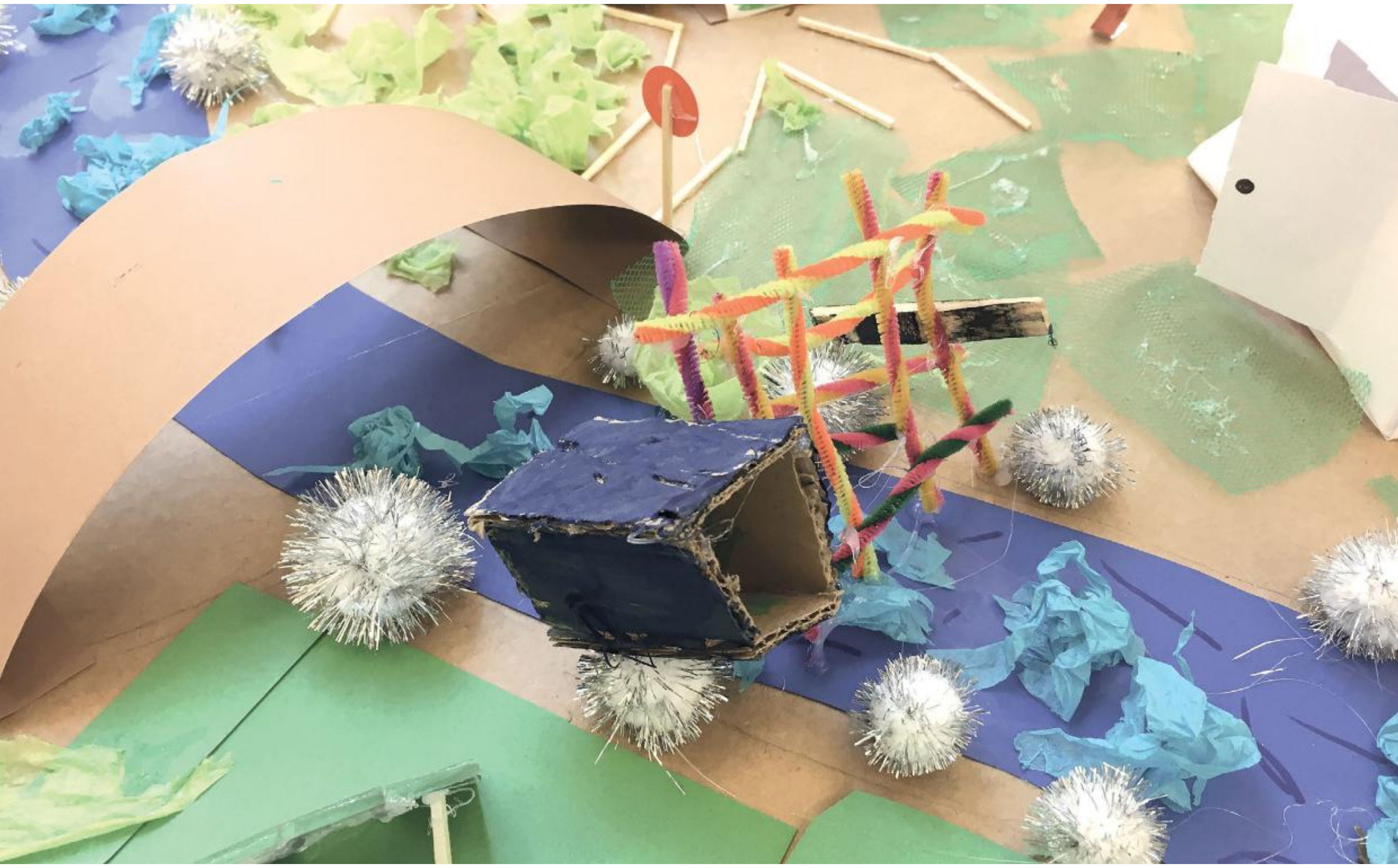
Making Engineering Playful in Schools

Lessons and stories about making, play, and collaboration from the Tufts-ISB Partnership



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Tufts University · International School of Billund · The LEGO Foundation

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Foreword

In the LEGO Foundation, we see play as essential for how children and students learn, an activity beautifully described in this report as playful making.

Back in 2015, we started our journey with Tufts University, the International School of Billund (ISB) and the LEGO Foundation to explore the development of a Maker Studio to promote the engagement, iteration and experimentation of learning through play, in ways that could be deeply integrated with the culture of this particular school.

This booklet represents the culmination of that work, providing a fabulous resource for anyone curious about how to develop and operate Maker Spaces in a school setting. Not only did it support the development of a Creator Space at ISB, but it also documented the features that allow and enable play, making, technologies and learning, to support the students and teachers in integrating the messiness and diversity of creative work into the fabric of the school culture.

The key features in this resource outline how elements of distributed expertise come together and complement each other, how to make use of research residencies at the school, and how to engage partnerships with teams of teachers and to embrace discussions with other research projects.

This booklet also illustrates the principles originating from early-childhood maker spaces, and how the values as well as the role of iteration, curriculum and assessment can all come together to positively change how children make and represent their work, and use play to learn with greater passion and depth in schools.

The booklet includes practical examples about the physical setup of the space and the technologies to use there, with tips on everything from glue guns to advanced CAD laser cutting. It elaborates on this with a wealth of practical knowledge about how to engage young schoolchildren in maker spaces, and how to teach students to code. It also shows how to engage the teachers and help them build a culture around engaging their students in making – for instance, how a simple challenge of building a shelter out of a piece of paper can spark tremendous learning, spread out over many different subjects.

The material concludes with the core principles for Making Engineering Playful Through Making and the differences and similarities with tinkering and engineering as a foundation for how children can succeed tomorrow.

We strongly encourage giving all students opportunities to get involved in Playful Making, enabling them to construct their way to new knowledge, while enjoying what they do, being actively engaged in iterating with materials and ideas, and producing meaningful things.

Per Havgaard and Bo Stjerne Thomsen
The LEGO Foundation

“It’s a form of play where the construction of a product or artefacts becomes a way of learning and being in the world”… “For children, it involves identifying problems that are challenging and interesting, framing and scoping those problems, playing with technologies and materials that could be used to solve those problems, learning new skills and processes, iterating frequently, engaging peers and mentors for support and assistance, and testing the solutions, over and over again, making revisions and refinements at every step.

Chris Rogers,
Professor at Tufts University
on what Making is.

Learning through Play at International School of Billund (ISB)

Somewhere among the rolled up blueprints showing various iterations of what would one day become ISB, there is a big, lopsided heart drawn in red marker. The heart was sketched by the project team after a conversation about the importance of making ISB's learning philosophy visible (and accessible) to students, parents, teachers and guests immediately upon entry. It is located smack dab on top of what would eventually be the Creator Space—literally the heart of our school and the hub of all things hands-on at ISB.

Thus, it is fair to say that even before ISB opened its doors, we knew that making and creating would play a vital role at our school, and in developing our philosophy of learning through play.

We purposely, and I think wisely, opened the Creator Space with very few high-tech resources, instead willing it to grow organically from the needs, interests and curiosity of the people who used it. Today, it does include a laser cutter, 3-D printer, robots, and other digital goodies. And yet the challenges of setting up a viable and healthy maker space with these resources is not so different than the challenges we faced in establishing its low-tech little brother.

Whether we're talking about a 3-D printer or a plethora of hot glue guns, we have learned that nice resources and a well-placed red heart do not a Creator Space make. Rather, we believe that learning through play and playful making are a mindset…a pedagogical approach that puts the motivation and interest of the student first and encourages teachers to tinker, explore, and sometimes to fail alongside their pupils.

As you will read in this collection by our friends at Tufts, developing this mindset and a healthy and viable culture of school-based making hinges on bigger discussions about values, design principles, iterative processes, and how making can be used to influence other types of learning. In our Pedagogy of Play project we often talk about the paradoxes of learning through play; that is, the tug of war between factors typically associated with school and those inherent to play. For example, play is led by children while in school the agenda is usually set by adults. Play involves risk, while schools should be safe. Play can be chaotic and messy while schools are places of order. Perhaps nowhere are these paradoxes more apparent than in a maker space, with its sharp tools, opportunities for intense, student-driven engagement and potential for mess.

