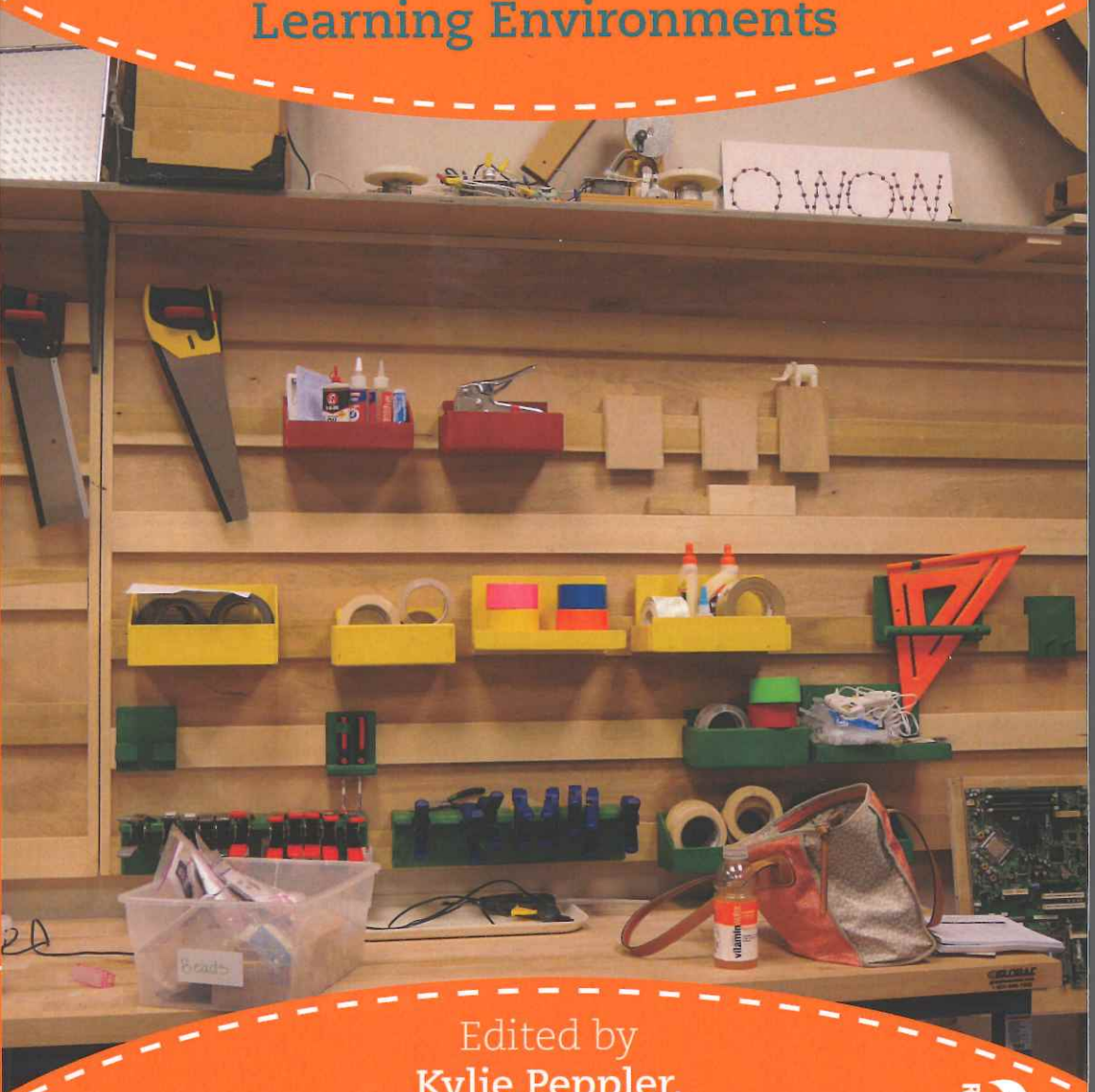
VOLUME 1

Makeology

Makerspaces as Learning Environments



Edited by
Kylie Peppler,
Erica Rosenfeld Halverson,

ROUTLEDGE

CHAPTER 1

Introduction to This Volume

KYLIE PEPPLER, ERICA ROSENFELD HALVERSON, AND YASMIN B. KAFAI

In a large recreational hall transformed into a full-fledged makerspace, laughter, chatter, and occasional screeches sounded from a table surrounded by youths and cluttered with laptops, LEGO bricks, and clay models. During a 2-week summer maker camp, the 16 youths (5 girls, 11 boys), 9- to 13-years old, were creating 3D models of a variety of items, from remixed superhero logos to miniature sports equipment. First, they used physical prototyping materials, including playdough, wax, LEGOs, or clay, to try out modeling in three dimensions. Then they created digital models of their ideas, and lastly they got to print their work using 3D printers. Lisa, curious mahogany eyes looking through peek-a-boo bangs, was among the campers. With concentration, she switched between a street-view photograph of her house and her 3D model of the same, seemingly trying to get just enough details into her model. Then another camper called on her for support. Despite not having used 3D modeling software or printer before, Lisa emerged as the go-to person during camp, jumping back and forth between crafting her personal project and helping out fellow campers. When others printed their projects, she lingered with them around the row of 3D printers, watching the models emerge. In this 21st-century version of shop class, 3D printers are part of the new set of tools youths are using to imagine, design, and make.

Introducing the Maker Movement

Open exploration, intrinsic interest, and creative ideas are but a few of the commitments at the core of today's Maker Movement—a grassroots culture dedicated to hands-on making and technological innovation. Popularized

by *MAKE* magazine, Maker Faires, and online communities like Etsy, Ravelry, and Instructables, the Maker Movement embodies do-it-yourself (DIY) production across a host of domains, ranging from textile crafts to electronics, advanced robotics to traditional woodworking (Anderson, 2012; Hatch, 2013).

