Maker Movement in Education: History and Prospects

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Abstract

The maker movement in education has been a revolution in waiting for a century. It rests on conceptual and technological pillars that have been engendered in schools and research labs for decades, such as project-based learning, constructivism, and technological tools for "making things," such as physical computing kits, programming languages for novices, and inexpensive digital fabrication equipment. This chapter reconstructs the history of the maker movement in education analyzing five societal trends that made it come to life and reach widespread acceptance: (1) greater social acceptance of the ideas and tenets of progressive education, (2) countries vying to have an innovation-based economy, (3) growth of the mindshare and popularity of coding and making, (4) sharp reduction in cost of digital fabrication and physical computing technologies, and (5) development of more powerful, easier-to-use tools for learners, and more rigorous academic research about learning in makerspaces. The chapter also explicates the differences and historical origins of diverse types of spaces, such as Hackerspaces, FabLabs, Makerspaces, and commercial facilities such as the Techshop, and discusses educationally sound design principles for these spaces and their tools. Finally, strategies for adoption in large educational systems are suggested, such as the inclusion in national standards and the local generation of maker curricula by schools.

Keywords

Maker movement • Constructivism • Constructionism • Hands-on learning • Experiential education

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Contents

Introduction: A Revolution in the Making for a Century

The maker movement in education has been a revolution in waiting for 100 years. The conceptual and material pillars upon which it rests – interest-driven curricula, project-based pedagogies, constructivism, constructionism, critical pedagogy, and rich, expressive, low-cost technological tools – have been engendered and engineered in schools, universities, and research labs for decades. Progressive educators and constructivist researchers have been prescribing interest-driven, student-centered, and experiential approaches for more than a century (Dewey 1902; Freudenthal 1973; Fröbel and Hailmann 1901; Montessori 1965; Von Glaserfeld 1995). Scholars have also dedicated considerable attention to the symbiotic relationships between the human mind and external artifacts when performing complex tasks (distributed cognition, see Hutchins 1995), as well as alternative orchestrations for learning environments such as apprenticeship-based models (legitimate peripheral participation, see Lave and Wenger 1991). Critical pedagogy then highlighted the importance of learners' empowerment, culturally authentic learning experiences, convivial tools, and the connection with local communities and their funds of knowledge (Freire 1974; Illich 1970; Moll et al. 1992). Critical theorists such as Freire fervently advocated that students should perceive themselves as change makers, capable of producing transformations in a world that should never be taken as static or immutable. Seymour Papert brought to the forefront the importance of rich tools and media. After working with Jean Piaget in Geneva for several years, Papert added to constructivist theory the idea that students' interactions and experiences would happen more robustly if learners were engaged in building public, shareable artifacts, such as robots, inventions, sand castles, or computer programs. Papert elevated the cognitive status of building and making and reevaluated the hierarchical relationship between abstract and concrete. His students and collaborators became increasingly focused on designing and making available rich computational materials and toolkits for children to build those sharable objects. Such protean technological tools would then enable students to design, engineer, and construct complex artifacts, also enabling a variety of new forms of work and expression (epistemological pluralism, Turkle and Papert 1991). Therefore, the main building blocks of what we call today the "maker movement" in education have been around for a long time, but never they have come together so forcefully. It was not until the advent of the *Maker Faires* and the *FabLabs* that the movement gained its current designation and started to enjoy high levels of popularity.

However, the fact that the movement now enjoys wide acceptance does not a guarantee that it will survive in school environments. A fundamental concern is to make sure that this movement does not join laptops, tablets, and video-based learning on the long list of overhyped educational fads of the past decades. A second issue is that, within the history of technology education itself, it has been common for hands-on activities to be considered second-class tasks in schools, inferior to scholastic work, and associated only to technical and vocational education (Bennett 1937). This chapter seeks to offer a definition of what the movement is, provide a brief account of its history, and make recommendations about how to build a sustainable future.

