***honoring histories and cultures of historically*** *marginalized groups, by employing multiple disciplines and perspectives to* ***critically analyze systems of oppression,*** *and by promoting* ***action in solidarity*** *with others to* ***transform students' lives and communities****.*

What better foundation for my own maker-centered classroom than this example of young students who organized, struggled, and resisted in collaboration to see the reflection of their own ethnicities in education, championing equity, and openly critiquing the system as a way to inspire each other and redirect authority from the bottom up? Is this not at the heart of hacking and making?

OUSD's Ethnic Studies Framework includes six operating principles, one of which is "Build community and promote healing."

Building community with students. Building community in a classroom means, as all educators know, that we need to get to know our students and they need to get to know us. In an effort to promote healing I chose to use an indigenous healing circle format for our daily "Do Nows." When I introduced the talking circle and its mechanics to students, they were already somewhat familiar with restorative justice practices but had no idea that these concepts originated in indigenous peacemaking and healing practices. Once I began to tell stories of the Lakota Nation talking circles and how First Nations peoples used them as ways of governance, students sat forward and became interested, taking turns to speak, not interrupting one another, and listening and speaking from the heart. I would be lying if I said a humanities lesson was enough to break habits of inequity, but we tried. We practiced taking turns, not interrupting, looking at the speaker, and writing thoughts down triggered by the speaker. I, like Sensei once said, was relentless in warmly demanding and reminding students why we chose this way of communication.

Once I laid the foundation of how we would communicate I knew I also had to reinforce it with how we would collaborate. The Ethnic Studies Framework operating principles helped me clearly define these expectations for my students. I asked how many of them thought it was fair that everyone, not just the teacher, has a voice and that if someone's voice was being shut down, how important it was for them to be able to do something about it. Not one of my students objected when they realized I was proposing a way that they could not only question but also debunk my "authority." In the Ethnic Studies Framework this operating principle is called "Critiquing the dominant individual/institutions/ideologies." It describes questioning as a "critique in positive/constructive ways that build a foundation for change, but are also honest and transparent, recognizing existing power structures and how to work around and/or change them."

Connections:
History to personal stories to projects

I could have simply jumped into our first sewing project, Felt Monsters, and explained how it connected to history and culture. But I realized that if I wanted students to not only honor but also critique history, they needed to know that what they learn in history class isn't the definitive story of our people or of them personally.

I happened to have coordinated with their humanities teacher and knew they were on the Mesoamerican unit of study. So I asked them where their indigenous and European ancestors were from and shared my Nicaraguan roots: indigenous and European with Middle Eastern influence. Their heads almost exploded when I explained that Nicaragua was mostly colonized by Spaniards from Andalucia, which was ruled by the Moors for eight hundred years.

The stories of precolonial Nicaraguan peoples—Niquirano, Chorotengano, and Chontal—made them curious about their native ancestors. Many of them knew of Mexicas or Aztecas but didn't know the many regions of Mesoamerica and their interconnectedness and were intrigued. Moreover, many newcomer Central American student refugees in class had never heard of these people and stories, and instantly became curious about their countries of Honduras and El Salvador.

While I taught them how to hand sew, I also shared how sewing is a sacred, family legacy for me. I was raised in a multigenerational, immigrant household with my grandma from Nicaragua, a single mother working in the Office of Social Security during the day with a clothes-making side hustle, supplementing her income to send her daughters to private school.

I told my students the story of how I started sewing, first hand-hemming clothes to fit me and then making my first purse. True story: my first sewing project in my first sewing class in 1999 was to make a purse, and I live in regret of not taking my idea of a cell phone pocket in purses to the market! We laughed together at my failure as an inventor and business tycoon.

Weaving personal storytelling into making, no matter what medium, helped humanize me to the students. When they started hand sewing, they would refer back to my story and find encouragement. "We should have an easier time because we're starting younger." Or students would also acknowledge each other's determination and celebrate victory, especially when learning how to first thread the needle and tying a knot on the end: "Ms. Cabezas, look! I did it!" It didn't matter if it took them half of the fifty-five-minute period to do it! As a favorite maker educator and colleague Susan Wolfe says, "Move at the speed of trust."

This spirit of sharing challenges and victories inspired them to collaborate further. Once they mastered threading the needle and tying a knot on the end, students were excited when I asked them to help a colleague with the same struggle. They would gladly take time out of their own project even if they sometimes forgot how they had done it. They'd call me over exclaiming, "Wait! I don't know how I did it. Can you help us?" I would gently encourage them to continue since "I just know you'll get it," and when they did, "I told you you'd get it!"

Detour 2:
Leaning on my community of practice

Celine Liu, math program manager at the Alameda County Office of Education, and I had started using the Critical Friends Protocol with our study group Radical STEMM Educators of the East Bay to structure how we shared problems of practice. Now I needed their help. Originally, before the felt monsters, I presented a remake of a ceremonial masks project to the group, and my fellow educators helped me reshape the project to make it sixth grader friendly. They pushed me to think about how I would guide students to discover ceremonial masks, connect them to history and personal stories, and redesign them to reflect these discoveries.

The plan and the reality

My plan was now complete, or as complete as any classroom plan ever is. The project(s) would be my first large-scale attempt at decolonizing STEMM, connecting history with personal stories from the students as we made personally meaningful objects.

At first the plan went smoothly. After four weeks into the trimester students had learned how to hand sew using the paper patterns. I saw a respectful, curious community develop. While they were spending their time and energy hand sewing some days they would get to sit together and chat, check in, build relationships. Most importantly for other content teachers, I spent about two weeks teaching them how to do basic online research, and they'd read about ceremonial masks, find images of ceremonial masks with intriguing shapes to them, and collect as reference. Other days I'd structure their chatting through prompts to share what they had discovered about ceremonial masks, play videos that show how peoples used ceremonial masks in ceremony, and talk about the symbolism of the mask and the ceremony.

The plan for the Felt Monster project would combine hand sewing, machine sewing, Tinkercad, vinyl cutting, and the heat press. They would use paper patterns to cut out the body of a felt monster, then hand sew and stuff them. Next, we would move online to use the Tinkercad design software, where they would design the eyes and mouth based on the design inspirations they collected from their own online research, listen to videos, and share their findings with each other. Last, they would take the Tinkercad files to the vinyl cutter to cut and to the heat press to place the features onto their felt monsters. Between the introduction of all these tools and materials, I estimated this would take the rest of the trimester = 13 weeks – 4 weeks of mini projects – 1 week of student-led parent conferences = 8 weeks total.

In reality, we ran out of time. Although almost all the students completed sewing their monster, too many of the students did not have a chance to fully design and cut the vinyl features. In spite of this, students were able to proudly show off their accomplishments to their parents and speak about the cultural connections they discovered and skills they had developed.

Lessons learned

Now that the class is over, I can look back at things that went right and things that can be improved. I confess, I lectured too much. Embarrassing.

In general the projects went well and the students were very satisfied with the felt monsters and the masks. Some were sad that they had run out of time, so they took them home, finished their felt monsters, and brought them back to school to show them off. To me that showed that they had connected with the project in a personally meaningful way. They learned a lot of skills that will be useful in their lives and in future makerspace projects. Skills like kind and clear communication, effective collaboration, and sharing the workload are hard skills to teach sixth graders, but by the last trimester they were leading our "Check-Ins," "Do Nows," and "Report Backs" as I sat back and took notes. They learned the foundational safety expectations before going into the woodshop, where we'd use more dangerous equipment. They learned the basics of online research: keyword search, using basic search commands to scrutinize information, and, all of our favorite, CTRL-F to scan text.

I take full responsibility for biting off more than we could chew, but it was fun to build community with a sewing project. Even though it took time, both structured and unstructured conversations were no big deal because they had to pay attention to their needle not poking them rather than each other's facial expressions distracting them from note-taking or listening. As a result, my students were much more personally invested than usual in these projects.

Because this was my first maker project outside of pure 3D modeling or robotics, I didn't have a clue how long students would take to get comfortable with hand sewing. I did have a good idea of how long they'd take to warm up to Tinkercad, so I gave breaks during the hand sewing to avoid project fatigue. If students wanted to explore Tinkercad, they had the opportunity to join me in small groups to get started. This was also a way for me to build a small student Tinkercad tutor army to support others in preparation for all of us moving on. I plan to keep my student mentors very busy in the future!

Nonetheless, while all students started Tinkercad, most of them did not cut out the facial features on the vinyl cutter, which was the next step in the path I initially imagined.

The main problem I faced was not the equipment, although I am still wondering where some needles went (I know the kids didn't eat those), why the Wi-Fi would betray us despite IT being there many days working on the issue, and how we could recycle the irregular pieces of leftover felt.

The main problem we faced was time. I spent too much time teaching ceremonial mask history, online research, and scaffolding hand sewing with the paper patterns. Instead I wish I could've planned more collaboratively with the humanities and English teachers. We could have gotten to vinyl cutting if they could have taught the online research and history. It may seem that the conversations with students took too much time, but I don't believe so. In fact, through hand sewing and the time they got to chat, content based or not, we built a strong learning community that I believe will pay off in the long run.

This was highlighted in my Critical Friends Group, but we didn't quite know how to mitigate this since those present had little experience with project-based learning in their classes. This group mainly helped by asking questions about the significance of ceremonial masks in cultures around the world. Each was curious and engaged through the lens of their own STEM content area. One area for me to address would be to add educators who have experience with project-based learning to my feedback group.

Trailblazing new paths

How can maker educators help students develop a maker culture that nurtures rather than extracts resources? How do we develop maker culture in this way? What are the considerations we must make as maker educators to use the supplies, technology, and materials that encourage student makers to develop a culture of repair instead of perpetuating a culture of waste?

These are just a few of the questions I continue to think about as I explore what it means to decolonize STEMM. I recently gave a short Ignite talk called "The Parts, Purposes, and Complexities of Decolonizing STEMM" to systemically unpack that thinking in order to be a more conscious educator in the way that I perpetuate and/or disrupt dominant maker cultural myths ("Parts, Purposes, and Complexities" being a thinking routine developed by Agency by Design [2010]). My students will only learn to question stereotypes and assumptions if I model that for them, so I am the first one that needs to check the implicit biases of projects in my maker classroom.

This is just the beginning of my paths and detours into many, many rabbit holes. Detours are the hallmarks of student and teacher creativity, which lead to maker opportunities for students to find their own maker mode. I intend to learn the lessons and continue to decolonize my STEMM lessons while still exploring new ideas.

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Convincing Yourself and Others: Why Bring Making into the Classroom?

How does making in education really happen? Where do we start? How is it different from what we have done in the past? Is it for all students or just some? How can I convince other educators, parents, administrators, and even students that making is the right approach to learning? What will I show my colleagues and administration as evidence of student achievement?

For educators launching a journey into a new kind of teaching and learning, answering these questions with certainty may seem like an impossible task. When the task expands to convincing others, it seems even more daunting. Many educators feel deep down inside that real and relevant projects are the best learning experiences but don't feel comfortable advocating for something that seems to challenge traditional school practices. This chapter contains articles from the FabLearn Fellows, who are working on answering these questions and towards becoming braver advocates. Like all iterative projects, these answers are never the final word, but as we share our stories we all benefit from the journey.

Experimenting: The Power of Hands-On Learning

by Koffi Dodji Honou

When I started working as a Fab Lab member and then as a Fab Lab manager, I never thought that it would be such a great experience in terms of leadership or professional and personal development.

Educator workshop

My journey as an "African Fablaber" started four years ago as a volunteer with an NGO in Lomé (Togo). I used to share my time and experience by providing basic computer training to students, kids, and everyone in the neighborhood who needed it or was just curious about it.

3D-printing workshop

When I discovered digital fabrication machines like 3D printers and everything that can be realized with them (especially in the African context), I decided to specialize and master them in order to share and disseminate my knowledge within my community. Indeed, my experiences with Fab Labs in West Africa, Europe, and the United States showed that teaching and learning this technology can promote local economic development as well as strengthen social cohesion and capacity building of local communities.

Learning to solder

With DefKo Ak Niep ("do it with others") in Dakar (Senegal),[1] we initiated many programs to bring this kind of hands-on learning to local schools, teaching both young people and educators. We started pilot projects and are impressed by the power of learning by doing—in just half an hour, eight-year-old students were able to solder electronic circuits.[2]

They could also design 3D models and print them out by themselves. Most of them had never used computers before nor had they soldered electronic components because IT or electronic classes are not available in their schools.

That is the power of hands-on learning, and I am looking forward to continuing to make it happen in our communities.

Notes

1. fablabs.io/labs/defkoakniep
2. youtu.be/EYZhbKdYgMQ

Building computers from recycled parts

Confessions of a Maker Educator

by Angie O'Malley

Although I choose not to bring it up often, I have a confession to make. You see, when I started considering teaching as a career years ago, my passion was to be a physical education teacher. Being the goal-orientated person I am, I got my undergraduate and graduate degrees in physical education. I got my state teaching endorsement in health and fitness. I attended conferences and workshops galore on physical activity and wellness. For my first employment opportunity, I found myself in an interview with administrators and teachers, where it was stated, "We only have a position for a part-time PE teacher, but we also have an opening for a technology teacher. Can you teach a kindergartener how to use a mouse?" Of course, I can teach a kindergartener how to use a mouse. I thought, "If it means I can teach PE, I'm in."

Fast-forward a few years. On Mondays, Wednesdays, and Fridays I taught students the proper footing for overhand throwing, set up a gym for a game of kickball, and stressed the importance of healthy eating. On Tuesdays and Thursdays I sat in a traditional computer lab, looking down the rows of computers, seeing the occasional eyes pop up over the monitor as I reminded students how to hyperlink slides and keep their fingers on home row. The students were excited to have screen time but were ultimately running through the motions. As hard as I tried to keep students engaged and be cutting edge, I was not doing well. I was bored with the routine and I thought, "If I'm bored, my students have to be feeling similarly." I knew of a school in the area that was incorporating engineering and design into its curriculum, a rare find at the time. That spring, I pitched an idea to my administrator: "I'd like to incorporate some engineering and design into technology. Would you support the idea?" He loved it, but neither of us had any idea of what was to come.

I was so excited, I started the next week. I knew third grade was learning about simple machines in science, so I went and bought a handful of wind-up toys. Third-grade students spent the next week taking them apart, documenting photos and labels with the tablet, attempting to identify any simple machines they found, then figuring out how to put them back together. The kids couldn't believe they were getting to take apart and explore toys in technology class. They were engaged. They were excited. They smiled, laughed, and shouted to their classmates when they made a discovery. They were hooked, and so was I.

The next school year, I set a goal. I was going to do one hands-on design project with every grade level. I just had to convince the classroom teachers that what I was doing was worthwhile. I needed to gain their trust so that when they sent their students to "technology class" once a week and they weren't setting eyes on a screen, they could still recognize the importance of it all. I started emailing and meeting with every teacher, listing their units of study. I turned to Pinterest and Instructables. I talked out ideas with friends and family, and I turned to my own imagination.

That school year, while we still did a lot of screen-based technology, there was more happening. I kicked off the school year showing students "Caine's Arcade,"[1] a viral video about a child who created a working arcade out of cardboard and other recycled materials. Then we made our own school cardboard arcade. The computer lab was so full of cardboard boxes during the weeks students were designing and making that I was told I was putting the school at risk of being in violation of fire code. We set up a giant arcade in the gym, and over a hundred students proudly shared their creations.

Throughout that school year, I slipped in hands-on design projects. Third graders screen printed geometric designs on T-shirts using homemade screens and geometry blocks to tie into their math unit. Second graders built a 3D city out of paper to learn about community helpers and city planning. Kindergarteners built and tested bridges made from toothpicks and marshmallows and learned about architectural engineering and design. Fifth-grade students learned about biomimicry and invented and constructed their own devices that were inspired by nature. Teachers were appreciating the collaboration. Parents were happy their children were coming home excited to talk about what they had done in class. Students were engaged, they were having fun, and they were learning.

The process continued to grow for me and for our school. The following year, I asked to change the name of my class from technology to STEAM. I wanted everyone to understand that more than computer and tablet usage was happening. The computer monitors that once sat as the primary feature on tabletops were now more often pushed aside to allow for cutting, gluing, drawing, designing, and constructing; I wanted a name to reflect the change.

The year after that, I pitched the idea that I would quit teaching PE and move to teaching in the lab full-time, where students would come to class twice weekly instead of once. The idea was approved. That same year, the school moved into a new building, where I was able to help design and plan our lab. We have moveable tables with tons of floor space for students to build. We have laptops and tablets that can be used when needed but set aside to allow for more space when making. We have a sewing machine and a workshop table with hand tools. We have a prototyping-materials cupboard filled floor to ceiling with everyday materials and recyclables. There is a cupboard with toys to spark imagination and reinforce ideas such as marble runs, robots, building blocks, and art sets. While it isn't a multimillion-dollar facility with laser cutters, multiple 3D printers, and CNC mills, we are making. Students are practicing the design process daily. There is room for play and discovery. Students are encouraged to prototype, test, and redesign. Their imaginative ideas are met with encouragement. They know the lab is a safe place to take risks and test new ideas.

So if you find yourself stumbling upon the maker movement, know that you don't have to have an engineering or design background. You don't have to find a school with a program already in place. You don't need the latest gadgets and costly equipment. But you do have to be willing to start. You have to be willing to collaborate with colleagues to gain their trust. You have to show that what you are doing is benefiting the students. You have to be willing to spend the time doing the research to find project ideas and inspiration that fit into your program. And just as you will ask of your students, you have to be willing to take risks. Trust me—the rewards are worth it.

Note

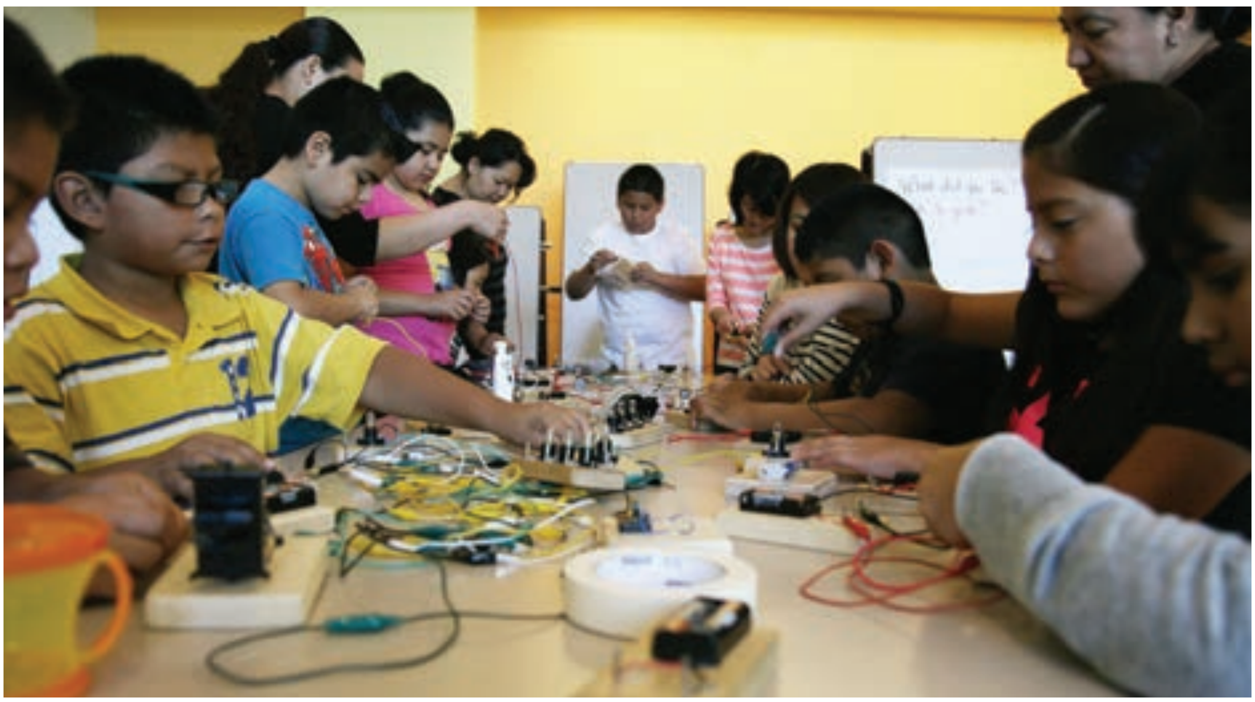
1. cainesarcade.com

Funds of Knowledge

by Aaron Vanderwerff

In most schools, we still use what Paulo Freire called the "banking" model of education as our dominant model—teachers depositing knowledge into students' minds. Seymour Papert asked us to think about who defines what constitutes a discipline; in other words, what is physics, and how is it taught? He posited that we continue to teach (even thirty years later) the same physics courses that were developed around the technology of paper and pencil, which are focused on solving word problems and carrying out labs with already-identified answers. Instead, he challenged us to reimagine our disciplines and what students can now do because of new technology so that students both lead the vision of what they are studying and so that they will deeply understand what they are learning. Too many students are learning algorithms and skills without understanding the true meaning of what they are learning because that learning is decontextualized. Contextualized, student-driven learning will be the driver for students to understand the math that surrounds us.

I read Paulo Freire in my teacher education program, but his words about the role of education in liberating the poor have taken on a much deeper meaning now that I have been a teacher for many years; I have worked with low-income students for over ten years, but I still have questions about how this looks in my own school setting. As a part of my credentialing program, we completed a Funds of Knowledge project that asked us to interview/observe/visit a student and their family to learn more about their own knowledge of the world and learn to see the assets they have. Clearly this project was created to help us to reject the deficit model that many people have about the poor; in addition, the project was



Hands-on learning about circuits

intended to help us to see that our students and families had resources that related to our content. For me, the connection to the humanities and the more philosophical and political issues Freire discusses was clear, but what about to algebra and physics?

After visiting and talking with my student and his family, it was clear that they had a strong fund of knowledge, that education was extremely important to them, and that the deficit model was indeed faulty. I believe now, as I did then, that all of my students can learn physics, and in general my classes are taught in a way that encourages collaboration, critical thinking, and conceptual understanding. Students learn by doing and learn through understanding, not through memorization or algorithms. But the family that I visited did not know too much about physics, and I would guess that if asked, for example, they would have had Aristotelean models of motion, not Newtonian models, and that without my guidance their son would not have come to understand the Newtonian model of motion. So I questioned how areas of study like physics and algebra fit into Freire's *Pedagogy of the Oppressed*. My student had a strong knowledge of the world around him, but he would not have learned much about physics without my guidance, even if that guidance were minimal and valued my student's own construction of knowledge rather than just transmitting it.

In Freire's description of a problem-posing education he states that students and teachers must learn from each other. It is through activities like open-ended design and making where I have seen this happen most clearly. With more than twenty-five students in a class pursuing different projects with different areas of focus, it isn't long before they exceed my understanding in many areas and I start to learn from them. In addition, these projects drive them to pursue understanding more formalized knowledge (e.g., engineering, math, physics) so that they can better design their next project or so they can explain what they are doing to others.

> For apart from inquiry, apart from the praxis, men cannot truly be human. Knowledge emerges only through invention and re-invention, through the restless, impatient, continuing, hopeful inquiry men pursue in the world, with the world, and with each other. —Freire, 1972

Finally, Freire says that "liberation is a praxis," and this makes me think about how we can push our students to truly "[reflect] upon their world in order to transform it." How can students use what they have learned to bring about changes to our society to lessen oppression? In today's context it seems that part of changing that equation is about technology, but it isn't just about access to technology—it is about who controls the technology. The activities that we are embarking on with our students allow them to own their technology and use it to level the playing field. In my own microcosm, thinking back to the Funds of Knowledge project, I think that I also need to do a better job of pulling parents into our program. So much of what we do in our design and making program plays into strengths that our families have as well as areas that they would be interested in learning more about if opportunities were presented to them.

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Cheikh Anta Diop Fab Lab Academy

by Koffi Dodji Honou

Cheikh Anta Diop is one of the most well-known and brilliant African scientists. He greatly contributed to knowledge on ancient African societies and has long worked for the emergence of science in the educational sector.

Inspired by his deep commitment, our Fab Lab DefKo Ak Niep ("do it with others") in Dakar, Senegal, decided to honor and acknowledge his dedication to science and technologies in Africa by naming our training program (or mobile fab lab) after him: Cheikh Anta Diop Fab Lab Academy. The Academy aims at promoting sciences through the popularization of new technologies, namely digital activities, digital fabrication, and making.

This project's objective is to open up an alternative, participative, and experimental pedagogical curriculum to all Senegalese who wish to discover digital fabrication. With the Academy participants will no longer be passive technology consumers but active creators, innovators, and designers who are invited to explore and develop their ingenuity, creativity, and potential.

Topics related to sustainable development and concepts such as *do it yourself* (DIY) and *do it together* (DIT) are the core of Academy trainings.

The program currently targets the large number of young people in the city of Dakar. After establishing the program there, the project and the concept will be expanded to more remote areas.

CAD training for youth

The Academy has two components:

Component 1: A Fab Lab team and volunteers visit schools all year long with appropriate tools and equipment to provide training and organize practical workshops.

During these workshops, participants are introduced to IT basics and different components of a computer and its systems. They learn how to handle a keyboard, mouse, and word processor. We also have programming training with Scratch and an introduction to electronics and 3D printing.

Component 2: The second component targets two specific groups: (1) young people in disadvantaged areas and (2) selected occupations such as shoemakers. In Dakar there are a large number of shoemakers who manufacture thousands of shoes daily.

CAD training for adults

We want to introduce them to digital manufacturing tools including laser cutting. We believe that training them on these digital manufacturing tools will improve their productivity and workflow and help them generate extra income.

The Cheikh Anta Diop Fab Lab Academy is an alternative education program and will evolve, for the better hopefully, over time. We continue to look for more things to teach, and to improve our own techniques to create and spread knowledge with DIY and DIT.

Megachanges and Programming Curricula

by Cassia Fernandez

Seymour Papert of the MIT Media Lab, whose ideas strongly influenced the maker movement, was among the first to propose that computers could be powerful tools to support learning, allowing kids to express themselves in meaningful ways and to reflect on their own thinking process while creating programs.

In his closing keynote address at the 1990 World Conference on Computers in Education, "Perestroika and Epistemological Politics," Papert reflected on the relationship between political and epistemological aspects of educational paradigms, using a perestroika metaphor to discuss resistance to change in education. In his talk, Papert posed the distinction between what he called megachanges—real, structural changes—and incremental evolution. He suggests that, similar to what happened in the early days of perestroika, educational reformers try to make incremental changes in schools, hoping that they will eventually lead to a new transformed and well-functioning educational system. But, in his view, these reforms require a deeper and radical restructuration of the conceptual and administrative organization of education, involving rethinking educators' roles, traditional curriculum organization, and school bureaucracy.

As a strong activist for the transforming potential of computers in the learning process, Papert imagined that technologies could play an important role to drive megachanges in education by providing opportunities for learners to develop knowledge and express themselves by programming.

While trying to understand the reasons leading some countries to incorporate programming in their schools' curricula, I looked at the situation in the United Kingdom, and much of what I read supported teaching programming as a way to ease a shortage of workers in IT jobs (The Royal Academy of Engineering 2009; Nesta 2011; The Royal Society 2012). In the country's future economy programming would be a valuable skill, and for that reason it should be taught in schools. As in the UK, many countries in the world are making efforts to bring programming to their schools for this same reason. In my own country, Brazil, I've been seeing new independent programming schools popping up everywhere, trying to attract students by stating that besides the benefits of formal reasoning developed through programming, acquiring these skills could be a strong professional advantage for the future. In both cases, a lot is said about what should be taught and very little about how it should be learned.

Although today there are many teachers concerned with new ways to use computers to make structural changes in our systems, it's evident that marketplace forces still drive (and will keep driving) the future of education. The introduction of computers in schools took place many years ago and still nothing has really changed. Can we expect the same with the introduction of programming curricula?

While there is no intention to make any changes in the way we use computers at schools—and intention is the key aspect to megachanges—programming activities become simply a way to achieve technical skills. As such it is a good example of incremental evolution. Yet so much more is possible. Today having great programming tools and robotics kits designed to support creative expression and new relationships with the learning process, this discussion should be pushed beyond skills and jobs. While achieving important technical skills, kids should have the opportunity to use computers to express their creativity and develop new learning attitudes, in exploratory processes driven by personal interests. But who will take up the cause of this megachange?

As Papert states paradoxically, “Technology should be the instrument for the achievement of a less technical form of education” since “having a strong technical infrastructure allows the system to be less technical in its methodology.” These shifts in the use of technology, however, will only happen if teachers are intentional in their goals. In this sense, more attention should be put on the approaches to introduce programming for kids—approaches that have the clear intention to change the relationship of learners and learning, and that doesn’t focus only in the achievement of technical skills and in the development of abstract thinking. At this moment, when programming is being introduced in many schools, considering the possibilities brought by the use of computers to create meaningful learning experiences—although an old idea—is more important than ever before and should be at the forefront of the educational debate by us, teachers.

One important question to be posed is why almost thirty years later we are still talking about ways to shift this trend. While having many more questions than answers, I would like to emphasize the importance of reflecting on the underlying structures guiding educational decisions, and on our role as teachers to be conscious and critical when confronted with new educational technologies and methodologies.

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Local Partnerships Empower Educators and Student Leaders in Rwanda

by Alphonse Habyarimana

The Kepler Tech Lab (now I4Fab) in Kigali, Rwanda,[1] connects with local/corporate organizations to implement practical education in schools or local communities for students to learn by doing and solve critical problems in their communities. One of the goals was to provide students with STEM and ICT education that moves away from textbook-driven memorization to approaches that are more student centered and focus on problem-solving. After a partnership with Igire Rwanda Organization of providing STEM education to its beneficiaries, the tech lab hosted teacher training with Pivot Academy of Mothering Across Continents (MAC) to train a team of facilitators who were training tenth-grade students in Southern Province, Rwanda.

Mothering Across Continents is a not-for-profit organization that provides "[consultancy], coaching and mentoring [to students] to develop dream projects that help raise tomorrow's leaders." Pivot Academy is a MAC program that creates "awareness of the need for and value of STEM education, coupled with ICT (information communication technology)."

Kepler Tech Lab hosted four day-long teacher training programs with Pivot Academy to train their seventeen facilitators plus five lab staff. The trainees were prepared to train four senior (tenth-grade) students from five high schools (at least 511 students) in Southern Province, Rwanda.

The training included performing experiments such as water filtration, solar desalination, solar dehydrators, zeer pots, and food preservation (putting food in different solutions such as salt, vinegar, and sugar to extend their expiration dates).

Facilitators were trained to help students perform the same experiments using the principles of design thinking. With this training, we took a leap forward to implementing hands-on STEM learning that has practical applications for the local community.

Note

1. keplertechlab.wordpress.com

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Maker Education and the STEM Monster

by Christa Flores

Ask . . . and ye shall answer your own questions

> I hope to apply a strong focus on place-based making and science while here in Atlanta. . . . I also noticed that this year's research panel was very program and project focused, or more practical in nature. This gives me hope that higher education is stepping up to the plate to support and study best practices around making in community programs in ways it has not in the past.

The above is a reflection from FabLearn 2016 from a prompt given to the FabLearn Fellows by our mentor Sylvia Martinez. How would I apply FabLearn lessons to my new role as a K–8 outreach manager at Georgia Institute of Technology (a.k.a. Georgia Tech in Atlanta, Georgia) within the Center for Education Integrating Science, Mathematics, and Computing (CEISMC)? CEISMC is a self-contained K–12 STEM education research and design hub that has been around for twenty years. Lately, CEISMC has caught the maker education bug, and I was hired to bring my experience to their partner K–12 schools wishing to start maker programs or makerspaces. As I no longer have a makerspace of my own, I am answering my own call-to-arms post about these lessons learned. I have shifted from being a teacher/researcher or makerspace coordinator to a curriculum and learning space codesigner, working with multiple educators in multiple disciplines at multiple public schools. This is the story of one of those schools and how I learned that STEM mandates could coexist with maker education.

The school for inventors

Named after African American entrepreneur and founder of Atlanta Air Michael R. Hollis, Hollis Innovation Academy is a Title I public school, meaning that it serves a high percentage of low-income students. It opened its doors to Pre-K to fifth-grade students in 2016. Hollis Innovation Academy was the product of an Atlanta public school program called "Turnaround," closing failing public schools and sending their displaced students to a new building with a new name, leaving behind failing track records. Turnaround offers a fresh start to envision a school's mission and often entails new leadership. Hollis has that leadership with Doctor Diamond Jack, former science teacher and a firm believer that Hollis is poised to be a model for what quality STEM education can be in a Title I school.

How might focusing on innovation literacy at this local public elementary school fulfill the vision of STEM education in an underserved area? It has a great start: Hollis has three dedicated STEM teachers with their own classrooms, and K–5 students meet for ninety minutes a week in STEM class. Add to this equation Hollis's partnership with CEISMC to design three makerspaces in hopes of bringing innovation to life for these elementary school children. Currently Hollis has a very traditional, teacher-led classroom environment that makes the progressive teacher in me a little uncomfortable, but I am patient and hopeful that the maker mindset will flourish in this new school.