Across these applications, the Maker Movement is propelled by the introduction of new technologies (like 3D printers, laser cutters, and Arduino robotics, which allow for faster prototyping and new forms of digital fabrication) and the rise of the Internet (which allows for the sourcing of parts, as well as the widespread sharing of ideas [Dougherty, 2013]). At the same time, there is a growing grassroots movement behind the technology that reclaims the deeply held cultural values arcing back to the DIY culture of mid-20th-century America (Gauntlett, 2010; Spencer, 2008). While these practices still have a distinct place among 21st-century makers, the influx of new technologies reinvigorates these ideas through thinking about small-scale productions instead of mass production and pushes the limits of what's possible in traditional domains. This burgeoning and distributed community identifies making as an alternative to the consumer culture and seeks to hack, mod, tinker with, create, and reuse tools and materials.

Who, then, are makers? In practice, anyone who builds or adapts objects by hand, often with the simple pleasure of figuring out how things work, creating an aesthetic object, or seeking to solve an everyday problem, falls under this distinction. Makers frequently have pride and a desire to share projects and/or their creative processes with others, which is what fuels the larger communities of physical and online makerspaces, as well as pop-up events like world and regional Maker Faires.

To date, much of the interest in this movement concerns how it can be leveraged to fuel the next generation of STEM (science, technology, engineering, and mathematics) innovators (Honey & Kanter, 2013). Such interest has ranged from White House Maker Faires (Kalil, 2010) to President Obama's Educate to Innovate campaign (Obama, 2009). Though this potential holds promise, these volumes take a concerted effort to better understand making as a new domain unto itself. While connected to traditional disciplinary ways of understanding, we feel making deserves to be understood and studied in its own right.