For an Alternative History of the Maker Movement in Education

It is tempting, but often less useful, to examine world history as a product of great kings, generals or leaders. Frequently, however, such individuals were simply in the right place at the right time, and larger infrastructural, economic, and technological transformations made their political or strategic projects possible. This lesson is as important for understanding the origins of the maker movement as it is for an understanding of world history. The history of the movement has been disproportionately attributed to visionary characters and specific individuals and focused on events that took place in the last 5 or 10 years (see, for example, Peppler et al. 2016). In place of such narratives, this history should be told as the conjunction of societal and economic preconditions and the contributions of the visionary individuals and organizations that helped shape it. Understanding the maker movement in this light can help us on two fronts. First, it shows us that the movement is the culmination of a long tradition of educators seeking to put children and youth at the center of the educational process; second, it helps us understand which infrastructural elements must be kept alive for the movement to thrive while keeping students at the center in complex institutions, such as schools, and particularly in technology education. In the following sections, the societal trends that helped create a favorable scenario for the movement to appear and become popular are discussed.

First Trend: Social Acceptance of the Ideas of Progressive and Constructivist Education

Since the beginning of the twentieth century the field of educational research and practice has been divided into two camps, *grosso modo*: traditionalists/instructivists and progressives/constructivists (this is an oversimplification: for a more elaborate discussion, see, for example, Kirschner et al. 2006; Papert 2000). The debate has swung from one side to the other several times throughout the past several decades, but especially over the last 15 years an unprecedented acceptance has emerged for many of the ideas of progressive education. It is a challenge to set a precise date for the inception of this trend, but several events contributed. First, there have been widespread demands from the business world for workers who are more creative and flexible, better able to function in the new global economy, and more capable of understanding the twenty-first century's manufacturing and business management workflows. These business groups have actively incentivized an increased focus on the STEM disciplines – especially computer science – and also newer, more up-to-date, educational approaches for teaching them. A second type of initiative came from governments, science academies, and international organizations in the form of new national curricula and international tests. In the USA, for example, the Next Generation Science Standards (*Next Generation Science Standards: For States, By States* 2013) placed a very strong emphasis on problem solving, scientific practices, and interdisciplinary work, and gave engineering and design a momentous place in K-12 education. Other countries, such as Australia, Finland, and Canada, also restructured their national standards to put engineering and design much more prominently. International organizations such as the OECD, which used to focus only on math, reading, and science (OECD 2006), also began to devise new international tests to measure skills such as collaboration, in line with the need for workers to move away from the isolated production modalities of the past. Many of those newly demanded abilities have been grouped under the heading "twenty-first century skills," a catchphrase that has been widely publicized and adopted by ministries of education, corporations, and educational organizations worldwide. However, it seems that as the term "twenty-first century skills" became popular, its connection to progressive education and constructivist theories was lost, and ironically, this very failure of recollection might have contributed to the popularity of the concept. Since most of the advocates of twenty-first century skills in education were unaware of their connection to progressive education and constructive/critical pedagogy theorists, it could well be that their adoption in national educational frameworks became less controversial, since it escaped the academic and political debate between traditionalists and progressive educators. The result of this trend is that previously controversial topics and practices, such as critical thinking, problem solving, creativity, design, and complex communication, were moved into the national agenda of many countries, not anymore as "nice to haves," but as necessities for modern societies to thrive.

Fig. 1 President Obama at the first White House Maker Faire in 2014 (Image source: United States White House)

Second Trend: Countries Looking for the Innovation Holy Grail

Virtually every nation on the planet wants to shift away its current economic activity to a knowledge- and innovation-based economy. Often, the first realization to confront such intentions is that innovative workforces must be educated differently and that such education should start early on. These governments are also quick to realize that "business as usual" in education simply will not suffice to achieve these goals. Even though governments are still caught between the desire to bring about radical educational change and its actual implementation, many are actively pursuing such agenda, creating environments much more favorable to progressive educational ideas and practices, and funding innovative research programs. In the USA, for example, the White House has been organizing science and maker fairs on its grounds since 2014 (see Fig. 1). Several states and cities, such as New York, are considering or implementing large scale programs for teaching computer programming as part of the official school curriculum. As recently as 2016, a large national initiative in England led by the BBC gave to thousands of seventh graders low-cost computer boards (the BBC micro:bit, Fig. 2) together with curricula and several programming environments.