Connections and frustrations

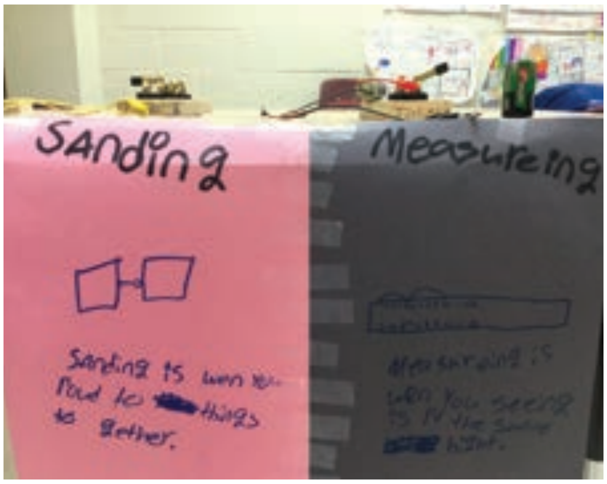
In short order working at CEISMC connected me to Atlanta's local maker movement network such as Lew Lefton of Georgia Tech's math department, founder of the Decatur Makers, a community makerspace and organizer of Atlanta's Maker Faire. I met the impressive STEAM program director Courtney Bryant of Drew Charter School and the cocreator of the TinkerYard, a playground designed by kids for kids. I also met the team of entrepreneurial educators behind STEAM Truck, Atlanta's first not-for-profit mobile maker lab, while at a design-thinking workshop facilitated by the Mount Vernon Institute for Innovation.

Despite these positive experiences, I was losing sleep at night, worried that I wasn't connecting with the three STEM teachers I was assigned to work with, or with the students at Hollis. My role as an outreach manager seemed ill defined and therefore prone to failure. More frustration came as I found out that my makerspace planning and project-based lesson codesigning would be derailed for months due to a district-wide plan to promote STEM.

The STEM monster rears its head

When I arrived on the Hollis scene, it was already mid-October. Lesson planning had already been done and classes had started. Then a new edict came down from the district saying that all kindergarten to fifth-grade students must participate in a science and engineering fair in December. I worried that not only would this derail the makerspace planning, it was a step backwards in creating STEM experiences that were less teacher directed. Then a friend shared her experience with an elementary science fair: "It's the only time I got to do science. I loved the science fair as a kid!" My friend reminded me that there is room in the world for both makerspaces and science fairs, and I resolved to keep both visions in mind moving forward.

Because the new Hollis Science Fair seemed like the district priority, the STEM teachers I was meant to codesign lessons with instead took understandable measures to help secure their students' success. Many chose topics for them to study and preordered all supplies for the predetermined experiments. It seemed as though there was no student voice built into the enterprise. With the fair looming large, every STEM class block of time would be devoted to the science fair projects. My attention shifted from makerspace design to asking how we might protect any possibility of student voice in these projects. In other words, how was I going to fight the STEM monster (STEM as a drill-and-kill approach) and design more student voice into STEM classes?



The students made their own signs for the workstations.

An array of choices

Go slowly, but GO!

Working with some of the teachers, we slowly introduced the idea of a makerspace and self-direction into STEM classes. I spend three days a week at Hollis, working with third graders in Ms. Battle's STEM class on Friday mornings. This particular section of third graders was assigned to create electronic frogs using Squishy Circuit dough, homemade dough with conductive properties. This would be part of a larger frog study for their science and engineering fair project. While waiting for supplies for the science fair projects to arrive, we introduced students to electricity in three lessons that spanned four to five hours of classroom time.

In our first lesson students were given an alligator clip, one C battery, and one small flashlight bulb. The prompt was simply to get the lightbulb to light. Perseverance is one of the "Habits of Hollis," so we used that word a lot in the first fifteen minutes when no one had figured out how to light the bulb. "I give up," said one girl, and her partner followed suit saying, "This is too hard." I shared that it sometimes takes fifth graders an hour to figure out the same problem and assured them they were tackling a real problem. The discouraged team turned out to be the first to find the solution, demonstrating beautifully for their peers what perseverance looks and feels like.

In the second lesson students rotated through stations. Some made the dough for the squishy circuit frogs with Ms. Battle. Some used computers to review digital media on frogs Ms. Battle had curated for them. Some were on the rug building with LEGO bricks, and some explored making series, parallel, and short circuits with me. It was great having two adults in the room—one to facilitate the very messy lessons of making dough, and one to watch as students discovered science concepts like short circuit, or open and closed circuits, while playing and exploring. These first two lessons were fun, and kids seemed to really engage with the material, but they were 100 percent teacher directed.

The third lesson came spontaneously because the supplies for the fair project had not arrived. On Thursday night I was in the hardware store parking lot when I texted Ms. Battle to see what she had planned for our STEM class the next morning. We seized the opportunity to design a follow-up lesson to the past two sessions on

Making circuits with no instructions

Happy makers at the workstations

exploring electronics. It was an opportunity to have the third graders start using real tools and making something real. Before students arrived, we set up the classroom as a makeshift makerspace. We pulled the tables and chairs out of rows and made work stations. We had a wood measuring station, a wood cutting station, a sanding station, an electric component assembling/testing/experimenting station, and a station where artists could work on making signs for our stations.

We started the lesson with a talk about what a makerspace is, what a maker is, tool safety, and mindfulness. Then we quickly got to work. For most, if not all the children, it was their first experience with woodworking. Cutting a piece of pine was clearly very gratifying for some of these makers. While sawing one young lady even declared, "This is what I want to do when I grow up." I wasn't sure if she was referring to woodworking or what, but I was happy to have exposed her to a new passion. During this lesson Ms. Battle and I noticed peer-to-peer mentoring, tool skill acquisition, moments of self-identity, applied mathematical literacy, and total engagement. The number of behavioral issues decreased significantly, and self-discipline reigned. I thank the magic of a makerspace for the change.

In these few lessons we moved from being entirely teacher directed to some student choice. It was a small window into their individuality, but it is a window with a great view.

If STEM is a monster, can it be a cuddly one?

I empathize more fully with frustrated non-STEM educators who feel the oppressive weight of STEM initiatives that consume grant funding and steal time away from equally important experiences. I now have a different view of the STEM monster. I am very grateful that I was in a school that has three talented teachers dedicated to exposing the Hollis students to science, technology, engineering, and math through invention *and* inquiry. I even hope to embrace the constraints of the science and engineering fair to promote more student voice and choice. I might be collaborating with a STEM monster, but I am a firm believer that maker education has the ability to rebrand old ideas and be a flexible vehicle for innovation literacy in young innovators.

Constructionism 800 Meters above Sea Level

by Nalin Tutiyaphuengprasert

Far from the big city

As a constructionist facilitator from the Darunsikkhalai School for Innovative Learning in Thailand, I received an invitation to teach fifty teachers in a corporate social responsibility program of Thaicom Public Company Limited. The location would be 780 kilometers (485 miles) away from the airport of Chiangmai. It would be a long journey to the highest-altitude spot of Thailand. It sounded terrific, and I thought it would be nice to get away from a big city for a couple of days, so I said yes.

There were thirty teachers from the Office of Non-Formal and Informal Education (Mae Jam, Chiangmai region). All of them can speak the Thai language, and for many of them Thai is their second language. Another group of twenty teachers was from Wat Khian Khat School, located in a temple in Pathumthani province

Examples of existing projects: (*left to right*) Mushroom project; Chicken Farm project; Sun-Dried Banana project

(70 kilometers [43 miles] from Bangkok). The donor, Thaicom Public Company, wanted the teachers to learn how to conduct project-based learning with the small grants that they had received.

From my observations and from documentation of their projects that I had received a week before this trip, I decided that creativity should be a main topic for this workshop because, even though there were a lot of projects, most of the projects were very similar. I had one-and-a-half days to run my workshop and a half day for final presentations. Thai Satellite arranged for all the teachers to travel from their villages to the most convenient spot in the area with electricity (on, well, most of the time) and teachers stayed at small guesthouses during the workshop.

It was amazing that for less than 200 US dollars per grant, they produced interesting and sustained results such as raising pigs, goats, and chickens, breeding them with fruitful results. Now they have inexpensive protein—enough to feed the hill tribe communities. They also grew coffee plants and learned how to roast their own coffee beans. There were twenty projects consisting of pig, goat, and chicken farming; coffee plants and products; and a sun-dried banana project.

Many projects had a goal of increasing income for local hill tribes, who live on the mountains with limited infrastructure. Electricity is mostly based on solar panels, and blackouts are common. Cellular phones are useless in their villages. Teachers spend eight days per month traveling back and forth to their homes in a small city three to four hours away from the schools. This is quite different from teachers whom I had taught before. I tried to think of what would be most efficient and sustainable in this particular context, with no computers, no cell phone, and no laser cutter.

I had planned to introduce fifty teachers to the design process in a simple way at the beginning and then integrate into their projects for the villages. At this point, it doesn't matter if they know what constructionism or the design process is—I mostly wanted them to learn how to have a clear picture of a continuous refinement process and to not be scared of thinking creatively as they innovate something new. These are the most important skills for them to have to be able to continuously improve their projects and to guide their students in how to think, make, and reflect, which is the core of the constructionism learning process. I chose papers, straws, balloons, rope, and a few more building materials to help them learn how to make paper prototypes for all ideas that we would be developing together.

(*Clockwise*) We kicked off with a low-cost prototype; getting the teachers familiar with design processes; the paper prototype process

I started off the workshop with making an artistic statue from simple materials to stimulate how we make something from collective ideas. Teams made a simple prototype by thinking, drawing, and discussing the work; getting frequent feedback; and not trying to make things perfect. I found that welcoming imperfection and always giving space for feedback and growth are new perspectives for them. They felt uncomfortable with the short time I gave them, but I insisted that imperfect work is fine and that it actually helps to keep your mind open to feedback. Some teachers struggled, but others started to accept ideas and learn to "let loose" a bit more. I went through another round of the design process by assigning them to interview each other and make prototypes of wristwatches for their partners before jumping into real-life projects.

Then I invited teachers who had common interests to work in teams. After a discussion we asked the participants to write their individual ideas on paper, and we put all the different ideas on the wall. There were a lot of different projects that came up such as growing avocado trees, growing different types of mushrooms (which bring a higher price), designing a closed system of goat farming, making a low-cost version of chicken feed from local materials, and making jasmine-flavored coffee beans.

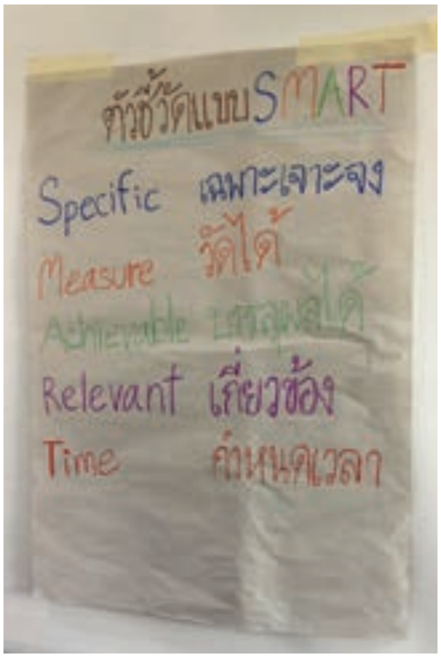
We went through the same design process but this time with their own project. The teachers were now more comfortable with all the processes and much more relaxed about quickly making a paper prototype. I combined design processes, making it simple for them to follow steps and repeat them by themselves with their own project. I introduced strengths, weaknesses, opportunities, and threats (SWOT) analysis to help them think of both advantages and disadvantages. This helped them come up with even more ideas on how to use the resources and opportunities that they have without getting stuck on problems. The ideas they came up with were all fascinating to me. They learned to cope with problems with local materials and available resources. They had ideas about recycling trash such as using eggshells as a source of calcium, the main ingredient of chicken feed.

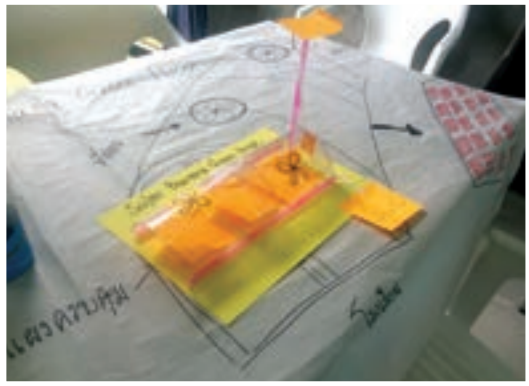


(*left to right*) Design-thinking process; designing wristwatches; discussion on design (thinking) processes


Mushroom cabin for growing mushrooms in winter

Avocado garden project to help reduce deforestation





(*Clockwise*) SMART indicator (how to evaluate a project); final presentation; solar banana greenhouse

In the final reflection, I asked participants to think of three words or phrases as their most important takeaway. These were their words and phrases:

- teamwork, faith, learning by constructing
- friend, buddy, think together
- problems, learn, understand
- differences, process, measurement and evaluation
- brainstorm, teamwork, and determination
- experience, brainstorms, and development
- fight and persist for your life

Participants reflected that they had found the benefits of diverse ideas from working with others. They became familiar with design processes and learned to plan things rather than just jumping into projects without planning or getting feedback on the ideas. They learned how to discuss, listen, and welcome ideas from people who may not usually speak up. During the final presentations, a few people who usually do not speak volunteered to give the team presentation, showing the pride they had developed in the projects they had been working on.

We are still in the process of supporting this group of teachers. I am working with the donor to plan follow-up workshops and determine how to track their progress. We are aware of complex issues involved as we implement these ideas in real situations. The teachers make decisions at different paces and have different levels of persistence. We are trying to take all this into consideration as we plan follow-up sessions and continued support for these projects.

I learned so much from this experience myself. To bring about change, we need to think of how to make it easier for people to perceive and be open to new ideas. Bringing materials from the outside can build up resistance and make it harder for participants to transfer ideas or localize knowledge from the outside.

In explaining constructionism, Seymour Papert said that learning happens "especially felicitously in a context where the learner is consciously engaged in constructing a public entity, whether it's a sandcastle on the beach or a theory of the universe" (Papert and Harel 1991). From sandcastles to bamboo-stick frog condominiums, constructionism is alive and well around the world.

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Projects to Explore in Depth

The projects in this chapter give the reader a lot to think about, try, and adapt for one's own situation. In contrast to the project snapshots in the final chapter of this book, these projects are more fully described and often feature interesting reflections and course corrections from the authors.

Desktop CNC: Linoleum Stamp

by Josh Ajima

I have been trying to figure out workflow and some project examples to share with teachers on the use of desktop CNC machines in the classroom. One of the advantages of CNC machines like the Bantam Tools Desktop PCB Milling Machine is that they can use a wider range of materials than a 3D printer or laser cutter. This linoleum stamp project is a useful quick reference of what I've found to work well for educators just starting out with desktop CNC machines.

Material: 2 × 3 inch linoleum blocks from Inventables. (I bought some during a Black Friday sale.) Cut the blocks in half on a bandsaw, creating blocks approximately 52 mm for *x*, 38 mm for *y*, and 22.5 mm for *z*, as measured using a pair of digital calipers. Per-stamp cost is around fifty cents.

Bit: I used an 80-degree engraving bit from Bantam Tools, which is recommended for general purpose engraving. You probably could save time using a combination of the engraving bit and a larger end mill, but the bit was already in place, so I just went with what I had to skip a tool change.

Fixturing: I used Intertape 591 Double Sided Flatback Paper Tape that I bought in bulk years back for CNC work.

Image processing: Download a .jpeg image of a tree from the internet. If you have Adobe Illustrator, import the image, then use the image-trace feature to create a vector outline. Save this image as an .svg file. If you don't have access to Illustrator, there are online sites that convert images.

Use a simple image with a single outline. The first image I tried had nested outlines, but the Bantam Tools Desktop Milling Machine Software does not recognize interior lines.

Setting up software: Enter the size of the material, and then open the tree.svg file. Select the 80-degree engraving tool (or the tool you are using) and delete the other tools listed. Change the Engraving Depth to 1 mm. Unselect Cutout. Open Advanced and change the Invert setting to Yes—everywhere.

Milling: Home the machine and check that the block is securely attached to the bed, that the correct bit is installed, and that the software preview matches the physical setup. Put in/on ear protection. Then click Mill All Visible. Ensure that everything is cutting correctly. In my case, the machine milled for approximately 45 minutes.

Finishing: Open the machine and vacuum up the dust. The stamp should pop off easily. Clean up a few areas on the edges with a hobby knife.

Stamping: Use an archival stamp pad to ink the stamp, then apply to plain white copy paper. I used a Ranger Ink pad, but the coverage of the stamp wasn't total; I would like to try a few different type of ink pads. (My seven-year-old used markers to decorate the tree. My daughter wants to use these as gift tags. We would use card stock.)

Optional finishing: Make a stamp on plain paper and glue this to the back of the stamp. You may wish to round off the corners using a band saw or a sander.

3D-Printed Lithophane

by Josh Ajima

This is a lesson plan submitted to the FormLabs: Innovate and Educate Challenge in hopes of winning a Form 2 resin 3D printer. Entries were composed of a lesson plan and related STL files posted to Pinshape.[1] In this lesson plan, students create a lithophane, which is an object that reveals a picture when a light is shined through it.

One of the dilemmas I had with my entry is that I have no idea what educators expect of a digital fabrication "lesson plan." Do educators want a word-for-word lesson with screenshots of every technical step and sample files? Do they want ideas that they can build off or just examples with some classroom context? Does anyone really need a list of standards and Bloom's levels for every activity?

Unfortunately I did not win the contest, so the Form 2 resin 3D printer remains on my wish list. But at least I have a lesson plan to share.

Subject:	Art, Technology
Grade Level(s):	Grades 6–12
Duration:	One hour

Lesson objectives

- To investigate concepts of opacity, translucence, and contrast using 3D-printed lithophanes
- To investigate the transformation of 2D images to 3D models
- To explore 3D printing as a new material/ method for creating art

Standards

Virginia Visual Arts Standards of Learning

- AI.6 The student will use a variety of traditional and contemporary media (e.g., two dimensional, three dimensional, multidimensional) to create works of art.
- AI.12 The student will identify technological developments in the visual arts.
- AII.5 The student will use contemporary media, tools, and processes to create works of art.

Materials

- Digital cameras
- Computer with photo editing software and internet access
- 3D printer

Sources

Lithophane test card models were created using a test card image downloaded from Wikimedia Commons[2] and converted online into an STL.[3]

MLK lithophane model was created from an image from the Library of Congress[4] and converted to an STL via an online customizer.[5]

Anticipatory set (8 minutes)

Preparation: Teacher has started a 3D lithophane printing before class starts, timed to end during student independent practice.

1. Ask students to think about what makes a good black-and-white photograph.
2. Have students take two black-and-white photographs using class digital cameras or personal devices and save the photos to a computer with photo editing software.

Introduce and model new knowledge (12 minutes)

Teacher explains that a lithophane is 3D artwork or an image that can be seen clearly when backlit.

1. Teacher shows MLK lithophane 3D print, first flat and then backlit. Teacher passes MLK lithophane for students to view.
   - Traditional lithophanes were etched or molded out of thin porcelain.

- The thickness of the material in a lithophane determines the amount of light that can pass though the material.
- If light is totally blocked by a material, the material is opaque.
- If light can pass through a material but objects cannot be seen clearly on the other side, the material is translucent.
- Contrast is the difference in tone between lightest to darkest.
- Black-and-white photos and lithophanes both rely on strong contrast.

2. Teacher shows the 2D and 3D versions of the test card. (Use test card model thickness that shows the widest range of tones between light and dark using available filament.)
   - Software can convert a 2D image into a 3D model by changing the height of the 3D model based on the lightness or darkness of the different areas of the 2D image.
   - 3D printing represents a new medium for creating artwork.

Formative assessment
Which part of the lithophane will allow the most amount of light to pass through? The least?

Guided practice (12 minutes)
Teacher models creating a lithophane STL file using a sample photograph taken in the classroom using available photo editing software. Students practice using same image.

1. Save edited photo.
2. Upload image to 3dp.rocks/lithophane/.
3. Change Image Settings to positive image.
4. Optional: Change settings for maximum size and thickness to match desired project size and opacity of filament being used.
5. Refresh and download STL. Save file.

Optional:

- Convert color image to black and white.
- Crop image.
- Adjust contrast of image.
- Erase background or distracting elements in photo.

Formative assessment
Which part of the 2D photograph will be the thickest on the lithophane? The thinnest?

Independent practice (15 minutes)
Students create a lithophane STL file using one of the black-and-white photos they took at the beginning of class.

Formative assessment
Are the darkest parts of the image showing as the thickest part of the lithophane preview? Are the lightest parts of the image showing as the thinnest part of the lithophane preview?

Closure (10 minutes)
1. Teacher demonstrates slicing an STL file using completed student lithophane as an example.
2. Teacher removes finished lithophane (ideally of sample image used in guided practice) that was printing at beginning of class from the 3D printer.
3. Teacher demonstrates starting 3D print of student lithophane.

Formative assessment
What term can be used for the thinnest part of the lithophane? What term could be used for the thickest part of the lithophane?

Notes
1. pinshape.com/items/29307-3d-printed -lesson-plan-3d-printed-lithophane
2. commons.wikimedia.org/wiki/File:Test _card.png
3. dp.rocks/lithophane
4. loc.gov/item/99404332
5. thingiverse.com/thing:74322

Making the Buttons

by Josh Ajima

One of the surprise hits of our makerspace this year has been the humble button maker. When we were setting up all the new equipment and tools in our renovated technology classroom, we ran across an old button maker sitting neglected in a storage closet. Luckily, we also found a box of button parts. The button maker was heavy and hard to use but worked most of the time. A month later, students in the makerspace had gone through 750 buttons.

We realized that the button maker is one of the most scalable tools in the makerspace. An entire class of students can make a personalized design during a single class period. Buttons are a timeless real-world product that students are happy to pin on their backpacks. Buttons also have great profit margins as they cost just ten to twenty-five cents but can be sold for one to two dollars.

When we ran out of buttons, we couldn't find the odd size that our old button maker took. After some careful research, we ended up spending a thousand dollars in punches and button makers from American Button Machines, a company recommended by a number of librarians. This may seem crazy but has been well worth it. Students have made more than a thousand buttons this quarter. The smaller buttons can also be made into a variety of keychains and zipper pulls. The graphic design for buttons can also serve as a stepping-stone to designing for other digital fabrication devices such as the laser cutter, vinyl cutter, CNC, or 3D printer.

How can buttons be used in the classroom?

There are countless ways to use buttons in a classroom. Here are a few ideas:[1]

- Campaign buttons: historical and student elections
- Political movements: civil rights, peace movement, Occupy Wall Street
- Wearable art
- Self-identity and self-expression
- Fundraising: school clubs, fields trips, charities
- Social awareness: anti-bullying messages
- Entrepreneurship and marketing
  - Sports marketing: team logos and mascots
  - Marketing: brand recognition, icons
- Role-play
- Collaborative job roles: buttons for each team role such as leader, recorder, and timekeeper
- Simulations: rock/water cycle, atoms making molecules
- Memorials
- QR code and Snapchat avatars
- Emoji: empathy/mood
- Mastery badges

Note

1. A great resource for button research: buttonmuseum.org

Make Your Own Low-Cost Computer with a Raspberry Pi and Recycled Materials

by Koffi Dodji Honou

This was an entry for the Make a Difference Challenge,[1] a competition to encourage openness and knowledge sharing to make the world a better place. It was organized by Helmut Schmidt University[2] in Hamburg, Germany, and the Arab German Young Academy and the Open Lab (OLab), also in Hamburg. The end product is called Pi-COMP, an all-in-one computer composed of a central unit interconnected with a flat screen from recycled computers. Pi-COMP was first prototyped at the Fab Lab DefKo Ak Niep ("do it with others"), Dakar, Senegal.[3]

This project is documented and licensed (Creative Commons CC BY-SA) to make it available to as many people as possible in Africa and around the world.

What problem were we trying to solve?

The social problem is the digital divide and limited access to technology resources in Africa. There is still limited access to computers given the high cost for most consumers in Africa.

To solve this widespread problem in Africa, in partnership with the OLab, we designed and built all-in-one, low-cost computers based on Raspberry Pi and recycled materials. We call this computer the Pi-COMP.

The Pi-COMP can democratize technology. It can help African kids and students acquire IT skills plus learn about CNC milling and laser cutting. They will then be able to unlock their creativity and contribute to the well-being of their communities.

Objective

The objective of this project was to design and build a replicable, low-cost computer locally and easily. Since computers are still expensive for most African consumers, Pi-COMP is a low-cost and open-source way to tackle this issue.

Once these devices are assembled and working, Pi-COMPs can be installed at local libraries, schools, bookstores, homes, fab labs, video game centers, offices—most anywhere. They can be connected with local data servers and the internet so that users have the opportunity to develop their IT skills, creativity, and imagination.

Materials and components

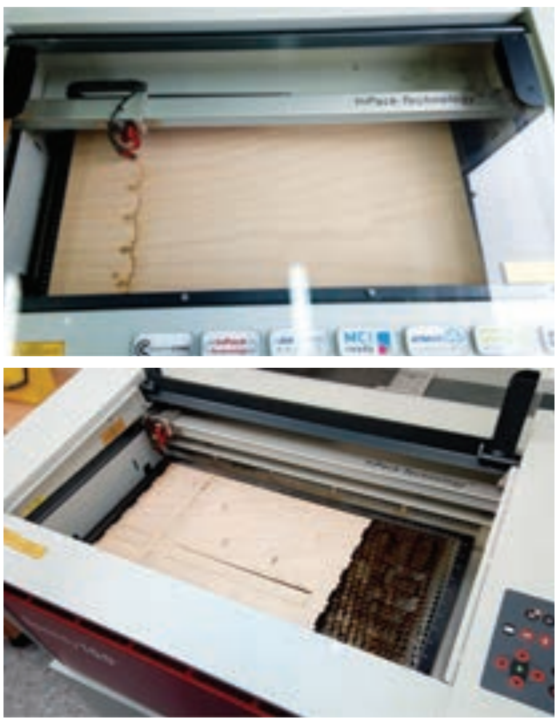
Raspberry Pi 3 model B	Micro SD Class 10 (8 GB or more)	Power supply (5 volts 2.5 amps)
		

- 3 mm Allen bolt cap hex screws
- Recycled computer screen (abundant and inexpensive in most African countries) or a flat-screen monitor (the Pi-COMP size depends on the size of the screen; we used a 15-inch flat screen)
- Plywood (4 mm recommended; this will be used to build the cover; other types of materials may be substituted)
- Transparent plexiglass (for the front cover)

Instructions

1. Remove all the plastic that covers the monitor as we just need the electronic part of the screen.

2. Measure the length, width, and depth of the screen. This measurement will be used to design the box when laser cutting, so be precise. Use CAD software to design all the pieces to be laser cut. We used SolidWorks, but other open-source software such as Inkscape work just as well. (All the DXF and SolidWorks files we used are available to use and modify.[4])
4. Laser cut the plywood for the case. If you are using other material and/or a different width of material, be sure to adapt the design and measurements in order for the junctions to fit.



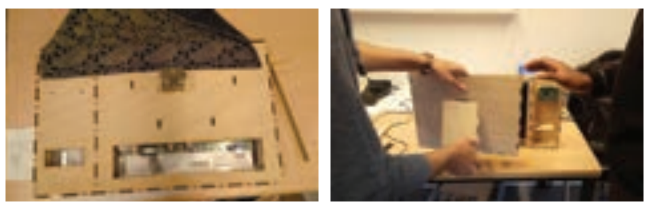
5. Assemble all the laser-cut plywood by connecting and screwing the joins.

6. Add the Raspberry Pi, screen, and cables.

7. Attach the front cover.

8. Install software that would be useful for your project or users.

9. Customize!

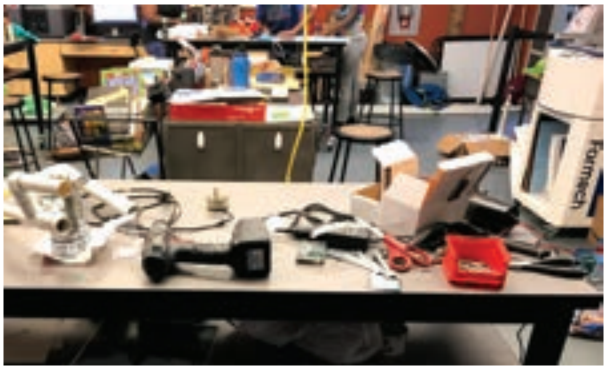


Notes

1. make-a-difference.info
2. openlab-hamburg.de
3. fablabs.io/labs/defkoakniep
4. goo.gl/dcVGf4

Animatronics: Making STEAM Move

by Sarah Alfonso Emerson



Materials:

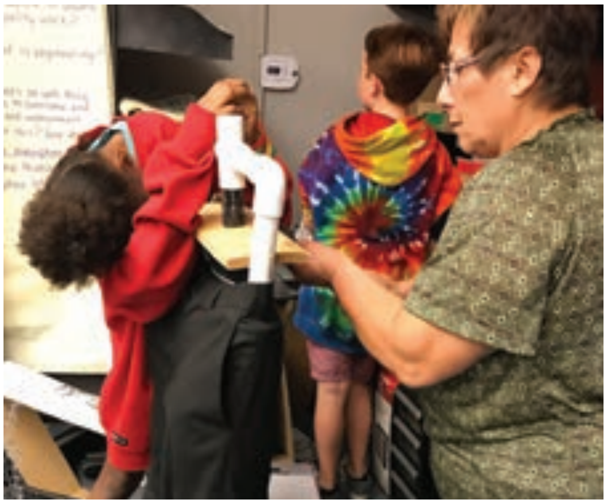
- Two-speed 12-volt DC windshield wiper motors
- PVC pipe
- Bubble wrap or foam pool noodles
- Various connectors and motor arms
- Metal fasteners and wires
- Wood
- Various hand and power tools
- Props and costumes
- iPad or mini projector

This unit was designed to explore how far into the world of animatronics students could go in our makerspace. Animatronics is a unique and mostly unexplored industry at the cross section of STEAM. Fortunately for the students at Bing Wong Elementary in San Bernardino, California, the world leader in animatronics happens to have its business center and warehouse five minutes down the street. Garner Holt Productions has adopted our school because of our focus on career exploration and STEAM.

As a thank you to founder Garner Holt for adopting our school, our students made animatronics to showcase for him at our adoption ceremony. We had never built animatronics before this project, but we had worked with servo motors. We had also built underwater remotely operated vehicles (ROVs) using a lot of the same materials we wanted to use with animatronics, so we had some background skills and knowledge to guide our exploration. We had five groups of four students (grades 4–6) working with one adult each, two days per week after school for an hour over the course of eight to ten weeks.

In this project, students decide on a character they want to build and up to two movements they'd like the character to make (including nodding of the head, waving an arm, shaking hands, spinning a rope—basically anything repetitive). Then they sketch the skeleton of the animatronic and measure PVC pipe, wood, and dowels to build the skeleton; study the wiper motor mechanisms; and figure out how to place the wiper motor to the skeleton in order to get the desired body part to make its movement. Finally, they cover the skeleton with bubble wrap and a costume so it looks like a realistic figure, record a video of the animatronic character (a student actor) speaking; and have the video playing on an iPad that can be attached as the head of the animatronic.

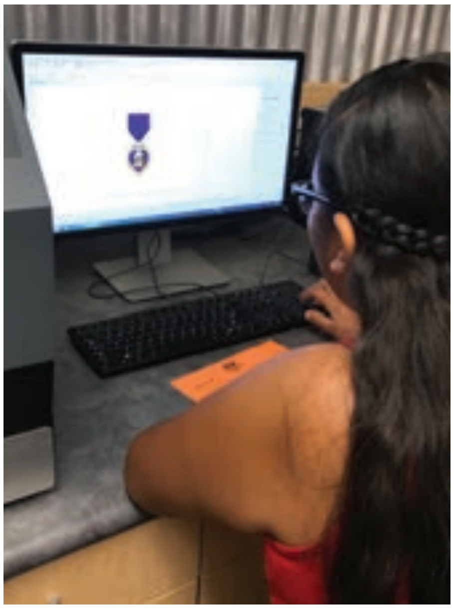
As we worked through this project, we realized that students needed to stop often for mini-lessons from their adult leader. Students needed to understand the electronics (and safety) of



the motor. Students needed to understand the physics of motion. Students needed help with measurement. Students found they needed parts that didn't exist. Students needed crash courses in fashion and costuming as well. We realized by the end of the project that the project itself could have easily been broken up into "chunks" or in ways that would have allowed for more creativity in the process. But because we went into the project blind, we learned through trial and error that we may have done things in an order that took entirely too long, or we overlooked important learning opportunities in order to meet a deadline, or we missed out on opportunities to share our knowledge across groups because of the way we were grouped. (Instead of working as one large team on multiple projects together, we worked as separate teams.) We also had never made anything so physically large before. Most of our projects in our makerspace are small tabletop projects. These animatronic figures were life-size and some of them slightly oversized!