Working with the researchers at Tufts has provided us with the priceless gift of outside perspective in trying to navigate these paradoxes in ISB's Creator Space. Amanda worked with our teachers to think about how we could structure a satellite maker space that would encourage more inquiry-based learning in Kindergarten. Matt helped us to think about how teachers could demonstrate risk-taking in exploring new technologies, with a foundation in familiar experiences. David encouraged us to consider how hands-on exploration of narrative and its many "messy" iterations can expand students' understanding of the world and their place in it, while reinforcing prior learning.

We do not pretend to be experts on making and playful engineering at ISB. Far from it. We still struggle with the management of glue guns, and we are constantly rethinking our use of the 3-D printer. We have gotten pretty good at reflecting on what it means to "learn through play" and our teachers spend a lot of time considering questions of culture and practice. But even here, we have made missteps and accept that there is always room for improvement and new ideas. We continue to fail. But at ISB, failure is something to be celebrated because it means we are learning. And how lucky for us to have had such inspiring and wise companions along for the ride!

On behalf of Play-Makers at ISB,

Camilla Uhre Fog
Head of School
International School of Billund

Introduction: Playful Making, Playful Engineering, and Learning in School

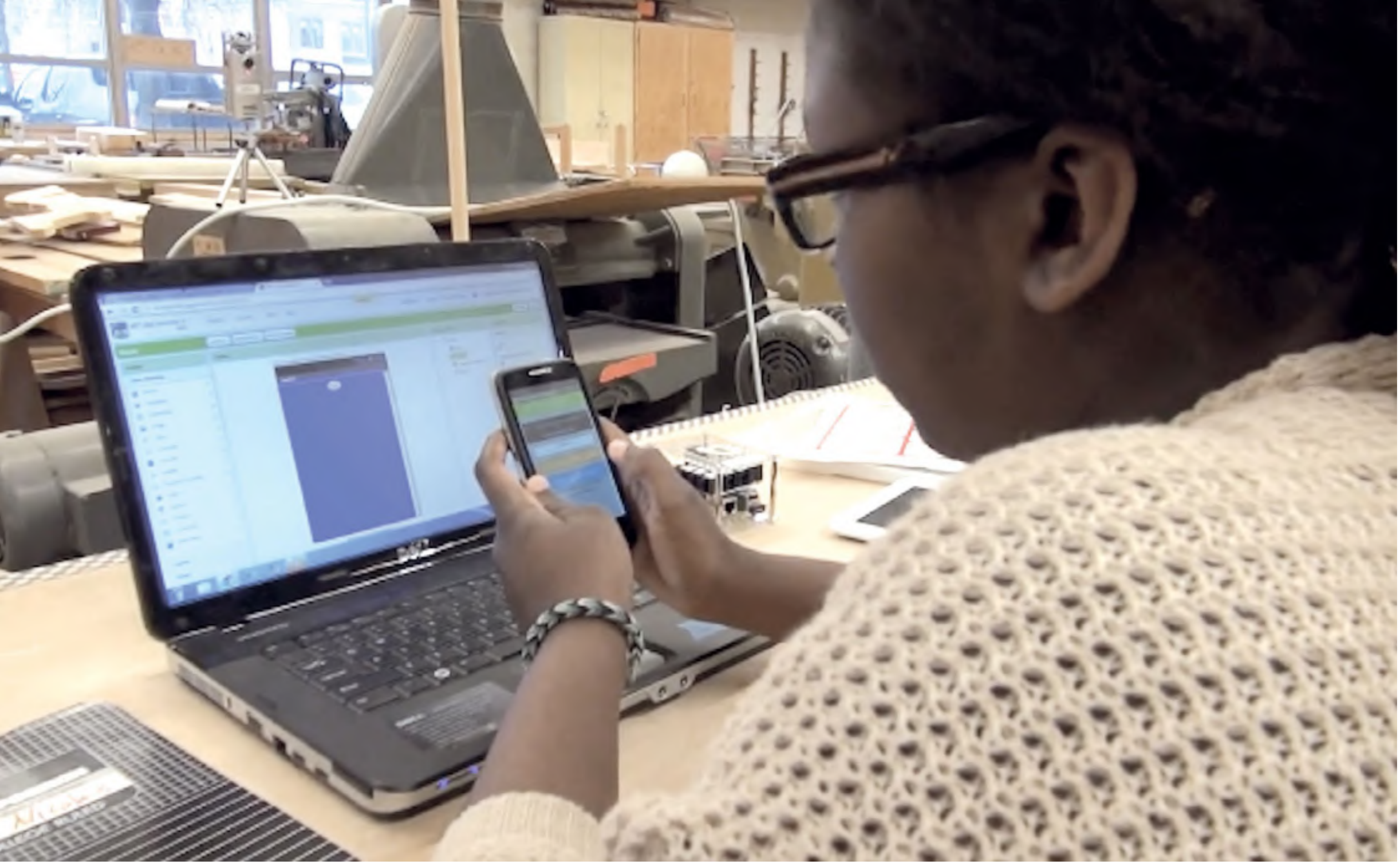
Brian E. Gravel, Marina U. Bers, Chris Rogers and Ethan Danahy

Owen likes boats. He has always been drawn to them. Building submarines out of magnetic blocks, reading stories about the Titanic, and obsessing over popular movies centered around oceans, voyaging, and sea life. As a 4 year-old, living near but not **on** the water, access to boats and time on the water is limited. This does not seem to hamper his interests, nor does it constrain his imagination. With scraps of wood, a winter snow sled, a plastic golf club, a collapsible stool, and a bucket, he builds a "pirate ship." Complete with a "captain's hat," which is actually a bike helmet, he sets "sail" on his ship. He barks out commands to those around him; he owns the seas; he exists completely immersed in the world he created.

We all recognize what Owen is doing as play. Some might call it make-believe play or construction play (Burghardt, 2011), but we choose to emphasize the relationships between Owen's imagination and his interest in making something. We call attention to the determination he shows for not only playing with an idea but building representations of that idea, so that he can exist within his imagination. He could have climbed into a box and called it a pirate ship and used his words and his gestures to create his story about pirates. But instead, he worked from his vision and his interest in the sea, and built real, physical objects alongside his imagination. He added features to his ship as the story unfolded--a mast, seats, and "treasure." The objects became part of his story, but they were also ways to explore the materials around him. New materials spurred new ideas; new ideas spawned the search for new materials. Owen talked like a pirate, imagined he was navigating the great seas, and he existed in the world he was creating. His story drove his making, and the making powered his imagination.

It is the marriage of **play** and **making** that is at the core of our work, the inherent relationship between being creative with stories, inquisitive with physical objects, playful with the forms those objects take, and engaged and inspired to continue on these journeys. In this **playful making**, we see many possible opportunities for learning, not just for 4-year olds in their driveways, but in schools and in other educational settings for people of all ages.


Pabst Blue Ribbon



Yasmin is a high school student, and she sits in front of a laptop. She has MIT's App Inventor open, and a she holds a black Android device between her hands. She's hunched over, her face is close to the computer screen. One hand is on the track pad of the laptop, the other clenches the phone. Brian asks her what she is working on, and she says, "I am working on an app that will play music, but at the moment... something's wrong." She places two thumbs on the smartphone to navigate the app she built. "The code is fine," she adds, "Just something's up with the ..." as she says this, she hits "run" on the app one last time, presumably just to see if things are working. Music plays from the phone's tiny speaker, a series of tones and chimes. "It works!" Yasmin shouts! "YES!" Her hands fly into the air. She turns to face her classmates, "It works!" Yasmin takes off, running throughout the making space, hands held high. She is proud, competent, and excited about her accomplishment. She is learning. And she is deep in playful making.

Think for a moment about these two stories. Both Owen and Yasmin are engaged in what we call **playful making**. They invite us to reflect about the powerful ways that people learn when making. In this chapter, we articulate some of the "big ideas" presented in this booklet. We hope to promote the role of playful making in schools and other kinds of learning environments.

