INTRODUCTION: FIFTY YEARS OF CONSTRUCTIONISM

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> People are both world makers and beings-in-the-world: they at once create their habitats, inhabit their creations, and become "inhabited" by them.
>
> —Ackermann, 2004, p. 26

More than fifty years ago, a computer language was created specifically to enable children to control what were then the world's most powerful and expensive machines. The goal wasn't to train the children to be mindless operators of these machines by punching in commands dictated by some expert. Nor was the goal to use the programming language to efficiently deliver information to those children. Instead, the language, and computers more generally, would be tools in the hands of children, who would learn that they are all creative, inquisitive, serious, and thoughtful young thinkers. This has been a core goal of constructionists ever since: to respect children as creators, to enable them to engage in making meaning for themselves through construction, and to do this by democratizing access to the world's most creative and powerful tools.

Constructionism, as a concept, was born from that premise. Constructionism is a framework for learning to understand something by making an artifact for and with other people, which, to be built, requires the builders to use that understanding. That said, Seymour Papert, the definer of the term and parent of the field, was somewhat cagey about a precise definition for constructionism, for a good reason: if he believed that constructionism is something worth understanding, the reader would have to construct his or her own understanding of the term rather than only read a definition.

Of course, this is but one possible definition. There are probably numerous similar definitions used throughout the history of constructionism, and each reflects its context. Early definitions of constructionism located it entirely in one brain: a learner learns something by making an artifact.

However, research in the learning sciences has shown that learning does not reside in one individual's brain. Consequently, as the field has integrated distributed, situated, and sociocultural models of learning, so too have our definitions of constructionism evolved.

Similarly, this volume too reflects that diversity. It follows two earlier books of collected works that describe core constructionist projects, ideas, and theories. The first book, simply titled *Constructionism* (Harel & Papert, 1991)—written almost entirely by Papert and his students—laid out this design paradigm's theoretical foundations. The second book, *Constructionism in Practice* (Kafai & Resnick, 1996), extended the constructionist agenda by describing new tools and implementations toward making a reality the vision of the child programming the computer rather than the computer programming the child (Papert, 1980). Constructionist ideas have not been static in the intervening years. In this book, *Designing Constructionist Futures,* we have invited original contributors as well as emerging scholars that have been inspired by and, in many cases, brought up on the tools and ideas discussed in those earlier volumes to articulate models of constructionism that engage deeply with culture, communities, contexts, race, ethnicity, modes of power, and modalities of agency. In other words, the book itself exists as an argument that constructionism can learn and has learned from learning sciences and educational research—from culturally responsive teaching, notions of power, redefinitions of the possibilities of education as resistance, and conversation—and that, in turn, educational research can, we hope, learn from constructionism—how to foster understanding and powerful ideas in humane, collaborative, cooperative, and other ways that deeply respect learners and their innate goodness and creativity.

A VERY BRIEF HISTORY OF CONSTRUCTIONISM

Although the term *constructionism* was officially coined in a chapter of that first volume edited by Harel and Papert (1991), many of the ideas were formed two decades earlier, as recounted by Feurzeig (2010) and Solomon (2016). The different time periods of constructionist activity over the past fifty years can loosely be categorized as the *Logo*, the *Project Headlight*, and the *Scratch* years.

When Papert arrived in 1964 at the Massachusetts Institute of Technology (MIT) after having spent five years at Jean Piaget's Le Centre International d'Épistémologie Génétique in Geneva, he was asked to join the Educational Technology Department, a research group formed by Wally Feurzeig at

Bolt, Beranek, and Newman (BBN), as a consultant. Logo was developed as a dialect of Lisp by Seymour Papert, Daniel Bobrow, Richard Grant, Cynthia Solomon, Wally Feurzeig, and Frank Frazier; the latter also published the first Logo manual in 1967. Together, these visionaries imagined the possibility of putting the most powerful and "protean" tool for knowledge construction—the computer—into the hands of children decades before the existence of the personal computer. The first version of Logo was piloted with students in the Hanscom Field School in Lincoln, Massachusetts, funded by the US Office of Naval Research, whereas later studies in various Boston schools were funded by the National Science Foundation.