Third Trend: Growth of the Mindshare of Coding and Making

As a result of this more favorable outlook for progressive education, many ideas, content, activities, and classroom practices that used to be restricted and limited

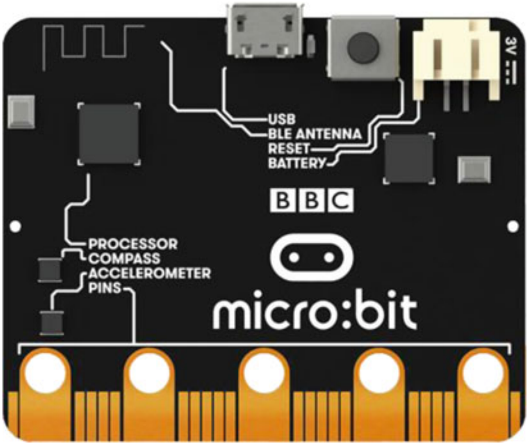

Fig. 2 BBC micro:bit, a small scale computer being distributed to schoolchildren in the UK

to just a few schools went mainstream. In the early 2000s, Neil Gershenfeld started teaching a course at the MIT Media Lab called "How to make almost anything" – a "crash course" in the nascent field of digital fabrication for MIT graduate students. Packed in the basement of the iconic 20 Ames St. building in Cambridge, MA, students of widely divergent interests, majors, and backgrounds rubbed shoulders building technologies and inventions that defy the imaginations of traditional engineers and technology educators. The course was the first ever to deliver such content to students from diverse disciplinary backgrounds – artists, programmers, educators, engineers, and interaction designers. At the same time, the regulations of the National Science Foundation in the United States mandated that scientists should increase the outreach component in their federal grants, so Gershenfeld devised the idea of packaging much of his lab equipment – including a laser cutter and small milling machine – into a "portable," standardized lab that could be transported to various Boston locations (Gershenfeld 2007). The first lab was deployed at an inner-city Boston community center that catered to underserved youth. Gershenfeld teamed up with Bakhtiar Mikhak, another MIT professor, to create precise specifications for the lab, and, after many redesigns, they ultimately deployed their project in Costa Rica, India, and Norway. In a 2002 paper (Mikhak et al. 2002) they termed these environments "FAB LABs," a humorous wordplay on "Fabrication" and "Fabulous." For a few years, FabLabs grew slowly, probably as a result of high costs, novelty, and a lack of mainstream publicity, and were concentrated mostly in the United States and Europe. Starting in the late 2000s, their growth accelerated and presently more than 1000 are estimated to exist worldwide. FabLabs are one of the crucial cultural and infrastructural roots of the maker movement, and their rapid growth in recent years can be also attributed to the arrival of two big players in the field: *Make Magazine* and the *Maker Faire*.

In January 2005, the O'Reilly publishing house produced the first issue of *Make Magazine*, founded by Dale Dougherty (2013). The magazine brought back the San Francisco Bay Area DIY ethos with a twist: it targeted a broader audience and made use of the new tools starting to appear in the marketplace, including new low-cost microcontroller boards such as Wiring and Arduino, electronics kits, 3D printers, and other digital fabrication machines. In April 2006, the first Maker Faire took place in the San Francisco Bay Area, attracting tens of thousands of people. The magazine and "Faire" were both seeds of a movement and beneficiaries of four existing developments: FabLabs, a new breed of low-cost microcontroller boards, a general sentiment against "black boxed," opaque consumer electronics, and the popularization of open source software and hardware. Through these media, the maker's movement reached hundreds of thousands of people and grew globally – there are currently tens of "Maker Faires" worldwide every year.