If I could do this project again, I'd spend time with the adult leaders, crafting a sort of construction manual divided into units. We would start with the structure of the animatronic and spend time sketching the skeleton with dimensions and teaching students how to frame such a large project. Next, we would move on to the motors, spending time teaching students and having them explore how the motor works with smaller objects. Finally, we would spend time "figure finishing" the animatronic, as it's called in the world of animatronics. This would include lessons on how to make the animatronic look lifelike, where all the fun art comes in. We could explore with makeup, sewing, vacuum forming—even skin and hair.

An animatronics project truly allows for so much creativity. We could easily have tried to improve the mechanisms of our finished animatronics with more electronic parts. The possibilities seem endless—sensors could be added, customized 3D-printed body parts could be designed, eyes could have eyelids that open and close, hands could have fingers that bend and move, speakers could be added—so many options to explore with this project. There are so many, in fact, that we have made animatronics a class elective at our school so students have the option to go into depth for longer periods of time.



Making Hope Happen

by Sarah Alfonso Emerson

When a tragic event happens in a community, the members of the community come together in an emotional connection of support and hope. When our city of San Bernardino, California, experienced such an event in 2015, a tragic mass shooting, our children felt compelled to be lights in the community, as children often are in times of darkness. In my iSTEAM Lab, students wanted to make something. Making is a very personal experience for a maker; it's an experience that draws creativity through passion. Students were passionate about the object they wanted to create. They wanted something that showed they had not given up hope—that they were in fact hopeful that light always shines during times of darkness. During times of difficulty, with the right mindset, there is always a way to see light and to see hope, and the students at Bing Wong Elementary wanted to illuminate the path to hope.

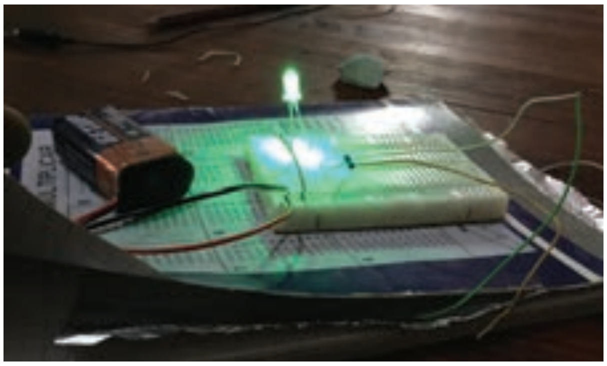
What they ultimately came up with (after much brainstorming) was to make luminary candle holders out of laser-cut and engraved wood. They graphically and mathematically designed the candleholders using CorelDraw, seeking images that symbolize pride, peace, and hope in their community. They fabricated them using a laser cutter and ultimately used their finished product to promote social action. They decided they want to sell these items at our community's memorial events, donating all funds received to families of victims.

It's fitting that our school district's motto is "Making hope happen." For the past few years, the San Bernardino City Unified School District, in partnership with the city, has pursued a mission to spread the infectious power of hope. We want our children to have a vision of their future success. We want them to have the emotional commitment and motivation to pursue excellence while serving others. We want them to believe in their sense of purpose. Our school district has a vision to develop a thriving and innovative community where every student is a lifelong learner and successful in reaching their hopes and aspirations.

I know our community has all the resources it needs to make hope happen in the lives of our students. We make connections, draw inspiration from each other, and learn together. When we as learners, both student and teacher, design and become our own solution to the struggles we face, we have the ability, will, talent, and dedication to thrive and innovate. When students are designing in the iSTEAM Lab, they become a part of their designs, and their designs become a part of them. Making something becomes making something of value, which becomes confidence in our ability to make something of value, which becomes visualizing our value, which becomes hope. When students are trusted to design and make, they're given the opportunity to choose their own path to success. These small luminary candles are designs brought to life through hope, ***making hope happen*** for everyone.

Helping Young Students in the Developing World Explore Electronics

by Alphonse Habyarimana



UNESCO Director-General Irina Bokova (2014) wrote in the 2013/4 *EFA (Education for All) Global Education Monitoring Report* that the "poor quality [of education] is holding back learning even for those who make it to school." This quote is about simple literacy, so the question must be asked: If so many people in the world are without access to the most basic of education, why should we be concerned with teaching fabrication and making? We believe it is a literacy to learn about electronics and fabrication, and to develop the skills to use modern tools and be part of the world's fast-growing maker movement.

Being exposed to the concepts of electricity and electronics for the first time may be scary but creates curiosity to further explore how things work. In developing countries, where the maker movement is lagging behind the developed countries, kids learn everything in theory, but hands-on experiments are rare—not because kids don't want to do them but because there are no means to practice what they learn. What if they get access to practical hands-on experience and get the freedom to explore how electronics work? There is no doubt that given the chance they can be part of the maker movement as independent inventors, designers, and tinkerers—on par with anyone in the world.

At the Kepler Tech Lab (now I4Fab), a science and engineering teaching laboratory based in Kigali, Rwanda, second-year (eighth-grade) students have been learning electronics by building their own electronic components. These students learn how electronics components such as capacitors and resistors are built and try to rebuild them using raw materials.

Homemade resistor

Every material is resistive, meaning that it resists charge going through it. Even a conductor like a copper wire has some resistance. A commonly available and easily shapeable resistive material is graphite, which can be molded into any size or shape. Given their background of theory-based knowledge, it took students in the engineering class at Kepler Tech Lab about two weeks to better understand how a resistor works through a variety of experiments. On a clean sheet of paper, they drew shapes with graphite pencil and used a calibrated multimeter on the "resistance" setting to measure resistance at various lengths of the pencil drawing.

Homemade capacitor

Breaking things down and showing students how things are built gives students a chance to compare what has already been made and what they are about to make. This leaves room for them to be more creative while arranging required materials to assemble their own components.

A capacitor is a component used to store charges. It had been broken into pieces, and students were excited to see how it was made with only layers, insulators, and electrodes (anode and cathode). Students can make a homemade capacitor with two sheets of aluminum foil as the conductor and sheet(s) of papers as the insulator.

How to do this in your makerspace

Separate the students into small groups. Have each group start with **two large sheets of aluminum foil** and **one large sheet of paper. Have them sandwich the paper** between the two pieces of foil, making sure that the foil pieces do not touch. If that happens, current will flow between the two pieces and no charge will be stored. In order to secure the placement of the sheets, have the groups tape the layers together and then use the multimeter on the "capacitance" setting to see if they are able to measure a capacitance between the paper and the tin foil.

Ask the groups what happens when they cut the pieces smaller and measure the capacitance again. They are exploring the effect of changing the surface area of the foil. What if they use multiple sheets of paper or other spacers to change the spacing between the two sheets of foil? Encourage the groups to keep iterating their experiments, noting all the changes they are seeing. The first group to finish the activity can mentor their fellow classmates.

Another capacitor can be made using **salt**, **water**, and **aluminum foil** as conductors, and **a plastic water bottle** as an insulator. First, the bottle has to be filled with water. Dissolve a spoonful of salt into the water. Wrap foil around the bottle without making any wrinkles. An easy way to do this is to flatten the foil and gently roll the water bottle into it, taking care to smooth out any wrinkles. After that, screw on the top of the water bottle and poke a **nail** through so that the bottom of the nail touches the water. Then, capacitance can be measured between the nail and the foil. Students should keep exploring what happens if they add more salt, use less foil, or if they add a sheet of paper between the tin foil and the plastic bottle.

Like all learners, young students in the developing world need to experiment with how things work. In learning electronics, they get the most out of making the components rather than our handing them electronic parts to be used without knowing how they are built. I can't wait to see what the future generation of makers will bring to the world's changing technologies!

Note

1. keplertechlab.wordpress.com

Reference

Bokova, I. (2014). Foreword. In UNESCO Teaching and Learning: Achieving quality for all. *EFA (Education for All) Global Education Monitoring Report*. Paris, France: UNESCO. Retrieved from unesdoc.unesco.org /images/0022/002256/225660e.pdf

Creative (and Squishy) Circuits

by Alphonse Habyarimana

The eighth graders who take engineering classes at Kepler Tech Lab (now I4Fab), in Kigali, Rwanda,[1] always surprise me. No matter what I prepare for, the creativity they add to the lesson completely changes the learning outcomes I had planned for them. Although Squishy Circuits dough is often used for younger students to learn about electricity, I still use it with older students because it supports creativity in the process. When I told the students we were going to make dough and use it in our electronic projects, they were all surprised and started joking around that they were going to eat it because they know they cannot eat or drink in the lab for safety reasons.

What is Squishy Circuits?

According to the Squishy Circuits website, it "uses conductive and insulating play dough to teach the basics of electrical circuits in a fun, hands-on way."[2]

Our engineering classes are structured so that kids work in pairs, and they switch teams after two weeks to experience working with diverse groups of fellow students. Since we are teaching a physical computing curriculum, they first learn how to use computers, competing with one another with typing games to become familiar with computer keyboards and interfaces.

Squishy Circuits was one of our first physical computing projects. I asked students to make resistors and capacitors, which they did, but they also made funny things I never anticipated. First, they made two different doughs, one conductive and the other insulating, with the help of recipes on the Squishy Circuits website. The conductive dough is the resistive one; after making the conductive dough, it is easy to make a resistor out of

it. You can simply take a piece of dough and use it in a circuit as an actual resistor.

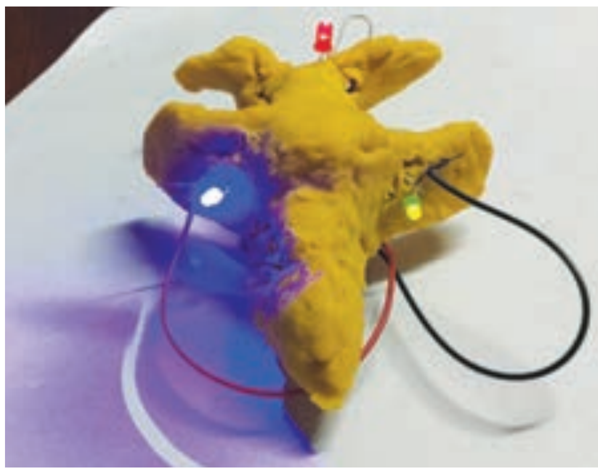
Next, the students used the insulating dough as a spacer between two pieces of conductive dough in order to make a capacitor. It worked, but the insulating dough seemed to be a little bit conductive too. As that was not expected in our experiment, we need to explore more.

What happened next!

Once all nine teams (two students on each team) completed the first challenge of making resistors and capacitors out of dough, they moved on to experimenting with Squishy Circuits. They added LEDs and buzzers as loads in their circuits. Throughout I was happy to see their smiling faces as they were telling everyone what they can do with the dough they had made. My reaction was to tell them, "Sure, the floor is yours, let's do it! We shall have an exhibition session to see what each team is going to make." They started testing all sorts of different things, and I thought to myself, "How crazy are these kids?" Yes, they were mad explorers, innovators, and tinkerers—just see some of what they've made.

Each team showed their creations to the whole class in an exhibition. The teams were so excited about their creations and they inspired me as well.

Lesson learned from this activity: giving students the freedom to do anything and spending your time assisting them is the way to creativity and learning.



Notes

1. keplertechlab.wordpress.com
2. squishycircuits.com

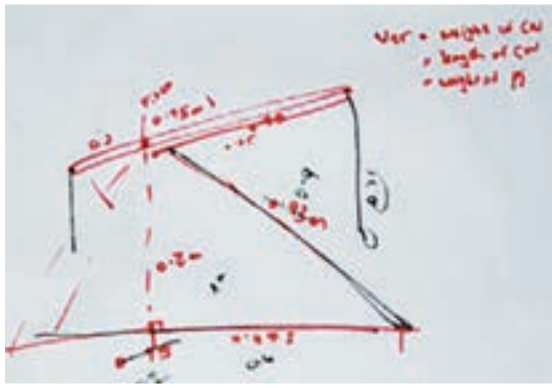
Trebuchet Making: STEM in Action

by Alphonse Habyarimana

We had covered computer programming (Scratch), physical computing (Arduino), and other electronics-related concepts with middle-school students at Kepler Tech Lab (now I4Fab) in Kigali, Rwanda. Another topic to explore in our workshop was how to use woodworking and metalworking tools such as a hacksaw and drilling machine through construction of a trebuchet—a type of catapult that uses the gravitational potential energy of a raised counterweight to throw something off the ground (Finio 2016).

Building a trebuchet is not only about launching a projectile (although that makes it fun) but also about the application of physics and mathematics, not to mention the ability to use wood- and metalworking tools.

Through trebuchet building, students explored the principles of physics and mathematics. They learned the applications of kinetic and gravitational or potential energies as well as conservation of energy, in which they were able to understand the difference between those energies and their working principles.



Note

1. keplertechlab.wordpress.com

Reference

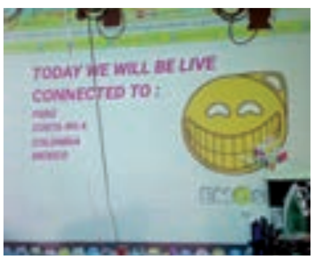
Finio, B. (2016, May 19). Build a Mini Trebuchet. Retrieved February 19, 2018, from scientificamerican.com/article/build-a-mini-trebuchet

Connecting Children around the World with the "Emotions Chair"

by Susan Klimczak

Ilaria La Manna is an extraordinary children's educator and director of Fab Lab Argentina,[1] who works with FabLat,[2] an organization that connects children and educators learning and making all over Latin America. While I was taking some courses in Boston, Massachusetts, she generously offered to connect our Fab Lab, the South End Technology Center @ Tent City in Boston,[3] to a network of Fab Labs doing an *emosilla* ("Emotion Chair") workshop in Mexico, Peru, Costa Rica, and Columbia. These chairs use a press fit design, which means they can be made without nails or screws, and the pieces can be cut with a laser cutter ahead of time.

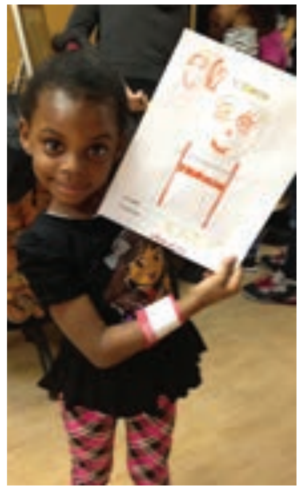
Fair Foods of Boston, an organization that distributes food and makes colorful benches, donated several sheets of 4 × 8 foot plywood that our ShopBot guru Brad cut using the chair templates. It took some creative collaboration with Ilaria to change the design to match the width of the wood that we had.



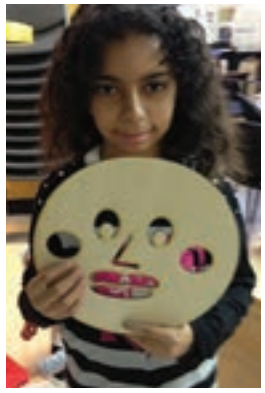
Ilaria started the workshop by exploring emotions with the six girls aged four to eight. She used a wonderful slide show of photos that really engaged the youth. Her blend of simple language, questions, and humor created a learning environment where the children could comfortably explore the full range of emotions, not just the happy ones.

Then Ilaria asked the children to draw an emotion that they felt on a worksheet handout with colored pens and crayons. When they finished, we got on Skype, and they shared their drawings with children in other workshops around the world.

Then each child started building their own press-fit *emosilla*. I was amazed at how even the smallest ones LOVED to sand the edges and take mighty swings of the rubber mallet to pound the chairs together. They were intrigued by the press-fit design and how to fit the pieces of the chair together like a puzzle. Ilaria used simple instructions and explanations to help them feel confident enough to try the new tools with gusto.



Then some children painted their chairs with water-based paints (we had four colors—white, blue, red, yellow—and they mixed the colors they wanted in recycled plastic food containers), using



cheap sponge paintbrushes from the hardware store. Others went into the computer lab and created their emotion faces, using GIMP and Inkscape to digitally reproduce the design that they had drawn. Then they laser cut their designs onto eleven-inch circles. They loved playing with the emotion faces as masks before we used wood glue to attach them to the chairs!

When the children needed a break, they spontaneously went over to the Skype panel and started interacting with other children around the world, sharing funny faces and gestures. They were proud of their colorful hands . . . as well as their colorful chairs, which they shared with other children in Latin America via Skype.

I have to admit that clean-up was pretty time-consuming because little people find endlessly creative ways to get paint outside of the plastic tablecloths that we used as drop cloths. But it was worth all the effort because, thanks to Ilaria, the children had "hard fun" (Papert 2002):

> Once I was alerted to the concept of "hard fun" I began listening for it and heard it over and over. It is expressed in many different ways, all of which boil down to the conclusion that everyone likes hard challenging things to do. But they have to be the right things matched to the individual and to the culture of the times. These rapidly changing times challenge educators to find areas of work that are hard in the right way: they must connect with the kids and also with the areas of knowledge, skills and (don't let us forget) ethic adults will need for the future world.

Notes

1. fablabs.io/labs/fablabargentina
2. facebook.com/fablatkids
3. fablabs.io/labs/southendtechnologycenter

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"PUSH ME!" Teaching Paper Electronics to a Crowd with a Switch Sampler

by Susan Klimczak

Learn 2 Teach, Teach 2 Learn (L2TT2L) in Boston, Massachusetts, is a sixteen-year-old maker program where annually thirty-six teens of color learn, build, and then teach six different technology, coding, and engineering modules.[1] Each year our youth teachers engage more than seven hundred children at over thirty community organizations with constructionism-based activities at free four-week summer STEAM camps. This article offers insights into the process and planning for teaching paper electronics to families at a large book festival as well as a switch sampler manipulative for teaching and reflections on how to make our activity better next time.

> It's not always . . . easy to turn attention to processes, strategies, and practices—but that is at the core of the learning experience. . . . Once you make something, it's something you can reflect upon, share with others.
>
> —Mitchel Resnick
> MIT Media Lab Lifelong Kindergarten Group

Boston Book Festival calling!

Well, actually they emailed. L2TT2L youth teachers were invited to conduct a paper electronics workshop. Inspired by Mitchel Resnick, I want to share the processes, strategies, and practices involved in planning and carrying out this opportunity. This is also an opportunity to reflect on and document the lessons learned.

I love "hatching two birds with one egg," so my plan was the following:

- Design a paper electronics activity to blend reading and STEAM with a focus on authors of color with characters of color who look like our youth
- Refresh an old "Blinkie Paper" activity with new ideas for summer STEAM camps

- Inject high expectations and STEAM opportunities in a complex setting
- Use preparation as a "project exercise" for the online Learning Creative Learning course I was taking with the MIT Media Lab Lifelong Kindergarten Group

OK, that's hatching four birds with one egg—a little crowded in that egg, but I enjoy a challenge!

Planning and execution

Blending reading and paper electronics

We decided to have a family activity based on favorite book scenes. To prepare I asked for book recommendations from two friends. Dr. Kim Parker is a multicultural literacy expert who helps educators connect youth to texts that can change their lives. Joyce King has been collecting children's books by and for people of color for fifty years. She cofounded St. Joseph's Community School in the late 1960s, a free, parent-run alternative school based on Nguzo Saba principles.

We created a poster of book covers based on their recommendations with the title "Good Books That Can Light Up Your Life!" It had an LED with a heart diffuser and battery that actually lit up the poster.

At the festival, each parent and child pair worked together to create an "electrifying" scene from their favorite book using LEDs, 3D-printed diffusers, and coin cell batteries with the help of the teen youth teachers.

Refresh "Blinkie Paper" and inject high expectations

At L2TT2L, we have been teaching paper electronics, what our youth affectionately call "Blinkie Paper," for over six years, inspired by a series of workshops that our friend Jie Qi had offered. (She now has her own company, Chibitronics! Check out her Love to Code Kit.[2]) We've used Blinkie Paper storytelling and pop-up cards as inspirations for the activities in the free summer STEAM camps taught by our teenage youth teachers. I wanted to try out some ideas for refreshing our Blinkie Paper activity:

- **3D-printed press-fit diffusers for 5 mm LEDs.** We have been using simple press-fit LED diffusers in a soft circuit bracelet activity. Using Tinkercad to create simple shapes with 5-millimeter holes is very easy, and the diffusers are very quick to print in a few minutes. We used shapes like balls, stars, and hearts.
- **Switch it up!** Managing the CR2032 coin cell batteries has always been a challenge in our paper electronic activities. Children easily drop and lose the batteries if they are clipped on with a binder clip. If the batteries are permanently taped on with cellophane tape, they run out very quickly. We've been using Jie Qi's paper battery holders.[3] (We make them ahead of time because the paper folding seems difficult for the children to do—and even challenging for some of our teen youth teachers.) The children also have a hard time manipulating the paper tab to turn the battery on and off.

  Children love interaction, so finding some cool switches seemed like a great solution. That way, we could use the paper battery holders (fixed in the "on" position), and pressing buttons or push/pull tabs could complete the circuit and turn them on.
- **Engage with solder.** Introducing children to soldering at an early age is very empowering and has a positive impact. We usually use copper tape that is conductive on only one side to save money. It's often hard to get children to fold down the places where two sets of copper tape have to join to complete the circuit. Those connections and LED legs connections are often easily disrupted if just cellophane tape is used to hold them in place. Soldering the connections between copper tape and the LED is one solution!

  We decided to have the children participate in the soldering by holding either the solder OR the soldering iron (if they were very good at the solder). Just touching the solder to the soldering iron tip was very exciting for the children.

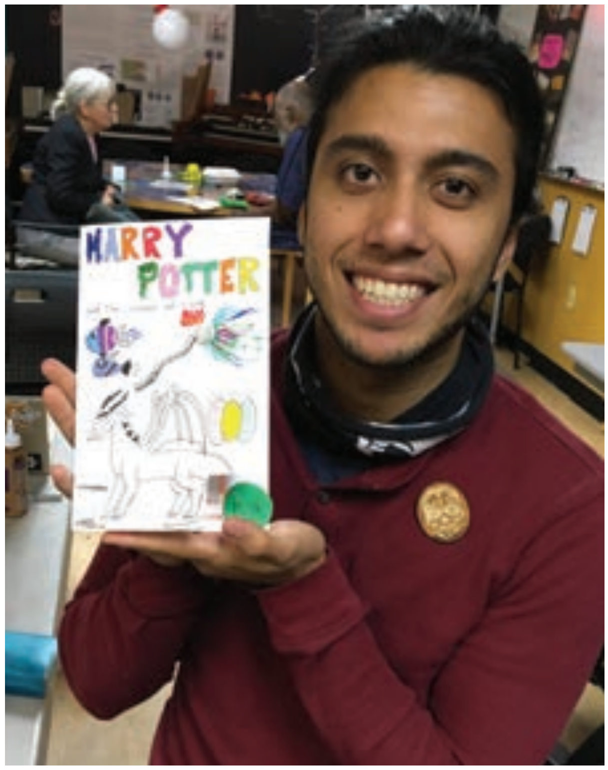
Updating a childhood inspiration for paper electronics

When asked to name a beloved childhood object during the first week of the Lifelong Kindergarten Group's online Learning Creative Learning class, I chose embroidery and spoke about the elaborate embroidery samplers I stitched as a child to learn all the stitches.

During the second week, we were assigned a project that involved animating a name. I came up with the idea of updating my childhood love to express my new interests by making a "Switch" sampler for the Boston Book Festival as a touchable and playful inspiration for children and youth teachers.

I found a paper switch sampler template by Becca Rose[4] and decided to incorporate Jie Qi's paper battery holder in the mix. I had so much fun making and decorating it in the twenty minutes here and there I could find on my busy days![5]

Having this manipulative as well as a "boss" Harry Potter example made by our Tisch Scholar Rohun Dhar turned out to provide a lot of smiles and inspiration as they got passed along at the Festival. Rohun even made his circuit look like an *H* for Harry Potter!



Tisch Scholar Rohun Dhar's Harry Potter "Blinkie Paper" example

Getting inspiration from a young friend

The South End Technology Center @ Tent City in Boston[6] is located in a mixed-income housing development that came about because of a Tent City protest in the 1960s led by Mel King, our executive director. Every Thursday we offer free open access to our Fab Lounge, and many young people like Damani from Tent City Apartments drop in to make things with our teen "Fab Stewards."

During Fab Lounge, I was working on my switch sampler and fourth grader Damani was fascinated. Her class is studying energy at school, and she had come up with many interesting theories about how the circuit worked that she was eager to test.

For the first theory—which startled me with its brilliant simplicity—Damani asked, *"Hey can't you close the switch with ANYTHING that is metal?"* This resulted in her and other children running (with gleeful chaos!) around the center looking for metal stuff to test. They used scissors, rings, spoons, needle-nose pliers, pieces of scrap copper tape, wires—you name it! Some found shiny things that were not metal and did not close the circuit. I got so energized listening to their conversations with each other about why some items worked to light the LEDs and others did not. It reminded me of something Mitchel Resnick always says: "Children don't have ideas, they ***make*** ideas!" I decided to bring a lot of metal items with us to the festival so that the children attending could try this too.

On a side note, when Damani was playing with the sampler circuit, she realized that all four switches did not work at the same time; only pairs would light up together. She came up with many theories about why that was, and then she tested them. We had a great time together asking questions and testing her ideas. Finally, she decided to make a mini sampler with two of the switches. Damani proudly showed it to her teacher, who gave her "bonus points" for her efforts even though she was already at the top of her science class!

Strategies and lessons learned

Prepping

Through the years our youth teachers from L2TT2L have offered activities at a variety of festivals that range from the World Maker Faire to the Cambridge Science Festival. We've learned to be prepared for anything and everything beyond what we planned to do:

- **Bring at least three times more material than you imagine you need.** For this book festival, we offered to do an organized two-hour workshop for eight parent-child pairs. When we arrived, we were in a large room shared with five or six other activities with no way to easily manage who participated and when they started. The actual number of parent-child pairs we served was thirty! We might have done more, but we ran out of materials—which was actually a blessing because it limited the numbers and allowed participants to finish on time.
- **Facilitating gets hectic, so have a template for the project and prep ahead of time.** We made all the paper battery holders and 3D-printed diffusers ahead of time and made a template for the paper electronics activity.

Inside

Outside

- **Divide the activity into parts and create stations.** We set up the activity with three stations—drawing, circuits, and soldering—and the festival parent-child participants moved among them. On each table, we had several signs with instructions to help teen youth teachers guide activities.

- **Make many lists of materials.** I LOVE lists, especially because lists really help when I work with teen youth teachers. We organized our materials list by station.

- **Packing and organizing are key.** I am a "box whisperer," fishing out wonderful boxes from the dumpster behind my building and whisking them away from folks who had received boxed gifts. Materials were put in labeled boxes or in Altoids tins (that our youth teachers love to spray paint).

  Materials for each station were packed in separate bags. A sewing volunteer made large bags with outside pockets for folders from remnant upholstery fabric, and we put cardboard reinforcing bases covered with scrap vinyl from vinyl cutter projects on the bottom. Then I stapled labels on the outside of the bags.

Facilitating

The festival was a success! Most of the participants really enjoyed the activity. Many parents were superexcited about circuit building and soldering. Their eager enthusiasm to share what they loved with their children was infectious. Overall we engaged participants in a pretty high quality of "hard fun."

Of course, it wasn't perfect. I always take ten minutes immediately afterward to jot down notes that help me remember how to improve. A number of parents would have preferred a quick fifteen-minute activity with spectacular results to the hour-long learning engagement we had planned for each parent-child pair. To increase the quality of learning that happens I plan to do the following:

- **Better engage participants in troubleshooting.** We needed at least two soldering irons (but only had one) and a guide so that the parent-child participants could have been more independent in troubleshooting.
- **Increase number of youth teacher facilitators and add dedicated explainers.** There were only five of us. To get the most learning out of the activity, we needed more "how to do it" facilitators and a youth teacher to be a dedicated "explainer" at each station, engaging participants in conversation about what they were doing.
- **Bring someone dedicated to photographing.** I got so busy helping with soldering and trouble-shooting that I did not have much time to take photos.

Final thoughts: Each one teach one

One of the most powerful things about L2T-T2L—which should be part of any maker education manifesto—is that **all youth should have the opportunity to teach and be responsible for what they learn, to share their knowledge with others**. For the past eight years, when youth teachers were given an opportunity to identify the most important part of L2TT2L to them, they have consistently reported that being part of an effort to create positive community change and teaching children at community organizations rank the highest. (Surprisingly, getting paid ranks the lowest.)

The thirty families participating in our workshop at the Boston Book Festival increased the number of Boston children (800+) that our youth have taught and for whom they have been role models of color enthusiastic about technology, coding, engineering . . . and, of course, making!

Recently, I have been reading the excellent and very inspiring interviews posted on the website People of Color in Tech (POCIT).[7] Asia Hoe, a product designer (who believes that curiosity is her superpower—I LOVE that!) says that this is her top advice for young people of color aspiring to careers in tech: "Each one, teach one. Whether through teaching, mentoring, writing, or speaking, passing on your knowledge is of critical importance to not only improve the state of the world but to help you develop in [a tech career]. When you impart your knowledge to someone else, you must first break it down into the smallest components so that someone new might understand, further validating and ingraining your knowledge" (Berhane 2017).

Being part of an effort to create community change for POCIT was also one of the inspirations for Ruth Mesfun, who founded the organization. She says, “The main goal of the site is to help people of color realize that, even though the numbers are low, there are so many of us who want to support each other” (Dicky 2015).

Acknowledgements

To awesome Learn 2 Teach, Teach 2 Learn youth teachers Ke’Brant (KB) Almond, Nyari (ND) Davis, Trinity Merren, and Dee Dee Pimentel, who taught this activity at the Boston Book Festival. To Bill from our Personal and Professional Empowerment program at the South End Technology Center @ Tent City, who took the time to help out. And, as always, to Eva Kerr, a wonderful eagle-eye editor and a 16-year volunteer at the South End Technology Center @ Tent City—no piece of my writing ever leaves SETC without being greatly improved by her careful edits and suggestions.

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2. chibitronics.com/lovetocode
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7. peopleofcolorintech.com

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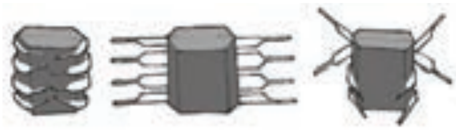
Tiny Adventures in Affordable Physical Computing

by Susan Klimczak, in collaboration with George Swallow and James Salvatore



The creative possibilities of the ATtiny85 microcontroller are awesome if you know the basic characteristics, how to set one up, and how to write code. But first let's lay a bit of groundwork.

Where might you have seen ATtiny85s before?

ATtIny85s are all around us unseen! They are used in alarm clocks, microwave ovens, washing machines, cameras, tablets, notebooks, mobile phones, and refrigerators.

If you've seen a light show at a concert, it could have included ATtiny85s to point lights in the right direction, change color, and control brightness. If you are a physical programmer, you're likely familiar with the Trinket (Adafruit) and the LilyTiny (Sparkfun), which use the ATtiny85 as their microcontroller chip.

Why would an educator want to use one?

It's inexpensive! ATtiny85s range from around three dollars each to less than a dollar in quantity on eBay (beware—there will be a three- to six-week lead time for shipping!). This price is significant for our free program serving low-income youth because we can now afford to have youth make physical programming projects and take them home.

It's small! ATtiny85s are very small but not so small that you can't handle them, so using one can significantly shrink the size of any project and keep individual beginner projects to a manageable size.

It's powerful! ATtiny85s are perfect for physical programming projects with just a few inputs/outputs because they can be programmed in the Arduino IDE. They accommodate digital (on or off) and analog (a value between 0 and 100%) components as well as servo motors.

Is it easy to get started?

While we highly recommend this microcomputer, we found that there were very few comprehensive guides for beginners, especially to explain how to connect and control servo motors. Some of the best introductory physical computing projects are kinetic sculptures, where servo motors are essential. The lack of a guide was a missing link for educators wanting to initiate fun physical computing projects with these very low-cost components—so we decided to write one!

George, James, and I spent nearly a year experimenting with ATtiny85s to create documentation and sketches for this guide because we could not find a beginner-friendly guide that was useful for maker educators who want to use servos. We hope you find this introduction to ATtiny85 and the full guide helpful. The following is a summary of the guide, entitled *ATTiny Adventures: Exploring the Mysteries*, which can be found online, downloaded, and freely shared.[1]

The basics

What is an ATtiny85?