Initially, Logo only allowed children to play with words and sentences. In an effort to expand what children could do with Logo, the team at MIT began experimenting with using Logo to drive a physical robot. Because of the domed shape of early robotic prototypes, the Logo robot became known as the "turtle." Eventually, the physical robot migrated to a digital screen and the turtle became a sort of digital cursor. By issuing simple commands to this turtle, the children could use Logo to create computer graphics. The language of Logo resembled play commands children might give to one another in a game of "Simon Says," imagining themselves as the turtle, walking out and drawing squares, circles, spirals, and more. These designs and explorations engaged children in playfully tinkering with complex mathematical concepts, leveraging their intuitive understanding of how their body functions in the world to experiment with and articulate ideas at the heart of geometry, calculus, and computing.

In 1970 Papert founded the Logo Laboratory at MIT and continued the research of educational applications in Logo. A report first published by the MIT Artificial Intelligence (AI) Lab titled "Twenty Things to Do with a Computer" (Papert & Solomon, 1971) captured the various programming activities that had been developed and tested in the previous years with Logo. It also became the foundation of the book *Mindstorms* (Papert, 1980), which introduced the larger public to the idea of how young children could engage and learn with computers. MIT also hosted several Logo conferences that brought together an international group of educators and computer scientists interested in the various applications of programming to not just mathematics but also the arts.

In 1982 three years before the MIT Media Lab launched, Seymour Papert and Nicholas Negroponte decamped to France to open (with support of the French government) the World Center for Computation and Human Resources, which put Logo and computers in classrooms in both Paris and in Dakar, Senegal, with the goal of making computers accessible to children all over the world. When Papert returned to MIT, he launched an initiative called Project Headlight in the Hennigan School, a public elementary school located in Jamaica Plain (an under-resourced neighborhood in Boston). Project Headlight would showcase a future of schools in which computers were readily accessible to all children and teachers and integrated throughout the curriculum. This was part of the MIT Media Lab's overall mission to "invent the future" (Brand, 1987).

In Project Headlight, over 80 computers were set up in one of the wings of the Hennigan School. However, rather than place these computers in a computer lab where students might only encounter them once every week for 45 minutes before returning to their classrooms, the project took advantage of the open architecture of the school, which had pods of classrooms with no walls around large open areas. Four circles with 20 computers each were set up in a way that not only made the computers accessible but also made what the students were working on with the computers visible to all passing through the school wing. Each student from first to fifth grades had access to these computers at least one hour every day, in addition to individual workstations in their classrooms. A team of adventurous teachers and hundreds of elementary students worked with a large group of graduate students from the MIT Media Lab to use these computers to develop new activities, curricula, and educational technologies.

What emerged from *Project Headlight* in the late 1980s and early 1990s were various illustrations of how computers and programming could become part of schooling in meaningful and novel ways. For instance, the Instructional Software Design Project, conceived by Harel (Harel & Papert, 1990), challenged many of the traditional programming approaches by asking students to develop and program software applications that would teach younger students in their school about mathematics. Rather than writing short programs, as was common in schools that introduced students to Logo, Basic, or Pascal, students worked on complex programs over long periods of time. Programming was integrated into the learning of mathematics and promoted by encouraging students to use code to explain and represent their ideas.

This approach was the bedrock for what today has become one of the most popular approaches to introduce programming in schools: rather than learning coding for the sake of coding, learning to code is contextualized as part of developing applications such as games (Kafai, 1995), stories, or animations (Kafai & Burke, 2014). The work in Project Headlight presented a bold vision, but it came to an end as personal computers themselves became less flexible: multimedia CD-ROMs and web browsers no longer required students to learn the language of computers. Programming was removed from schools entirely in the 1990s when high-stakes testing took over.