When considering these stories, some important questions come to mind:

What is the relationship between playing and making?

- Is there an advantage of having physical objects as part of the imaginative and creative play that Owen is doing?
- How do the presence of technologies and computers enhance Yasmin's experience?
- What supports are Owen and Yasmin receiving that help them learn in their making, and how are they getting the help they want when they need it?
- Whether building a pirate ship or a music app, what are children learning? And, could the learning they experience in playful making support the learning they need to do in schools?

Based on these questions, we introduce and outline four big ideas of playful making that have the potential to change how children could learn in school: playing and making, technologies for making, making's relationship to learning, and the potential for making in schools.

1. Playing and Making

- Children engaged in a variety of playful activities and forms of play are **making their worlds**. They are making rules, making objects, making scenarios, making problems, making solutions, and creating knowledge as they go along. They are making beliefs about the world they live in, and at the same time they are exploring the ways in which that world works: how materials behave, how people behave, how tools are used. This leads children to take charge of their worlds, and to be decision makers and owners of their interests. In this way, play is more of a way of being than a specific activity.
- We position making as central to this activity. Play and making are interchangeable at some level; tethered to each other; part of the same activity. We are playful in our approach to making things – it feels good, we have fun, we do it because we feel connected and proud – and these characteristics of playful engagement keep us going, they drive our progress and the meaning we make of our work.
- "Making" is a relatively newly constructed description, or label, for a kind of activity that has happened for centuries: a sort of creative, purposeful engagement with materials in the world for the explicit purposes of producing something—a toy, a piece of art, a gadget to fix a problem, a kinetic sculpture—either because you need it, want it, or because you simply want to express yourself. This work is fun, engaging, and motivating. When you are making something, you are deep in the work, you are committed and focused. Your mind is nimble and sharp. Creativity is piqued, and you are producing things that you can imagine and that **you** care about. These are the characteristics of play that we know produce moments of meaningful learning, and they are also what comes about in powerful moments of making.
- **Playful making** is how we see the intersection of the wonderful world of play and the power of making things. It is a form of play where the construction of a product or artifact becomes as a way of learning and being in the world.

2. Technologies for making

- Historically, making has taken form with natural materials like wood, stones, grasses, and plants, as well as designed materials like textiles, papers, clays, and plastics. Humans have built shelter from the materials they find in the world, and they have developed technologies to build materials for better shelter. That is, technology has not always been foregrounded in the landscape of making things. At times, the materials have driven the process. More recently, the maker has begun to invent new technologies from what is available. And with those new developments, new technologies have been built based on the desire to do new and interesting things with materials and objects. But what can new technologies do to **enhance** or provide variety to the existing landscape of making? How can new technologies encourage and empower both new and existing ways of working with and learning about materials?

- Contemporary instantiations of making have placed creative technologies at the center of the work. Microprocessors, robotics, computational tools, and digital fabrication machines are now more available to a broader range of people, lowering barriers to entry and participation. They have played a big role in how making has taken hold in the past decade, particularly in conversations about learning and school. And we acknowledge the tension this has produced, where 3D printing becomes more valued than knitting, and where particular brands of making dominate conversions and attention (e.g., MAKE Magazine). But, we argue that as playful making, which includes the ways of making that have existed for a long time, comes into contact with new kinds of tools and technologies, new possibilities are created for learning through play and making. These new possibilities could transform how we think about learning in schools. The technologies generate new avenues or pathways for playful making to become opportunities to learn programming, engineering, and tools for inquiry that empower youth as learners, and as agents of change in their communities.
- Yet, the technologies currently available to makers are not designed with children in mind. The barriers children face when making—like not being able to read the instruction manual, or having the strength to tighten a bit into a mill's chuck—are different from those of adults. Children can use tools designed for adults, but what supports do they need to really make digital design and fabrication technologies the tools of their imagination?

3. Making and Learning

- Some of the earliest theories of development and learning pointed to the individual's manipulation of objects in the world as a way of constructing knowledge about that world. These theories are called "constructivist", and they argue that people learn by constructing reality in our minds. That happens through the use of language, objects, materials, and representations available to us in our individual contexts and communities.
- Making objects, drawings, and other external representations of our thinking gives us a chance to see our thinking in another form. The process of producing representations of our ideas leads us to reflect on and refine our ways of understanding the world. Producing these public artifacts enhances our abilities to construct meaning. And making privileges the construction of objects in ways that align with long-standing theories about learning.
- And, as we work with objects in the world, they continually "push back on us." We try and make a piece of wood bend and it won't. We try and make a tower of blocks that stand, but it falls. These are examples of objects in the world pushing back on us, and they are opportunities for us to understand why; to construct knowledge about those materials and objects and how they work. This pushback creates opportunities for us to learn because these are moments where things do not behave as we expect, and that tension drives us to make sense of things. Through this exploration, experimentation, and most importantly failure, we gather knowledge about materials and tools that help us learn new and better ways to do things.
- Further, making things to **share with others** engages us in conversations, forcing us to think about differences, critiques, and how to make improvements to our ideas so they are more coherent, clear, stable, or enticing.
- Engaging in this work with others, collaborating in teams, and identifying challenging problems without obvious solutions leads to opportunities for learning disciplinary practices, like engineering design and computational thinking. As we get

stuck, we must identify sources of knowledge we need—from other people, from disciplinary knowledge—and this develops us into refined, disciplined thinkers. The practices are not only powerful for continued problem solving in the world, but they are precisely the stuff that schools have to care about teaching. Making is an authentic activity where many of the elements of good, meaningful learning come together.

- In sum, making things, especially making with different kinds of things—crafts, technologies, large objects—means we have many chances to explore how the world works, and to construct knowledge about that world that we can continually refine as we grow and develop.

4. Making in Schools

- Much of what excites the education community about making, and makerspaces, is that these kinds of activities are examples of all the of "good stuff" of learning. Countless case-studies of learning in making exist in the literature: students pose their own problems, they collaborate to solve them, they iterate on solutions, they develop their creativity, and cultivate pride and care in their work; these are examples of learning (see Peppler, Halverson, & Kafai, 2016). Yasmin's exuberance at the success of her app, or Owen's complete immersion into his pirate world, are both examples of how engaged one gets when making, and the powerful learning opportunities this affords.
- And yet, making is messy. Making requires breadth of knowledge and skills about different kinds of materials, tools, and sources of information. The best making happens in spaces where different people know different things and can support each other. This sounds like a classroom in many ways, but within schools, where the teacher still possesses most of the authority in the room, this can be hard work to enact. It means the teacher facilitating twenty or more students doing a variety of different projects, needing to offer different kinds of supports at different times, and having tools and experience to troubleshoot and navigate all of those unforeseen issues that arise in this messy way of working.
- Furthermore, schools are tasked with teaching children particular things—content and practices of science, mathematics, language, and culture. As the leaders of the Tinkering Studio at the Exploratorium have famously said, "It looks fun, but are they actually learning?" (Petrich, Wilkinson, & Bevan, 2013). The issue of how to assess the learning that students are doing is daunting. And yet, if making is to play a significant role in schools, describing the learning that happens when making is critical.
- Successful making means fostering solution diversity, where each student or group develops something different and unique from their classmates. Thus, we need new ways of thinking about assessing students' ideas and thinking; we cannot rely only on measures of content knowledge, but we must also think about how we assess the practices student develop when making, as problem solvers and agents of change.
- We are at a time where schools all over the world are ready to embrace making as a powerful form of learning. There is both opportunity and tension, opportunities for meaningful change in the ways we think about teaching and learning, and tensions with existing systems of practice and values in many schools. These opportunities and tensions raise big questions for making in schools: What kinds of supports do teachers need? How can we think about learning through making in these school contexts? How do we use making to find rich and engaging connections that span school, home, church, and community lives?
- To bring making into schools, we must contend with the realities of curriculum and the need for assessing what is being learned. We need an assurance that when children engage in playful making, they are doing the learning that school needs them to do.

The Project and Goals of the Booklet

The four big ideas presented above are the results of a 2-year collaboration between researchers at Tufts University (in particular the Center for Engineering Education and Outreach-CEEO, DevTech research group in the Department of Child Study and Human Development, and the Department of Education), the teachers and leaders of the International School of Billund, and the LEGO Foundation.