At the same time, the Maker Movement has begun to infiltrate the education enterprise (Peppler & Bender, 2013). Schools are building makerspaces and FabLabs in their buildings and incorporating making into curricula. As with any instructional innovation, questions about the pedagogical value of making as a discipline are front-and-center and researchers are beginning to wrap their heads around how people learn to make as well as how they make to learn. Current research on the Maker Movement in

education can be classified into three categories: understanding *making* as a set of designed learning activities, studying *makerspaces* as communities of practice, and exploring *makers* as identities of participation (Halverson & Sheridan, 2014). While there is clearly overlap among these three categories, it is useful to explore activities, communities, and identities independently, especially if we want to avoid reductive policy questions like, "Is making good for kids?" or "Should we put a makerspace in our school?" These two *Makeology* volumes capture the range of research across makerspaces, making, and makers.

In this first volume, *Makerspaces as Learning Environments*, we analyze the wide range of makerspaces that provide multiple pathways to learning where participants create projects that vastly differ in terms of scope, function, production time, and support received. Where are the makerspaces located? Who engages in these practices? Who defines learning outcomes in such spaces, and how does this relate to local and historical forms of making within communities? Ultimately, why are they successful learning environments? The chapters in this volume describe making in a variety of educational ecosystems, spanning nursery schools, K–12 environments, higher education, online communities, museums, and afterschool spaces. In the second volume, *Makers as Learners*, we focus on makers themselves—in particular, the multiple cultural, historical, and social practices of making that shape learner trajectories. In this investigation, we discuss the role of tinkering in the process of teaching and learning; how adaptive expertise and identity development are supported through making; and how new and playful tools can be used to assess informal learning.

Throughout, the chapters consider linkages among learning outcomes, equity issues, and the social and historical uses of tools, materials, and processes within makerspaces. We highlight a key set of transformative tools and materials that heighten possibilities for learning and create consequential invitations for a broader and more diverse group of learners to participate. While not comprehensive of the range of making found in maker communities, this collection of chapters provides the reader with an innovative range of maker tools and materials that expand what it means to merge high and low technologies. Lastly, we explore how making does and does not adhere to various disciplinary views of the world.

As the editors of the two volumes, we identify both as makers and learning scientists, deeply entrenched in the study of learning in and through making. As such, these volumes seek to bring together the emerging wealth of research and practice on making in one central location: Leading academics, nationally recognized educators, key designers, and other emerging thought leaders inform the field of "Makeology" (i.e., the scientific study of making). In short, we want to better understand the emerging cultural

phenomenon of making as a starting point for further discussion on how and why making might help us to reinvigorate the 21st-century learning landscape. Collectively, these portraits help us to better understand the kinds of makers, processes, products, environments, and educational outcomes needed in order to foster rich educational ecosystems.

Makerspaces as Learning Environments

This volume focuses on makerspaces, which are often centered in physical spaces such as hackerspaces, FabLabs, schools, museums, libraries, homes, and church basements, as well as online communities. Makerspaces provide their patrons with resources, both human and technological, to advance their craft, ranging from community expertise to access to professional-grade tools for personal fabrication. While the concept of a makerspace is new to most, the spaces themselves seem familiar in many ways. They have a lot of the tools and materials that we recognize from our grandparents' generations (e.g., soldering irons, screwdrivers, sewing machines), recalling home economics or shop classes of yesteryear. And yet, they incite our imagination because they contain new objects as well, such as 3D printers, CNC mills, and hobbyist electronics, creating environments where you can design virtually anything. Makerspaces offer us an opportunity to re-envision our learning environments, often seen as the sole domain of schools, in ways that extend beyond the school day. As we venture deeper into the 21st century, the benefits of such forms of learning are becoming increasingly understood.

Makerspaces have emerged as learning environments from all directions. Top-down approaches, such as those developed and disseminated through Neil Gershenfeld's FabLab movement (2005), indicate a specific set of tools and practices that educators ought to use to bring a constructionist approach to teaching and learning (Martinez & Stager, 2013). There are also bottom-up designs that have resulted from groups of independent people who have wanted to transform their solo garage spaces into shared community endeavors that value mentorship, joint engagement, and access to a range of tools and materials. Finally, informal learning spaces, like museums and libraries, offer something in between—opportunities to tinker and play, often guided by experts, that encourage newcomers to pursue their own interests (Bevan, Gutwill, Petrich, & Wilkinson, 2015). This range of environments is present across our two volumes; the authors share with you design challenges and successes, theoretical insights about the nature of learning in and through making, as well as opportunities to legitimize making as a 21st-century discipline.