For those reasons, the *Scratch* years, which continue to the present, did not start in schools like the previous projects. Instead, Scratch was developed as part of the Computer Clubhouse, which was launched in the early 1990s at the then Computer Museum in Boston (Resnick, Rusk, & Cooke, 1998). Eventually the Computer Clubhouse, which offered youth from underserved communities access to creative computing, grew into a network with over 100 clubhouses located in community centers around the globe (Kafai, Peppler, & Chapman, 2009). Computer Clubhouses showcased a rich Photoshop and remix culture, in which members connected to digital media in new ways. In an effort to connect coding with this digital media production culture, Resnick, Kafai, and Maeda submitted a proposal in 2002 to the National Science Foundation that outlined the development of a programming environment and community that would be focused on the manipulation of multimedia; this led to the development of Scratch. In 2007, after several years of prototyping various versions in Los Angeles and Boston clubhouses, Scratch, the programming tool, was released together with the ability to upload and share programs on an MIT server.

Of course, there are many, many other examples of constructionist activities that, because of space constraints, we are unable to detail. There were international efforts to spread Logo to communities in Thailand, Costa Rica, and Brazil; telecommunication technologies and Logo activities that encourage learners to play with language and writing and decades-long cycles of development and iteration of physical computing technologies that included both open-source hardware and the hugely popular Lego brick (Blikstein, 2015; Resnick & Ocko, 1990). Furthermore, the development of parallel programming was captured in programming tools such as StarLogo (Resnick, 1997) and NetLogo (Wilensky, 1999), introducing K-12 students once again to powerful modeling tools.

Today the computer is ubiquitous, Logo-like software can be found on devices of all kinds, and new fabrication tools and technologies that enable anyone to create sophisticated physical artifacts continue to emerge. Though Papert's work and the Logo language were central in the initial formation of constructionism, the past fifty years has seen constructionist thought and design nurtured and extended by teachers, facilitators, parents, practitioners, and scholars around the world. This volume is an effort to capture that work, to reenvision constructionism in this new context, to claim constructionist activity in emerging educational movements, and to offer potential directions for how constructionism can continue to evolve into the future.

RECONSTRUCTING CONSTRUCTIONISM

Papert famously enjoyed offering parables to explain the ideas behind constructionism. One of his most famous was that of Mathland. Mathland wasn't a video game, or a virtual environment; it was a hypothetical community whose culture and language was mathematics. Just as a child who grows up in France easily learns not only the French language but also what it means to *be* French, so too would mathematics become a core part of a Mathland resident's language, identity, and way of being. Logo (and many of the other technologies innovated by constructionists over the years) was not only a tool for teaching coding or even mathematics but also an attempt to build a community, culture, and context.

Constructionism is about playing and creating with powerful ideas in meaningful and authentic contexts. As constructionists, we aim to leverage design and theories of cognition to create spaces, tools, and technologies that empower more learners to do more things. What it means to do that work has changed, just as the world has changed considerably since constructionism first reached widespread awareness in the form of *Mindstorms* in 1980. Technology is not just smaller, faster, and cheaper, it is ubiquitous and has fundamentally transformed how we exist and interact with our environment and one another. Likewise, theories of cognition have begun to recognize that cognition extends beyond the head and into the world, that all knowledge is cultural and that learning is interaction. And so, as constructionism invites us to do, we must take apart our prior conceptions of constructionism to examine its core components, affordances, and relationships; bring in new perspectives and possibilities offered by evolving theory and technology; and then rebuild constructionism to suit this new context in which we find ourselves.

CONSTRUCTIONISM IN A NEW AGE OF TECHNOLOGY

Papert's predictions about the availability of computers have come to fruition. Computational power has become ubiquitous, and few still debate whether technology has a useful role to play in the learning process. Smartphones—which are multiple times more powerful than the classroom computers that first ran Logo—are owned by over a third of the world's population (eMarketer, n.d.). Though it is reasonable to question whether access to these devices, which are often closed to tinkering, has truly democratized access to computational practices, their inclusion of powerful cameras and sensors and their always-networked architecture have enabled users to engage in a variety of creative digital media construction enterprises, including movie making, app development, game making, and more. Smartphones are, of course, powerful in part because of their ability to make the internet mobile. The Internet, which Papert (1993) described in vivid detail in his book *The Children's Machine*, has reached maturity and become a place not only for information retrieval but also for public construction and sharing.