The project involved collaboration between between Tufts and the International School of Billund to explore the possibilities of a makerspace within an elementary school where creativity and play are part of the fabric of the school's culture. The collaboration took place from Fall 2015 through Spring of 2017. During this time, researchers at Tufts spent time as residents at ISB, while also working in local makerspaces and schools to continually explore questions of play, making, and learning. The network of spaces (including Nedlam's Workshop, the Cambridge Friends School, the Newtowne School, and the Eliot Pearson Children's School at Tufts University) and partners (ISB, Project Zero, and researchers at TERC and other institutions) allowed us to construct a robust partnership over the course of two years. This collaboration was designed with several key features that led to its success, which we describe briefly below:

- **Distributed Expertise:** Researchers represented a unique and complimentary collection of expertise: early childhood technology, engineering education and technology design, and the study of representations and the science of learning. This collection of expertise meshed well with the interests and expertise of the faculty and staff at ISB.
- **Researcher Residencies:** Tufts research assistants (doctoral students) conducted six different residencies at ISB focused on specific questions. These researchers were embedded into ISB for 3 weeks at a time, following the rhythms of the school day, working with teachers and students, and introducing supports and interventions to both encourage the use of the Creator Space for playful making, while also studying how the school saw the power of the makerspace in advancing their mission.
- **Partnerships with teams of teachers:** Each Tufts researcher visited ISB at least twice over the course of the project, working with the same teams of teachers to develop relationships and to advance the works. This allowed teachers and researchers to get to know each other, to develop some trust, and to sustain conversations even when Tufts researchers were back in Boston. These collaborative teams talked frequently over Skype, and remained partners in their development of pedagogies, tools, curriculum, and approaches to using the Creator Space to promote playful making.
- **Collaboration with complimentary project at Harvard's Project Zero:** The **Pedagogy of Play** project was also working with ISB at the time, promoting teachers' own study and learning about play in learning, and we were able to coordinate their efforts with the Tufts research efforts. This collaboration supported how relationships developed with teachers, how we understood the evolving nature of the Creator Space at ISB, and it multiple data points for conversations around play, making, and the wonderful work at ISB.

This booklet was compiled to share the findings of this 2-year collaboration. Our goals are to present stories of the work, our successes, and our challenges, so that other schools, teachers, administrators, and researchers may build on some of what we were able to do as partners at ISB. We acknowledge that this was a very specific context, and that we were fortunate to have such a meaningful and well-constructed partnership; ISB and Tufts shared many questions, goals, and commitments, and this relationship supported students and teachers to do amazing things in the Creator Space in a relatively short period of time. This booklet is not intended as a manual or playbook for how to do this work in other contexts. Rather, we hope that we present interesting and compelling stories of playful making at one school, to advance the conversation around how play and making could help to transform learning in more schools around the world.

The chapters of this book cover fertile and expansive ground; that is, they span the ages and dimensions of playful making in schools. We present a brief summary of each chapter here, connecting them to the larger project theme of playful making.

Chapter 1

Design Principles for Early Childhood Makerspaces: In this chapter, Strawhacker and Bers describe how they discovered and articulated design principles for early childhood makerspaces. Responding to the needs and concerns of teachers at ISB, the authors identified an exciting area for design: converting "big kid spaces" (i.e., makerspaces as they currently exist) for use by little people. Building from Amanda's first residency at ISB, and her observations in a number of different settings across ISB, the authors distilled a set of seven key principles to guide the design of a makerspace for Kindergarteners. They explain each principle, citing examples from children's work, and offer a provocative guide for the future development and refinement of early childhood spaces that promote playful making.

Chapter 2

Values Underlying the Power of Makerspaces in Schools: Strawhacker and Bers present a powerful story of how teachers at ISB were supported in identifying, describing, and wrestling with some of their core values around playful making and makerspaces for early childhood education. Whereas Chapter 1 articulates principles to guide the design of these spaces, this chapter articulates some of the values that inform how pedagogies in early childhood makerspaces emerge. The goal of this work was to help teachers feel as though they understood the power of the space, reasons for being there, and how it related to their classroom work. This chapter shares the story of some talented teachers exploring new territory: what it means to teach in an early childhood makerspace, and how that is different and complimentary to the playful work happening in their classrooms everyday.

The Appendix to this booklet offers an example of how the Creator Space for Early Childhood unfolded at ISB. This is a collaborative effort between members of the Tufts team and the team at Project Zero's Pedagogy of Play project. We include it in this booklet to give a vivid snapshot of what this work looked like, and some of the ideas and lessons learned that were produced along the way.

Chapter 3

Iteration in Playful Making with Glue Guns and Laser Cutters: We turn to a focus on the particular tools in makerspaces, where Mueller offers a thoughtful analysis of how specific tools and materials both support and hinder playful making in elementary schools. Mueller focuses his analysis on the role of iteration—a practice central to engineering, computational thinking, and playful making—emphasizing the importance of iterating, and the complicated landscape of how that takes form across different technologies and processes. Mueller draws from his work helping to stand up the Creator Space at ISB, calling upon moments of playful making with students, teachers, and his own experiences as a mechanical engineering student. He makes some recommendations for thoughtful and intentional decisions around different technologies, and he offers a set of guidelines for thinking about how tools can support playful making for children of all ages.

Chapter 4

Shelters Curriculum: This chapter outlines an effort to develop curriculum for teaching in the Creator Space that allowed us to understand the thinking and learning students are doing when engaged in playful making. Alsdorf describes the development of this intervention—the Shelters Curriculum—and how it led to the study of narrative and representations as ways of **understanding children's understanding** while making. This curriculum was constructed over two years, in consultation with teachers at ISB, and serves as a model for thinking about how projects can support the ways children share stories of their making.

Chapter 5

Narrative Assessments of Playful Making: Alsdorf and Gravel share data from their research at ISB on how narratives are central to making processes. Using data from stories that students wrote about their making, they describe how storytelling and narrative construction are ever-present in making and how cultivating these practices opened new avenues for assessing what students are thinking about when they make things. When engaged in making, students are constructing narratives that help them make sense of the world. This chapter presents a theoretical and empirical argument for a novel way of thinking about children's stories in making, and how centering those stories in their work can support children's learning as well as our abilities to assess their progress and development.

Chapter 6

Representational Praxes: In this chapter, Alsdorf and Gravel pay specific attention to the role of representations in playful making, and how curricular interventions and decisions about practices within the Creator Space can influence how students make sense of what they are doing. In turn, a focus on different aspects of representation (i.e., drawing vs. photographs) can help us understand how a variety of representations supports narrative construction in making. This chapter articulates some subtle points about basic assumptions around documentation and recording in makerspaces, and encourages practices of sketching, mapping, and drawing as ways to help students make sense of their experiences in playful making.

We end this compilation with **Chapter 7**, where we distill the findings of our work into some characteristics of makerspaces and central principles for playful making. We hope these can serve as guides for those interested in building more making into the school curriculum. Within this final chapter, we briefly discuss our emerging views on the relationships between engineering, play, and tinkering, and recommendations for future work in this area, where partnerships between practitioners and researchers could be particularly fruitful to the efforts of getting playful making in schools.

Finally, we would like to formally acknowledge the incredible generosity, willingness, and hospitality showed by the whole community at ISB. Tufts researchers felt welcomed into your schools, communities, and even your homes. Good work requires strong relationships, trust, and a belief that all parties have brilliance and experience to share. This sentiment was embodied in this project, and the results of what we were able to achieve together are directly related to students, teachers, staff, and families at ISB opening their hearts, minds, and doors to us at Tufts. For that, we are thankful, and forever grateful.