As embodiments of the self-reliant ethos of DIY culture, makerspaces engender learning that is propelled through a maker's curiosity, trial and error, and resourcefulness. And yet, a maker approach to learning is as much do-it-yourself as it is do-it-with-others. Makerspaces are deliberately open-ended, targeted to support the many wildly divergent ways of making with high- and low-tech tools. This means that makers are constantly exposed to different levels of ability, genres of projects, and differing approaches to making as they work. Furthermore, the concept of a personal workstation is antithetical to makerspaces, which emphasize making processes that are mobile, transparent, and social. In this way, the emphasis in makerspaces is much more on peer-to-peer learning and spontaneous inspiration than didactic approaches. Makerspaces are often true communities of practice where newcomers' ways of participating look very much like the apprenticeships of old, and old-timers serve as both models and mentors. However, the ethos of making means that newcomers can bring their ideas to bear on the making process right from the very beginning: while old-timers often mentor around *how* to make, *what* to make is driven by the individual.

So where do these ideas for what to make come from? Makerspaces embody a general pedagogy and approach to making, oftentimes described as "tinkering" (Resnick & Rosenbaum, 2013). Tinkering entails an iterative way of exploring a material or technique. Often undervalued in schools, tinkering affords a deep conversation with the material that is undermined when learners are rushed ahead to find a solution to a predefined problem. Tinkering is supported by having access to and visibility into the environment, meaning that learners have access to a wide variety of tools and materials, as well as different solutions from the community. From a wide survey of makerspaces (Chang, Keune, Peppler, & Regalla, 2015), we've found that many makerspaces aspire to offer greater visibility into the learning environment. This includes open cabinetry, see-through bins, and visible access to the tools, materials, and existing projects that spark ideas for new makes. In much of our prior work, we've argued for the principles of visibility within our toolkits being important and coupled with high-quality learning outcomes (Kafai & Peppler, 2014). This stands in stark contrast to the kinds of commercial design principles around invisibility and having a device work as the extension of the self, almost unseen to the user. Instead, by increasing visibility in the places in which we work and with the tools we use, learners are encouraged to ask questions, to take things apart and put them back together again, to try out new solutions, and to think in a concerted way about the intentions of the designer as well as the maker's ability to hack new solutions.

It is important to note that the concept of "space" in makerspace is wide-ranging. The range includes everything from a dedicated, permanent place for making to a permanent, online community, to a pop-up space supported by a more permanent location, to a mobile makerspace that serves a

wide range of communities. With a focus on tinkering, ideation, iteration, creativity, and collaboration, the outcomes for participation across these spaces is often the same. This volume captures some of this variation while maintaining a focus on what and how makers learn.

Opportunities and Challenges in the Maker Movement

Cognitive scientist Don Norman (1994) described artifacts not as a set of fixed features, but rather as those features having affordances and constraints depending upon who was using them and for what purpose. If you are trying to hike, for example, you will likely want a map. But a road map will not help you to decide where the steep trails are. It will help you to know how far away you are from civilization should you get lost. Deciding which artifact to use in which setting is not a choice, then, of right and wrong, but rather a matter of *tradeoffs*. The same can be said of the design of learning environments. There is no silver bullet answer to the question, "What is the best learning environment?" Instead, we need to consider the tradeoffs that emerge when we consider what it would take to fundamentally change our learning environments. We see three primary tradeoffs that the authors of this volume either surface through their work or tackle in their understanding of the design of learning spaces: 1) individualization vs. standardization in learning environments; 2) formal vs. informal education divide; and 3) technology vs. hands-on making in learning environments. We briefly consider each of these.