As these technologies proliferate, corporations, government officials, parents, and children across the world have come to agree that coding is not only a useful skill but also an invaluable one. Coding movements in the United States, Europe, and Asia promise to make programming as core to the curriculum as reading, writing, and arithmetic (Obama, 2016). And while educators continue to debate the very important question "to what end," the idea of the child programming the computer (rather than the computer programming the child) is no longer considered revolutionary. And yet, as computation is increasingly embedded in physical spaces such as our homes, schools, parks, transportation, and others, our ability to function in, move through, and be identified in physical spaces is determined and defined by algorithms—algorithms that are not visible to citizens and, with the advent of neural nets, may even be opaque to their designers (Shapiro, Fiebrink, & Norvig, 2018). To meet this demand, new authoring environments, curriculum, and education infrastructure have been developed to lower the floor, raise the ceiling, and widen the walls of participation in computer science. While worldwide efforts to increase access to coding practices are promising, these efforts have come quite late and have yet to diversify the homogenous community of coders that have built the computational world we now live in (National Science Foundation [NSF], 2015).

The extremely low cost of computer hardware and high-tech prototyping equipment has also led to a revolution in making and fabrication. Three-dimensional (3D) objects designed on a computer can now be printed or cut out in a huge variety of materials using machines that fit onto a desk. Computers themselves can be built with few components and a couple dollars and be made of metal and wire, or fabric and thread. Devices that can read data from the world and drive motors, actuators, LEDs, and sensors are not only widely available, they're increasingly understandable, playful, and personal. Further, making is no longer restricted to electrical components. Our understanding of biology itself has reached a level where tinkering with the building blocks of life is no longer science fiction but is becoming accessible in school classrooms (Kafai, Telhan, Hogan, Lui, Anderson, Walker, & Hanna, 2017). Research on and with these tools and practices has provided new insight into constructionist commitments such as the centrality of sharing (Brennan, Monroy-Hernández, & Resnick, 2010), the role of personal choice and play in construction activities (Berland, 2016; Honey & Kanter, 2013; Kafai & Burke, 2016; Weintrop, Holbert, Horn, & Wilensky, 2016), the trade-offs of different representations of code (Kahn, 1999; Weintrop & Wilensky, 2017; Wilkerson-Jerde, Wagh, & Wilensky, 2015), the relationship between materials and practices (Buchholz, Shively, Peppler, & Wohlwend, 2014), and a new appreciation for values in addition to interests (DesPortes, Spells, & DiSalvo, 2016; Holbert, 2016) to name but a few.

While technological innovation has led many to embrace construction activities in coding and making, too often these efforts neglect the social and cultural values at the heart of the constructionist design paradigm.

CONSTRUCTIONISM IN A NEW AGE OF COGNITIVE THEORY

Constructionism's birth from Piaget's constructivism has meant that much of the community's research on learning has focused on the individual. While constructionist designers have always acknowledged the importance of social interaction, tools, representations, and context, learning in constructionist spaces is generally described in terms of changing mental knowledge structures. However, new theories of cognition have gained prominence since the two previous volumes of constructionist writings were published. These new theories don't just suggest that tools, social interaction, the environment, and the body support conceptual change; rather, they propose that cognition is at the intersection of these interactions—that cognition is in fact interaction itself. What, then, is the story of learning in constructionist design in light of these new theories of cognition?

Constructionist design fits neatly into descriptions of learning described by theories of embodied cognition. The earliest constructionist environment, Logo, relied on what Papert called *body syntonicity* (Papert, 1980). Creating with the turtle meant putting oneself inside of this external agent: imagining walking and rotating to draw the shapes and objects that were drawn onto the floor or screen. But as we shift from seeing the body as an external appendage of the brain, and instead define it as part of the cognitive system itself, body syntonicity shifts from being a useful design principle to a fundamental description of learning. This shift raises new questions for how to design and study constructionist environments. For example, what does our understanding of the role of the sensorimotor system in cognition suggest about both how learning happens in perspective taking systems ("playing turtle") as well as how we might observe and measure this learning (Ackermann, 1996; Lindgren, 2012; Wilensky & Reisman, 2006)? How does our understanding of gesture and embodiment explain prior research with Logo, or what does it suggest about the design of new constructionist environments using emerging immersive technologies or motion tracking (Abrahamson, 2009; Enyedy, Danish, Delacruz, & Kumar, 2012; Nemirovsky, Tierney, & Wright, 1998)?