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Chapter 1. Makerspaces for Early Childhood Education (Principles of Space Redesign)

Amanda Strawhacker & Marina U. Bers

When the ISB Kindergarten teaching team wanted to involve their young children more in the Creator Space, the administration agreed that combining their emerging maker philosophy with the pedagogies of early childhood education was an exciting idea. However, Kindergarten teachers struggled to use the ISB's Creator Space, which to them felt "like a big-kid room" (M. Barbon, personal communication, January 2017). The storage is too high, tables and chairs are too tall, tools are too complex, and the room itself is too large and open for young children. Early childhood and makerspace education researchers from the Center for Engineering Education and Outreach and DevTech Research Groups (Tufts University) engaged in a collaborative project with the Pedagogy of Play research team at Project Zero (Harvard Graduate School of Education) and the Kindergarten teachers at ISB in order to design a d**evelopmentally appropriate Creator Space** for Kindergarten students at the school.

Much of the work of conceptualizing and designing the Kindergarten Creator Space (KCS) occurred through creating an experimental "sister space" at Tufts University, informed by ethnographic observations in ISB Kindergarten classrooms, Kindergarten play-sessions in the existing Creator Space, and one-on-one interviews with ISB Kindergarten teachers conducted by Tufts researchers (Bers, Strawhacker, & Vizner, 2018). The lessons learned from developing the space at Tufts were used to inform decisions about the construction of the ISB Kindergarten Creator Space. As this new space at ISB took shape, Kindergarten teachers were supported in different ways to promote their ownership of and enthusiasm about the space. This support came through experimental play-sessions with interested classrooms, as well as collaborative conversations within the Playful Classroom Environments Study Group, a working group of Kindergarten teachers facilitated by Project Zero, in which the teachers investigated playful learning settings through a participatory research process (Baker et al., 2016; Strawhacker, Tontsch, & Baker, 2017). Through these efforts, the space continues to evolve and serve the Kindergarten ISB community."

Makerspaces are a new concept for education, which promotes an emphasis on "learning-by-making," creating over consuming, and learner-directed projects (Honey & Kanter, 2013). We know that especially in early childhood (ages 3-6 years), children learn best by manipulating, building, and sharing physical creations, and by exploring new ideas with teachers and friends as guiding resources. Currently, there is very little research at the intersection of makerspaces and early childhood education. The DevTech Research Group, which focuses on developmentally appropriate technology design and integration, has explored principles of Positive Technological Development in the context of traditional children's space design (Bers 2012; Bers, Strawhacker, & Vizner, 2018). In addition to research conducted in a diversity of school settings, play spaces, and museum settings, the authors, Professor Marina Bers and Ph.D. student Amanda Strawhacker, conducted research at ISB to learn more about how making and early childhood fit together (Bers, Strawhacker, & Vizner, 2018). Based on observations collected at ISB's Kindergarten classrooms, the authors identified a new set of general design principles and best practices for developing an early childhood makerspace that fosters making, creativity, and learning through exploration (see table 1). This new set of principles informed the design of the Kindergarten Creator Space at ISB. This chapter describes the principles in detail, as well as their practical application in space design. All images in this chapter come from the KCS at ISB.

Table 1.
Evidence-based Guidelines for Designing Early Childhood Makerspaces.

Principle	Example
1. **New technologies** should let children explore making with contemporary forms, tools, and ideas	Offer developmentally appropriate robotics, film-making equipment, or circuitry kits
2. **Materials** should be visible, accessible, and inviting	Store materials in glass jars or wire baskets on low, uncrowded shelves.
3. **Furnishings** should be child-sized and functional for children's needs	Adjust wood work tables to approximately 51cm height, use wide floor areas for work
4. Elements of the room should promote **exploration and risk**	Learn about and practice safe use of tools like hot glue guns and sharp knives
5. The space should **reflect the children** who use it	Display children's work and pictures at child-height
6. Facilitation and space design should **"say yes" to children**	Before telling children what not to do, learn why they are doing it
7. **Building and sharing ideas** is as important as the finished product	Let children make mistakes and test ideas instead of correcting

Figure 1
Children designing with KIBO.

Principle 1. New technologies should let children explore making with contemporary forms, tools, and ideas

The major difference that separates makerspaces from other learning environments is that they offer learners a way to engage with novel tools, technologies, practices, and forms of expression. There are many technologies available to children today, and many of them come from their parent's generation (like phones and pagers), their grandparent's generation (like LEGO bricks and polaroid cameras) and from many generations before that (like pencils and paper). However, a makerspace offers children a place where they can form their own community, and engage with the tools and skills that will become part of their own generation. Today, that includes programming, robotics, and engineering (Bers, 2008).

To serve this need, the ISB makerspace offers the screen-free KIBO robotics kit to engage children in developmentally appropriate coding experiences. Experiences with KIBO contribute to children's developing computational thinking. Computational thinking can be defined as a range of creative problem-solving and algorithmic strategies that comprise an expressive process to develop technological fluency (Bers, 2018). In 2016, Kindergarten children and teachers engaged in an intensive 2-week exploration of the KIBO robotics kit at ISB. This brief introduction sparked over a year of ongoing excitement and exploration with this developmentally appropriate robot kit. Young children have created working city maps with moving KIBO cars, built "cave explorer robots" using blankets and KIBO lightbulbs, and explored packaging and loading using KIBOs to transport plastic "grocery foods" across the makerspace. Currently, KIBO is a regular offering in the makerspace, and young children incorporate it into their engineering solutions, their models and experiments, and their free play in the space.

Figures 2 & 3
Materials are offered in baskets and boxes that can be easily moved, and laid openly on tables for children to play with.

Principle 2. Materials should be visible, accessible, and inviting

The first principle comes from long-standing early childhood pedagogy (e.g. Reggio Emilia and Montessori philosophies). Children, just like adults, enjoy working with beautiful objects and materials. Colorful materials, natural elements, and a variety of textures and sizes invite curiosity, and easy access to materials promotes a creative atmosphere (see figures 2 and 3). "Coziness" is already a popular Danish design concept involving soft, calm spaces that invite intimate social experiences. This kind of coziness is not just important for children's comfort, but also for their ability to focus. While many children can find it in themselves to give something a first try, it takes confidence to persist in the face of failure. Children's willingness to play and explore is inversely proportionate to their fear and safety-seeking reactions (Grossmann, Grossmann, Kindler, & Zimmermann, 2008). A space that is soothing, safe, and comfortable encourages children to persevere through disappointing moments, and to self-stimulate through creative and even challenging play. This adds to children's developing competence and perseverance in the face of many frustrations that can occur as they attempt to master new skills. In the KCS, this was implemented in the form of soft carpeting and cushions in the circle area, lots of wood details in the furniture, and a wide mirror near the light-filled windows. Children noticed these details as soon as they walked into the space for the first time, and many of them even exclaimed "it's so cozy in here!"

Principle 3. Furnishings should be child-sized and functional for children's needs

Just as materials can invite or discourage children, so too can furniture. One way to invite children to use furniture is to make it child-functional. Tables can be height-adjusted for the shortest setting (e.g. 51cm tall), and a variety of seating or standing options can create different comfortable options for children of all sizes. Similarly, the floor is one of the best workplaces for children, but a bare floor is not nearly as inviting as a cushioned or carpeted one. All ISB Kindergarten classrooms have a carpet, not just because it is comfortable, but because carpets indicate a gathering area to children. This is important for young children, who are still developing their collaboration and communication skills. The KCS includes familiar furnishings like carpet areas, low tables, and a variety of seating options to help children feel welcome (see figures 4 and 5).

Figures 4 & 5
Children sit cross-legged or on "bubble" seat, and use easy-to-reach storage baskets.

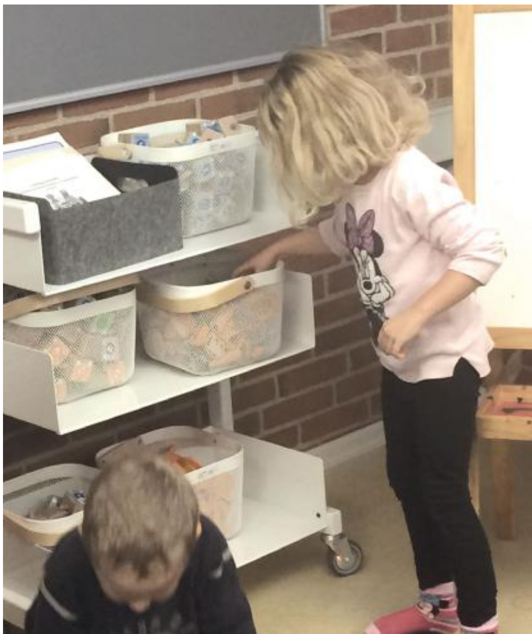

Figure 6
A boy uses a hot-glue gun to build a structure.