Learning in and through making is not interchangeable with schooling (Halverson & Sheridan, 2014). In fact, the Maker Movement is pushing educators, policy makers, and researchers to reexamine the relationship between schooling and learning in fundamental ways. First, research and practice considers whether and how maker-based pedagogies and activities can engage students in STEM learning, careers, and pathways. Schools are potentially interested in new ways of doing that engage students in the disciplines they care about, and the federal government has placed the Maker Movement front and center in describing pathways to reform. However, despite general enthusiasm, local and federal policies continue to push for accountability and standards-based curricula which are a mismatch with the pedagogical practices of making. If we take seriously the challenge of using making as a legitimate part of schooling, how do we connect it more tightly with goals of classroom learning environments and how do we prepare teachers to create robust learning ecologies with a maker ethos? Simultaneously, how do we maintain the emergent, messy, whimsical, engaging process of making while adhering to standards and shared practices? In short: Is making fundamentally at odds with schooling? This question is of great interest to many of the contributors in this volume including Paulo Blikstein and Marcelo Worsley, who consider how to merge the diverse cultural traditions of hacking and schooling, as well as the second section here that considers making in P–16 education.

Another tension is to consider the longstanding divide between formal and informal learning environments. Practitioners make the separation—teaching in school and teaching afterschool are considered independently. Policy makers make the separation—the National Science Foundation, for example, has a funding directorate dedicated to "Advancing Informal STEM Learning" which is distinct from other funding for STEM education. Researchers make the separation—when we frame studies and research questions we always name our setting—schools are formal; anything outside the school day is informal. But the Maker Movement offers opportunities to stretch across the formal/informal divide, encouraging formal spaces to think informally and informal spaces to think like formal learning environments. As our understanding of what learning looks like across these spaces begins to blur, what is the role of out-of-school learning environments? What do community-school partnerships look like? How do we take seriously the concept of lifelong learning? How can out-of-school environments grow their capacity to reach a broader range of learners? While not explicitly about the formal/informal divide, many of the chapters in this volume address the tradeoff between thinking formally and informally within the design of maker-based learning environments.

Finally, we consider the relationship between technologies and hands-on making. "Technology" is a nearly ubiquitous term in makerspaces; for most, the Maker Movement conjures images of 3D printers, laser cutters, robots, and power cars. This is one of the great appeals of making in education—using a learning-by-doing approach to give learners access to previously inaccessible tools and skills that are necessary for success in the 21st-century economy. Though these tools all fall into the "technology" bucket, they all require physical, face-to-face work and mentorship. This volume provides some examples and evidence of the power of technologies in physical spaces. On the other side of the technological spectrum are computing technologies that allow virtual access, both synchronous and asynchronous, to otherwise unavailable tools, materials, processes, and people. New technologies that allow people to document and share their physical lives online including tablets, phones, and portable computers are omnipresent in makerspaces. Web-based platforms offer structured opportunities for documenting and sharing that have started to move physical space to online spaces to connect makers who are not together physically in one location. We see evidence of this in chapter 16 by Tseng, as well as in chapter 10 by Peppler and Hall. Virtual spaces seem an ideal match for the

Maker Movement, which emphasizes building communities of interest and independent work. While several of our authors find that building communities of interest around making via the Internet is possible and productive, there is still much work to be done in terms of virtual spaces serving as democratizing opportunities to learn through making. How do we bring making to a virtual space? How do we teach in these kinds of spaces, and how do we use virtual space to connect and extend a physical maker community? Various chapters in this volume address the tradeoffs afforded by technology in different ways.

Overview of Volume 1

We have organized this first volume of *Makeology* into four broad sections: Section 1 introduces different makerspaces in out-of-school settings; Section 2 moves on to cover makerspaces in formal educational settings, covering a wide age span from prekindergarten to college level; Section 3 examines examples of hybrid and online makerspaces that combine online communities with physical spaces; and Section 4 highlights reports from makers and designers as they have sought to heighten learning in makerspaces through new types of making, new online communities, and new ways of creating reflective documentation on making.