The advent of sociocultural theory both offers theoretical underpinnings for some prior constructionist commitments, such as the importance of sharing or of building with materials and artifacts, and expands how we think about and study what it means to learn in a constructionist system. Rather than define learning as in-the-head conceptual change, sociocultural theory invites us to view all knowledge as cultural and learning as an interaction between a community of learners, the materials and tools, the local environment, the historical context, and more (Cole, 1995; Lave & Wenger, 1991; Rogoff, Paradise, Arauz, Correa-Chávez, & Angelillo, 2003). Learning in a constructionist environment then isn't just a story of mental knowledge structures mirroring the hands-on construction of an artifact, it's a description of a distributed and social activity system evolving and changing in interaction—the construction itself is the learning (Barron, Gomez, Martin, & Pinkard, 2014; Calabrese Barton & Tan, 2018; DiSalvo, Crowley, & Norwood, 2008).

Furthermore, when adopting a sociocultural model of cognition, the methods of capturing and describing learning in a constructionist space must also change. Here the unit of study is not the head of the learner; it is layers upon layers of ecosystems (Bronfenbrenner, 1979). Rather than attempt to isolate particular concepts or skills and measure how these change before and after the use of constructionist tools and interventions, or between a constructionist and nonconstructionist tool, we must instead leverage techniques and technologies that allow us to capture the process itself. We need to document the dialogue between the learner and the materials, the building primitives, the physical space in which they work, other builders, the instructor, the framing of their construction activity, and more. As always, this dialogue is bidirectional with these artifacts, materials, spaces, and communities not only affecting the learner but also being changed, defined, and modified by the learner as well.

THEMES IN DESIGNING CONSTRUCTIONIST FUTURES

These technological and pedagogical innovations have been central to the evolution of constructionism over the past fifty years. A key motivation for the design of this volume was to document that evolution, as well as to lay claim to the ways in which constructionist efforts have defined many of today's most exciting areas of educational research. Constructionism in the last decade has gone far beyond the initial successes of Logo and Mindstorms: the return of coding in school, now an international phenomenon, the growth of the Maker Movement and efforts to bring these into schools, the development of constructionist communities around Scratch, ScratchEd, and Globaloria are but a few of many recent accomplishments. Indeed, the massive numbers of the Scratch community (30+ million projects and 30+ million users) suggest that these ideas are significant, spreading, and growing.

Putting together a volume that captures the breadth and complexity of activities, research, and designs has been a tall order. The chapters in the book are a testament to the many directions constructionist ideas have developed. We intentionally invited an international and diverse group of scholars who situate their work in a variety of traditions and methodologies. We have asked these authors to be brief in their writing and to limit their citations to those most central to their argument; we suggest that readers interested in going deeper on a topic follow up on those cited sources for more information. We hope that by continuing to expand the scope of the community, we can together reconstruct constructionism for our present context and offer perspectives and possibilities for how constructionism might evolve in the future.

This volume is divided into five themes reflecting the wide space of work currently being done in constructionism. In the first section, *Increasing Scale*, we examine how constructionist design can both support large numbers of learners and function within diverse contexts from schools, to the home, to virtual spaces addressing one of the early concerns that only individual classes or small groups could engage in such activities. Perhaps not surprisingly, the many ways in which young people and educators encounter and use Scratch are a dominant theme of this section. But Scratch is by no means the only success story of constructionism increasing in scale. The innovations documented in the creation and expansion of Globaloria, principles behind the design of constructionist toys and technologies for children of all ages, and DIY technologies that support learners in sharing constructions have all been important in the expansion of constructionism to millions of students around the world. Finally, this section also examines how constructionist design might be used to enrich the learning experiences of educators, whether during a few weekends in the summer or over two decades in a small school in Thailand.

Possibly the most critical challenge faced by constructionism is the equitable distribution of and access to resources, facilitators, tools, projects, and activities. Scale must not come at the cost of equity. Making emerging and powerful technologies available to children should not mean many of the projects and ideas are only available to wealthy schools and communities. And empowering learners to pursue ideas of interest, or to take time to explore and experiment, must not be only for those with the means and privilege to elevate personal interests above community values and needs. In the second section, *Supporting Equity,* authors explore how young people use their unique individual and communal perspectives, values, and voices, through constructionist design efforts, to make meaningful change in their environment, communities, and world. The nature of and the culture surrounding the tools and materials matter, as do the ways in which constructionist design communicates what it means to make and why.