In 2013, a group of Silicon Valley entrepreneurs and CEOs created *Code.org* (http://code.org), a nonprofit organization aimed at popularizing computer programming for children. The organization released an introductory video featuring the most important CEOs of the technology world. The video, which includes Mark Zuckerberg and Bill Gates, has received over 13 million views to date. Propelled by an efficient marketing machine, *Code.org* (http://code.org) created popular (although controversial, see Resnick and Siegel 2013) campaigns such as the Hour of Code, which made the idea of coding popular in ways not seen since the heyday of the Logo programming language in the 80s (Papert 1980). At the same time, many large corporations jumped on the making and coding bandwagon and started programs of their own further increasing the momentum of making and coding in K-12 education.

Fourth Trend: Dramatic Reduction in Cost of Digital Fabrication Technologies

Another important occurring over the past 20 years has been the dramatic cost reduction in several technologies closely related to fabrication and making, a trend that Gershenfeld (2007) compared to the shift from mainframes to personal computers. At the beginning of the 2000s, 3D printers could only be found in large corporations and would cost hundreds of thousands of dollars. Halfway through the decade they had fallen to several tens of thousands of dollars, and in 2017 some models are available for $300 or less (see Fig. 3).

In the 1990s, the use of microcontrollers required an enormous technical knowledge, and a plethora of electronic components were required to power them, enable their sensors, and trigger external devices such as motors. New products lines from Atmel and Microchip, together with much cheaper (or free) development platforms, led to inexpensive and easy-to-use microprocessors. Microcontroller boards such as the Basic Stamp (for hobbyists) and the MIT Crickets (for education) made microcontroller use even simpler by providing on the board itself much of the circuitry necessary for sensing and device control. In 2005, the Wiring and Arduino

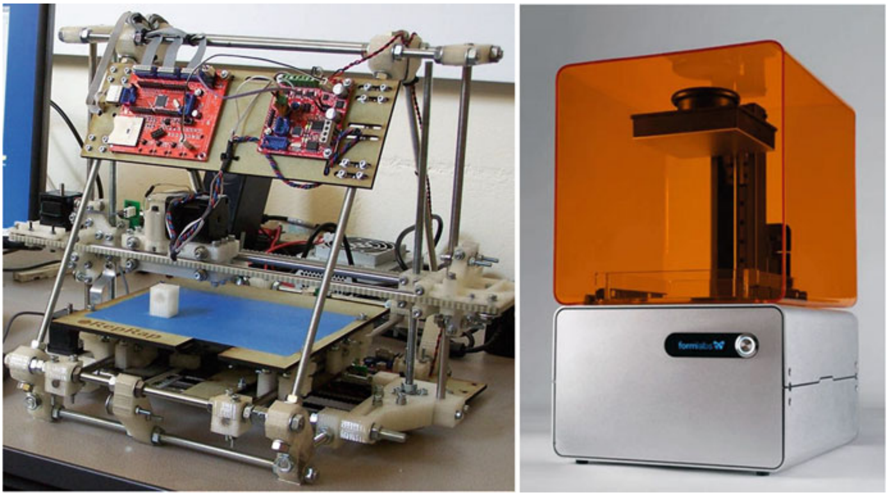

Fig. 3 The evolution of low cost 3D printers: from the first RepRap Mendel in 2005 (Photo: Adrian Bowyer) to Form 1 in 2011, which can reach resolutions of 25 μ using stereolithographic technology

platforms started a new chapter in this revolution by offering an inexpensive hardware platform, free development tools, and stable software and hardware design (for a full review, see Blikstein 2015). At that point, the Internet was already ubiquitous, so self-sustaining web communities propelled the use and adoption of Arduino to levels never before seen (see Fig. 4 for several of these platforms).