An ATtiny85 is a microcontroller, which is a tiny computer designed to run small programs that can listen to or control electronic components that people connect to its "legs" (pins).

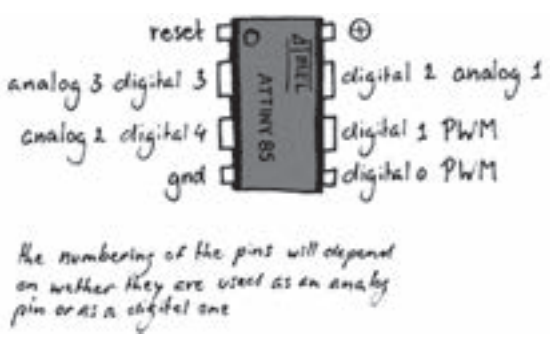
There are two types of ATtiny85s: through-hole types with legs and tiny surface mount types. This guide assumes the use of the through-hole type. The ATtiny85 program memory is flash memory, so when you remove power from the device, the program and data you have on it do not get erased, which means the next time you power up the ATtiny85, your code is still there and runs as soon as the ATtiny is connected to power (a battery, USB port, or wall plug).

An ATtiny85 is a scaled-down version of the main chip on Arduino Uno or SparkFun RedBoard development boards, which you might be familiar with:

	ATTiny85	Arduino Uno with ATTiny328
Size		
Pins	8	20
Programming Space	8Kb	32Kb
Dynamic Memory (SRAM)	512 Bytes	2K Bytes
Clock Speed	1 or 8 MHZ	16MHz
Making Connection	Must connect directly to pins	Has a power jack and header pins that make things easier to connect
Power Requirements	2.7–5.5V supplied directly to pins	5V 7–12 regulated onboard by power jack and 5.5 V regulated by USB connector

What's on the ATtiny85, and how do you wire it in a circuit?

Wiring diagram for ATtiny85:



Five usable pins. There are five usable pins that can be set up as inputs or outputs. All of the pins can be used for digital components. Some can be used for analog components. For practical purposes, all five of the pins can be used for LEDs, buttons, or servo motors.

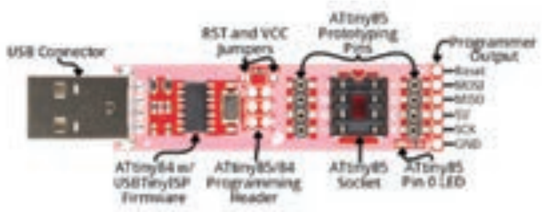
Use with a socket. The through-hole ATtiny85 most conveniently sits in a socket so you can take it in and out when reprogramming it. There are two kinds of sockets, but only one works well with ATtiny85 projects that require flattening the pins (as we found out the hard way!).

This one with round legs and beads at the top does *not* work well because the legs snap off when you try to bend them 90 degrees to solder them onto paper-based projects; however, they work fine for breadboard projects.

This kind with flat legs works well if you want to do a paper-based project where the legs need to be bent 90 degrees. You can buy these on SparkFun for less than a dollar. However, they are even cheaper on eBay (search "8 Pin DIL/DIP IC Socket" and you can get hundreds for a couple of bucks).

Line it up. The ATtiny85 needs to be lined up *exactly* the right way when you put it in any socket. It has a dot by the reset pin, which lines up with the notch on the socket.

Connect to the computer for coding. To program the ATtiny85, an interface to a computer is needed. The easiest way to connect is by using a little board with a socket to plug in the ATtiny and the USB port to connect to the computer. The best ATtiny85 programmer we know and love is the Tiny AVR Programmer board from SparkFun, which has an awesome tutorial and support.



The Tiny AVR Programmer board can take code sent from the computer and load it into the proper locations in the ATtiny85's program memory.

Note: There are other ways to program an ATtiny85 using an Arduino UNO that can be found online, but we highly recommend the SparkFun Tiny AVR Programmer because it is designed to allow you to prototype projects directly on it.

Setting up your ATtiny85 to talk to Arduino IDE

The best guide to setting up your Tiny AVR Programmer to talk to the Arduino IDE is the tutorial found on the SparkFun site.[2]

Coding with the Arduino IDE

Coding with digital inputs and outputs. For digital inputs like buttons and digital outputs like LEDs and buzzers, the code generally looks exactly like it does for any standard Arduino-like microcontroller development board.

Coding with servo motors gets a little more complicated. Here are two things you need to know and some example code we know and love for you to remix:

- **Servos can be used on any of the five digital pins 0–4.** This is because the servo library code does its own pulse width modulation (PWM).
- **You must use an alternate servo library with the ATtiny85.** The standard Servo.h library does not work with the ATtiny85 because it relies on a 16 MHz clock and the ATtiny85 uses an 8 MHz clock.

The library we find works best with servos is a modified version of the smaller SoftwareServo.h library.[3] George Swallow modified the Software-Servo library and called it SoftwareServo1, with some improvements that make coding the servos a little easier.

How does using the SoftwareServo1 library change the Servo code in sketches?

This comparison chart shows the changes needed for a simple sketch. The code commands a servo named "Tyrone" to move from 0 degrees to 179 degrees every 1.5 seconds or 1,500 milliseconds.

Using the Standard Servo Library	Using Software Servo Library	Notes
#include <Servo.h> Int servoPin = "pin # of servo"; Servo Tyrone;	#includeSoftwareServo1.h> Int servoPin = "pin # of servo"; SoftwareServo1 Tyrone; Int i;	*Change name of library* *Same for both* *Create and name a servo object* *Set up variable refreshing*

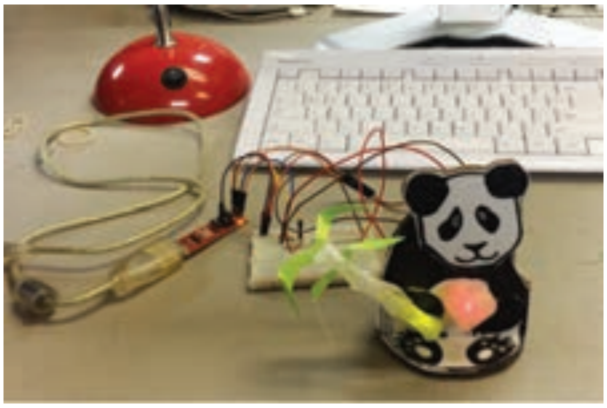
void setup () {
Tyrone.attach(servoPin);
}
	void setup () {
	Tyrone.attach(servoPin);
	Tyrone.setMinimumPulse(496);
	Tyrone.setMinimumPulse(2245);
	}
		Same for both
		Need to modify servo parameters

void loop () {
Tyrone.write(0);
 	
delay(1500);
 	
Tyrone.writer(179);
 	
delay(1500);
}
	void loop () {
	Tyrone.write(0);
	
	for(i=1; i<30; i++)
	{ SoftwareServo1::refresh();
	delay(50);
	}
	
	Tyrone. write(179):
	
	for(i=1; 1<30; i++)
	{ SoftwareServo1::refresh();
	delay(50);
	}
	}
		Same for both
		
		Modify delay using "for loop" that refreshes the servo position every 50 milliseconds, 30 times for total of 1500 milliseconds
		
		Same for both
		
		Modify delay using "for loop" that refreshes the servo position every 50 milliseconds, 30 times for total of 1500 milliseconds

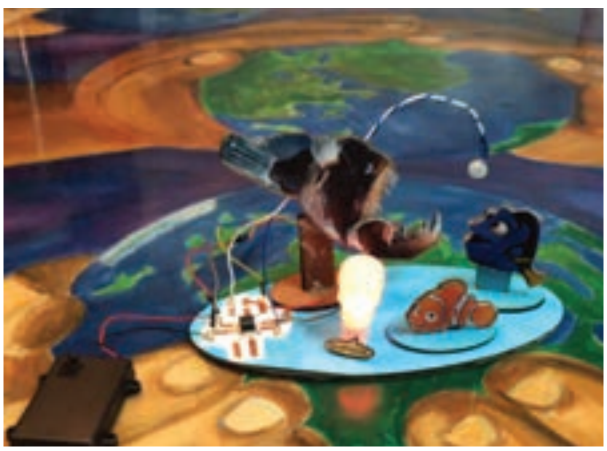
Making with the ATtiny85

One cool introductory activity is a kinetic sculpture with LEDs and servo motors.[4] We have been experimenting with using ATtiny85s in a kinetic sculpture activity inspired by the work of Jeannine Huffman[5] and the work of Per-Ivar Kloen & Marten Hazelaar ("Easy Electronic Circuits with a Vinyl Cutter," page 140). We are remixing Jeannine Huffman's kinetic sculpture panda. We added 3D-print diffusers for the LEDs to inject a little fun!

You can program the sculpture with the ATtiny on the Tiny AVR Programmer board and use a breadboard to test the connections.



Once the coding is done and the circuit is tested, you can integrate the ATtiny chip into your sculpture, making it stand alone. Here we are using vinyl-cut copper circuit traces (using Per-Ivar's design) in a kinetic sculpture called "Nemo & Dory Danger! Anglerfish!"



Acknowledgements

With gratitude for encouragement and assistance from our friends Per-Ivar Kloen and Jeannine Huffman. All the beautiful hand-drawn ATtiny85 illustrations are through the kindness of one of my favorite graphic artists of the maker movement, Marten Hazelaar from the great country of The Netherlands.

Notes

1. Full downloadable ATtiny Physical Computing Guide: docs.google.com/document/d/1j8A7e_TzYgqrm-Z8aqnHQWNH-5SzWI8R7GLIwK2TYag
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Easy Electronic Circuits with a Vinyl Cutter

by Per-Ivar Kloen

Using a vinyl cutter, you can make your own electronic circuits of copper tape. It's a very easy and extremely cheap way to create your own circuits.

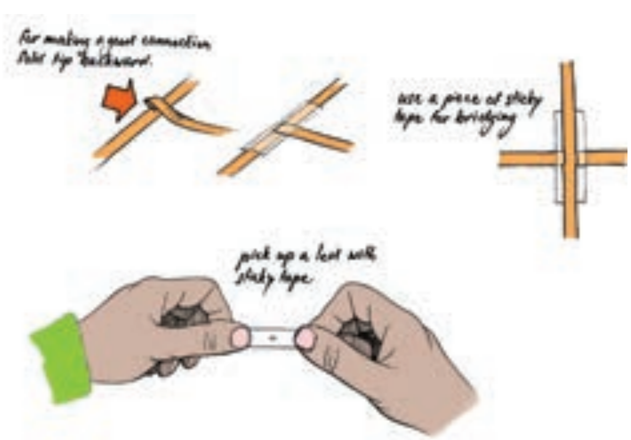
Idea

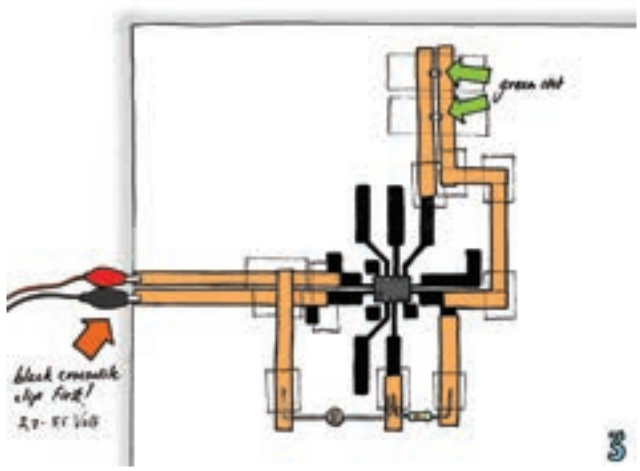
Building circuits made with copper tape is not a new idea. You can take small pieces of copper tape and create a circuit by hand. But what if you could design a more sophisticated and reliable circuit cut out of a large piece of copper tape using a programmable cutting machine like a vinyl cutter? The only problem would be to find suitable copper material. The options are often very expensive—too expensive to use for classes with thirty students.

Out of frustration I searched other ways. In particular, I wanted to program the paper circuits with an ATtiny. (The ATtiny is a small and cheap programmable chip.) The idea eventually evolved into a technique for screen printing the circuit traces.[1] The break-out trace allows you to easily connect to the pins of the ATtiny and makes it easier for students to work with.

During the 2016 FabLearn conference, I met Jeannine Huffman and fellow FabLearn Fellow Susan Klimczak. They have been using the ATtiny and paper circuits for their youth projects for a lot longer than I have and do wonderful things! They were very excited to learn how our ATtiny circuit trace was designed as I demonstrated it for them. During that conversation, we also found that we shared an enthusiasm for finding new ways to use programmable and expressive paper circuits with students, inspired by the poetic work of Jie Qi.[2]

Susan started to use our break-out trace, and a few months later I got a tweet saying that she had made the circuit traces by vinyl cutting copper tape. What? Wait! She uses this to make small pieces of kinetic "art with a message"! Crazy! Soldering also proved to be easy to do. What a great idea! (See "Tiny Adventures in Affordable Physical Computing" on page 136.)





Encouraged by Susan's enthusiastic tweets and even more convinced of the usefulness of her work, I gave the idea another chance. After finding a reasonably priced roll of wide copper tape, we started to experiment.

What do you need?

Making is about using materials, so we need to buy stuff. The key piece of equipment needed for this technique is the vinyl cutter (although you might also be able to cut circuits with a sharp knife). With a vinyl cutter, you can cut a lot more than just circuits. To have an idea and to be able to make it and hold it in your hands is a powerful thing. There really should be a vinyl cutter in every school; they are cheap and easy to use. It's the ideal stepping stone toward digital fabrication.

One-time purchase:

- Vinyl cutter (I recommend ordering an extra knife.)
- ATtiny programmer
- Tweezers
- Power supply (adjustable)
- Power jack to crocodile clips adapter
- Soldering iron

Consumables:

- Copper tape 3 mm, 5 mm, and 100 mm wide
- Transfer film
- ATtiny
- DIP 8 socket
- Surface mount (SMD) LEDs 1206
- Solder

Tips and tricks

Creating a circuit takes four steps:

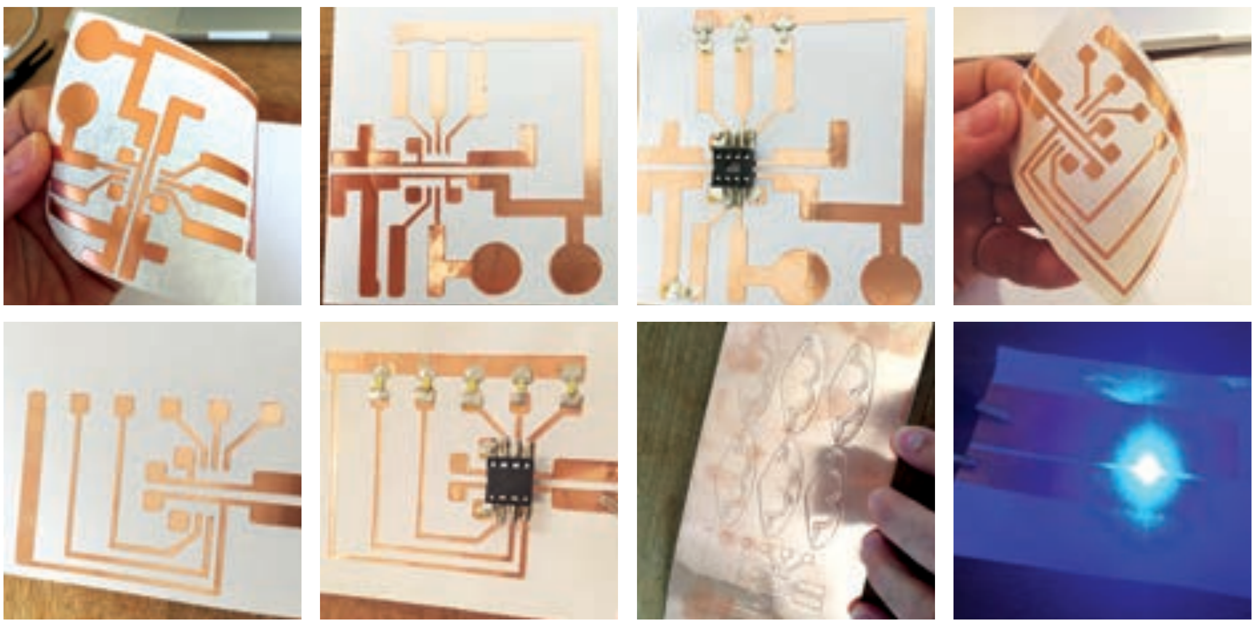
1. Draw the circuit.
2. Cut the design.
3. Transfer the design and solder the components.
4. Program the ATtiny.

Drawing the circuit

You need a vector drawing program. I use Affinity Designer for the designs and Adobe Illustrator to operate the vinyl cutter. I build the design in pieces and finally unite them into one circuit trace design. Remember to do this; otherwise, they will be cut as individual pieces, and the circuit will not work.

Cutting the design

While designing your circuit, do not draw line traces that are too thin because the design may be cut all the way through. Lines thinner than 1.5 millimeters are likely to break during cutting. Because we use a 100-millimeter-wide roll of copper tape, your design can be up to 200 millimeters long (the



width of our vinyl cutter, Roland Stika SV8) and 100 millimeters wide. You always have some loss, so the actual size is a bit smaller.

Transferring the design and soldering the components

After weeding—or taking off the extra copper pieces to leave only the copper circuit trace (which is easy to do with tweezers), transfer the design with transfer film. You can stick it on plain paper or any smooth surface. Soldering is very simple. Put the tip of the soldering iron on the copper tape, wait for a second, and apply some solder. To solder the socket or SMD LED, I place a little puddle of solder at the place where I want the components to go. Then, with the tweezers, I put the socket or SMD LED in place. Just heat the solder again and everything flows together. If you make a mistake, just reheat the puddle and remove the component.

The leftover pieces can be used to make an SMD test strip. Just use strips of copper tape with a gap of 2 millimeters on a piece of paper, then connect the power supply (3 volts) with crocodile clip leads, and you're ready to go. You can test all LEDs before soldering them in place. You can also test them afterwards by keeping the crocodile clips in the right place and powering each component. You can do this without having the ATTiny in the circuit.

Programming the ATtiny

If you have never programmed anything with the Arduino IDE, there's a little learning curve. It is really not that hard; you probably only have to do it once. All it takes is time and attention. You can always ask others to help you. There's always someone around with Arduino experience, or you can visit a neighboring Fab Lab, library, or maker-space to find folks that can help.

You can use the Arduino IDE to create programs for your circuit. If you are not familiar with Arduino, you may use Circuits on Tinkercad. It's a simulation (with the ATtiny) and uses block programming. It's really easy. Once you get your simulation to work, you can download the program as an Arduino-compatible file. (See page 136 for programming details.)

Why bother?

In the following paragraphs I explain why I'm enthusiastic about this technique.

It promotes problem-solving

As with any design or creation, you have to deal with constraints. Constraints really help with the creative process. With the ATtiny the space for your design is limited. The ATtiny is very powerful, but it has a finite number of possibilities. When making my prototypes, I had to solve a lot of little puzzles. How do I get what I want? Thinking, trying, thinking again—that's a powerful path to learning, and it gets you focused.

It became once again clear to me that the level of understanding I get when I make something is quite different from when I learn from reading a circuit on paper. When I was designing a circuit for Charlieplexing–-using a microcontroller to control an array of LEDs–-I thought I understood the circuit by studying it on paper, but that wasn't the case. I finally "got" how it works only when I actually built it myself.

It's iterative

This is a very powerful point. Because we use digital manufacturing, you can quickly make your idea into a prototype and have it in hand. You'll soon find out if your idea works–-or doesn't. That's the fun part! Your concepts and ideas can be tested in the real world. Did you do something wrong? Then you can make changes quickly, redo the circuit, and have a new prototype in your hands within minutes. This is the major advantage of digital manufacturing. It's shifted what used to be just making skills to "thinking through making" skills. Paulo Blikstein calls this "the democratization of invention" (2014).

It's affordable

Affordable? Making takes money. That's just the way it is. What I like here is that you have a working project for about a dollar. Students can take their projects home. They can reuse the chip to create a new project for a few cents. Few techniques are so affordable. For around $500 you are all set for a class of students, including the vinyl cutter—keeping in mind you can do so much more with a vinyl cutter.

It has a low floor

You can already see the "low floor" between the lines in the easy way this project can start. The 2D drawing, programming, and the vinyl cutter—all have a very low floor for beginners. And because it's inexpensive, you can repeat the project and extend it with new challenges, criteria, and constraints that create new learning experiences for students.

It has a high ceiling

The more students use these materials, the more imaginative and creative they can be, all while learning new skills. Yes, you can learn programming or understand electronic circuits better. But you can also use it creatively and expressively. What could you do with the subject that you teach? Can LEDs indicate the metric rhythm of a poem? Students usually invent unexpected things when they have expressive freedom.

Even though the ATtiny is very small, it is really versatile and powerful. At the end of this article there are some helpful resources for ideas about the various possibilities of the ATtiny.

Vinyl circuits and cardboard are natural partners. An ATtiny, a servo, Make Do fasteners, and cardboard—imagine the possibilities!

What's next?

I received a tip to use an ESP8266 module instead of an ATtiny. It's somewhat more expensive ($1.75 instead of $0.85) but much more powerful, with more pins and Wi-Fi enabled.

You could also use the BBC micro:bit as a "brain," using crocodile clips to control your design. However, this makes letting students take their design home a lot more expensive.

Because the circuits bend, Susan Klimczak suggested making bracelets. You can use a 3-volt coin cell to power it (and a magnet as the clip for both turning on the circuit and fastening the bracelet). The advantage with this is that your circuit traces can become the design. Imagine beautiful patterns decorated with working LEDs!

I'm thinking of doing something with the ATtiny touch-sensitive pins—maybe a project that is like a Makey Makey in function. It could be a project about cells, for example, where if you touch parts of the cell, it is programmed to light up an LED next to descriptive text. I just have a feeling there's a meaningful activity calling my name.

Resources

A treasure trove of ideas, materials, and techniques: How to Get What You Want: Kobakant DIY wearable technology documentation. kobakant.at/DIY

Here you'll find my designs and used code: dropbox.com/sh/zrf6ijlavrhrtye/AABU6-0QczbFhLU-zonCUeH7a?dl=0

Notes

1. dropbox.com/sh/nspx6oyf9hw5h17/AAAr0-6fpdAVqhVwm5bxDow9a?dl=0
2. technolojie.com

Reference

Blikstein, P. (2014). Digital fabrication and "making" in education: The democratization of invention. In J. Walter-Hermann & C. Büchung (Eds.), *FabLab: Of machines, makers and inventors.* Bielefeld, Germany: Transcript-Verlag.

3D Printing with Primary Students

by Angie O'Malley

When I started teaching my students about 3D printing, I limited it only to students in intermediate and middle school grades. I knew there could be value in also having younger students experience the process, but I wasn't sure where to start. In my experience, many of the apps that transform 2D drawing to 3D files didn't work well enough to risk using them with whole classes of students. However, Tinkercad is stable and easy to use, eliminating this issue.

Here are some tips on how to best teach 3D printing using Tinkercad to primary students (ages five to seven):

- Have students work in pairs, sharing one computer.
- Make sure students have prior usage of computer/mouse/trackpad navigation. The fine motor movements of shaping and rotating objects alone in Tinkercad can be challenging for the youngest makers.
- Before working in Tinkercad, have students use patterns on a table to stack, rotate, and otherwise manipulate shapes. Discuss terms like *rotate* and *flip*.
- Explain to them that computer-aided design (CAD) programs aren't always designed with their age group in mind. Remind them to have patience with themselves and their partner through the process. Learning something new can feel hard, and that's okay!

- Start with the basics. You don't have to show them all the capabilities in one session. Slowly add to their repertoire as they gain confidence and understanding.
- Start with creating objects that allow for more imagination than realism. Students are less likely to get stuck on the fact that it doesn't look the exact way they had in mind. Some ideas include: robots; an animal that doesn't exist; creating a hole with obstacles for a miniature golf course (using a marble as a golf ball); or snowflakes
- Have the 3D printer running so they can feel excited and inspired. While it's printing, walk students through the process of how designs get from the computer screen to a completed print.

Toy Hacking for Accessibility

by Angie O'Malley

One of the most impactful projects my fifth-grade students take part in is a project to hack toys to make them accessible for kids with disabilities. This simple project, which results in toys that might otherwise cost families upwards of a hundred dollars, can be done for under one dollar.

The toys, which began as a standard plush toy with a push-button to produce sound and movement, were transformed into a toy equipped with a 3.5-millimeter stereo jack. This new plug, which students installed, allows for any standard adaptive switch to be plugged in and used. This modification allows kids who already have specialized switches to plug in and play. In addition, the fifth-grade students made their own tap switch that can be activated by a slap, tap of a foot, or nod of a head.

To begin, students took apart the seam of the stuffed animal, leading to the press switch. Once inside, they cut the wires attaching the original press switch. From here, they stripped the two wires. Next, students took a 3.5-millimeter stereo extension cable and cut it in half and stripped both cables. Then, they took the stereo extension jack and wired it into the two wires in the stuffed animal. My students used electrical tape to secure the wires, but you may also want to solder them for a more secure connection. Once the new jack was in place, students tucked the extra wire into the stuffed animal and sewed it so just the end of the jack was sticking out.

Students then worked on creating switches in a most basic and economical way. They took two squares of recycled cardboard and covered them with foil, then "sandwiched" the two boards together with extra bare cardboard placed in the middle. Students then took the remaining half of the stereo extension cable and taped one wire to each side of the "sandwich." The switch could now be plugged into the stuffed animal and activated.

There is a lot of room here for modifications and creativity. Challenge students to invent their own switches to meet the needs of various children for whom your class is making the toys. Perhaps a child can only use a foot tap, a head nod, or a breath sensor. Encourage students to create switches that will work for specific situations.

Wood Block Phone Charger Workshop in Uganda

by Juliet Wanyiri

One Saturday afternoon, Yvette and I headed to Mpigi in Uganda, which is about an hour from the capital, Kampala, representing Foondi Workshops. Watoto Church Vocational Training Institute in Mpigi is based at the heart of a village and is home to hundreds of students, most of whom are orphans and some of whom come from the nearby villages.

Many homes in the villages do not have access to electricity and use candles for lighting. While most people have phones, you need to pay 500 UGX ($0.20) to charge your phone in town. Like several places in Uganda, *boda bodas* (motorcycles) are used for transport everywhere. We thought, "What if people could charge their phones using the battery from a boda boda, which is more easily accessible than a charging shop? What if boda boda drivers could build or buy these portable mobile chargers and earn some extra money?" We ventured out to Watoto Church find out.

Livingston Sebyatika, one of the institute's administrators, gathered together fifteen students from the technical school. These students, in their late teens, are currently studying carpentry, electrical installation, and metalwork at the center's technical institute. After leaving the institute, most students want to become adept engineers and designers, which came through strongly as we carried out the workshop.

Rolling up our sleeves and diving in

Our plan for the afternoon was to build a wooden phone block charger simply by using a 12-volt car/motorcycle battery, a car phone charger, wood, sheet metal, wires, and a 13-ampere fuse.

We put together the tools and materials, split the students into two teams, rolled up our sleeves, and dove right into the build-it session. A build-it is a guided design activity aimed at systematically teaching an engineering concept. It also teaches the use of basic hand tools and fabrication processes.

The first step was to prepare the wooden block. This is where the phone charger would be plugged in, so we needed to make four charging ports using a 7/8-inch drill bit. Alternatively, you could use a brace and bits of the same size (which is what we did later when we encountered a power interruption).

For conduction purposes we cut and bent the sheet metal to form cylindrical inserts for the four holes that we had previously drilled. The tabs from these cylindrical inserts would stick out of the board and form the negative terminal of the circuit.

With the remaining sheet metal, we cut out the positive terminal for the circuit. This sheet was nailed over the holes. A second sheet was then nailed over the tabs for the negative terminal.

Lastly, we connected the positive terminal using a wire and 13-ampere fuse to the battery. After ensuring we had a complete circuit and that there were no short circuits, we tested and pow-

ered up the phone. It worked! The students were so excited that their first reaction was to build more phone chargers and start a business selling them in town. They could definitely see how these units would come in handy in the neighboring town and village.

Reflections

Great tools make everything run more smoothly and increase the chances that the outcome will meet the design requirements of the build-it activity. Our team is deeply grateful to the vocational institute, which shared its tools with us for the workshop.

At one point, one group's wooden block broke in half as the participants were nailing the pieces, and their first reaction was, "That's easy to fix. We'll just hold it together with a metal piece and some nails." And they did. And it worked perfectly.

Having a smart, energetic, and driven team of participants made the workshop have more meaning and impact as they were eager to learn a new technology that could solve a local challenge. What also stood out was their dexterity and attention to detail at every point of the build-it activity. It will be exciting to see how their inspirations and creativity will have an impact on their community.

Future plans

Foondi Workshops[1] plans to continue working with these students by following up on this phone charger project as well as conducting more creative capacity-building sessions with them.

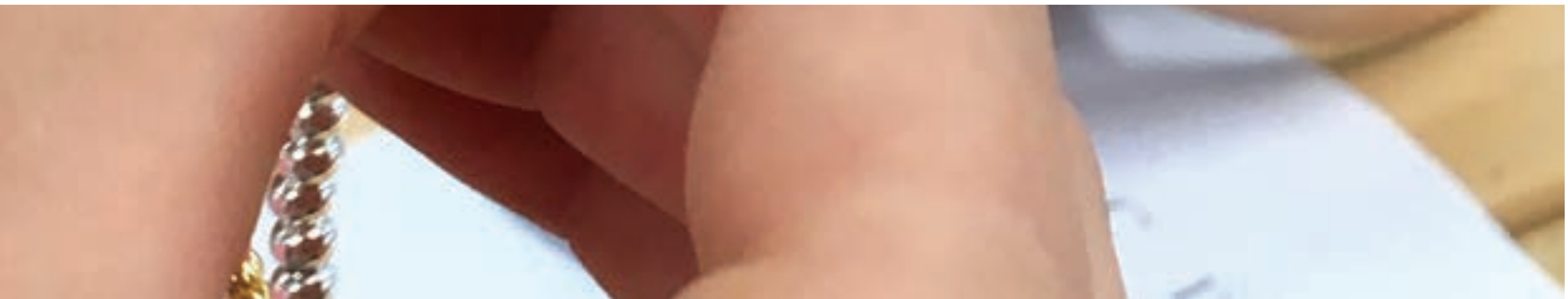
We're looking forward to holding more workshops with relevant projects for the communities we work with. We want to see more people make use of their hands-on skills and design background to develop tangible, appropriate technologies for their communities.

Our workshops will continue to provide a platform for problem setting, designing, and prototyping entrepreneurial-based ventures.

Note

1. foondiworkshops.com

Project Snapshots



This collection of projects contains some of the favorite projects of the FabLearn Fellows. These are go-to activities that always work, projects that were especially engaging, or tried-and-tested projects that showcase thoughtful educational practice and student-centered learning with modern materials. The projects are short and free-form, capturing the essential heart and soul of the project instead of trying to fit them into a one-size-fits-all "lesson plan" template.

These project snapshots accommodate a wide variety of grades and experience levels; vary in length and expertise needed; and use many different tools, materials, software, and hardware. This wide variation may seem random, but it is deliberate. One of the challenges of creating a coherent set of resources about making in learning spaces is that there are so many variations in tools, spaces, time, subjects, and experience levels. We have embraced the chaos with this grab bag of favorites.

These projects showcase the remarkable variety and range that happens in student-centered environments rich in materials and imagination. To give this collection some organization, we have sorted them loosely by grade level. The projects in the first section have been identified by the author as suitable for all ages. The subsequent sections start at lower grade levels and go up from there. These are suggestions, of course; in many cases these projects can be leveled up or down by changing the tools, materials, time allotted, or scaffolding.

We invite you to view these projects as starting points rather than complete recipes. Some projects have resources to learn more, and every FabLearn Fellow has a page on the FabLearn site (fablearn.org) where they can be contacted. Browse and find the ones that speak to you. Many are works in progress, but that's how making works! (Iterative design isn't just for kids.)

The following tables provide recommended age or grade, tools and materials, additional supplies, and recommended software for the projects in this chapter. All ages and grades are approximate; accommodations can often be made for different ages. Use your own judgment to decide if these projects are appropriate for your own environment and participants.