While early constructionist writings focused on the individual—effectively ignoring the sociocultural implications and ramifications of their work—by incorporating emerging cognitive theories, constructionists have made important headway in understanding the social dimensions of learning. In the third section, *Expanding the Social*, we see the implications of social practice taken up across multiple contexts in multiple projects. For instance, what is created and learned in the construction process is greatly affected by who we build with, and for whom we build. By moving our analytical lens beyond the individual, we begin to see how ideas, artifacts, and experiences emerge from interactions among bodies, conversations, and the physical space itself. However, creating communities around creativity and technology is hard, and success is not ensured.

In constructionism there has always been a focus on the creative. For example, creative computing in Logo and beyond emphasizes the notion that learning to code can serve to express creativity rather than to simply develop technical skills. In the fourth section, *Developing the Creative*, authors engage deeply with the implications of learning as a creative process of construction. What can constructionists learn from the arts and research on creativity? How can constructionist design expand to incorporate new materials, practices, and epistemologies? And how can these creative enterprises be supported and enacted in the constraints of formal classrooms?

But the process of constructing constructionism is not yet complete. And so, as we look forward to the challenges of the future, we also hope that this volume offers a few critical agendas for the current and next generation of constructionist researchers, educators, and designers to consider. In the fifth and final section, *The Future of Constructionism,* we engage leading constructionist visionaries in a conversation about where constructionism, design, and research might go next. While admitting to the many barriers to expanding constructionism into existing educational systems and spaces, Mitchel Resnick is optimistic that with active efforts to develop new technologies and to engage a broad range of stakeholders and communities into the learning experience, the future of education will be one where kids have the time, opportunity, and support to meaningfully engage with and transform their world. Leah Buechley imagines that this transformation will necessarily require looking beyond science and mathematics disciplines—to being inspired by aesthetics, to experiment with new materials and practices, and to embrace the humanities. Orkan Telhan and Yasmin Kafai examine how innovations in molecular biology will increasingly play a role in transforming our thinking from *building* toward *growing* in the future. Echoing Buechley's recognition that the world's social, political, and environmental challenges are increasingly beyond the scope of STEM domains as they have been traditionally conceived, Telhan and Kafai see biological materials and new molecular engineering techniques as a central tool in humanity's future. And yet, Ben Shapiro points out that in our excitement to engage learners in imagining and creating new systems and technologies, we must take time to encourage designers to consider both the good and evil that might be done with their designs. Finally, in a conversation that occurred shortly before his passing, Michael Eisenberg reminds the constructionist community to continue to elevate children's playful ideas and idiosyncratic passions. Eisenberg also warns that society's corporate-skewed notions of science, and of what it means to be a success, is incommensurate with the constructionist value system.

CLOSING WORDS

In one of his earliest writings, *Teaching Children Thinking,* Papert (1971) outlined a

> grander vision of an educational system in which technology is not used in the form of processing children but as something that the child himself will learn to manipulate, to extend, to apply to projects, thereby gaining a greater and more articulate mastery of the world, a sense of power of applied knowledge and a self-confidently realistic image of himself as an intellectual agent. Stated more simply, I believe with Dewey, Montessori and Piaget, that children learn by doing and by thinking about what they do. And so the fundamental ingredients of educational innovation must be better things to do and better ways to think about oneself doing these things … (p. 1)

Papert saw clearly that innovative technologies often perpetuate traditional practices rather than providing new, better agencies; these struggles were present then as much as they are today. Nearly fifty years later, we can see powerful realizations of this vision, many of them captured in this volume. But we cannot rest there, because educational innovation should never be just about becoming an intellectual agent but always also about becoming a critical agent (Freire, 1972). The constructionist work of today, and tomorrow, must be dedicated to laying a foundation for learners' critical engagement that allows them to question how the world in which they live is constructed, interrogate and challenge that construction, and to imagine and participate in the construction of an improved, more equitable world.

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