Fifth Trend: Better Tools and Research from Academic Labs

The last important trend necessary for understanding the growth of the maker movement in education is the improvement and creation of new software and hardware tools specifically focused on children and the increased research output of academic labs. The best example is the Scratch programming language (Resnick et al. 2009), developed by the MIT Media Lab beginning in 2002. Scratch took the world by storm, making computer programming much easier through the substitution of manual entry of typed code for a block-based graphical coding interface. Other tools, such as Alice and NetLogo, extended programming to new areas, including 3-D worlds and storytelling (in the case of Alice, Cooper et al. 2000) and scientific modeling (NetLogo, Wilensky 2006). All such tools benefited from a research field that was then taking form: interaction design for children. This nascent field adapted the lessons of human-computer interaction and applied them creatively to the design of computational and tangible tools for children. The first Interaction Design for Children Conference (IDC), in 2002, solidified this emerging movement of designers and researchers, and the community remains extremely active and behind many of the most significant efforts in bringing the maker movement to

Fig. 4 The evolution of technology kits for children: the Erector Set (1940s), the Lego Mindstorms kit (1998), the GoGo Board (2001), the Arduino (2005), the Lilypad (2006), and LittleBits (2011)

education. Some of the seminal papers on digital fabrication and physical computing for children were published at IDC. Mike Eisenberg, in a visionary and trailblazing paper, first proposed the use of new "output devices" such as 3D printers in education (Eisenberg 2002), and Leah Buechley pioneered the use of e-textiles and new, flexible materials (Buechley 2006; Buechley and Eisenberg 2008).

However, researchers did not simply design new interfaces and toolkits; they were also studying them and publishing research focused specifically on the effect and impact of these new technologies on learning. This research tradition had a strong start at the MIT Media Lab, but Northwestern University also contributed significantly with its creation of the first Learning Sciences program in 1991. This new research field spread quickly within the United States and Europe, as well as in other countries such as Singapore and Australia, offering new perspectives for research at the intersection of technology and learning. Breaking away from the strict traditions of educational psychology, large econometric studies, and critical theory, the learning scientists began developing, refining, and applying novel methods, often adapted from other disciplines, including design-based research (Edelson 2002; The Design-Based Research Collective 2003), computational modeling (Abrahamson et al. 2007; Blikstein 2013b; Worsley and Blikstein 2013), new types of ethnographies, and thick descriptions of learner-produced artifacts (Nemirovsky 2011; Sherin 2001). At the same time, they generated a much more plastic and diverse body of research that significantly influenced the creation of the Next Generation Science Standards in the United States and research that inspired innovative educational experiences worldwide. Additionally, learning sciences researchers were very well equipped to study the complex, unconventional, and at times eccentric educational interventions typical in maker environments, including small workshops and after-school environments. Not by coincidence, the field of the Learning Sciences brings together the main researchers studying the maker movement in education (Halverson and Sheridan 2014; Martin 2015; Peppler and Bender 2013), many of whom have recently published an entire volume on research on the maker movement in education (Peppler et al. 2016).

FabLabs, Makerspaces, and Other Fabrication Spaces: A Primer

The confluence of these five trends brought us to a special moment in the history of educational technologies and technology education. There is an unprecedented social acceptance for the changes that the maker movement can bring to education, as well as a strong research infrastructure to measure its outcomes. The costs of software and hardware tools are quickly dropping, and several new, student-friendly tools are being created in research and design labs. Not by coincidence, many types of spaces and formulations are being attempted in schools and informal learning spaces. Therefore, it is useful to understand the exact nature of each of these new spaces for making and fabrication and how they differ (see examples in Fig. 5).

Hackerspaces

Hackerspaces began to appear in the 1980s and 1990s in several cities in the USA and Europe as places where technology enthusiasts could come together, invent devices, repurpose them, or explore the nascent technologies, such as low-cost microcontrollers. Such spaces were also inspired by the open source software community. Hardware engineers also began imagining a world in which hardware design would be free and open source, in a reaction against the overly protected model of most consumer electronics manufacturers. Hackerspaces were envisioned as places of resistance, the breeding grounds of a counterculture opposed to

Fig. 5 Three different spaces for making and fabrication, in East Palo Alto, USA (top); Bangkok (middle), Thailand; and Melbourne, Australia (bottom)

overconsumption, stringent intellectual property, programmed obsolescence, and proprietary devices. Even though hackerspaces were inspirational for the maker movement, their typical audience were high-end programmers, hackers, and engineers, and some authors have noted that the male-centric, technical culture that developed in many of these spaces is problematic and exclusionary for novices (Buechley 2013) and that the culture of autodidactism in which their adherents live and breathe might not be the best for young learners and schools (Blikstein and Worsley 2016).