GRADE- AND AGE-APPROXIMATE EQUIVALENTS

Level	Grade	Age
Lower Elementary	PK–3	Under 8
Upper Elementary	3–6	8–10
Middle School	6–9	10–13
High School and Beyond	9–12 (and up)	13 and up

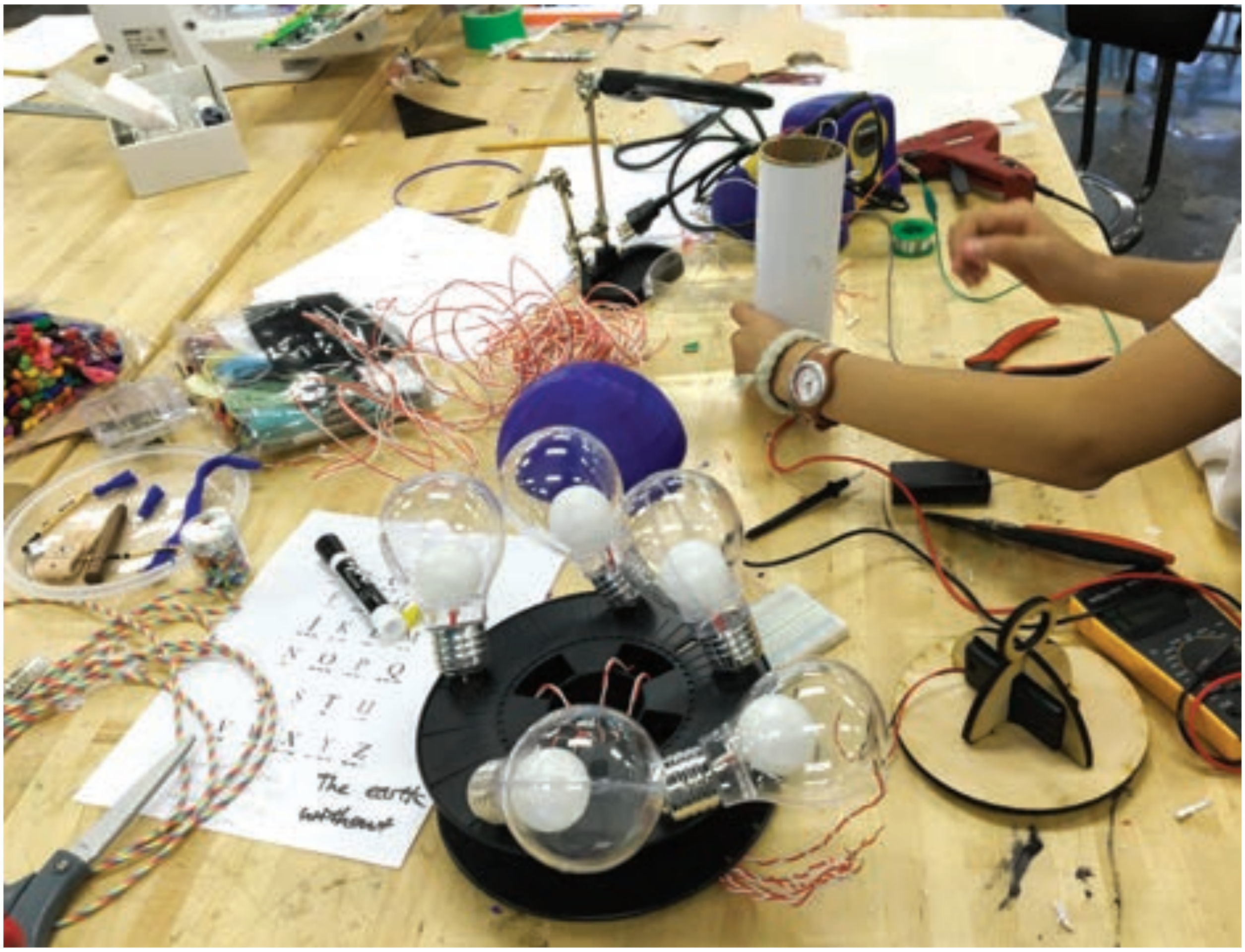
The next table provides examples of the types of tools, materials, and supplies used with the project snapshots. Makerspaces also typically provide students with traditional arts and crafts materials, standard tools such as scissors and pliers, and computers, which are not listed here.

TOOLS AND MATERIALS

Tools and Materials	Examples
Conductive Fabrication	LEDs, copper tape, conductive thread, conductive yarn, conductive fabric, batteries, battery holders
Sewing	Fabric, felt, needles, snaps, buttons, sewing supplies, sewing machine
Digital Fabrication	3D printer; laser cutter; CNC router, engraver, or mill; vinyl cutter and associated consumable supplies
Craft	Tape, glue, scissors, art and drawing supplies, office supplies, decor items, cardboard, paper, recycled materials
Electronics	Resistors, small motors, capacitors, breadboard, wire, potentiometers, buttons, switches, soldering iron
Microcontrollers	Arduino or other microcontroller board, shields, sensors, actuators, displays
Building	Wood, metal, PVC pipe, nuts, bolts, screws, hand and power tools

ALL GRADE LEVELS

Project Title	Page	Tools/Materials	Additional	Software
Electric Pop-Up Cards	156	Craft, conductive fabrication, digital fabrication (*optional*)		
Reverse Engineering	157		Small toys and interesting objects	
Rube Goldberg Chain-Reaction Machines	158	Craft, building		
Sunbeam T-Shirts	160	Craft	A big vessel for washing the T-shirts once the T-shirts are done, T-shirts, cyanotype printing chemicals	
Tons of Stuff	161	Craft	Anything you have a lot of	
Upcycling Packaging	162	Craft, building		
Signs That Matter	163	Craft, building, electronics, digital fabrication		Graphics software or word processor



LOWER ELEMENTARY AND UP

Project Title	Page	Tools/Materials	Additional	Software
Mini Makers: Food-Grade Paint	164		Flour, salt, food coloring	
Mini Makers: Houses	165	Craft, digital fabrication		
Biomimicry	166	Craft		
School Post Office	167	Craft, conductive fabrication, building		
Makey Makey Crafty Controllers	168	Craft, conductive fabrication	Makey Makey	Scratch, Minecraft
Hard(ware) Fun	169	Microcontrollers	Any robotics kit or electronic components	
Bristle Bot Maze	170	Craft, building, conductive fabrication	Motorized bug toys (Hexbugs)	
Glow Golf	171	Craft, conductive fabrication, electronics, microcontrollers	Glow sticks, golf balls, toy golf clubs	
Board Game: Missing Pieces Provocation	172	Craft, digital fabrication (*optional*), micro-controllers (*optional*)	Makey Makey (*optional*)	Tinkercad, MakeCode, Scratch
Laser-Cut/Engraved Pins	173	Craft, digital fabrication	Pin backings	Vector software such as CorelDraw
Tracing Images for 2D and 3D Design	174	Digital fabrication	Materials or supplies not needed if students are just practicing tracing and not printing anything	Graphic design software such as CorelDraw, CAD software such as SolidWorks
Robot Storytelling	175	Craft, sewing	Robots (we used Dash and Dot)	Blockly (block program on iPads for Dash and Dot) or Scratch
Using Low-Resolution Prototyping to Learn Design and Solve Problems	176	Craft, conductive fabrication, sewing		None required, but some wireframing apps can be used to create low-resolution app prototypes
Group Puzzle Frame	177	Craft, digital fabrication		Teacher uses Inkscape
Build-tionary	178	Craft, building	Anything you want, but try not to overcomplicate things	
Choose-Your-Own-Adventure Role-Playing Games	179	Craft	Paper, pencils, dice, tokens	Twine, Scratch

UPPER ELEMENTARY AND UP

Project Title	Page	Tools/Materials	Additional	Software
Solar Bobble	180	Craft, electronics, building, digital fabrication (*optional*)	Solar cells, geared motors, soldering iron	Libre Draw (if designing their own bobbles)
Laser-Cut and Makey Makey Game of Operation	181	Craft, conductive fabrication, building, digital fabrication	Makey Makey	Scratch, vector design software such as CorelDraw
First-Hand Sewing Project: Stuffed Animal or Smiley Face	182	Craft, sewing		
Interactive Body Systems Exhibition	183	Craft, conductive fabrication, electronics	Makey Makey or other physical interface	Scratch
Locker Mirrors	184	Digital fabrication		Adobe Illustrator or Inkscape
Talking Historical Quilt	185	Conductive fabrication, sewing, digital fabrication	Makey Makey	Scratch, Inkscape
Customized Rubber Stamps	186	Craft	Mold making, casting, alginate, two-component silicone rubber	
Earthquake Engineering	187	Craft, building, digital fabrication	Earthquake-simulating table	3D CAD software
Dia de los Muertos Laser-Cut Calavera Art	188	Craft, building, digital fabrication		CorelDraw or other vector software
Tinkering with Spinners	189	Building, digital fabrication		Inkscape or similar
Quick Cuts: A Flash Film Festival	190	Craft, building, sewing	Video camera or phone with video capture; cheap and plentiful building materials, e.g., cardboard foam core, hot glue, scrap fabric; miscellaneous props (the stranger and more unusual, the better)	Video editing software, e.g., iMovie (Mac/iOS), Adobe Premiere, WeVideo (free, cloud-based video editing), or Adobe After Effects (if you're fancy!)
Paper Bits	191	Craft, conductive fabrication, electronics, microcontrollers	micro:bit	MakeCode, Scratch, or Snap4Arduino
PLA Melts	192	Digital fabrication	PLA scraps, thin PLA prints, toaster oven	Any 3D modeling software if creating prints for melting
Cardboard Fashion Show	193	Craft, conductive fabrication	Box cutter knife, cutting mat	*Optional:* vector program for designing shapes
Hack Your Classmate	194	Craft, conductive fabrication	Box cutter knife, cutting mat	
Shadow Tinkering	195	Craft, conductive fabrication		

MIDDLE SCHOOL AND UP

Project Title	Page	Tools/Materials	Additional	Software
The Cucumber Slicer	196	Craft, digital fabrication	Food-safe PLA filament, saw, glue or hot glue gun	Tinkercad, Cura
Escape Room Design	197	Craft, electronics, digital fabrication (*optional*), micro-controllers (*optional*)		
Write It Do It	198	Craft		
Algorithmic Art	199	Sewing, digital fabrication		Turtlestitch, Beetle Blocks
Prosthetic Hand Design	200	Craft, conductive fabrication, electronics, building, sewing, digital fabrication (*optional*)		
Programmable Pinball Machine	201	Craft, electronics, building, microcontrollers	Beta kit (our own Arduino-based physical programming kit)	Scratch for Arduino or similar
Marbling Plywood for Laser-Cut Parts	202	Craft, digital fabrication	Wood	2D vector design software
Pixel Art	203	Craft	Color printer, wood, Mod Podge, acrylic paint and/or markers	Pixel-by-numbers app
Material Exploration in Mold Making	204	Digital fabrication	Silicone, supplies or silicone molds	Any 3D modeling software
Contact Mic Synthesizer	205	Craft, conductive fabrication, electronics	Arduino or Makey Makey; contact mic, cigar box, rice, Slinky, springs, cans, etc.	
Office Supply Flair	206	Craft, conductive fabrication, electronics	Soldering iron	
Repair Café in the School Makerspace	207	Craft, conductive fabrication, electronics, building, sewing		Internet research, e.g., ifixit.com, YouTube tutorials for fixing stuff
Recycling and Upcycling Furniture for Your Makerspace	208	Craft, building	Furniture: chairs, workbenches, tables	Design software, photo/video software for documentation (time-lapse, etc.)
3D Maps	209	Building, digital fabrication	Geodata acquisition and processing	QGIS, netfabb, Cura, or others
Turnery for Kids	210	Craft, building	Wood lathe, chisels	
Round, Arched Rain Roof	211	Building	Cordless screwdriver, handsaw, hammer, yard-stick or measuring tape	Inkscape

MIDDLE SCHOOL AND UP (Continued)

Project Title	Page	Tools/Materials	Additional	Software
Microfilms and Microstills	212	Building, digital fabrication	Wet and dry art materials; computer for image capture	QuickTime
Creating Physical Interfaces to Minecraft with a Raspberry Pi	213	Electronics, microcontrollers	Raspberry Pi, Sparkfun PiWedge	PiForge
Cardboard Chair Challenge	214	Craft	A lot of cardboard!	
Animating a Model of Myself in Scratch	215			Scratch
Make History	216	Craft, conductive fabrication, electronics, building, microcontrollers	Hummingbird kit, mBot, Makey Makey, Grove sensors for Arduino, micro:bit	Scratch, Snap!, Tinkercad circuits
Liver It Up!	217	Craft, conductive fabrication, electronics, building, sewing, digital fabrication		Vector graphics program

HIGH SCHOOL AND UP

Project Title	Page	Tools/Materials	Additional	Software
Creative Capacity Building	218	Craft, conductive fabrication, electronics, building	Cardboard and other prototyping materials	SolidWorks
Introduction to Physical Programming	219	Microcontrollers, electronics	Squishy Circuit dough	
Creative Robotics	220	Craft, electronics, building	mBot off-the-shelf robotics kit, LEGO WeDo 2.0, or whatever kind of robotics kit you have	mBlock, Scratch
Spaghetti Tower	221	Craft	Spaghetti, marshmallows	
Glitch Art—Happy Accident or Controlled Chaos?	222		Computers, digital cameras, printer, photo printing paper for final exhibit	Word processor like TextEdit; GIMP, Photoshop, or Preview
Above/Below	223	Digital fabrication	Black adhesive vinyl	Inkscape, Illustrator
Fashion Design with Circuits	224	Craft, conductive fabrication, sewing, microcontrollers	Adafruit Circuit, Playground, or LilyPad Arduinos	Processing
Tin Puzzles	225	Digital fabrication	Altoids-type tin	2D vector design and 3D modeling software

Electric Pop-Up Cards

by Jaymes Dec

Students use paper engineering techniques and paper circuits to create unique and fun greeting cards. This project can be done with a wide range of ages with appropriate scaffolding.

The results are often unique and fun. Also, since they are designed as gifts for others, students really care about the project. The cutting can be done by hand or with a vinyl or laser cutter.

Tools/Materials	Additional	Software
Craft, conductive fabrication, digital fabrication (*optional*)		

Reverse Engineering

by Sarah Alfonso Emerson

Students are asked to reverse engineer an object. Objects can be as simple as a paper snowflake or a toy, or as complex as a kitchen appliance or car motor. They analyze and label the parts, explain how the parts work together as part of a system, and present their findings. They may also be asked to reassemble the parts successfully.

Students practice thinking like an engineer as they analyze how parts work together. They practice design by sketching isometric views of the various parts that make the system work. They communicate their findings in a visual or oral presentation.

This activity takes at least one 45-minute session if the object is small like a clickable pen. At least three 45- to 90-minute sessions may be necessary to reverse engineer a more complicated machine.

Tools/Materials	Additional	Software
	Small toys and interesting objects	

K12

Rube Goldberg Chain-Reaction Machines

by Sarah Alfonso Emerson, Cassia Fernandez, Angela Sofia Lombardo with Giulio Bonanome and Alphonse Habyarimana

Rube Goldberg (or chain-reaction) machines are built with the goal of doing something simple in a very complicated way. They typically include a chain of events, where each part triggers the next, creating one long sequence. This favorite maker activity is extremely flexible and fun. It teaches physics, simple machines, and laws of motion. It can be an introductory activity with physical programming and building since it requires very basic programming and building skills.

It reflects soft skills (like teamwork and problem-solving) and the gap between expectation and reality. It's also a wonderful project for big groups of students with different backgrounds and experience levels, or even for educator workshops.

The machines are often built in teams, so students must think creatively and collaboratively to achieve success. Students have to integrate all the projects into one and help each other a lot to get the collective project working. Humor is a crucial aspect of Rube Goldberg designs, so students should be encouraged to bring their personalities into their designs and have fun. There are many online videos of chain-reaction machines for inspiration, and the life of Rube Goldberg (a real person!) is interesting. Students can even enter their projects into official Rube Goldberg competitions!

At the simplest level, ask students to use a few given or found materials to complete a simple task like dropping a ball into a cup. Increase or decrease the level of difficulty by adding constraints or criteria like using at least two steps and two simple machines, having students fill a given square area, or use at least twenty different energy transfers! Facilitators can help by asking

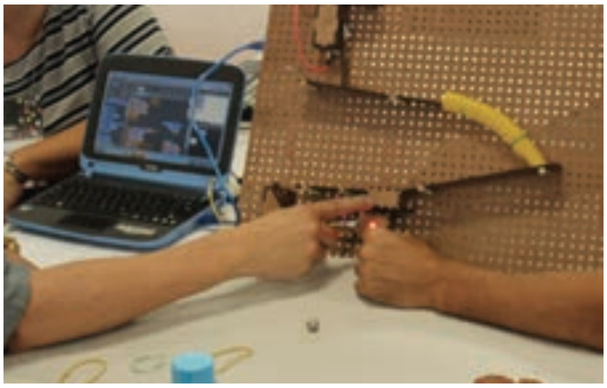
How do you expect this part to work?, *Have you tried it?*, or *How do you think the two parts can connect to let the reaction move on?*

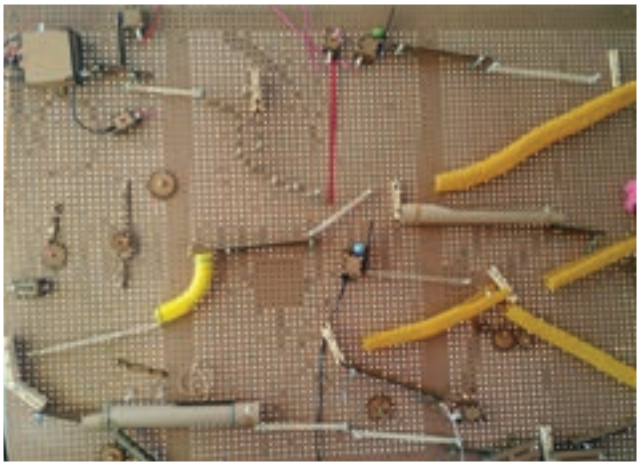
Materials can be open to student choice, required, or an interesting twist of giving each student team the same set of materials. There could be requirements to laser cut or 3D print some part of the machine.

Enhance the activity by adding programmable elements. Use a microcontroller, motors, buttons, light sensors, lasers, and LEDs. Each team's section of the machine must start with a trigger from the previous section, and end with an action that triggers the next part. After programming their machine sections, the groups connect all the sections together to create a big collective project.

Expect this activity to take at least 90 minutes, but it could go much longer or take multiple class periods. (Make sure the machines can sit undisturbed.)

Tools/Materials	Additional	Software
Craft, building		






66

K12

Sunbeam T-Shirts

by Per-Ivar Kloen

Create a print on a T-shirt using cyanotype printing, which uses sunlight to make prints. Many kits and tutorials are available online. Explore shadows, gather materials from nature, explore light bending—then create a T-shirt. Just add some sunlight.

Cynotype printing is very versatile. It can be used in biology (printing leaves, feathers), math (making shapes with Logo or Beetleblocks), physics (making focal points visible), and art (because it's beautiful).

This takes 30 minutes or more. This technique is easy to combine with a vinyl cutter (e.g., for making outlines), a laser cutter (making flat shapes), or a 3D printer (shadow casting 3D objects).

Tools/Materials	Additional	Software
Craft	A big vessel for washing the T-shirts once the T-shirts are done, T-shirts, cyanotype printing chemicals	

Tons of Stuff

by Mathias Wunderlich

Sometimes a makerspace has a chance to acquire "tons" of stuff for free—a hundred beautiful tiny bottles or thousands of similar wooden rods. As a facilitator do you accept such gifts? Do you have storage space for it all? We do, and once in a while we announce a featured activity in which students are asked to make something out of the given material. While this is not an activity that we count on to build specific skills, the results are often surprising and fascinating.

These projects can range from the simple (completed in 45 minutes) to the more complex (requiring several weeks).

Tools/Materials	Additional	Software
Craft	Anything you have a lot of	

K12

Upcycling Packaging

by Mathias Wunderlich

Unbelievable amounts of plastic and compound materials are used for packaging of food and all kind of goods all over the world. Schools can help to develop awareness of the environmental implications by having students make useful things out of used packages. This helps kids to understand limitations of scarce natural resources and the concepts of economy versus ecology.

These can be mostly smaller and shorter projects, some of which can be done in 15 minutes, others in about a week.

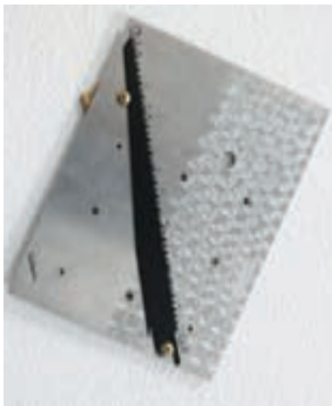
Tools/Materials	Additional	Software
Craft, building		

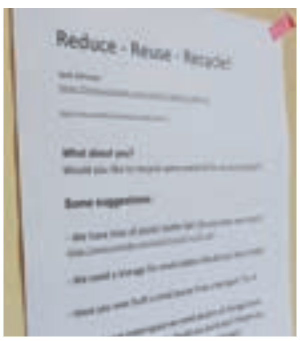
Signs That Matter

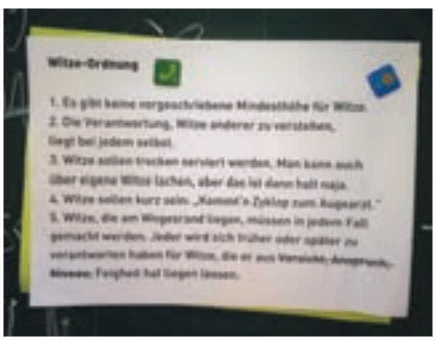
by Mathias Wunderlich

Signs in makerspaces can provide orientation, inspiration, and support. They should be uniquely designed for your specific situation, and they should look good. Some can be simple and clear, but in other cases they may contain mysteries, jokes, or even riddles. Students can be engaged in making signs for their classmates for use within the makerspace. These signs help orient students within the makerspace and can even feed students' curiosity and imagination.

These tend to be smaller projects of under 45 minutes.







Tools/Materials	Additional	Software
Craft, building, electronics, digital fabrication		Graphics software or word processor

PK+

Mini Makers: Food-Grade Paint

by Christa Flores

This project helps introduce preschool makers to art, science, and measurement. They can begin a love of chemistry by making paint from safe-to-touch household chemicals. Using safe household ingredients, three- to five-year-old makers can make paint—a tool that helps them continue to be creative by experimenting with color, texture, and chemical mixtures. All that's needed are salt, flour, water, food coloring, and a plastic bag.

1. Mix ½ cup of salt with ½ cup of flour.
2. Mix salt and flour mixture with ½ cup of water.
3. Add food coloring to make paint colorful.
4. Mix it all together and put the mixture into a plastic bag.
5. Cut the tip of one corner of the bag to squeeze out the paint!

With this "paint," young makers can discover the three primary colors that can be combined to make the three secondary colors. They can describe properties of matter like slippery and viscous.

By giving children open containers and the right-sized measuring cup, they can practice measurement. You can also premeasure the ingredients and put them into cups to just pour into the mixing bowl. You can use scientific terms like a "smooth, homogenous mixture" when describing the need to mix ingredients well.

You can introduce this project with literacy by reading *Mouse Paint* by Ellen Walsh.

This project can be done in 20–30 minutes, not including set-up and clean-up for the facilitator.



Tools/Materials	Additional	Software
	Flour, salt, food coloring	

Mini Makers: Houses

by Christa Flores

Using two basic laser-cut cardboard shapes (a 4 × 4 inch square and triangle) with precut holes for easy connecting, a three- to five-year-old can make a wide variety of high-quality structures. In this activity, preschoolers learn shapes and angles (square, rectangle, arch), structures and loads, 2D and 3D modeling (spatial reasoning), counting, and fine motor skills.

Tiny hands can work with an adult or alone to make easy connections with these precut cardboard construction shapes. Use twist ties or pipe cleaners cut into three- to five-inch segments to connect the shapes. Once the structure is sound and stands alone, additional decoration can be easily added to this sturdy platform. Houses are only one possible theme; you can use the cardboard shapes as three-dimensional tangrams or any kind of art or sculpture project that you do not want to glue or tape.

This activity took 45 minutes because we began by reading *We Were Tired of Living in a House* by Liesel Moak Skorpen and *Building a House* by Byron Barton.

Tools/Materials	Additional	Software
Craft, digital fabrication		

PK+

Biomimicry

by Angie O'Malley

First-grade students complete a unit on biomimicry, including designing and prototyping their own invention inspired by nature. We introduce this unit by showing visuals and contrasting many human-made products with objects found in nature. We then play guessing games, showing images of products made with biomimicry, and guessing what item from nature it was inspired by. Students start the design process by selecting, drawing, and labeling something in nature, and then brainstorm an invention with the piece of nature in mind. Students finish the unit by prototyping and presenting their invention.

Biomimicry inspires many inventions, and even the youngest students can follow this concept. Students learn the science behind biomimicry and can practice the design cycle when inventing and making their object. This project requires very few materials, but if working with older students, it could be enhanced by using sewing, building, or robotic and electronic materials.

Tools/Materials	Additional	Software
Craft		

PK+

School Post Office

by Angie O'Malley

Each year, our second-grade students learn about community helpers in social studies. To integrate this into our innovation lab, the same students are in charge of building and running a school post office. Students design stamps and paper circuit postcards to sell to the school community. They also build carrying and organizing devices that help deliver and sort mail. Devices students have made include backpacks, ramps for moving and lifting heavy packages, and file sorters to sort mail by classroom.

Third-grade students also help with this as they study and then create simple machines such as pulleys to get mail up and down stairs, scooters to deliver mail in the hallways, and catapults to sling mail into classrooms.

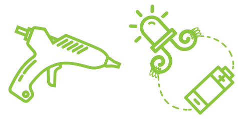
This project brings together the whole school community, and students can use any tools, materials, or technology available. Adults send mail to their children, teachers send mail to students, and buddy classes send letters to their buddies. This encourages literacy, community, and science and design. Each year students look forward to their turn running the school post office.

The activity takes approximately two to three months of 45-minute weekly classes.

Tools/Materials	Additional	Software
Craft, conductive fabrication, building		

PK+

Makey Makey Crafty Controllers

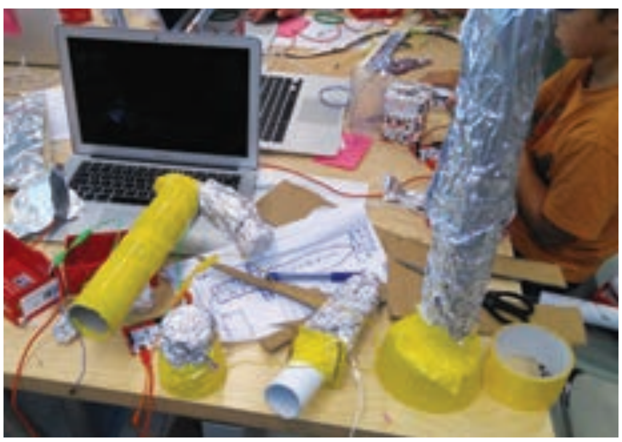


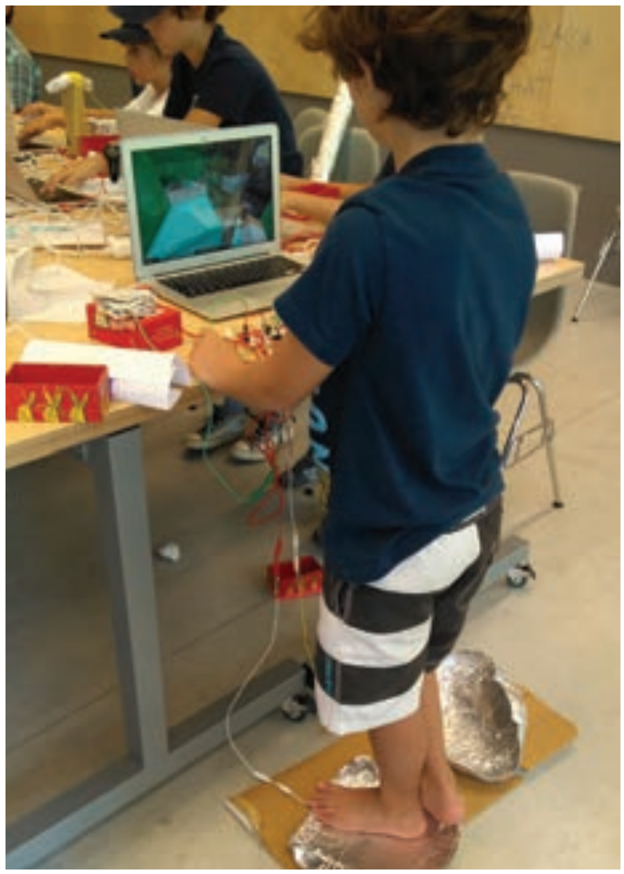
by **Angela Sofia Lombardo**

Students are first introduced to the Makey Makey with two Scratch projects: a Minecraft Maze and a Conductive/Not Conductive game (inspired by a similar game by Susan Klimczak in *Meaningful Making* volume 1, page 107).

Students (or a group of students) have to think about the kind of action they want to control with the Makey Makey (e.g., movement, crafting, destroying, shooting), then think about how they want to control the action, and finally design the final product on paper. Students then choose between different types of materials to create their own controller and play Minecraft in a creative and crafty way. The next day facilitators challenge students to play Minecraft using a Makey Makey instead of a mouse and keyboard.

This is a good way to let kids play and discover how a circuit works while exploring the conductivity of different types of materials. In addition, this activity challenges kids to experiment as active, collaborative, and creative beings in the physical world as they do in Minecraft's virtual world.





Tools/Materials	Additional	Software
Craft, conductive fabrication	Makey Makey	Scratch, Minecraft

PK+

Hard(ware) Fun

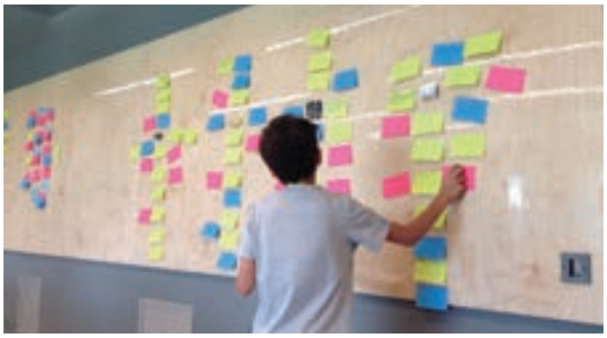
by Angela Sofia Lombardo

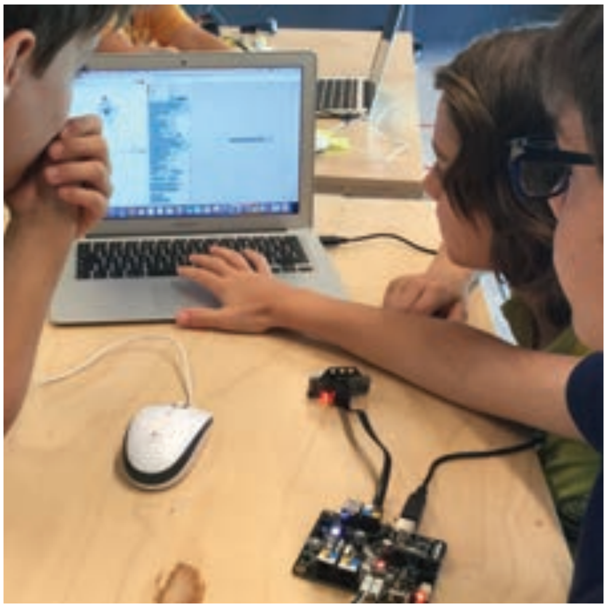
In this activity students are introduced to robotics through a process of computational tinkering, reflection, and design. This works for any off-the-shelf robotics or electronics kit, microcontrollers, or components. Step by step, component by component, kids discover how the hardware works and how to program it; then they create an interactive project using both the computer and the hardware.

Each time a student discovers how a component works, they have to write it onto a sticky note and put it on the "Our Components" wall. At the end of each discovery-tinkering process, kids share their projects with the class, reflect on what that component can be used for, and write ideas on sticky notes for the wall. Facilitators read the sticky notes to the entire class so that the group can discuss ideas and develop even more theories about how each component works.

This activity helps students learn the basics of programming and robotics. It helps students understand how to be creative with each component so they can later design their own robotics creations going far beyond the concept of robots as "things that move on wheels." Discovering by themselves and tinkering with that knowledge, students understand deeply how each component works, how to be creative, and how to express their ideas while working on something meaningful through robotics.

In early iterations of this activity, we only asked that students discover how to code with the components but without any time to tinker with that knowledge or share it with others. We found this led to less interactive, inventive creations. By adding the component wall, students heard many ideas about how things work rather than just sticking with their own theory. Sharing ideas is useful for reflecting on things and finding inspiration. It was wonderful to see different kinds of interactive games and so many different ideas about how to use a component for final projects.





Tools/Materials	Additional	Software
Microcontrollers	Any robotics kit or electronic components	

PK+

Bristle Bot Maze

by Angie O'Malley

This maze unit is introduced to students by having them first complete different types of 2D mazes. Next, students map out their own mazes on graph paper, and these mazes are enlarged with a photocopier. Students then begin mapping and using recycled materials such as straws, cardboard, and craft sticks to create walls.