Principle 4. Elements of the room should promote exploration and risk

Makerspaces are unique learning spaces, because they put the learner in the position of collaborator, co-teacher, and self-motivated inventor. Children take these roles seriously and understand the responsibility they are being offered. In order to truly promote responsibility, facilitators can teach children how to use tools that require skill and care.

It's important here to point out the value of risk in learning experiences, especially as children's spaces (particularly in the US) have slowly become more sanitized of any potential risks or discomforts. While it's true that sometimes risks are unnecessary and potentially harmful (such as driving without a seatbelt), there are many learning experiences that simply cannot occur without a certain level of risk, and the absence of these experiences may even be harmful to children's development (Sandseter & Kennair, 2011). For example, tools like knives and hot glue guns have inherent risks and potential dangers such as injury. However, because it is impossible to remove the risk without also compromising the tool's effectiveness, children have a chance to learn about the responsibility associated with using them. In a sense, "danger" in a makerspace is not related to tools themselves, but rather to a lack of understanding or knowledge about how to safely use them. Similarly, "risks" are not preventable evils to be avoided, but real-world opportunities to explore safety and responsibility. For example, the boy in figure 6 (opposite page) was allowed to use the hot glue gun with help from a trained maker, and so learned about safe handling of hot tools. He also learned that he is a valued agent in the makerspace who is worthy of an adult's trust.

Children can benefit from working in a space that offers real responsibilities and risks. However, "risky" opportunities do not always have to be dangerous. Sometimes a risk for a child is as simple as trying to play with a new friend. To promote necessary multi-sensory and collaborative experiences that may require risk-taking, the KCS offers a diversity of unique materials for children to explore (such as delicate sculptures), as well as a variety of individual and shared making experiences (such as large building materials that allow more than one child to build).

Figure 7
A display of children's work alongside images of the maker, with captions of their own words.
Mette: "Look at this clay thing! Where did it come from? Is this his?" (gesturing to the picture)
Sara: "It's the same, the sculpture and the picture!"
Karl: "I know the boy in this picture! Look Max it's your brother!"

Principle 5. The space should reflect the children who use it

Putting children's work on display in the makerspace allows children to feel ownership of the room, and promotes community feeling for children who recognize their friends in the images.

Additionally, presenting work this way shows children that their creations are valued. When a group of children sitting at KCS carpet noticed a visual display at their eye level (see figure 7), they began a conversation.

The children not only recognize a unique creation, but they can even identify the maker and connect him to their own classroom community. "Museum-style" displays like this can communicate a lot about the work that happens in the KCS, even when the finished products do not stay constructed, such as with KIBO robots (see figure 8).

Principle 6. Facilitation and space design should "say yes" to children

Children have a hard time understanding things that they cannot see or touch, and much of what they can see from child-height is deliberately sized or stored in a way that makes it impossible for them to touch. Even young children know which tools and materials are "for little kids." Objects that are out of reach, shelving that is locked, and posted signs with lots of text all communicate "Off Limits" to children. By comparison, objects presented on tables or low shelves, stored in clear, open containers, and labelled with helpful images send a clear invitation to touch, play, and manipulate. Teachers came up with the concept of "saying yes to children" as a goal in their study group conversations with the Harvard PZ team, and brought it into their discussions of space design with Tufts researchers as well.

Another way to interpret this principle is by imagining ways to remove situations where teachers and facilitators have to say "No" to children. Teachers at ISB found that when they removed inappropriate tools and furnishings, they also removed opportunities for

Figure 8
Museum-style display of children's work and written quotes demonstrate the work they have done in the KCS.

Figure 9
Seeking a dark place, children test KIBO light bulbs underneath a dangerous shelf.

children to "misbehave" by using the room incorrectly, and spent less time redirecting students. For example, three children who wanted to test the KIBO robot's light bulb began testing their robot underneath a tall, unsecured bookshelf (see figure 9). Their teacher correctly interpreted that, rather than trying to "break the rules," these kids just wanted a dark space for testing light bulbs. She knew that making a rule about avoiding the potentially dangerous bookshelf would only create a new problem (she now needs to police the bookshelf) without solving the first problem (children need a dark place to test). Instead, she created a dark place that was safe by adding blankets to the KCS. During their next visit, children chose to made a "dark cave" under a tall table to test the light bulb, which was much easier than crawling under the bookshelf (see figure 10). This is what is meant by providing a space that "says yes" to children: a space should naturally invite the kind of activity that is desired and allowed.

Principle 7. Building and sharing ideas is as important as the finished product

Although it is valuable for children to master skills and learn new tools, the most important lesson that children can learn in a makerspace is how to collaborate with friends, test ideas, and revise their work. For this to happen naturally, children may make dozens of failed attempts before creating something that "works." For example, a group of children requested to come to the KCS to build and test paper planes, a popular activity in their classroom (see figure 11). After 25 minutes of testing, researching directions online, and looking at a prebuilt model, they had made around 6 planes, and had iterated on each of them multiple times. They tested things like adding pieces of string to the planes "because it will be like the tail of a kite," and coloring the planes blue "so they will want to be up in the [blue] sky."

Figure 10
When given blankets, children constructed a "dark cave" to test KIBO light bulbs.

Although an educator could have stepped in to guide their ideas, the children were inspired and curious about seemingly illogical factors. Rather than interpreting this as a sign of misconceptions, this demonstrates the value of allowing children to make mistakes and learn from each other during the design process. By the end of the building session, children had discovered that one boy's plane always flew to the right. After testing everything they could think of, they eventually noticed the folds on his plane's wing. Without an educator's help, they made a new discovery about paper planes that they were excited to share with friends back in the classroom.

Taken together, these principles can serve as a guide for early childhood educators and administrators hoping to cultivate a strong makerspace and maker-mindset for young students. Using these principles, almost any space can be repurposed to be a "little kid space," supporting risk taking, exploration, innovation, and community building. Developmentally appropriate makerspaces can support creative learning in a way that is unique from and complementary to the learning that happens in the classroom and on the playground. In the next chapter, we discuss how we meaningfully engaged early childhood teachers at the ISB in the KCS, by supporting their own teaching values and goals for cultivating a maker community.

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Figure 11
Children explore many hypotheses about building paper airplanes.

Chapter 2: Maker values of early childhood educators, organizing a grassroots space

Amanda Strawhacker & Marina U. Bers

If we ask teachers in the same school, "What is the value of a makerspace for your students," would we get a clear answer? And would three different people have the same response? The question of why to introduce a makerspace is central to the development of any successful new makerspace project. This makes it surprising that few schools are able to answer it with certainty and clarity. A school's purpose and mission is usually well-articulated, such as the ISB's mission to "guide and stimulate children to become ambitious lifelong learners who achieve personal fulfilment and who will make positive contribution to our ever-changing world" (International School of Billund, 2013). Just as with a school, the identity of a space is driven by its purpose, and this identity also shapes a space's values. In the following chapter, we explore how ISB Kindergarten teachers set out to define the identity, purpose, and values of the new Kindergarten Creator Space.

When Camilla, the principal of ISB, told the Tufts research team that she wanted the Kindergarten teachers to have a Creator Space, she said that she only had one goal:

"I want the teachers to actually **use** it."

This was a very insightful goal. Our research has shown that in makerspaces that lack certain key elements, the space's expensive and promising equipment collects dust. One of the most important design elements for a makerspace is that it should have an "identity" before it is made. This means more than just knowing the audience, the scheduling, and the staffing for a space (although all of that is important). A space with an identity is designed with specific values in place to serve a specific purpose, such as a religious sanctuary or a sports stadium. A makerspace with no values is a space with no purpose, and a space with no purpose goes unused.