FabLabs

FabLabs followed hackerspaces in the desire to open up and demystify everyday objects and technologies. They were the first spaces designed for digital fabrication and rapid prototyping at low cost (Gershenfeld 2007; Mikhak et al. 2002). Engendered at the Massachusetts Institute of Technology Media Lab, they had a strict list of machines and rules required for all labs seeking a FabLab designation. The idea behind standard equipment was to allow collaboration and cross-pollination of ideas among participating labs and the creation of a worldwide network of very similar small scale fabrication facilities. FabLabs must also follow the Fab Charter and they must employ at least one staff member trained at the Fab Academy, the training program sanctioned by the global FabLab community. The mindset of the FabLab network, with these more prescribed forms of organization, certification, and training, assures that all labs allow the fabrication of products at a minimum level of complexity, using similar technologies and practices. FabLabs around the world enjoy relative freedom and independence, but the denomination itself is centrally controlled by the Fab Foundation, so the labs – even in schools – have to possess a minimum set of equipment.

Makerspaces

Makerspaces represent a radically different mindset that arose from the culture and community of the *Maker Faires* and the *Make Magazine*. Makerspaces are physical spaces for making that range enormously in format. They represent a flexible set of technologies and concepts put forth by Dale Dougherty and his Make Corporation and MakerEd nonprofit organization (Dougherty 2013). Makerspaces started as a new kind of digital fabrication and invention space intended to be much less structured than the MIT FabLabs. Whereas FabLabs are required to contain a specific set of machines, a connection to a global network, and affiliation to a virtual academy for lab management training, makerspaces are more of a label than a well-defined, intentional project. There is no set formula or specification to build a makerspace; as a result, they are able to play a variety of roles, may range greatly in size, capability, and cost, and permit a number of management possibilities. Makerspaces may contain a few basic craft and woodworking tools or they may offer cutting-edge 3D printers and laser cutters. However, this lack of any precise definition for the concept has led to confusion for school leaders and teachers. Some schools provide a small room with a table and some glue guns and consider that a makerspace, while others offer professional-grade 3D design equipment. The fact that the Make Corporation, the movement, the “faires,” and the nonprofit activities of MakerEd all share the “make” denomination, has also brought some confusion to schools and criticism by scholars as to the need to better separate the institutions and brands (Bean and Rosner 2014). Compared with FabLabs, despite their flexibility, makerspaces have a much harder time comanufacturing products, connecting with each other, and sharing best practices.

Commercial Ventures and TechShop

Apart from the three main types of digital fabrication spaces, private companies have sought to create commercially viable fabrication spaces. The TechShop is the best known commercial version of FabLabs and makerspaces. Started in 2006 in Menlo Park, California, the company now operates in three countries at 11 locations. Most TechShop installations have similar equipment, usage policies, costs for facility rental, and architecture: users pay for access to the machines and receive support from the staff. The TechShop is perhaps the best example of an economically sustainable digital fabrication space, and it is used mostly by inventors and entrepreneurs, with little impact on formal education.

Challenges and Opportunities for the Maker Movement in Schools

This multiplicity of spaces and maker “philosophies” certainly creates difficulties for schools attempting to understand the differences between them. It is challenging to choose between the models and know, in each case, how to build the spaces, train teachers, manage labs, and incorporate the particular maker practices pertaining to each model. The final section of this chapter offers some research-based insights and recommendations for building robust maker infrastructure in schools and districts and for the creation of national initiatives aimed at democratizing the maker movement for students.