Students are given a vibrating toy bug (we used a HEXBUG toy) to work its way through the maze, requiring students to make adjustments to walls and angles so the bug would successfully travel through the maze. Additions such as copper tape and LED lights enhance the maze. Students finish the unit by making their own bristle robots.

This is a great beginning-of-the-year project, allowing for team-building and collaboration. This also allows for students to practice the design cycle as they begin with a 2D map of their maze and work up to a 3D working model. This project requires a lot of modifications and improvements as the motorized bug needs to successfully get through the maze. In addition, students are allowed to use any recycled materials, so it gives elementary students an opportunity to explore different materials in the lab.

This unit usually takes about six 45-minute class periods.

Tools/Materials	Additional	Software
Craft, building, conductive fabrication	Motorized bug toys (Hexbugs)	

Glow Golf

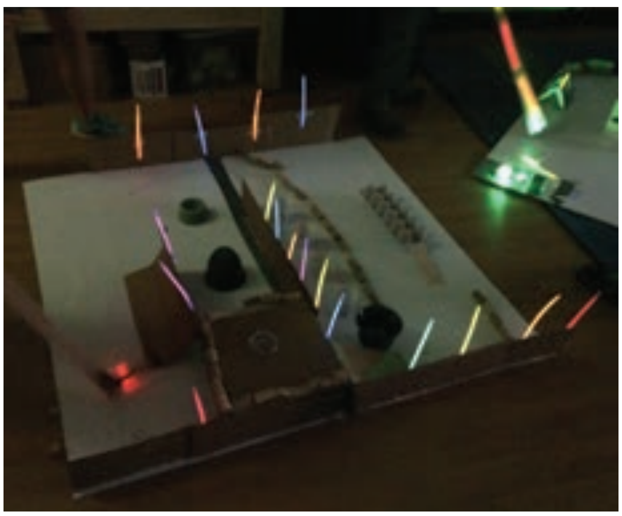
by Angie O'Malley

Create an interactive glow-in-the-dark miniature golf course. Students start this project by sketching golf course designs. Then, each student creates a hole along the course, with moving obstacles and light-up components such as ramps, tunnels, and windmills. Students can use recycled materials, glow sticks, an Arduino with a servo motor and LED lights, and even a plastic golf ball with an LED and battery placed inside.

This can be a fun community-building project. Once students create the course, staff, parents, and other students can play.

Bonus: Primary-age students can plug motors and lights into the Arduino, a motivating way to learn how that hardware functions. Intermediate students work on more advanced Arduino programming. You can use any microcontroller or robotics kits you already have.

Students should be able to complete the project in four 45-minute blocks.



Tools/Materials	Additional	Software
Craft, conductive fabrication, electronics, microcontrollers	Glow sticks, golf balls, toy golf clubs	

Board Game: Missing Pieces Provocation

by Sam Phillips

In my after-school program, we have many board games with missing pieces: player tokens, funny money, dice, spinners. Instead of throwing out these games, I use their incomplete sets to provoke kids to create their own tools for the game. I challenge them to brainstorm both analog and digital/computational solutions to the problem. For younger kids, this can be a terrific context for introducing simple coding and 3D design. For example, I've helped kids make spinners in Scratch, game pieces in Tinkercad, and dice with the micro:bit microcontroller programmed with MakeCode.

Tools/Materials	Additional	Software
Craft, digital fabrication (*optional*), microcontrollers (*optional*)	Makey Makey (*optional*)	Tinkercad, MakeCode, Scratch

PK+

Laser-Cut/Engraved Pins

by Sarah Alfonso Emerson

Students graphically design pins for people to wear and laser engrave and cut them. The pin can be a name badge with a fun emoji, a campaign message, or a school logo. The possibilities are endless.

We use CorelDraw, but any vector design software will work. This teaches students the basics of a graphic design software as they design with shapes and text. They differentiate between raster and vector. They also get to learn how to safely use a hot glue gun. Students love to have something they can take home with them the same day.

This activity takes from 30 to 60 minutes.

Tools/Materials	Additional	Software
Craft, digital fabrication	Pin backings	Vector software such as CorelDraw

PK+

Tracing Images for 2D and 3D Design

by Sarah Alfonso Emerson

I like to have kids practice tracing images so they become more precise in their sketching on the computer. Students learn how to import images into CorelDraw or SolidWorks. Then, they practice the various line tools in each program for tracing outlines of the images. Starting with simple images like a Batman or Wonder Woman logo works well. This is good practice even if you do not print or laser cut the sketches.

I like this project because it helps students become proficient with sketching tools as they sketch a popular image they are interested in. Students who can trace quickly in the design software become less daunted by the design tasks of more complex projects.

This is a 30- to 60-minute activity.

Tools/Materials	Additional	Software
Digital fabrication	Materials or supplies not needed if students are just practicing tracing and not printing anything	Graphic design software such as CorelDraw, CAD software such as SolidWorks

PK+

Robot Storytelling

by Nico Janik

Students turn a story into an algorithm, then program robots to act it out. This project was done with Dash and Dot robots along with integrated English Language Arts (ELA), coding, and art. Students made costumes and "sets" for the robots as part of the project. The story was written in English class, coding was done in the makerspace, and costumes and sets were created during art class.

During ELA fifth-grade students were reading myths and folktales. Our district uses Lucy Calkins's Units of Study; students were in the "Magic of Themes and Symbols" unit. Students wrote their own stories with their classroom teacher during ELA time. In the makerspace students learned about algorithms and applied this to their story. They simplified the story to one or two characters, and one beginning, middle, and end interaction. Then they turned this into an algorithm on paper. In the next makerspace session, students turned their algorithms into block code on the iPads (using Blockly). They had to code the robot to act out the story with no help from the humans (after hitting Start). During art, students designed their "stage/maze" and costumes for their character. Once back in the makerspace the whole unit culminated in the Dash and Dot robots acting out the story.

This project is a great example of integrating multiple content areas and is very flexible. It can go back and forth between classroom and lab space, and different teachers can be involved. It can be a simple story or, with more time, can be made more elaborate with costumes, sets, or more complex robots.

Tools/Materials	Additional	Software
Craft, sewing	Robots (we used Dash and Dot)	Blockly (block program on iPads for Dash and Dot) or Scratch

Using Low-Resolution Prototyping to Learn Design and Solve Problems

by Kevin Jarrett

> "Prototypes are not solutions. They are a way of asking questions." —Snook Design Agency

Prototyping supports inquiry learning, an essential aspect of maker-centered learning programs, especially those rooted in the application of design thinking. Students prototyping with found materials make powerful connections to the intended users, each other, and the problem they are trying to solve. For example, students tasked with finding a way to make the morning routine more efficient and less stressful designed an automated, internet-aware closet linked to an app that would preselect outfits based on the day's weather and the user's style preferences. In another example, students imagined a "smart locker" that would communicate with students at home, telling them what books they needed to be sure to bring in their backpack to be prepared for school.

By asking students to fabricate easy-to-construct models representing these ideas, the resulting thought processes were deeper, more nuanced, and robust. Best of all, low-resolution, "looks-like" prototypes like these are easily constructed with ordinary craft and found materials, keeping costs low.

Tools/Materials	Additional	Software
Craft, conductive fabrication, sewing		None required, but some wire-framing apps can be used to create low-resolution app prototypes

PK+

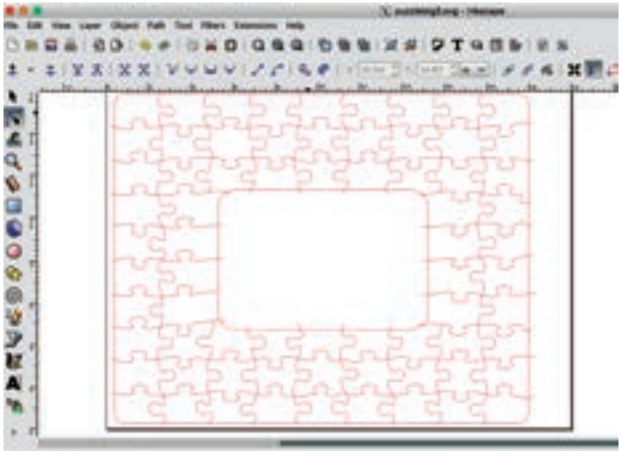
Group Puzzle Frame

by Heather Allen Pang

A puzzle in the shape of a photo frame can bring a class or a grade level together. Use Inkscape to design the puzzle and a laser cutter to cut the frame and puzzle pieces.

Each student decorates a piece, and they come together to create a frame for a group photo of the class. Make sure to put some kind of image (I used a map) on the back so that students all decorate the correct side of their piece and it will be possible to put the puzzle together.

This is a great bonding activity for an icebreaker or later in the year. It creates a reminder of the unity of the class and only takes 20 minutes.



Tools/Materials	Additional	Software
Craft, digital fabrication		Teacher uses Inkscape

PK+

Build-tionary

by Sam Phillips

Build-tionary is like Pictionary, but you build things instead of drawing them. To play, assign each team (pairs or small groups) an object (or series of objects) to build out of provided craft materials within a given time constraint. You can play for points (ask your class to make up house rules) or just build for the sake of building.

This activity is a fun, quick diversion to sprinkle between longer-term projects, to fill some spare time, or to use up material odds and ends that are taking up space in your classroom. It can also be a casual, low-stakes way to assess 3D design techniques and to practice setting group agreements as your students customize the rules to fit their needs.

The beautiful thing about this game is that it can fit a range of time constraints but typically takes 15 minutes to an hour.

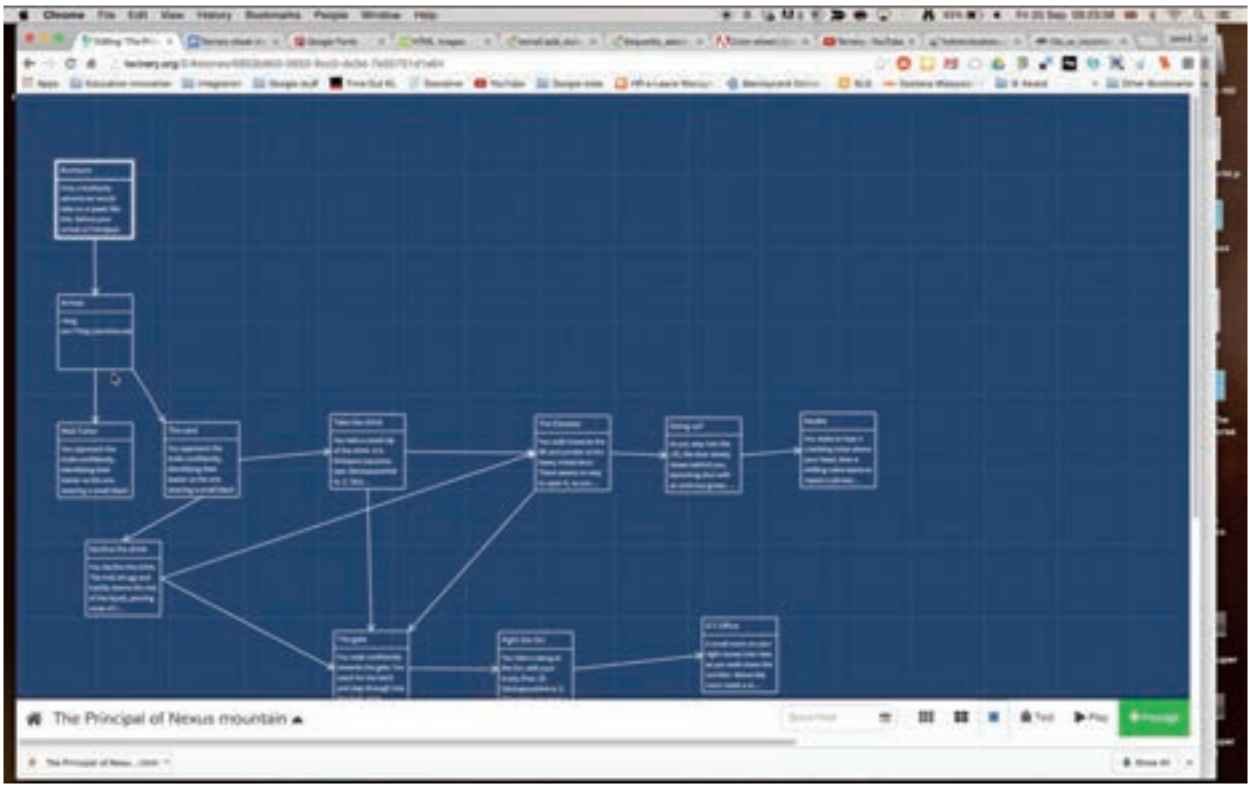
Tools/Materials	Additional	Software
Craft, building	Anything you want, but try not to overcomplicate things	

Choose-Your-Own-Adventure Role-Playing Games

by Sam Phillips

There are a million ways to create and play choose-your-own-adventure games: aloud, Dungeons & Dragons style; through making a short zine booklet; or by coding an interactive adventure with Twine or Scratch.

A choose-your-own-adventure game is always a co-construction between maker and player, and can happen anywhere at any time. I play them every day walking to the park with five- to eight-year-olds, and have seen older kids publish complex rule sets and fabricate props to live-action role-play their game stories. A lot of children love video games and want to learn how to make them. The easiest starting point that I've found is by creating choose-your-own-adventure role-playing games in Twine, a coding platform that is less complicated than basic HTML. You don't need any special materials besides your imagination, but paper and pencil, dice, and tokens are useful.



Tools/Materials	Additional	Software
Craft	Paper, pencils, dice, tokens	Twine, Scratch

3+

Solar Bobble

by Susan Klimczak

Participants create and decorate personalized solar bobbles, which are small kinetic sculptures with a crank mechanism, geared motor, and solar cell. They learn the difference between nonrenewable and renewable energy with a focus on solar energy. Participants learn how a crank mechanism works and how to power it with a motor and solar cell. Finally, they extend their maker skills, learning how to properly use a hot glue gun and a soldering iron.

This is a great expressive introduction to solar energy. It is also a great troubleshooting exercise, as the solar bobbles never work exactly right at first, but the fixes are simple enough that children feel a genuine sense of accomplishment when they work. It's an easy solder, so it is also a great introductory activity to soldering.

We usually bring about twenty different solar bobble tops to decorate for a 90-minute activity; however, it can be extended to two 90-minute activities if one is dedicated to designing and laser cutting solar bobble "toppers."

Tools/Materials	Additional	Software
Craft, electronics, building, digital fabrication (*optional*)	Solar cells, geared motors, soldering iron	Libre Draw (if designing their own bobbles)

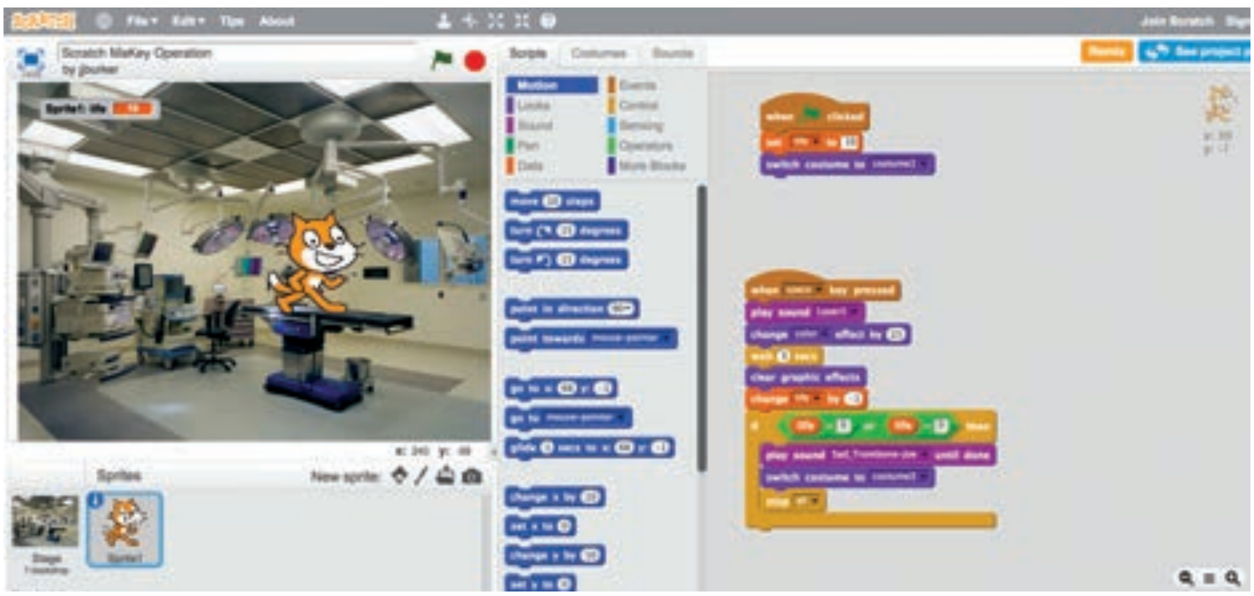
34 Laser-Cut and Makey Makey Game of Operation

by Sarah Alfonso Emerson

Students re-create the popular game of Operation. They design and laser cut a box to hold the game. They laser engrave and cut an outline of a body with holes for various organs. They use conductive tape, foil-lined cups, and chopsticks connected to a Makey Makey attached to a computer. They code in Scratch to trigger responses to game play.

This project teaches so much: you can incorporate body systems, coding, graphic design, and digital fabrication. Students have a lot of fun remixing the code (or creating it from "scratch"), and they have lots of fun playing the game!

Allow for least three 60-minute sessions; it may take a couple of weeks.



Tools/Materials	Additional	Software
Craft, conductive fabrication, building, digital fabrication	Makey Makey	Scratch, vector design software such as CorelDraw

34

First-Hand Sewing Project: Stuffed Animal or Smiley Face

by Heather Allen Pang

Students learn a basic running stitch and/or a whip stitch to create a felt-stuffed toy using either a circle (for a smiley face) or a silhouetted pattern. Students can design their own or use pieces precut by the teacher. This is a quick project to get students started thinking about the ways 2D fabric pieces can be put together to create a 3D shape with the addition of stuffing.

This activity gives quick results with basic skills and materials. Students with some experience can complete this in less than an hour; double that for beginners.

Tools/Materials	Additional	Software
Craft, sewing		

Interactive Body Systems Exhibition

by Jaymes Dec

Students design an interactive Scratch program about a body system that a user can walk right up to and engage with. This program should educate the user about some part of a body system that the student finds fascinating. This could be a video game, an interactive story, or other digital exhibition.

This is a culminating project for our body systems unit in life sciences classes in seventh grade, and while some of the work also occurs in the technology classes, there is very little teacher direction. Examples:

- A video game, complete with controls, where the user becomes the food going through the digestive system, encountering obstacles along the way and doing their best to avoid digestion!
- An interactive presentation showing a diagram of the body system with touchable elements that reveal information about each part.
- Use of the laptop camera to interact with a program about the user's body system.
- User interaction through a Makey Makey device: hooking up a physical object like a drawing of the body system, a sculpture, or 3D-printed or laser-cut item to a Makey Makey board. The user presses on different parts of the object, which can trigger actions on the screen in a Scratch program. For example, pressing on a hand-drawn picture of the stomach triggers the Scratch program to play student-recorded audio about the function of the stomach in digestion.

- Use of other types of sensors: camera sensors, heart rate sensors, sound sensors that a user can blow into, bend sensors, all of which pick up on the user's actions and can be linked to a Scratch program to trigger an action on the laptop. For example, the camera sensor could detect the user's body movements and trigger on-screen movement of a red blood cell around the body, blowing on the sound sensor could show the lungs expanding and contracting during breathing, or the heart rate sensor could trigger a beating heart animation on the laptop screen that matches the person's own heart rate.

At the end of the project, we host an exhibition of the students' work. This project takes several weeks of science and tech classes—approximately five 1-hour classes per week.

Tools/Materials	Additional	Software
Craft, conductive fabrication, electronics	Makey Makey or other physical interface	Scratch

3+

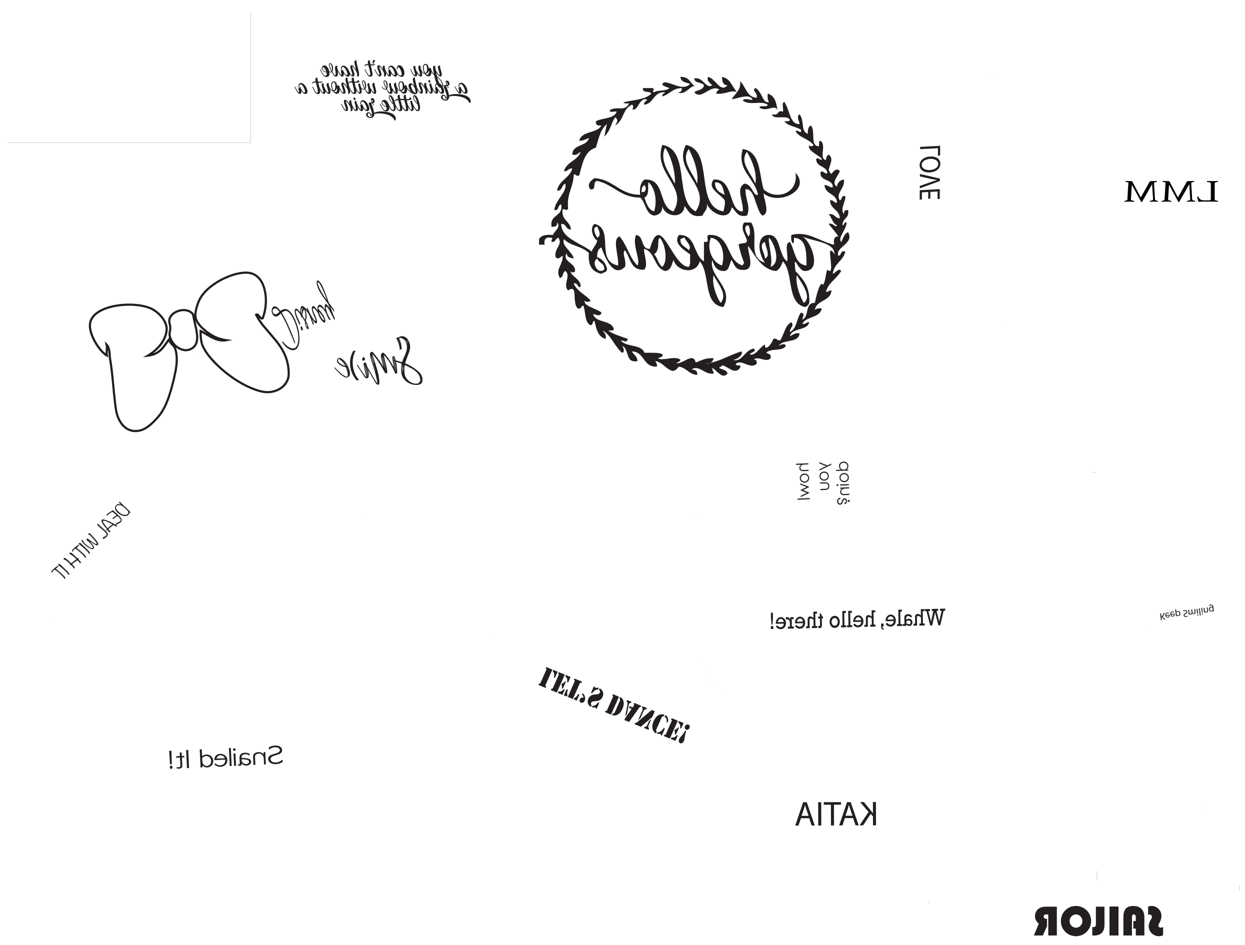
Locker Mirrors

by Jaymes Dec

As an introduction to 2D design and digital fabrication, sixth-grade students design and laser cut mirrored acrylic with etchings for their lockers.

Students love mirrors! When they see that they can cut their own mirror in any shape they want and engrave quotes or designs, they are motivated to learn the basic tools of vector drawing such as Adobe Illustrator or Inkscape, and using a laser cutter or engraver.

We completed this project over a six-week period, spending one hour per meeting per week.



Tools/Materials	Additional	Software
Digital fabrication		Adobe Illustrator or Inkscape

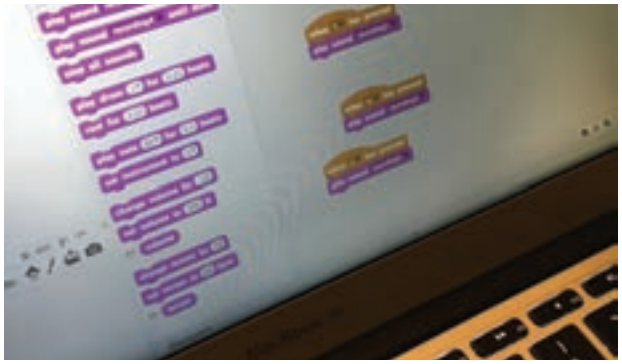
3+

Talking Historical Quilt

by Mark Schreiber

Create a touch-sensitive historical quilt that plays recorded loops when each square is touched. Use a Makey Makey (or touch-sensitive code for another microcontroller) to trigger each sound loop. You will need regular and conductive sewing supplies.

Have students record an audio narration of each event in Scratch. Program each sound recording to play when a key is pressed so by touching each square a different narration will play. Laser cut silhouettes on felt squares of each event and wire together. This project helps integrate making into the history classroom and is a great introduction to computer science and physical programming. This project can be used with other subjects as well—just think creatively!



Tools/Materials	Additional	Software
Conductive fabrication, sewing, digital fabrication	Makey Makey	Scratch, Inkscape

3+

Customized Rubber Stamps

by Mathias Wunderlich

In this project students make their own rubber stamps by using a two-step silicone casting method. At the same time they learn the principles of making products by casting liquid compounds, one of the main principles of industrial mass production. To start they put single adhesive letters in a line onto an acrylic glass base in order to form a word or phrase. Alginate paste is applied, and this becomes the first mold. The second step is to fill this negative form with 2K silicone to make the final rubber stamp. The single letters of the first mold can be removed from the base, sorted, and stored for later use again and again.

In under 30 minutes students are able to cast their own rubber stamps. A 45-minute class is very comfortable for making one rubber stamp, even if the first attempt fails.

Tools/Materials	Additional	Software
Craft	Mold making, casting, alginate, two-component silicone rubber	

3+

Earthquake Engineering

by Jaymes Dec

This activity was inspired by an activity developed at the Exploratorium Teacher Institute.

Students plan and construct buildings that can withstand earthquakes. In the process, students learn about various methods of designing earthquake-resistant structures, then create their own skyscrapers with balsa wood sticks as the main structural material. In technology class they use 3D computer-aided design software to design and print custom connector pieces for the sticks.

This ties in with our earth sciences unit on earthquakes. We built an earthquake shake table[1] for this activity. The unit finishes with a competition to see which building can hold the most mass under the stress of a simulated earthquake. Students really enjoy the competition aspect.

Materials

Balsa wood sticks, 17 × 17 cm paper for measuring the base, index cards, rubber bands, masking tape, binder clips

Design Requirements

Height	The structure must be at least 40 centimeters tall.
Function	The top of the structure will be an open-air parking garage and must be able to hold 150 grams of mass, even during an earthquake.
Area	The base of the building must not exceed 17 × 17 cm.
Weight	The building must be constructed to be as lightweight as possible.
Connectors	Design your own 3D-printed connectors to hold the structure together. No tape is allowed for stick-to-stick connections.

Note: You may use tape or binder clips to attach gussets, shear walls, etc.

Testing Procedure

A shake table will be used to simulate an earthquake to test the quality of your building design. The goal is for your building to survive as long as possible and as strong an earthquake as possible.

1. Buildings will be taped to the table.
2. The specified 150 grams must be sitting on top.
3. Film the test using PhotoBooth or QuickTime Player.
4. Time how long the building stays intact without any part breaking.
5. When the weight falls off or the building breaks in any way, the test is done.

Time to complete is three weeks of one-hour classes (about five classes per week)

Note

1. howtosmile.org/resource/smile-000-000-001-798

Tools/Materials	Additional	Software
Craft, building, digital fabrication	Earthquake-simulating table	3D CAD software

34 Dia de los Muertos Laser-Cut Calavera Art

by Sarah Alfonso Emerson

Students design elaborate Calavera-style skulls using any vector-design software (we use Corel-Draw) and laser cut them. They add colorful paper behind the laser-cut holes. Then they attach the skulls to a wooden pallet to hang on the wall.

These projects look amazing when they are finished. Students have so much fun adding their own flair to their designs. This project also brings in a lot of culture.

The projects take at least three days of 30- to 60-minute sessions.

Tools/Materials	Additional	Software
Craft, building, digital fabrication		CorelDraw or other vector software

3+

Tinkering with Spinners

by Cassia Fernandez

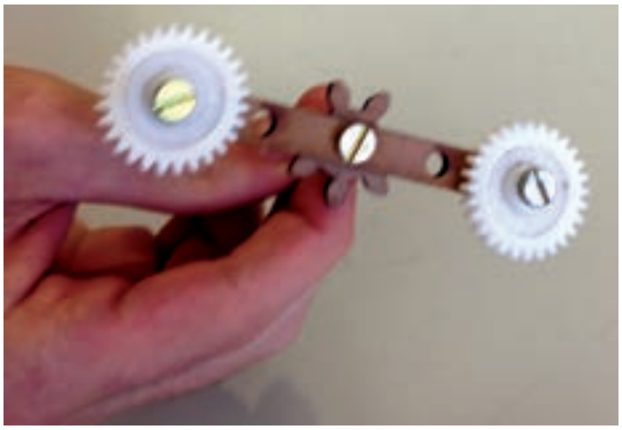
In this project, students create their own design for a fidget spinner and explore how different variables impact the way the spinner spins. The goal is not to reproduce a well-known model of spinner but instead to experiment with different structures, shapes, and balances. With materials such as screws, nuts, and laser-cut gears and connectors, students can find their own ways to explore the materials and create diverse designs.

Since changes in a spinner's design can be made really quickly, the project allows for iteration and personal expression, allowing kids to feel confident about exploring new ideas and to express their creativity. Also, since the materials are not expensive, students can take their creations home and keep exploring them.

It's also a good interdisciplinary project that connects making to mathematics and physics. After creating the spinners, the group can reflect together about the variables explored and connections that can be made to physics topics such as friction and inertia.

There are many other ideas that could be further explored in this project, such as adding LEDs to create stroboscopic effects or exploring materials other than wood. If a laser cutter is available to students, they can further optimize their designs by creating their own personalized parts.

One hour and 30 minutes is enough for an initial exploration, but depending on the time available and on the curricular connections to be explored, it could take up to 5 hours.



Tools/Materials	Additional	Software
Building, digital fabrication		Inkscape or similar

3+

Quick Cuts: A Flash Film Festival

by Sam Phillips

Quick Cuts: A Flash Film Festival is a multiday movie-making exploration where kids work in small groups to devise, produce, edit, and showcase short films in their community. Each team is given a location (real or imaginary), a conflict, a bag of mystery props and materials, a camera, and free reign to construct costumes, travel to various locations, assemble actors, and get their project done before the time is up.

A film festival is a great opportunity for different age groups to compete, collaborate, and celebrate together. When I coordinated this project, we matched groups of middle- and high-schoolers with college-aged mentors who were studying cinema studies, so there could be opportunities for near-peer mentorship and everyone could feel supported. It also embeds making (prop making, costume making, movie making) within a storytelling context and ends with a natural showcase at the end. The time constraint lends a nice madcap energy to the whole proceeding, which leads to a lot of quick decisions, compromises, and creative problem-solving.

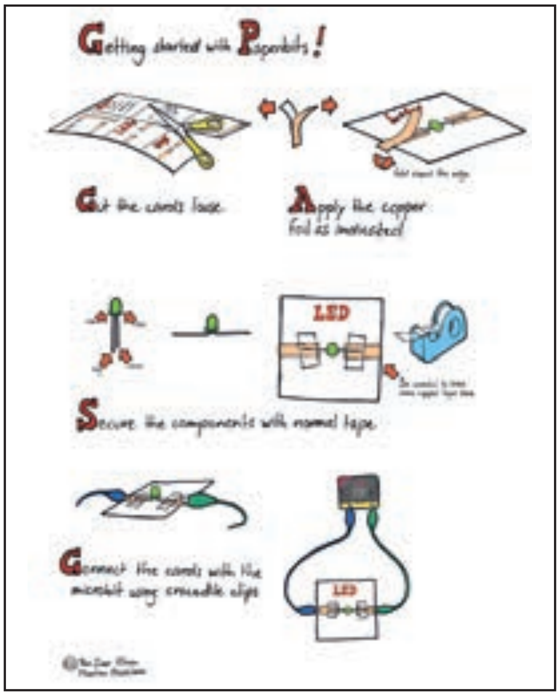
This kind of project works best when there's a very short time constraint with plenty of unbroken time for getting the films made, for example, in 24 to 72 hours, overnight, or across a weekend.