That first section on out-of-school makerspaces presents rich opportunities to connect to families, to rethink some of the constraints typically found in schools, and to develop new skills and dispositions not traditionally valued in schools. Here, Lisa Brahms and Kevin Crowley (Chapter 2) explain how to design to support learning in museum settings. They take us back to the Makeshop (Honey & Kanter, 2013) to better understand how families and facilitators can support learners in becoming makers. Kimberly Sheridan and Abigail Konopasky (Chapter 3) explore a community-based makerspace to illustrate what makes makerspaces distinctive learning environments and the design features that encourage resourcefulness among the members. Ricarose Roque (Chapter 4) illustrates an emerging practice called Family Creative Learning as a model for intergenerational learning among adult family members and their children. Finally, Paulo Blikstein and Marcelo Worsley (Chapter 5) describe the cultural roots of making and discuss how we can transform a makerspace from a hackerspace culture to a true learning culture.

In the second section we examine the growing popularity of makerspaces in P–16 schooling environments. While there can be inherent tensions to this work, making presents new ways to reenvision the traditional classroom, connecting back to many of the foundations of schooling, reminiscent in many ways of Dewey's lab school, Montessori education, and the first Froëbelian kindergartens. Karen Wohlwend, Anna Keune, and Kylie Peppler (Chapter 6) begin by taking Squishy Circuits (Thomas, 2014) into a preschool setting, allowing for a space for new technologies to exist beside wooden blocks and paints. Additionally, the authors present a model for ensuring that makerspaces have an equitable emphasis on play, design, collaboration, and science learning. Peter Samuelson Wardrip and Lisa Brahms (Chapter 7) explore a model for taking out-of-school learning into school spaces while preserving what we know to be most important. They find that the success of such initiatives relies heavily on the school's leadership, allocation of space, and integration with the existing curriculum, as well as ongoing professional development. While writing and making seem like two separate ways of approaching teaching and learning, Christina Cantrill and Paul Oh (Chapter 8) explore their connections. Further, they present ways of cultivating a peer-based, cross-disciplinary network of educators through a connected learning massive open online collaboration called CLMOOC. They share experiments within this community that focus on different forms of making among educators, including interactive videos, hip-hop, and paper circuitry, as well as the role that writing has in deepening these learning outcomes. Deborah Fields and Victor Lee (Chapter 9) bring making to higher education in the Craft Technologies 101 course. They share the struggles of integrating making in post-secondary education as well as the specific designs of the course and discover among many outcomes that making quickly situates the learner as expert.

The third section moves us out of solely physical makerspaces to look at the role that online communities play in supporting learning through making. Kylie Peppler and Ted Hall (Chapter 10) take a closer look at the Make-to-Learn Challenge on Instructables.com, one of the largest online communities for makers. The Make-to-Learn Challenge sought to understand where and what youth were making as well as what they felt they learned in the process. The chapter describes how youth makers see themselves as learning STEM concepts as they make a diverse range of projects—contest entries included custom kitchen knives, propane forges, fashion designs, *objets d'art* and more—but youth also recognize that they are learning so much more in the process. Next, Matt Rafalow (Chapter 11) explains what it means to take the physical practices of making into the online community of Ravelry.com. He explores the various digital supports needed for making and sharing and for stitching together broad networks of makers across the Web. Mike Petrich, Bronwyn Bevan, and Karen Wilkinson of the San Francisco-based Exploratorium (Chapter 12) take making into a massive open online course (MOOC) through Coursera. As they do so, they play with the genre of teaching online using social media in ways that are aligned with the emergent pedagogies of what makes a good makerspace

to reinvent online learning. Ultimately, Breanne Litts, Erica Halverson, and Maria Bakker (Chapter 13) explore the relationship between a physical makerspace and the online community that extends and supports the space, including discussion forums, requests for help, external opportunities, and project ideas.