Lab Design that Is Well Adapted to the Needs of Schools

Tool and environment design turned out to be quite fundamental in the creation of inclusive, functional spaces for making (Blikstein 2013a; Buechley et al. 2008; Perner-Wilson et al. 2011). The architecture and workflow requirements of labs destined for students are quite different than those of labs designed for high-end engineers working professionally. Students normally come to a digital fabrication space in large groups for short periods of time and require intense facilitation, whereas inventors are typically few, work long hours, and are autodidacts.

Consequently, the number of machines and the architecture for these distinct kinds of space cannot be the same. Many schools stumbled on this issue in their attempts to install traditional, “adult” FabLabs, hackerspaces, and makerspaces within their walls. Schools often purchased equipment that was designed for individual use, not for large groups, which made direct manipulation by students all but logistically impossible. For example, whereas in a professional space it would be more useful to have one high-end 3D printer, in educational spaces it would be better to use the same amount of funds to buy several low-end machines that can be used simultaneously by students.

Educational designers also struggled with gender bias and self-selection. Architecturally, special concern must be given to making these spaces well organized, inviting, colorful, and engaging. Consequently, it is necessary to avoid creating the appearance of “a hacker’s garage,” which would appeal mostly to male students and children with previous engineering experience (Blikstein 2013a). Standardization was a hallmark of the MIT FabLab model, but that requirement conflicted with the differing needs and funding levels of individual schools. Many schools had small amounts of funding available to get started, so they could not afford the entire set of equipment mandated by the FabLab network. At times, some of that equipment, such as machines to create printed circuit boards or large routers, were not very relevant to projects typically undertaken by young learners. At the same time, the Make Corporation’s vague recommendations for makerspaces did not offer schools a definition of what constitutes a proper space for making, generating a plethora of ad hoc characterizations that did not offer much guidance for the design of robust programs. In summary, there is still considerable latitude for designers to create and adapt models that would efficiently work in schools, with their differing instructional, workflow, and funding requirements.

Systemic Incentives for Innovative Schools and Teachers

A second component that could democratize the maker movement in schools is the creation of incentive systems that reward the teachers who promote innovation in schools. For the most part, the creation of spaces for digital fabrication in schools is driven by visionary, energetic teachers who take initiative to do things differently. Rarely, it is the case that the development of such spaces is driven by top-down models. This has much to do with the very nature of the activities and learning requirements of children. It would make no sense, for example, to have a rigorously scripted maker curriculum for an entire nation, because making in education is committed to some level of free choice and project-based learning. Before adopting such top-down curricula, countries considering the institution of standardized spaces for digital fabrication should weigh very carefully the outcome of such approaches for their teachers’ creativity and innovation. Detailed implementation plans certainly do require structure and planning, but they also require real incentives at the local level for innovative teachers and schools to continue their innovation and experimentation with new curricula, pedagogies, and tools. Such incentives might include fellowship programs for innovative teachers, national prizes for innovative educational experiences, national science and engineering fairs, and other high-profile national events.

Inclusion in National Standards: They Should Reward Innovation!

A third very important component in ensuring the movement's sustainability is its inclusion within national standards. In the USA, the Next Generation Science Standards (NGSS) was quite felicitous in its inclusion of engineering practices beginning in the early grades. The inclusion of such considerations into national documents has a twofold advantage. It rewards teachers and schools already producing and teaching innovative curricula, even if they are not specifically seeking to comply with national standards. For example, in the USA, thousands of teachers have been teaching robotics and engineering in public schools, but outside of the school day or the school curriculum. Budget cuts and the natural wear and tear of sustaining an innovative educational experience have led many creative and innovative teachers to reduce or curtail such projects. However, as the NGSS is being enacted in several states in the USA, these teachers are finally gaining recognition and institutional support because, now, their innovative activities are acknowledged for their compliance with national standards.

The second advantage of including maker activities in national curricula is that they offer immediate incentives for entire school systems to restructure themselves to offer such activities and to devise concrete and objective schedules for implementation. The Australian government, for example, created a brand-new Information Technology curriculum and will deploy it over the next several years, thus Australian schools have been preparing for the types of content that will be required. Therefore, to ensure the promise of making in education, national standards should reward innovation in schools rather than compliance with past approaches and standards. Such standards should also offer guidance for the creation of new types of content, labs, and activities to be implemented nationally.