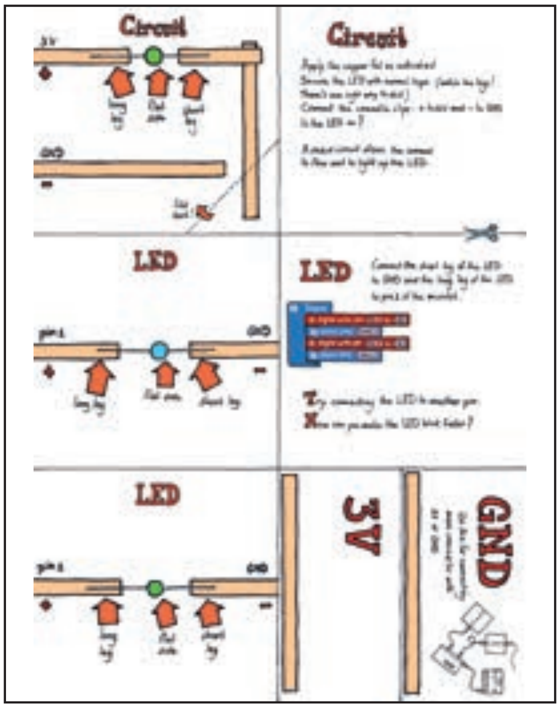
Tools/Materials	Additional	Software
Craft, building, sewing	Video camera or phone with video capture; cheap and plentiful building materials, e.g., cardboard foam core, hot glue, scrap fabric; miscellaneous props (the stranger and more unusual, the better)	Video editing software, e.g., iMovie (Mac/iOS), Adobe Premiere, WeVideo (free, cloud-based video editing), or Adobe After Effects (if you're fancy!)

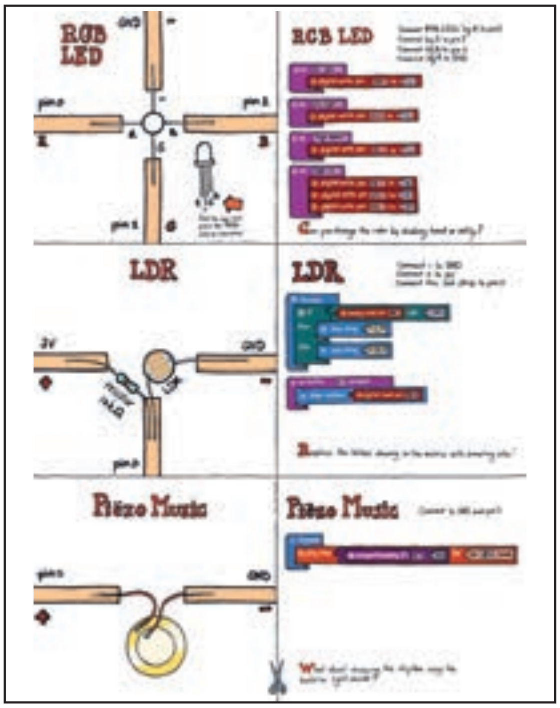
Paper Bits

by Per-Ivar Kloen

Paper bits are electronic parts on paper. They can be used as an add-on component for microcontrollers like the micro:bit. It's aimed at "lowering the floor" for physical computing by making the components more understandable and easier to use. The bits can be used in lots of different ways, like doing science with sensors or making an interactive object (e.g., a talking monument in history class). For the lower grades consider preparing the bits for them (which may be a good project for the upper-grade students).





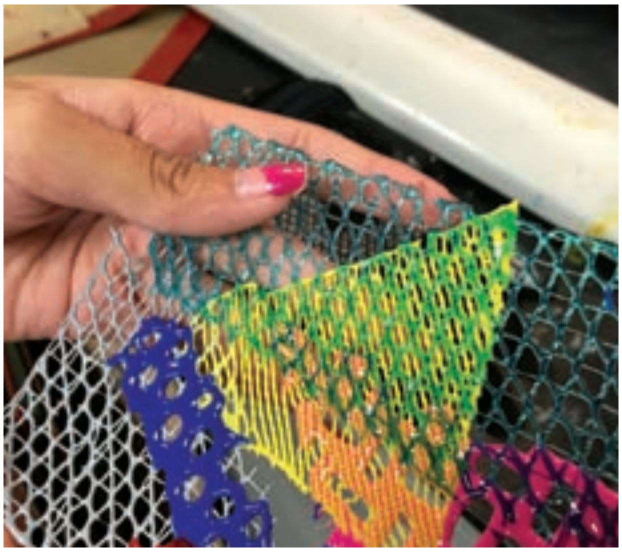


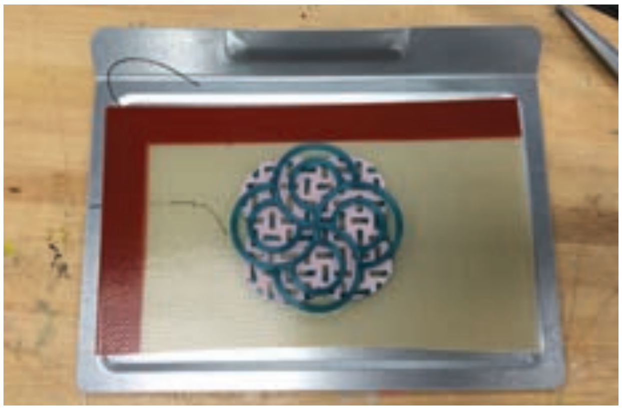
Tools/Materials	Additional	Software
Craft, conductive fabrication, electronics, microcontrollers	micro:bit	MakeCode, Scratch, or Snap4Arduino

PLA Melts

by Erin Riley

If you use 3D printers, undoubtedly you have encountered beautiful scraps. The drizzles, mishaps, and glitches take on a mind of their own and have the potential for upcycling into new art objects. PLA filament (the most common type of 3D-printer filament) can act like paint; it can be sticky and viscous when heated to melting temperature and used for flat design, or it can be shaped into 3D forms when warm. In the lab, we save PLA scraps, students often mixing them with thin prints (under 3 mm thick) of their own design, and melting them into glass in a toaster oven. This process is a great use of throwaway 3D-printed material, including the tiniest of scraps. The glossy, melted transformation of PLA material is beautiful, and watching the material change properties before your eyes, at a very low melting point, is magical.





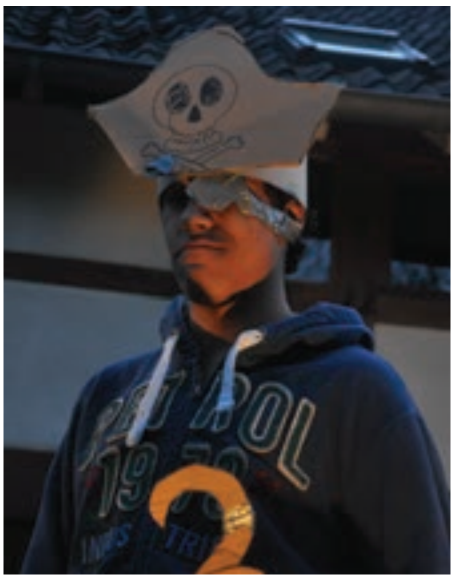
Tools/Materials	Additional	Software
Digital fabrication	PLA scraps, thin PLA prints, toaster oven	Any 3D modeling software if creating prints for melting

Cardboard Fashion Show

by Per-Ivar Kloen

Make a catwalk. Have students (any age!) pick a song and make costumes out of cardboard. Let students perform, showing their creations on the catwalk while playing the chosen song. Add LEDs and coin cell batteries for some extra spice. It's a playful way of getting to know each other. It's a simple way of exploring the possibilities of cardboard and so much fun! Laughs guaranteed!

This activity takes a couple of hours minimum but can be spaced over a period of time.



Tools/Materials	Additional	Software
Craft, conductive fabrication	Box cutter knife, cutting mat	*Optional:* vector program for designing shapes

3+

Hack Your Classmate

by Per-Ivar Kloen

Make something to change, enhance, help, modify, or . . . hack your classmate! Like a decision hat for someone who has a hard time making decisions. Turn the wheel and get your decision: yes, no, maybe later.

Supply a limited amount of material like cardboard, or for something different add facial paint. This activity is a good icebreaker with its simple construction techniques, and a fun way to get to know classmates.

Two or three hours is enough time to complete the "hack."

Tools/Materials	Additional	Software
Craft, conductive fabrication	Box cutter knife, cutting mat	

3+

Shadow Tinkering

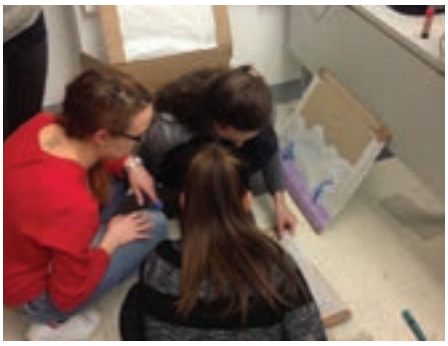
by Angela Sofia Lombardo

Students create a story for a shadow play, build the puppets and sets, and perform the play.

To start, each student writes the following three elements, each on a separate sticky note: a fantasy character, a tool or object they like, and a place they care about. All of the sticky notes are shared on the classroom wall and then three elements are randomly assigned to student teams. Each team creates a story using the three elements and starts to plan a shadow theater performance. The teams tinker and experiment with different materials and tools to create everything from theater sets to character puppets. The sets and puppets can be built with any kind of building or recycled materials, or include electronics. Phone flashlights are very useful for this project.

Each group will face challenges like how to work as a team, how to use the provided materials to represent their ideas, how to integrate new ideas into the original one, and how to change their original idea when it doesn't work as expected. This can also be extended by adding time, requiring more elements, or requiring the stories to follow a storytelling framework like Propp's narrative framework.

This is a project that can span many ages. We used this in a 2½ hour workshop for students at the University of Bologna Undergraduate School of Education. This was a great project for these future kindergarten teachers to see how fun and easy it can be to create and perform their own stories, even without expensive technology. It was their first time playing with LEDs, and the facilitators give them no instructions on how to light them up. Teachers working with very young children tend to think that technology will not be used in their classrooms—or is even dangerous for younger kids. This project offers them the chance to experiment with technology as a creative tool and open their eyes to the possibilities. One teacher wrote about this "creative confidence" in her journal: "During the construction we realized the difficulty of coordinating light with the characters, but it was also a fun and creative experience, which allowed me to put myself into play. In fact, once we encountered the difficulty, we decided to modify some aspects of the initial design to make the final product easier and clearer." I hope they will spread this creative tinkering confidence to their students!



Tools/Materials	Additional	Software
Craft, conductive fabrication		

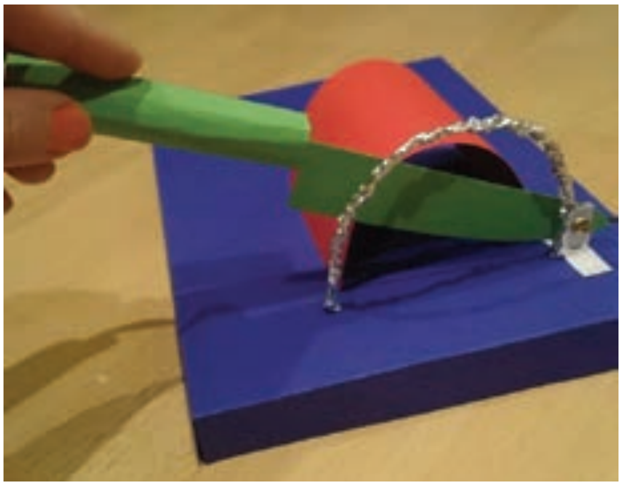
The Cucumber Slicer

by Mario Parade

A summer program funded by the Federal Ministry of Research and Technology supported the integration and participation of people with special needs in the development of small personalized tools. During the first workshops it was discovered that many students lacked sufficient gross motor skills needed to prepare food in the kitchen. This included cutting vegetables such as cucumbers, paprika, and zucchini.

One of the students' ideas was to develop a so-called safe cucumber slicer. Starting from a cardboard model, a 3D model was developed with Tinkercad and then printed on the 3D printer. After several iterations, a successful result was achieved—a slicer that can safely be used in the kitchen. These little helpers don't have to be electronic gadgets but can be simple adaptive structures that can be printed with any 3D printer.

The project took two hours to complete.



Tools/Materials	Additional	Software
Craft, digital fabrication	Food-safe PLA filament, saw, glue or hot glue gun	Tinkercad, Cura

Escape Room Design

by Justin Brown

There are many approaches to introducing maker projects to students. We have found that planning and building an escape room is very useful in developing both skills and the maker mindset. Students gain mechanical skills, learn about the fabrication tools available, and become familiar with the user-centric mindset needed for success in future projects.

Choosing a theme is one of the most important parts of an escape room. There needs to be a reason why the participants are in there for 60 minutes–a story that connects the puzzles, locks, and obstacles. There should be a title for the room and decorations that set the stage for users. All of the challenges should logically work in the theme. Students also need to sketch the flow of challenges for users. This does not have to be linear; there can be multiple paths. Students should test their designs with users and document the results. These skills can be learned in more traditional engineering projects, but students seem to "get it" better via the escape room.

The end product should be fun. Students should make sure the puzzles are challenging but also not too difficult for anyone to actually solve all the puzzles and escape. Users should enjoy trying to break out of the room and not be confused about what to do next. The instructions to users should be clear but still reflect the theme.

By developing themes, lock time tables, and the physical locks/puzzles, students make worlds with purpose and get rapid user feedback. Making escape rooms allows both experienced and novice makers to refine their craft while also not being dependent on any platform, technology, or equipment. We use craft materials and electronics plus supplies like locks, boxes, black lights, and UV pens. If desired, 3D printers and microcontrollers can be integrated as well.

I give the students six weeks to build and test the whole room, culminating in a community showcase. They have four in-class sessions to work on this as a team (two 1-hour sessions and two 1½-hour sessions). About ten days before the showcase we have a full test run so there is enough time to fix problems and improve the experience.

Tools/Materials	Additional	Software
Craft, electronics, digital fabrication (*optional*), microcontrollers (*optional*)		

6+

Write It Do It

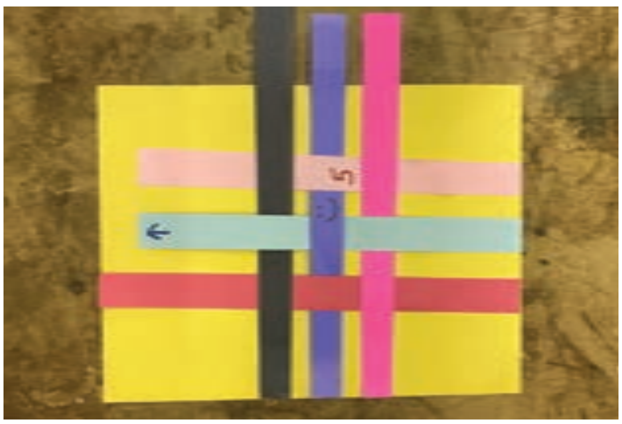
by Justin Brown

Write It Do It (WIDI) is an international STEM competition that focuses on technical writing. It is a great way to engage English classes in doing (or making). One student writes a detailed technical description of how to make an assembly; then their partner (the doer) tries to re-create it. I have my students make a WIDI report the first time they do it. This can be done with a wide variety of materials and tools.

WIDI is a great way to get students to build capacity in technical writing. I've seen English teachers take to this assignment more than other traditional maker assignments. This also aligns with international Science Olympiad, which is pretty awesome.

This can be done in one class period. When I added the report format, I gave students two days to finish that up. Rarely are the final products better if you use a full hour; 15 minutes to write and 10 minutes to "do" works well.

Tip: Have two models so each student can both "write" and "do" once.



Tools/Materials	Additional	Software
Craft		

6+

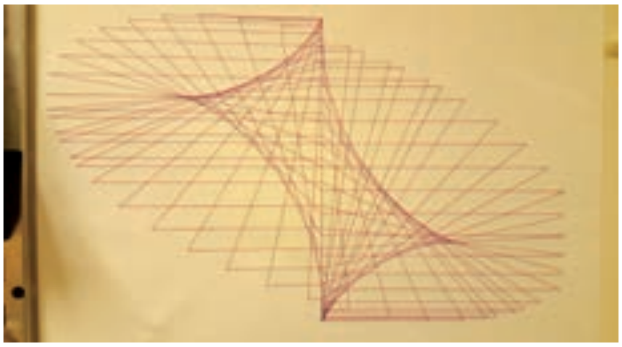
Algorithmic Art

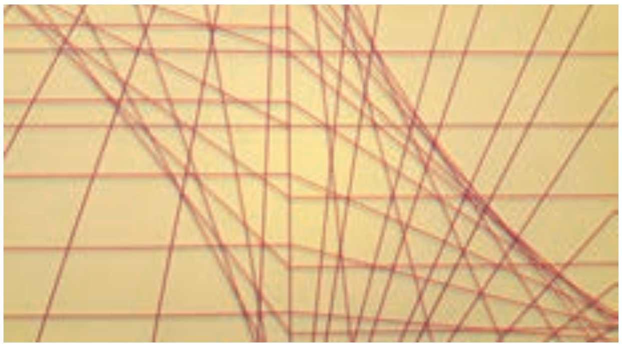
by Jaymes Dec

Students use a variety of Logo-inspired programming tools to design and fabricate physical objects that are evoked by geometric forms. Students use Turtlestitch and Beetle Blocks to design objects for embroidery, 3D printing, laser cutting, plotting, etc. My seventh-grade students really got into this, especially embroidery.

This is a very open-ended project and can be tailored for different ages, tools, and materials. Required materials are computers as well as one or more embroidery machine, 3D printer, laser or vinyl cutter, sewing equipment, and Turtlestitch or Beetle Blocks software.

The project took eight to twelve weeks of one-hour weekly meetings.





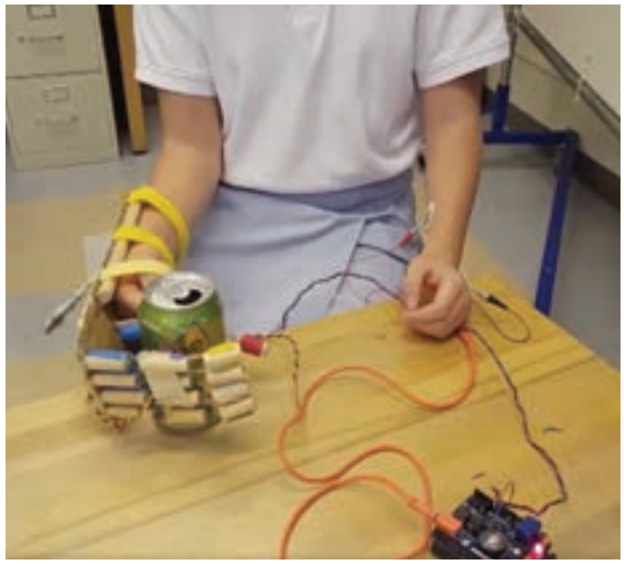
Tools/Materials	Additional	Software
Sewing, digital fabrication		Turtlestitch, Beetle Blocks

Prosthetic Hand Design

by Jaymes Dec

As a science project when seventh-grade students are learning about the bones and ligaments in human hands, they design and make prostheses that have to accomplish a series of tasks: pick up a can, turn a page in a book, and a challenge of their choosing. We have done this project the last three years, and it gets better every year. The kids use a lot of craft and woodworking tools. Each year students have experimented with upping the ante with motor-activated arms. Last year two students made a wearable claw that was activated by EEG sensors!

The project lasts about two weeks with kids working about five hours per week.



Tools/Materials	Additional	Software
Craft, conductive fabrication, electronics, building, sewing, digital fabrication (*optional*)		

6+

Programmable Pinball Machine

by Cassia Fernandez

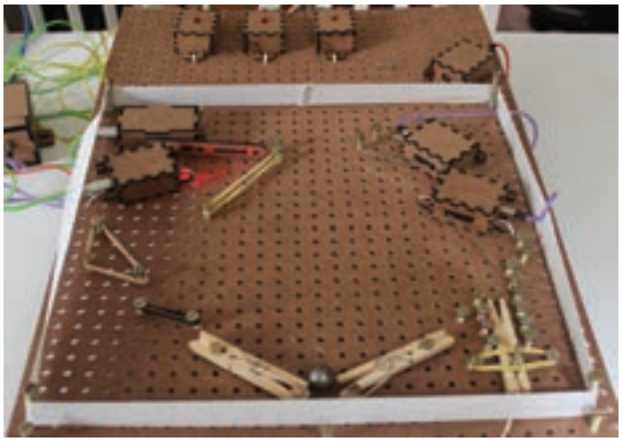
The idea of this project is to build a pinball machine that can be programmed to create different kinds of interactions, integrating everyday materials with physical computing. Pinball machines can be explored in diverse ways, incorporating diverse features, technologies, and materials. It's a good starter activity for kids who are not very familiar with physical computing since it creates a high level of engagement and is suited for rapid prototyping and tinkering explorations.

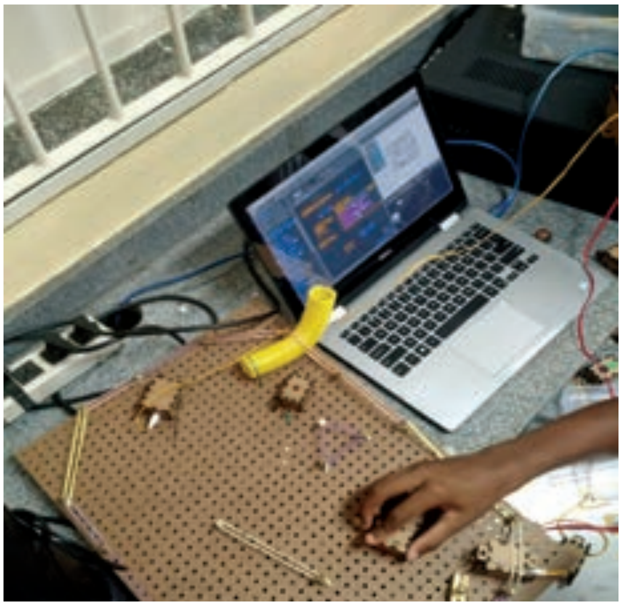
A great diversity of materials and technologies can be integrated into this project. Everyday craft and recycled materials, electronics, pegboard, and building materials can be used. And since pinballs can have so many different features, it's a good activity for tinkering, allowing people to focus on different types of things in their creation process, based on the resources available and on the things that they find more interesting and fun to explore.

It is a great way to introduce programming in a contextualized way so students can create programs to add new features to their machines with high levels of motivation. This activity can also create a great emotional climate in the classroom, especially in the sharing moment when kids can play with other groups' machines and have free time to enjoy their own creations.

We use a "Beta Kit," which is a kit I co-created to allow tinkering explorations in physical programming. The kit is composed of an Arduino with a shield that converts the pins to audio jacks, and small boxes with servo motors, buzzers, LEDs, lasers, light sensors, switches, and potentiometers that can be connected to the Arduino through audio cables. We use Scratch4Arduino for the programming. This makes construction and programming easy; however, any Arduino or robotics kit could be used.

Allow at least 3 hours—up to 6 hours. It works best when divided into 1½-hour classes.





Tools/Materials	Additional	Software
Craft, electronics, building microcontrollers	Beta kit (our own Arduino-based physical programming kit)	Scratch for Arduino or similar

6+

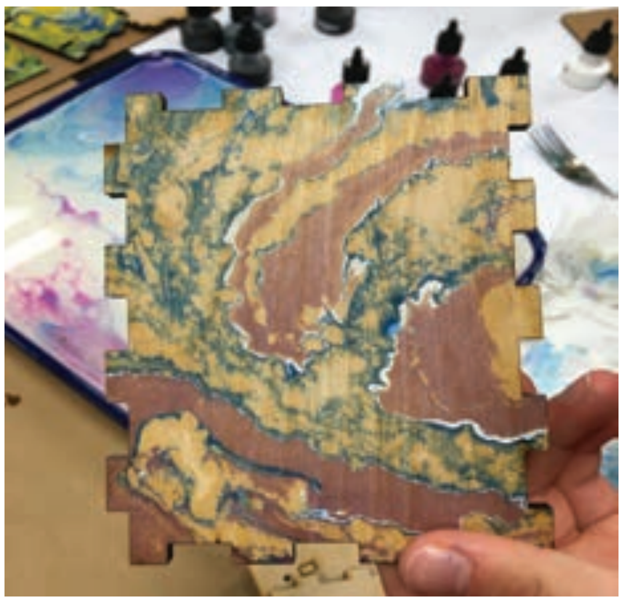
Marbling Plywood for Laser-Cut Parts

by **Erin Riley**

With its absorbent surface, plywood is a great material for marbling, offering the opportunity to combine a traditional art process and softening the look of machine-made parts. We can cut parts on the laser cutter and marble them using carrageenan and waterproof drawing ink. Once dry, the surface is porous again and can be remarbled for additional stacking of texture and color effects. Marbled wood also works well with engraving on the laser cutter. We use quarter-inch plywood as it is less likely to warp, and both sides can receive the wet media.

Marbling is a process that everyone loves. The behavior of the ink is somewhat unpredictable, and wonderful results emerge at the intersection of science and art.

The process of marbling can happen in one 45-minute period. For two-sided wood marbling, do the process over two days or speed dry with a hair dryer.



Tools/Materials	Additional	Software
Craft, digital fabrication	Wood	2D vector design software

Pixel Art

by Erin Riley

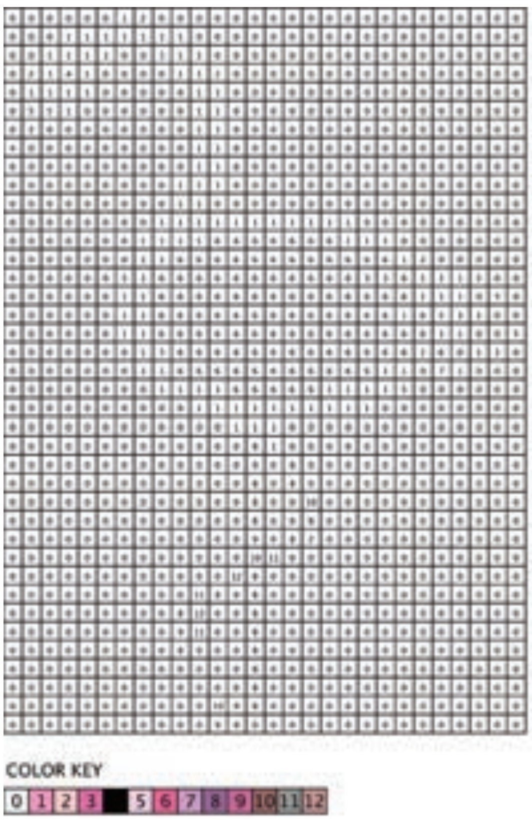
In digital art and design, as well as in digital fabrication, knowing the difference and the applications of raster and vector graphics is a foundational understanding. With the help of Erik Nauman, who created a pixel-by-numbers app in Processing,[1] students are able to convert images into color-by-number pixel maps. Students decide the density of pixels and range of color, and the program generates a numbered grid with color key. The grid is in vector form and can be printed or exported for digital fabrication.

Our students mounted and sealed the printed grids on wood with Mod Podge and painted the pixel art grid with acrylic paint. Not only do students enjoy selecting images to convert to pixel art, they are excited by the process of making as their pixelized image emerges from the blank grid.

This project could be done in two class periods if working with small printed grids or could be extended for larger-scale grids.

Note

1. openblackboard.com



Tools/Materials	Additional	Software
Craft	Color printer, wood, Mod Podge, acrylic paint and/or markers	Pixel-by-numbers app

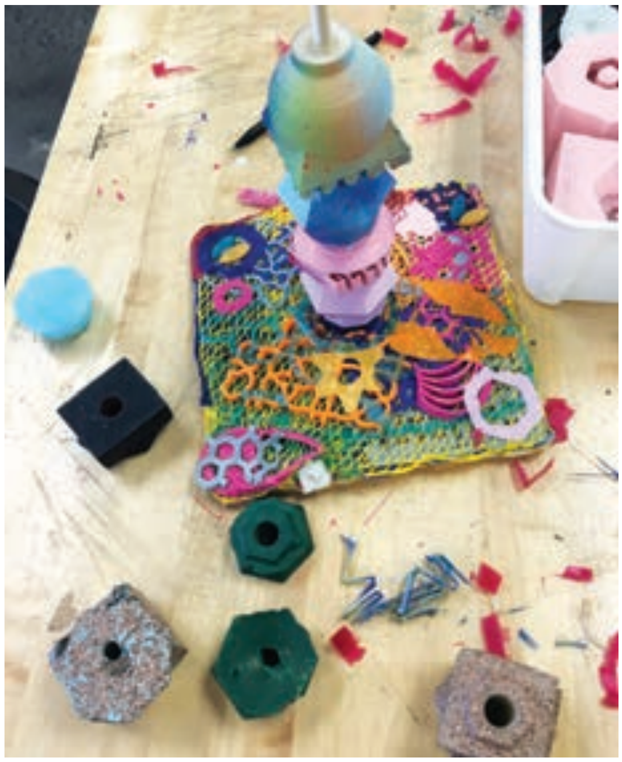
6+

Material Exploration in Mold Making

by Erin Riley

Additive technology gives artists the power to explore form with precision and imagine 3D forms that in some cases would be challenging to create with subtractive approaches. Mold making takes possibilities even further as the postprint design step offers a whole world of art materials for students to explore for making sculpture. Students have been creating one- and two-part silicone molds from 3D prints and casting plaster, concrete, CelluClay, wax, and hot glue. Additional materials used for surface treatments include gold leaf, spray paint, glitter, and 3Doodler drawing elements. The variety of materials to explore with this process is endless!

Multiple class periods are needed for 3D modeling and printing, making a silicone mold, and casting materials.



Tools/Materials	Additional	Software
Digital fabrication	Silicone, supplies or silicone molds	Any 3D modeling software

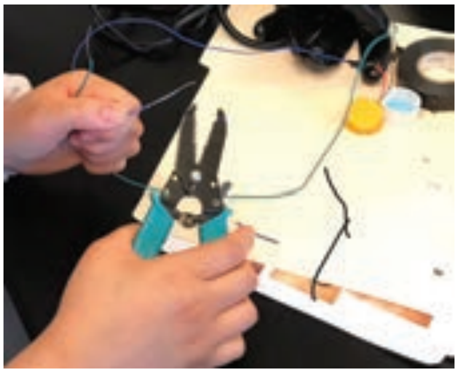
6+

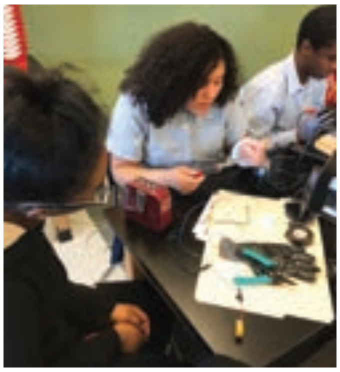
Contact Mic Synthesizer

by Daniel Schermele

This project aims to create learning opportunities for students to make natural connections between vibration frequencies and key concepts of music theory such as timbre and pitch. Students explore amplification, timbre, and pitch with a contact mic and found objects. Students then can record the sounds on Scratch and create a program to play back the sounds using either an Arduino or a Makey Makey. There are many ways for students to interpret this project. They are encouraged to use the contact mic to explore new sounds and decide what sounds they want to include in their eventual "synthesizer." The design of the synthesizer is also individually based. You can buy contact mics or make them using the many instructions found online.

This is a good cumulative project that takes at least a couple of weeks. It can be taught with lessons that focus on creating found instruments.





Tools/Materials	Additional	Software
Craft, conductive fabrication, electronics	Arduino or Makey Makey; contact mic, cigar box, rice, Slinky, springs, cans, etc.	

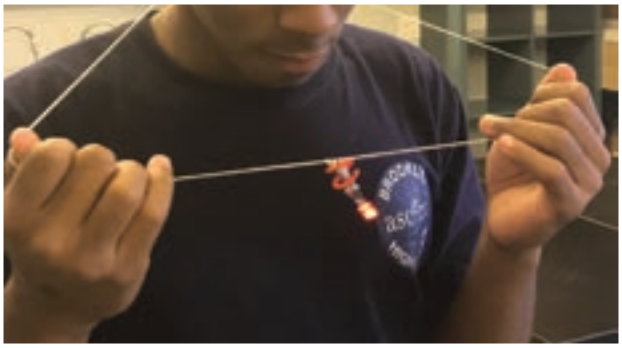
6+

Office Supply Flair

by Dan Schermele

Students learn how to solder by creating fashionable LED necklaces, headbands, and bracelets out of paper clips and chosen craft supplies. Students are also challenged to design solutions that incorporate a switch and a battery holder that allows them to remove and replace dead coin batteries.