The DevTech Research Group at Tufts University, directed by Professor Marina Bers, focuses on designing, implementing, and evaluating new technological learning experiences for young children, including technology-rich spaces like makerspaces (Strawhacker, Portelance, Lee, & Bers, 2015). Professor Bers' framework for Positive Technological Development offers an approach for integrating digital experiences that can enhance children's learning, and their engagement with six positive behaviors associated with positive development: communication, collaboration, community building, content creation, creativity, and choices of conduct (Bers, 2012). DevTech researchers know how to design spaces to promote each of these positive developmental behaviors, and have designed an early childhood makerspace at Tufts University to illustrate that mission (Bers, Strawhacker & Vizner, 2018). However, the identity of that makerspace

Figure 1
Gaby, a lead Kindergarten teacher, selects pictures of makerspace activities that she thinks are the most important for children to experience.

is necessarily different than the identity of the Kindergarten Creator Space at ISB, because the ISB space must reflect the values and purpose of the school community there. DevTech's research offers a developmentally appropriate framework, which the Kindergarten teachers at ISB used to begin designing a makerspace with its own unique identity.

Researchers worked closely with the Kindergarten teaching team to identify their personal teaching values, so that they could plan for a successful Kindergarten Creator Space (KCS) together. Since makerspaces are still an emerging concept in education, there are many diverse values that educators might have when using them, including entrepreneurship, community service, technical expertise, self-expression, and more. Even among the makerspace researchers at Tufts, different individuals have unique personal views about the qualities and benefits of a "good" makerspace. Ph.D. student Amanda Strawhacker observed Kindergarten classrooms, attended teacher meetings, and interviewed lead teachers. All teachers participated in a card-sorting task developed at Tufts (Meehan, Gravel & Shapiro 2014) that helps teachers to identify their maker values (see figures 1 & 2).

In this task, Teachers looked at cards which listed many diverse values, learning outcomes, tools, and skills that could be associated with makerspace learning environments. These included items like "problem solving," "entrepreneurship," and "hot glue guns." They also viewed cards with pictures of activities that children might do in a makerspace, such as "building a community garden," "creating a model of a dream house," and "building and rehearsing a puppet show." For both sets of cards, teachers were asked to select the ones they found most meaningful to their teaching practice, and what they most would like to see their students doing in the KCS.

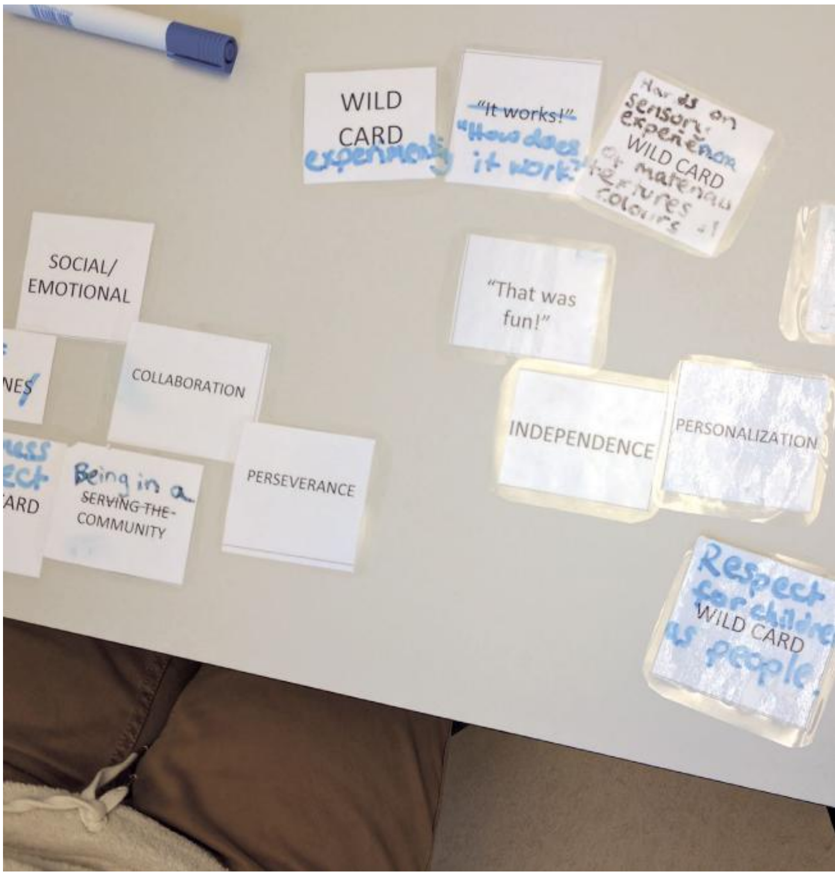

Figure 2
Ruth, another lead Kindergarten teacher, selected and organized these cards to represent her vision of important maker learning for 3-4 year olds in her room.

Selecting the cards was only a portion of task. Teachers discussed their choices with researchers, organizing cards in ways that made sense to them, and through their conversation, often arrived at a smaller subset of values that they felt very strongly about. For example, sometimes the cards reminded teachers of a vignette from their classroom that they considered a powerful learning moment, and which they would hold as a model for the kind of learning they'd hope to see in the KCS. Through these semi-structured interviews, teachers and researchers arrived at a deeper understanding of the true values and goals for the space.

Several core values emerged across the Kindergarten teaching team. Figure 3 shows the four main values of **sensory exploration, independence, social/emotional growth**, and **confidence**, along with practical examples of each that emerged in conversations and observations with teachers. While other makerspaces for older children or adults might focus on certain tools, skills, or finished products as part of their values (e.g. a makerspace specifically for woodworking), the KCS is unique in that its underlying values are almost entirely about making as a path toward social and personal development. This is perfectly appropriate for the 3-6 year age range of the KCS makers. At this age, children are still learning how to work together with others, how to persevere in independent work, and how to confidently continue to explore new interactions and ideas, even after a failure. In other words, children in the early years are learning how to be makers of community as well as makers of physical products.

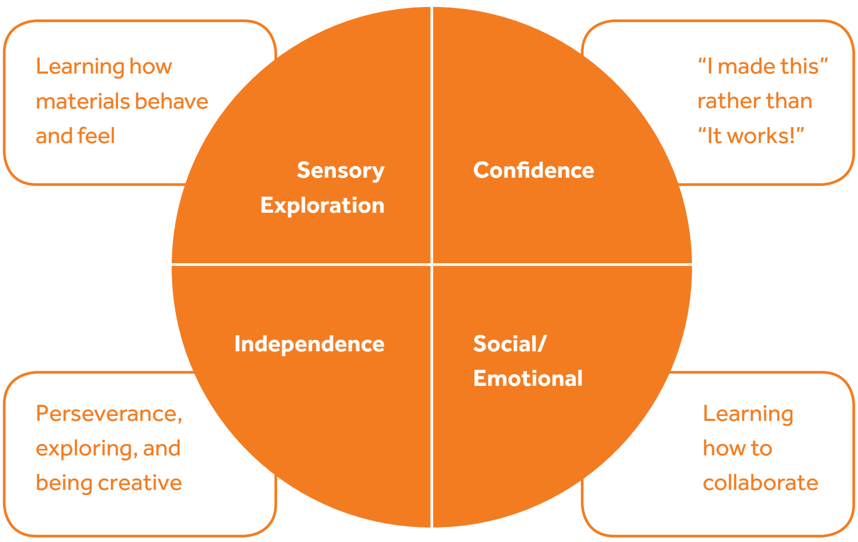

Figure 3
The four pie slices in this chart show the four key maker values that ISB Kindergarten teachers identified. The squares next to each pie slice offer more detail about each value.

These values all impacted the mission and design of the KCS, and the teachers clearly recognized the importance of knowing their values before using the room.

For example, Gaby said about the value of **social/ emotional growth**, "collaboration another skill that is important to have and I think it's not just in the children, but also in the room. We're three teachers there, so I think it's important that the children see how all the grownups also work together."

Ruth pointed out that specific tools and choices in the room can foster independence, saying, "there should be room for [the children] to try to solve problems themselves. For example, opportunities for them to choose which tool they think they might be able to use for a particular job."