The fourth section highlights insights from designers as they start to build out and improve makerspaces as learning environments. In creating ideal learning environments out of makerspaces, the tools we have available in a makerspace determine in a large way the activities and types of engagement that can be expected there. In our first chapter, Jie Qi, Jennifer Dick, and David Cole (Chapter 14) talk in detail about their designs for paper electronics (as leveraged by Cantrill and Oh in Chapter 8). Paper electronics, which lend a familiarity and simplicity to working with electronics, cause us to rethink both the expense and the expressivity of today's electronics, as well as the new types of projects that can emerge out of this intersection. In addition, the space of makerspaces and understanding the multiple ways that people connect through making, online and offline, can be challenging. In the next chapter, on ecrafting.org (Chapter 15), Orkan Telhan, Yasmin Kafai, and Breanne Litts highlight how to design and foster new online subcommunities out of the larger Maker Movement, as well as theorize the different ways that members within these communities can connect online in meaningful ways. While the work produced in makerspaces has the potential to be collected in a personal portfolio and reflected on by the learner over time, thus heightening learning outcomes, most makers find this engagement in the documentation and reflection processes to be challenging, and, as a result, much of their work goes undocumented. In the last chapter in this section (Chapter 16), Tiffany Tseng details a new platform, called Build in Progress, where makers share their stories about how their project developed, as well as the trials and errors experienced in the act of design. Such a platform celebrates not only the act of documenting a finished product, but lends a closer examination of the process of creating something.

In the closing chapter of this volume (Chapter 17), Lisa Regalla, one of the thought leaders behind the Maker Movement's education initiative called Maker Ed, outlines the habits of mind necessary to develop a "maker mindset." Such a mindset requires fostering a sense of curiosity, an interdisciplinary approach to challenges, social and emotional competence, a disposition to share and collaborate, a growth mindset, and an appreciation for the iterative process. Cumulatively, these chapters detail the multiplicity of ways that makerspaces are being realized across the United States—in out-of-school programs, within schools from kindergarten to universities, and in online and hybrid contexts—and in the process, deepen our understanding of what makes the Maker Movement, and making itself, so effective for today's learning.

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"*Makeology* is the first broad and comprehensive examination of the Maker Movement as a catalytic force for young people's learning. Practitioners and scholars interested in implementing and studying making as a force for creative expression and student-centered learning will find in this two-volume collection a wealth of thoughtful and significant information."
—Margaret Honey, President & CEO, New York Hall of Science, USA

"Our goal should be helping children see themselves as good learners, as lifelong learners. The impact of what they create, design, shape, and build will be known in the future, but the time for making it happen is now. This book can increase the opportunities for making in educational settings by sharing the insights of many leading practitioners."
—Dale Dougherty, Founder & Executive Chairman, Maker Media, Inc., USA, from the foreword

"One thing we have in common is our commitment to putting more power in the hands of people from all backgrounds, enabling everyone to develop their voice and express themselves. There's a special opportunity right now. But that moment could also slip away, so it is all the more important to make connections and join forces with other communities with shared values, to make sure that all children have the opportunity to grow up as full and active participants in tomorrow's society."
—Mitchel Resnick, LEGO Papert Professor of Learning Research and head of the Lifelong Kindergarten group at the Media Laboratory at Massachusetts Institute of Technology, USA, from Volume 2

Makeology introduces the emerging landscape of the Maker Movement and its connection to interest-driven learning. While the movement is fueled in part by new tools, technologies, and online communities available to today's makers, its simultaneous emphasis on engaging the world through design and sharing with others harkens back to early educational predecessors including Froebel, Dewey, Montessori, and Papert. *Makerspaces as Learning Environments (Volume 1)* focuses on making in a variety of educational ecosystems, spanning nursery schools, K–12 environments, higher education, museums, and after-school spaces. Each chapter closes with a set of practical takeaways for educators, researchers, and parents.

Kylie Peppler is Associate Professor of Learning Sciences at Indiana University.

Erica Rosenfeld Halverson is Associate Professor of Digital Media and Literacy in the Department of Curriculum & Instruction at the University of Wisconsin–Madison.

Yasmin B. Kafai is Professor of Learning Sciences at the University of Pennsylvania.

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