Because of these revised national standards, schools will need to redistribute time throughout the school day, and it will soon be apparent that there is no way to offer maker activities within the confines of the traditional school day and structure. The hiring of new types of teachers with new skill sets will be necessary, and existing teachers will require retraining. Spaces will need to be retooled and assessments redesigned. Such changes may appear overwhelming, but with the correct planning, incentives, and resources, they are quite feasible.

Local Generation of Curriculum and Redesigned Lesson Plans

The year 2011 saw the creation of one of the first digital fabrication spaces in the world at a school in the San Francisco Bay Area. The methodology utilized to develop a local curriculum for this project demonstrates the existence, in a real educational environment, of a sustainable implementation model based upon the creation of a critical mass of curricular units by local teachers. In this school, one of the main elements of the implementation was the establishment of a "curriculum factory." Teachers would bring their current lesson plans to the maker lab teacher/manager and they would redesign them to make use of the best features of the lab. The school released both parties from their normal duties for a few hours a week to write these maker lesson plans. For the disciplinary teacher, the collaboration with the maker lab teacher meant that he or she did not need to learn in depth the technical details of the machines, which made for a much less intimidating experience. Since the lab teacher was available for assistance on these technical issues, the teachers could concentrate on course content and pedagogy, while the lab teacher's focus was on lab usage ideas. Typically, the process would continue for several weeks until a satisfactory quality was achieved for the lesson plan redesign. The curriculum units generated through this process would range from a week to a month and would include various elements such as the creation of materials, design of a final exhibition, assessment rubrics, evaluation, and technical tutorials. The redesigned lesson plans would then be implemented, evaluated in conjunction with the school leadership, and refined. The following year, the lesson plans were again implemented and further refined. Within 4 years, the school had built a database of maker units and lesson plans tightly integrated within its curricula, so the maker activities are now implemented during the regular school day on a regular basis. This school is now one of the most well-known models for a successful implementation of a maker space in middle-school.

Conclusion and Future Directions

Every few decades or centuries, a new set of skills and intellectual activities become crucial for work, conviviality, and citizenship – often democratizing tasks and skills previously only accessible to experts. But in the history of technology education, rarely there has been special attention to going beyond strict vocational and technical skills (Bennett 1937). In fact, there are two ways for the maker movement to be radically innovative. First, going beyond stereotypical views of technical education and breaking the dichotomy between hands-on and intellectual work. Second, when operating in schools, the maker movement could pay special attention to the insights of developmental psychology, interaction design, constructionism, and progressive education. Digital fabrication and "making" could be a new and major chapter in a process of bringing powerful ideas, literacies, and expressive tools to children, instead of merely providing technical training for the job market. Theorists such as Papert advocate technology in schools not as a way to optimize traditional education, or teach technological skills for better alignment with the demands from the professional world, but rather as an emancipatory tool that puts the most powerful construction materials in the hands of children. The machines and tools made available through the maker revolution have been proven to enable student design, engineering, and construction of unimaginable objects and inventions, and cater to many forms of working, expressing, and building (Martinez and Stager 2013). The chameleonesque adaptivity embedded in the technologies of the makers' movement permits the acknowledgement and embracing of different epistemologies, engendering convivial environments in which students can concretize their ideas and projects with intense personal engagement. We have enough research into the efficacy of the learning experiences that students undergo when they are engaged in making. But the main issue with educational technologies is always going beyond the demonstration phase. The next challenge for the maker movement will be the challenge of democratization: how do we bring such experiences to the children with the greatest disadvantages to make the movement an equalizing force, rather than another type of technology that widens the gap between private and public schools, affluent and low-income communities? This time, it seems that we have all the elements needed to formulate an answer and to realize, at last, the promise and the potential of educational technologies and progressive education.

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