This is a great way to introduce students to soldering that only takes one to two class periods.



Tools/Materials	Additional	Software
Craft, conductive fabrication, electronics	Soldering iron	

64 Repair Café in the School Makerspace

by Mathias Wunderlich

Repair cafés provide space, tools, and know-how for people who don't want to support the common throwaway convention. Makerspaces in schools are able to support such a paradigm change, too—with kids as involved players. Local community members are invited to repair sessions with coffee and cake, where students, their parents, and other volunteers help them to fix broken devices, furniture, toys, etc. Engaging students in repairing items develops their environmental and self-consciousness in addition to their technical and research skills.

This should not compete with commercial repair services but be supplemental, for example, in niches where commercial services wouldn't be profitable. We have run a monthly repair café in our middle school in Germany[1] and have received favorable notice by newspapers and television.

Note

1. fasw.de/repaircafe

Tools/Materials	Additional	Software
Craft, conductive fabrication, electronics, building, sewing		Internet research, e.g., ifixit.com, YouTube tutorials for fixing stuff

64 Recycling and Upcycling Furniture for Your Makerspace

by Mathias Wunderlich

Sometimes recycling and refurbishing is a better option than buying new items. Older furniture that is made of natural wood is often far more durable than modern products. While equipping a new makerspace, it can make sense to refurbish old but durable workbenches instead of buying new ones. Students can be involved in the refurbishing process, gaining an appreciation of valuable materials like natural wood and traditional handcrafting. Additionally, they'll use their furniture in a more respectful manner if they invest time and sweat in it.

Extension: Document the process using time-lapse photography techniques.




Tools/Materials	Additional	Software
Craft, building	Furniture: chairs, workbenches, tables	Design software, photo/video software for documentation (time-lapse, etc.)

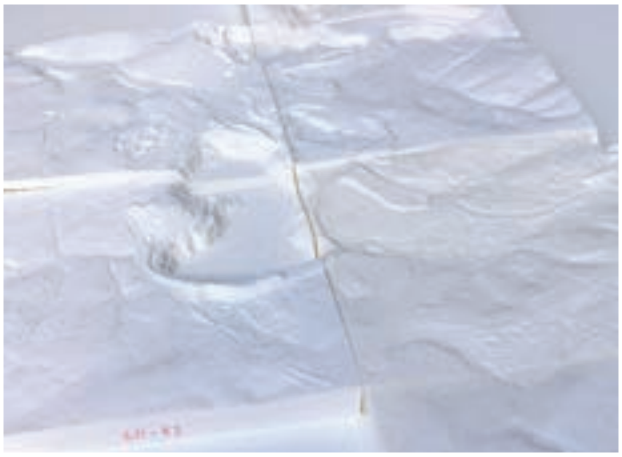
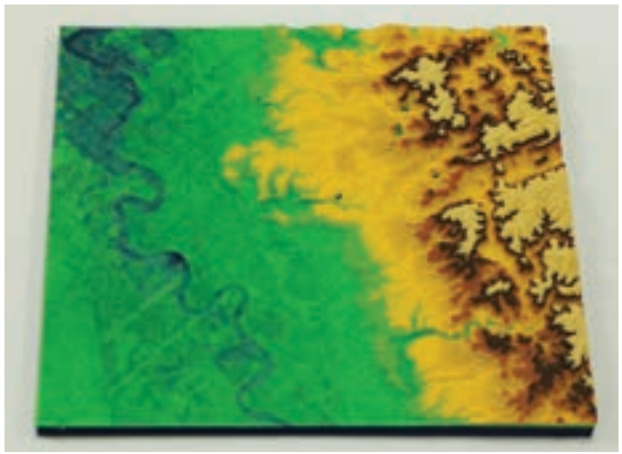
6+

3D Maps

by Mathias Wunderlich

Many kids have lost the connection to the geography and landscape of their region. They don't hike; they are just transported in their parents' car from point A to point B with their eyes on their smartphones. For such students, geography is a theoretical science with little importance to their lives.

Teachers who can acquire high-resolution geodata of their region may spark their students' interest in geography by having them use a 3D printer to print 3D maps of their hometown and surrounding landscape. We made a model of our neighborhood, consisting of thirty 3D-printed pieces, each 19 × 19 centimeters, which represents an area of 10 × 12 kilometers. Additionally we constructed a system for projection of different data to the surface of the 3D map.

Tools/Materials	Additional	Software
Building, digital fabrication	Geodata acquisition and processing	QGIS, netfabb, Cura, or others

Turnery for Kids

by Mathias Wunderlich

Turnery (using a lathe) in our school makerspace is a very popular activity. Actually this very old technology has a high level of desirability for students. It has the right amount of danger—it's not too safe, but it's not too dangerous either. It works with sharp blades, and kids feel the vibrations of the machine and the power of the motor—it's definitely learning with all senses. Most important of all, turnery, in comparison to many other woodworking techniques, doesn't require much physical ability or experience to get quite a good result even at the first attempt. After some basic safety advice, even students as young as fifth grade can work on their own pieces.

Plan for 45 minutes for first steps and the first piece, then some extra hours to explore for rather good results.

Tools/Materials	Additional	Software
Craft, building	Wood lathe, chisels	

6+

Round, Arched Rain Roof

by Mario Parade

In a workshop, eighth-grade students designed and then built a round, arched roof. Although it consisted of a few simple elements, it has been very useful and is expandable for maximum versatility. The basic building blocks are 5-meter-long wooden slats and square plywood panels (approximately 20 millimeters thick). After the construction and sketching of a prototype, some of the wood was sawn to 0.5 meter and then screwed in parallel with the plywood. Each subsequent parallel element was screwed on at an angle until a semicircular arch was created. The second arch was made as a copy of the first arch without taking any measurements. Covered with a tarpaulin, this rain protection system stands on an area of almost 25 square meters and has survived two storms.

Our combined seventh- and eighth-grade class planned and built the structure in our agricultural area in one day.

Tools/Materials	Additional	Software
Building	Cordless screwdriver, handsaw, hammer, yardstick or measuring tape	Inkscape

6+

Microfilms and Microstills

by Erin Riley

Changing scale is a powerful design tool—one that can transport the viewer into a world that they do not recognize, or alternatively, one that invites us to look even more closely. Inspired by the work of Pieter van Boheemen at the Waag Society in Amsterdam, I have created a laser-cut microscope for use in our art and science classes for capturing still and video images. The design has two enlarged stages, one for a foreground and background, useful for painting and using wet media, and a place to mount a smartphone for backlighting or displaying digital images. The enlarged stage offers a large surface area and space for painting and adding materials into the composition.

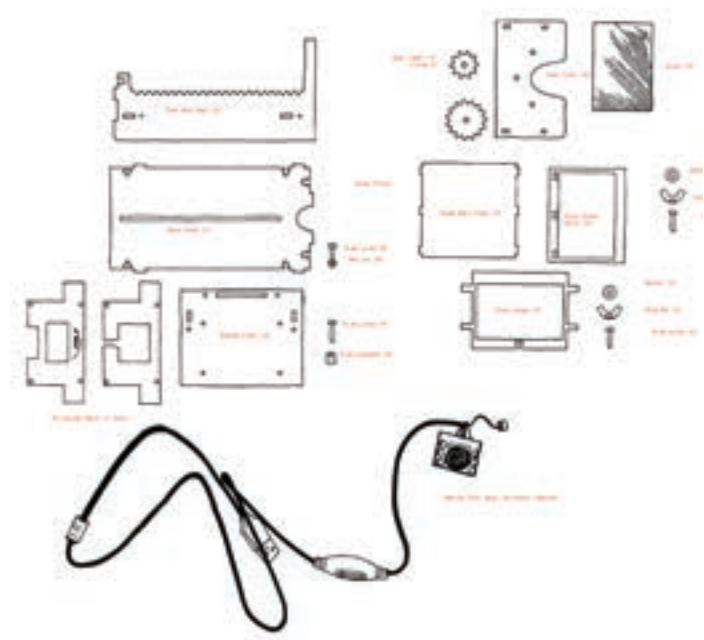
For those without a laser cutter, a cardboard and foam version was designed by Abraham Orozco and is available.[1]

This project gives students the opportunity to explore many variables that often occur in both science and art curricula while creating opportunities for a wide variety of outcomes. The variables include distance from camera (foreground, middle ground, background), focus, 3D space in enclosure, still photos, films, wet and dry media, flipping the lens for greater magnification, modifying the enclosure or building a new one from scratch, material exploration, audio input, and LED light intensity.

This project is open ended. It could be a single-period project or could be extended.

Note

1. artofdigitalfabrication.com/resources. Shared with permission.



Tools/Materials	Additional	Software
Building, digital fabrication	Wet and dry art materials; computer for image capture	QuickTime

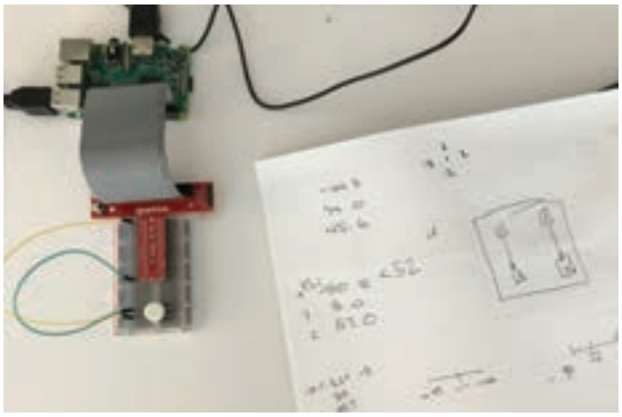
Creating Physical Interfaces to Minecraft with a Raspberry Pi

by Kevin Jarrett and Trevor Shaw

Physical computing makes learning to code more meaningful and engaging, and few things are more engaging these days than Minecraft, so an opportunity to mix the two is compelling indeed.

Students can create physical interfaces to Minecraft with a Raspberry Pi, a SparkFun "Pi-Wedge," and a free web-based Raspberry Pi IDE called PiForge.[1] PiForge's block-based programming interface is powerful yet simple and easy to use. Once a connection to the Raspberry Pi is established, kids can easily learn how to code event behaviors (e.g., a physical device state change like a button press causing action in Minecraft, or an event in Minecraft like crossing over a designated border causing an action on the Raspberry Pi like illuminating an LED or sounding an alarm). Along the way, students' creativity soars as they develop more and more complex programs. Minecraft and this activity are both easy to learn, so programming concepts like variables, looping, conditionals, and more all come to life powerfully and meaningfully, even for students who do not play the game.

We did this project as part of a four-day summer camp. It could easily be broken into several 45-minute lessons depending on the depth of programming desired.



Note

1. genlrn.com/piforge

Tools/Materials	Additional	Software
Electronics, microcontrollers	Raspberry Pi, Sparkfun PiWedge	PiForge

6+

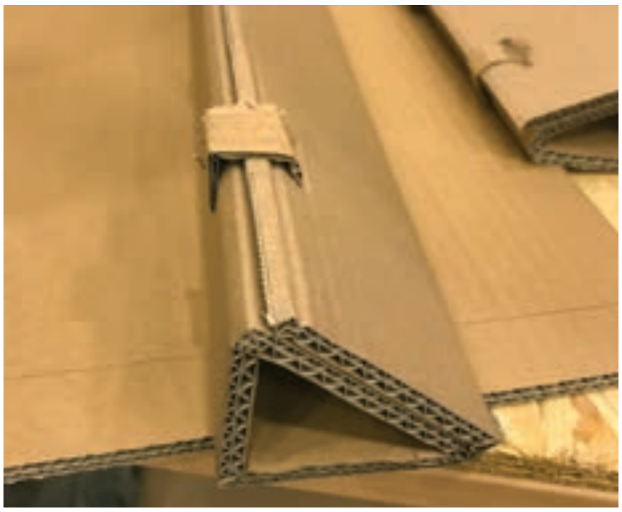
Cardboard Chair Challenge

by Wojciech Karcz

Building a sturdy cardboard chair is a great basic-level design challenge. Students learn about mechanical properties of cardboard, which is useful in many projects. The challenge is to build a chair that meets two conditions: (1) the chair must be built only using cardboard without any fasteners (e.g., no glue, tape, zip ties), and (2) it must support a student's weight while sitting.

Students need to figure out a design, tinker with how to connect cardboard, and iterate through setbacks. We do this in middle school, but it's also a good design challenge for older students or adult workshops. It's suitable for both teams and solo designers.

We typically spend three to four hours—and make sure you have a LOT of cardboard!



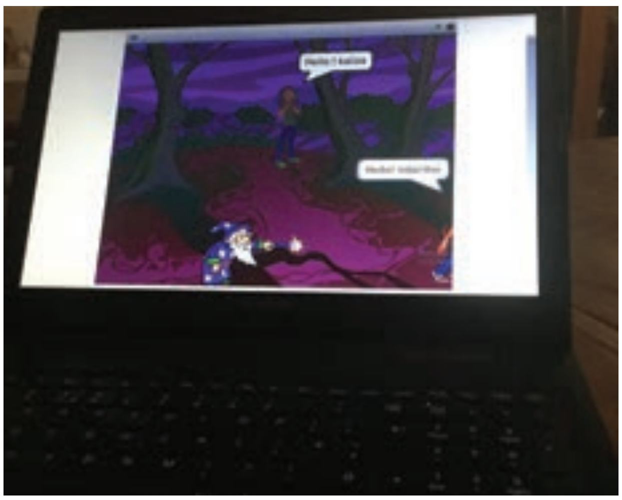
Tools/Materials	Additional	Software
Craft	A lot of cardboard!	

6+

Animating a Model of Myself in Scratch

by Alphonse Habyarimana

Students who have never programmed or used a computer before learn how to make animations, games, and stories about themselves using Scratch. Scratch makes it easy for students to learn programming due to its use of building blocks; there is no need to memorize syntax and other complicated conventions found in many programming languages. Students work together to write stories, organize them using sticky notes, and then animate them using Scratch. They present the stories to the entire class for feedback. We plan to add physical projects to this class in the future.



Tools/Materials	Additional	Software
		Scratch

6+

Make History

by Per-Ivar Kloen

Students research a historical person, item, or event that deserves a monument but doesn't have one. They design an interactive model of the monument that reacts to visitors or the surrounding environment. This is a "low-floor, high-ceiling, wide-walls" project that can be modified for different technology, materials, and student skills. It can include writing a report or doing a presentation or video. Students can choose their own technology. We use the Hummingbird Robotics Kit, mBot, Makey Makey, Grove sensors with Arduino, and micro:bit; a variety of software such as Scratch, MakeCode, and Snap4Arduino; and Tinkercad for circuit design.

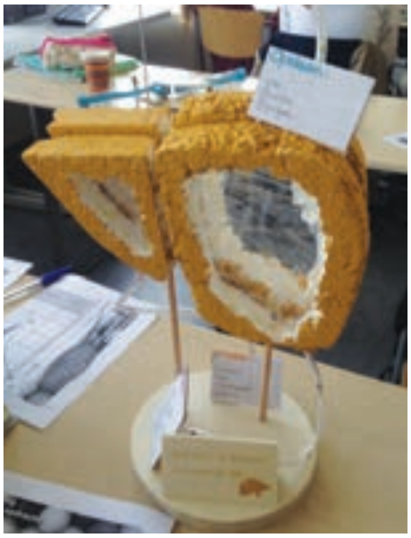
Tools/Materials	Additional	Software
Craft, conductive fabrication, electronics, building, microcontrollers	Hummingbird kit, mBot, Makey Makey, Grove sensors for Arduino, micro:bit	Scratch, Snap!, Tinkercad circuits

6+

Liver It Up!

by Per-Ivar Kloen

Students research the functions of the human liver. Then they make a product that explains these functions, animating and illustrating with found materials and electronics. It's an easy way to tie the curriculum to a maker project. Endless variations are possible as these objects can be as simple or complex as there is time and technology. It is also a project that can be spaced over a long period of time.






Tools/Materials	Additional	Software
Craft, conductive fabrication, electronics, building, sewing, digital fabrication		Vector graphics program

9+

Creative Capacity Building

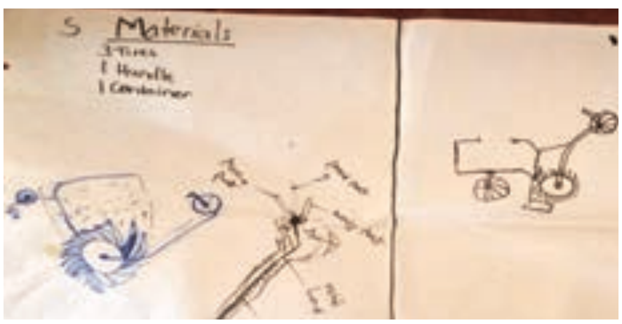
by Alphonse Habyarimana

Creative Capacity Building (CCB)[1] is a course framework and curriculum of Massachusetts Institute of Technology's D-Lab that trains participants to "create or adapt technologies that will improve their lives and strengthen their communities." During the course of the CCB program at Kepler Tech Lab in Rwanda, sophomore university students came together to work on projects to solve community needs in (1) energy, (2) agriculture, and (3) waste management sectors. Students were invited to work on different designs and prototypes of their projects using microcontrollers, electronic components, cardboard, and other materials, and to do sketch modeling of the projects and 3D design in SolidWorks. During the workshop, participants were encouraged to use the principle of design thinking to solve critical needs in their communities. One of the projects was an automated irrigation system, which was expected to improve a farmer's irrigation experience by saving time and water used.

This program took two months, one session a week, three hours per session.

Note

1. d-lab.mit.edu/creative-capacity-building



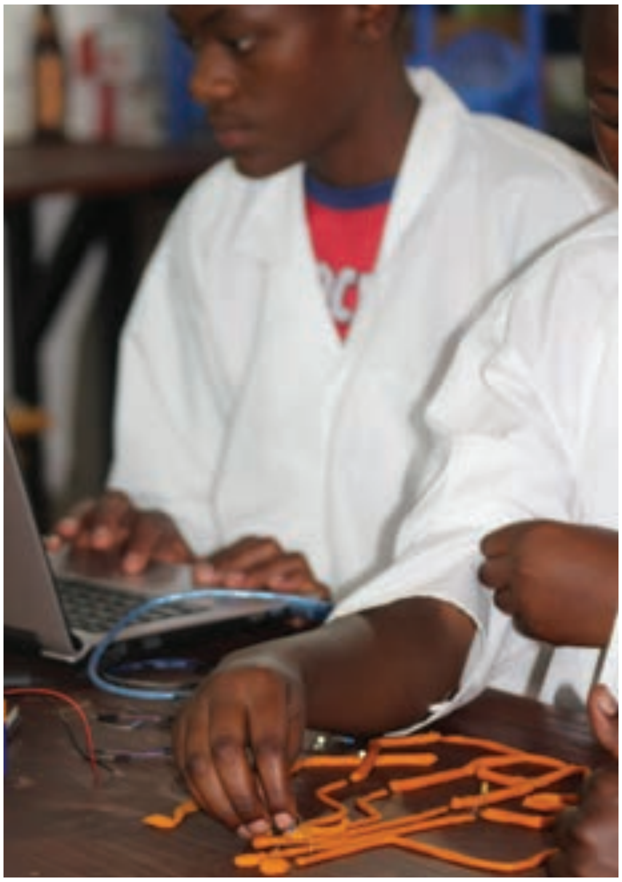
Tools/Materials	Additional	Software
Craft, conductive fabrication, electronics, building	Cardboard and other prototyping materials	SolidWorks

9+

Introduction to Physical Programming

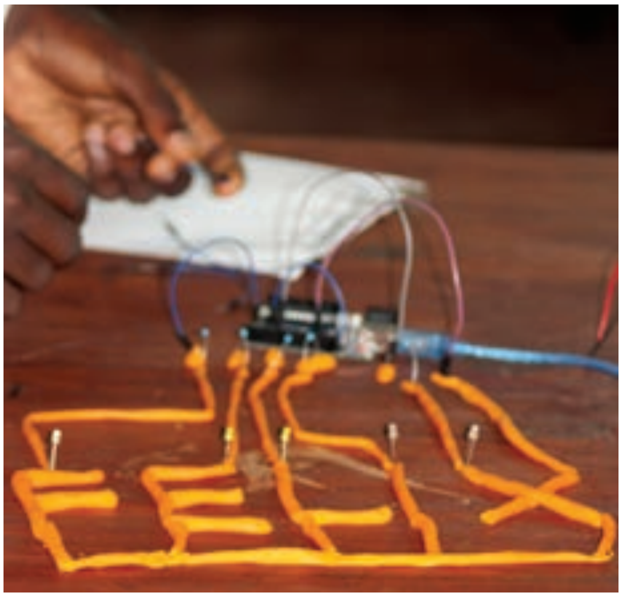
by Alphonse Habyarimana

At Kepler Tech Lab in Rwanda we introduced this physical programming class to our students to let them explore and provide them with great opportunities learning by doing that they couldn't otherwise get a chance to experience. Ninth graders learn and explore different engineering concepts in a year-long course. Part of the year is spent on physical computing using Arduino. Students work in pairs to learn what they can do with Arduino such as controlling LEDs, servo motors, LCDs, and more. They learn to code in the Arduino Integrated Development Environment. In one getting-started activity, students use Squishy Circuit dough (homemade conductive dough)[1] to make their own names, using the dough like wire and then decorating the names with LEDs.



Note

1. squishycircuits.com



Tools/Materials	Additional	Software
Microcontrollers, electronics	Squishy Circuit dough	

9+ Creative Robotics

by Angela Lombardo

After a process of experimenting and learning about programming with Scratch and about how the robotics components work, students are challenged to work in teams to create an interactive robot. We used the mBot robot, but it could be done with any robotics kit.

Each team had to present in four different areas: (1) the actual robot, (2) scenery and sets for the robot, (3) a project journal, and (4) a video commercial. Robotics creations had to be "interactive," meaning people had to be able to play or interact with the robot.

To spark some ideas and inspire creativity, facilitators shared some videos and set up a "tinkering zone" full of different kinds of materials. Facilitators provided students with a "robot design canvas" to help them brainstorm and discuss ideas. The learning path was designed to offer kids opportunities to experiment with taking a different, more active role in their learning, creating a safe environment where they could express their creativity and see themselves as inventors. Instead of following detailed instructions, students were encouraged to explore, document, and reflect on the result of their choices and their own thinking process. It helped them learn how to manage time; how to work as a team; and the importance of prototyping, testing, and iterating while working on a project—skills that they can use in everyday life.

Tools/Materials	Additional	Software
Craft, electronics, building	mBot off-the-shelf robotics kit, LEGO WeDo 2.0, or whatever kind of robotics kit you have	mBlock, Scratch

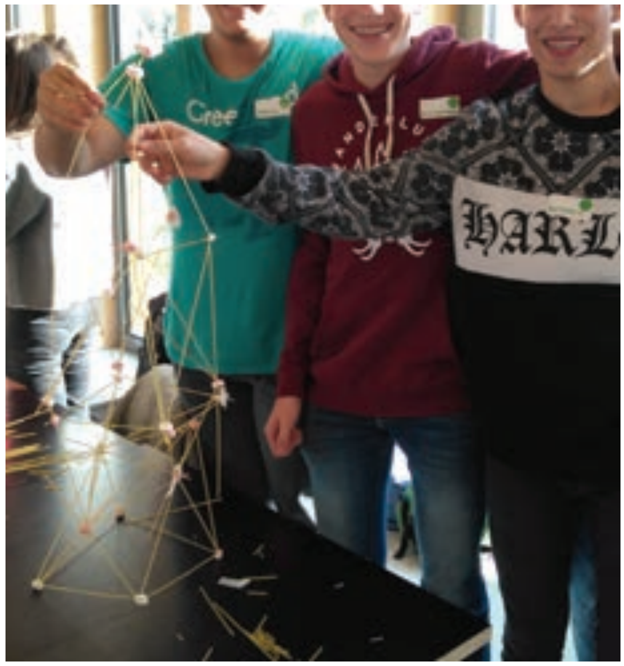
9+

Spaghetti Tower

by Angela Sofia Lombardo and Giulio Bonanome

Participants are challenged to work in teams to build the tallest tower using only a few provided materials in a set amount of time. The only available materials are spaghetti, 1 meter of tape, marshmallows, and scissors. The tower is required to stand without human intervention. At the end of the activity, participants reflect on how the tinkering or design process can be useful in a creative task and discuss the strength and weakness of each process.

It's useful to let students experience a rapid prototyping process and to reflect on it. This helps students understand basic concepts of physics and engineering. This activity is a good icebreaker and team-building activity. It's fast, fun, and cheap.



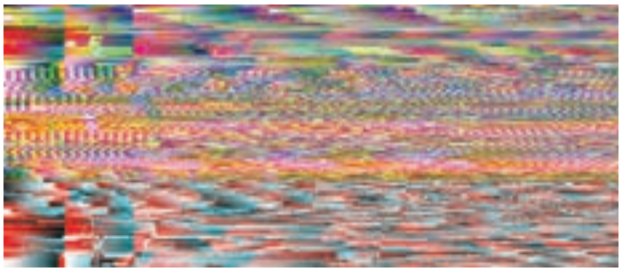
Tools/Materials	Additional	Software
Craft	Spaghetti, marshmallows	

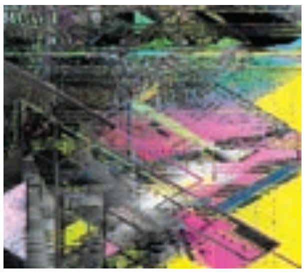
91 Glitch Art—Happy Accident or Controlled Chaos?

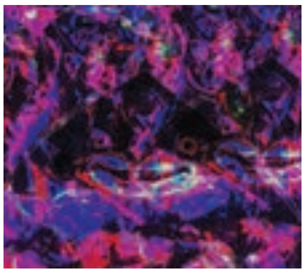
by Anne Bown-Crawford

Students at any level of expertise with digital imaging can learn to incorporate accidental or purposeful changes to a digital image file—corrupting, removing, or replacing digital data to change the look of a digital image, also called datamoshing or databending.

The process relies on editing the underlying data composing digital images to create something new. Conceptually databending presents opportunities to exploit the imperceivable systems that control the digital world.







Here's how it works

1. Save an image in an uncompressed file format such as BMP, RAW, or TIFF. Uncompressed files have more data to edit/bend/destroy than compressed files, and the image is less likely to completely break when corrupted.
2. Reopen it with TextEdit or something similar. Scroll down at least a tenth of the way into the file. You should see a bunch of data jargon. The first part of the data is the header. If you edit the header, it will break the entire image—try to avoid that! Try adding symbols like %, $, {, and } all over the file, or copy large parts of the data and paste them in new places, or delete information all over the file. Use the Find and Replace function to delete and replace large batches of data at once.
3. Save the file, open it again with your image-editing software, and see what happened. Trial and error is perfectly appropriate here!

This is usually a two- to three-day project to start, with the opportunity to go deeper into advanced glitching using the programming language Processing.

Resources

Daniel Temkin's Glitch Tutorials
danieltemkin.com/Tutorials

Eight Cool Tools for Glitching Images
bashooka.com/resources/8-cool-tools-for-glitching-images

How to Glitch Images with WordPad
datamoshing.com/2016/06/26/how-to-glitch-images-with-wordpad

How to Glitch JPG Images with Data Corruption
datamoshing.com/2016/06/15/how-to-glitch-jpg-images-with-data-corruption

How to Glitch Images Using Processing Scripts
datamoshing.com/2016/06/16/how-to-glitch-images-using-processing-scripts

Tools/Materials	Additional	Software
	Computers, digital cameras, printer, photo printing paper for final exhibit	Word processor like TextEdit; GIMP, Photoshop, or Preview

9+

Above/Below

by Anne Bown-Crawford

This project results in a series of vinyl graphics that fill the wall of a hallway at school. Students work in pairs to design for a space on a wall that is divided in half horizontally, conceptualizing a composition based on the theme "Above and Below"—what may be visible and what is the hidden narrative beneath that story. Students then work as a whole class to create a collaborative artwork down the hallway wall, deciding what comes first, second, third, and so on.

There are three critiques: conceptual development critique, midpoint critique, and final critique. Students are asked to consider the **elements and principles** of design for the **composition**: contrast, picture plane, positive and negative space, overlapping, and movement.

Students develop an understanding of the difference between **raster** and **vector graphics**. They learn to draw by hand on paper with pencil, then draw with a digital tablet, iPad Pro using Adobe Sketch, or on the computer using Illustrator or Inkscape. Student teams learn how to prepare their files to send to a vinyl cutter and how to operate the vinyl cutter loaded with black adhesive vinyl.

This project takes one to two weeks.

Tools/Materials	Additional	Software
Digital fabrication	Black adhesive vinyl	Inkscape, Illustrator

9+

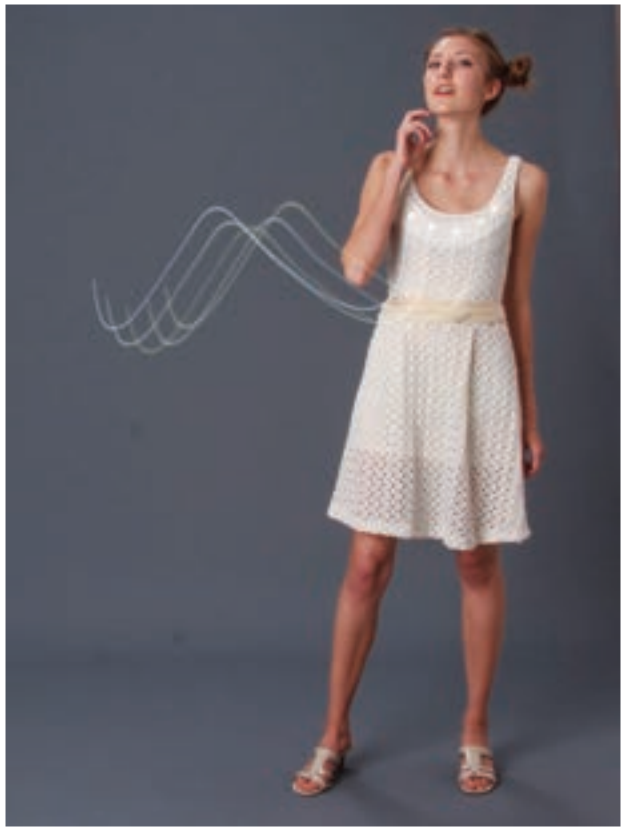
Fashion Design with Circuits

by Anne Bown-Crawford

Go beyond the basics of soft circuitry design to add the dimension of lights to clothing designs. Lessons begin with designing patches or cuffs. Advanced-level projects revolve around designing for the runway—from beginning concept to fashion show—with LED lights integrated into the design. The culminating activity is a digital fashion design runway show.

If programming is desired, the Adafruit Circuit Playground or SparkFun LilyPad Arduino can be used with software like Processing. The book *Make: Wearable Electronics* by Kate Hartman is indispensable to our program.

This can start and end within a couple of days for the cuffs/patches or extend to a six-week project for those designing for the runway.



Tools/Materials	Additional	Software
Craft, conductive fabrication, sewing, microcontrollers	Adafruit Circuit, Playground, or LilyPad Arduinos	Processing

Tin Puzzles

by Erin Riley

Students are challenged to make a two-color puzzle that fits within an Altoids-type tin. The learning goals are designing for fit and considering tolerance with 3D-printed parts. This requires multiple class periods for each of the following: 3D modeling, prototyping, and final printing.

The process involves measuring, offsetting shapes, extruding flat shapes into 3D form, converting 3D models into G-code, and 3D printing. Testing fit involves making very thin (1-millimeter) prototypes before printing the final pieces.

This project offers a high level of technical learning while not overworking the 3D printers. It offers extra practice with 2D vector design going to 3D modeling. The flat format is no fuss, no cleanup, and is less likely to cause a bottleneck, which happens with larger, more complicated prints.

Tools/Materials	Additional	Software
Digital fabrication	Altoids-type tin	2D vector design and 3D modeling software

A LEARNING REVOLUTION is in the making around the world. Enthusiastic educators are using the new tools and technology of the maker movement to give children authentic learning experiences beyond textbooks and tests.

Meaningful Making 2 is a second volume of projects and strategies from the Columbia University FabLearn Fellows. This diverse group of K–12 educators work at the forefront of this movement in all corners of the globe. They teach in Fab Labs, makerspaces, classrooms, libraries, community centers, and museums—all with the goal of making learning more meaningful in the modern world.

In this book, FabLearn Fellows share inspirational ideas from their learning spaces, strategies, and recommended projects across a broad range of age levels. Illustrated with color photos of real student work, the Fellows take you on a tour of the future of learning, where children make sense of the world by making things that matter to them and their communities. To read this book is to rediscover learning as it could be and should be—a joyous, mindful exploration of the world, where the ultimate discovery is the potential of every child.

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