Marina talked about the importance of changing the children's physical space to allow them more opportunities for **sensory exploration**: "it doesn't need to be fancy, but giving my kids some dark areas to test [the KIBO robot's] light, some small things to have KIBO carry, it's enough motivation for them to see if they can move things here, or see what happens if they put something upside-down there. I think it's more work to be responsive to them, but it's actually worth it because then you know what they like, what they want. They just need someone to listen to them."

With the values for the space clearly outlined, the plan for the KCS quickly became easy to implement. Since the values of the space are centered around individual confidence and social development, the logical purpose of the space is to offer a range of inviting, functional spaces for children to practice working alone, in pairs, or in groups to develop their social interaction skills. To serve this goal, we filled the space with a carpeted "group" area, work table spaces for individual work, and larger building materials (like bubble chairs and cardboard boxes) that require children to work in pairs or small groups to use. Additionally, the identity of the space as a distinct location within the school soon emerged, as a space for young children at ISB to grow and learn about themselves and others by engaging in unique, exploratory building and making experiences. For example, unique materials and activities such as foot painting and large-scale building, typically more difficult to implement in the classroom, are perfect sensory activities for the makerspace, and the space is outfitted with those materials.

Now that the identity, purpose, and values of the Kindergarten Creator Space have emerged, what is the result of this project in addressing Camilla's main desire, that the space be regularly used? In support of our hypothesis that a space with an identity can foster a community, we're pleased to say that the makerspace is regularly used by the Kindergarten classes. Marina has even said, "We've got a room! And it's not like yeah, we got a room and we're done – no, we're cat fighting for time in it!" After the makerspace was opened, Camilla wrote in the school's newsletter, "the Kindergarten Creator Space (KGCS) is a hit! The K teachers and children are working hard to care for and maintain the space."

The cards in this example offered a structure to facilitate conversations among ISB Kindergarten teachers, conversations that were critical to designing a successful learning space. The ISB's space is uniquely its own, but this kind of work could be successful in any school setting. The richness of identifying these values can come from any reflective conversation among teachers, administrators, or other stakeholders involved in the design of a new space.

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Chapter 3: Iteration in Playful Making with Glue Guns and Laser Cutters

Matthew Mueller

One of the earliest examples of my inclination towards engineering is how I would ask my dad, "can we make something out of wood?", a question which became a catchphrase of mine among my family. We made model boats and cars, boxes to hold beetles and fireflies, and mechanisms that launched corks and rubber bands. The workflow would typically start with my idea, then my dad would come up with a design and direct me where to squirt hot glue or hammer a nail. While saying "yes" to my ideas encouraged creativity, my father never conveyed his overall design to me, keeping the plan in his mind and explaining it to me one step at a time, improvising as we went. Following a dynamic design process that was mostly confined to my dad's head, it was never clear to me how we were iterating while making. Many of these projects ended with my dad as the driving force because the power tools were too dangerous for me and the design was never truly my own.

As I have become an engineer and maker of my own right, I often follow a dynamic process similar to my father, but am constantly aware of the small and large scale iterations of the design as my creation takes shape. When doing my own woodworking projects now, I recognize small scale iterations when I adapt the design when a cut doesn't turn out as expected, and full iterations when I decide to start from scratch using all I've learned from the first attempt. Becoming aware of iteration in my design process has enabled me to think more critically about the quality of what I'm creating, constantly evaluating potential solutions to any problems I come across. Giving students ownership over designs and reflecting with them on iterative practices are great ways to get the most value out of maker education.

Especially as I have started using digital fabrication tools, I will often end up with a number of 3D printed or CNC routed parts that are broken or not quite right, which comprise a visual story of the design's iterations. Makerspaces have become a venue for learning about technologies and incorporating them into making, and one of my goals at ISB was to help empower the community to feel more comfortable using and learning these tools. Technologies in these spaces range from low-tech tools like hot glue guns and hand tools to high-tech computer aided design and coding experiences. New interfaces and methodologies for creating with these technologies are constantly being developed, with the intention of making it easier to get started. Yet, there is still a great amount of work to be done to address the issues of how beginners are introduced to new technological tools and making practices.

In this chapter, I tell stories of my experiences with students and teachers in educational makerspaces and recommend materials, tools, and best practices with the goal of helping educators effectively use their space to teach engineering design.

Low-Tech Materials in Makerspaces

One of the biggest and most common misconceptions about makerspaces is that they need a 3D printer and other high-tech tools. While the new tools enable high quality, rapid prototyping at a low cost, people have been learning by making without these tools for hundreds of years. The roots of these practices were established with simpler forms of technology, and there's no reason that a makerspace needs robots to be effective. The constraint of using basic materials can even enable deeper creativity, and making by hand allows for improvisational iterations on the design that digital tools can be less conducive to. 3D printing or laser cutting lends itself to creating, testing, and modifying an entire part over and over, whereas modeling with clay or cutting cardboard allows the maker to intimately evaluate the quality of the part and as it is slowly formed.

Recyclables are one resource that I have seen used effectively in makerspaces due to their abundance and structural stability, along with a maker's willingness to experiment more freely with things that would have otherwise been thrown away. Lots of valuable materials can be collected if the stakeholders in the makerspace are reminded to save bottles, boxes, and larger structures. For example, teachers can be asked to bring in enticing materials that can be sorted into plastic, cardboard, and miscellaneous bins, but each space should develop a system that works best for them. With enough hot glue sticks, these materials can become kid-sized structures or functional design prototypes.

Figure 1

(left) Bins at Shady Hill School in Cambridge where teachers are asked to bring in specific materials for the makerspace. (right) Bins in ISB collecting found materials for Billund Builds Music that accumulated both great stuff and "junk".

The Story of the "Candy Wall"

When I arrived at ISB in the fall of 2015, the Creator Space had just opened and most of the school was still under construction. One task I took on during the first week was unpacking countless boxes of materials and sorting them into labeled bins. We unpacked beads of all colors and sizes, cotton balls and pom-poms, corks and multi-colored bottle caps, canisters of glitter, popsicle sticks, leather scraps, and countless other crafting supplies that were arranged onto shelves soon dubbed the "candy wall" because of how sweet and enticing it all looked.

In the first week or two of the candy wall being open to the students, a group of girls had started taking bottle caps into the woodshop, hammering them flat on the workbench, and saying the gold ones were worth 20 and the silver ones were worth 5. A couple girls had even folded felt into something of a purse to hold their money. After a few days of this, a teacher took the bottle caps off the candy wall and put them in a locked closet because he wanted to make sure there was enough left for everyone else to use.

One day when I was in charge of running the after school club, a couple girls wanted to make a gift for their mother that involved putting glitter on a wood block. I showed them the glitter and some glue, asked them to please be as careful as possible, then returned ten minutes later to find them dipping the wood blocks into cups full of water and glitter. Amazed that they had re-invented a manufacturing technique for dyeing materials (although it wasn't very effective for coating wood in glitter), I asked them to dump their glitter water down the toilet when they were done, then discovered the bathroom floor wet and covered in glitter as we were cleaning up.

Figure 2
The Creator Space door before construction was finished and the candy wall just after being set up.

At the end of my first time at ISB, about four weeks after the Creator Space first opened, it was shut down because of concerns about the way people were caring for the space. These two examples, making bottle caps into coins and painting the floors with glitter water, show both the awesome potential and the danger of having beautiful crafting materials in a makerspace. Students created a micro-economy with their own currency generation and value system. They theorized and implemented a novel way to coat a wood block with glitter. But along with the invention came lots of mess and material waste that the administration did not think was conducive to sharing the space with the larger community.

When I returned in the winter of 2017, one of the first things I noticed in the Creator Space was a sign showing statistics of how many hot glue sticks they went through, encouraging more conservative use. All of the extra materials for the candy wall were in a locked closet and under the control of one teacher. Access to new materials can lead to powerful and playful learning, but it also introduces a number of tensions as the whole community shares the resources and space. I saw ISB wrestle with these challenges, wanting students to explore and be playful as they make while instilling a respect for the limited materials. These tensions are not easily resolved, but ISB's willingness to constantly adapt and iterate on the design of the space models the kind of playful making expected of the student users.

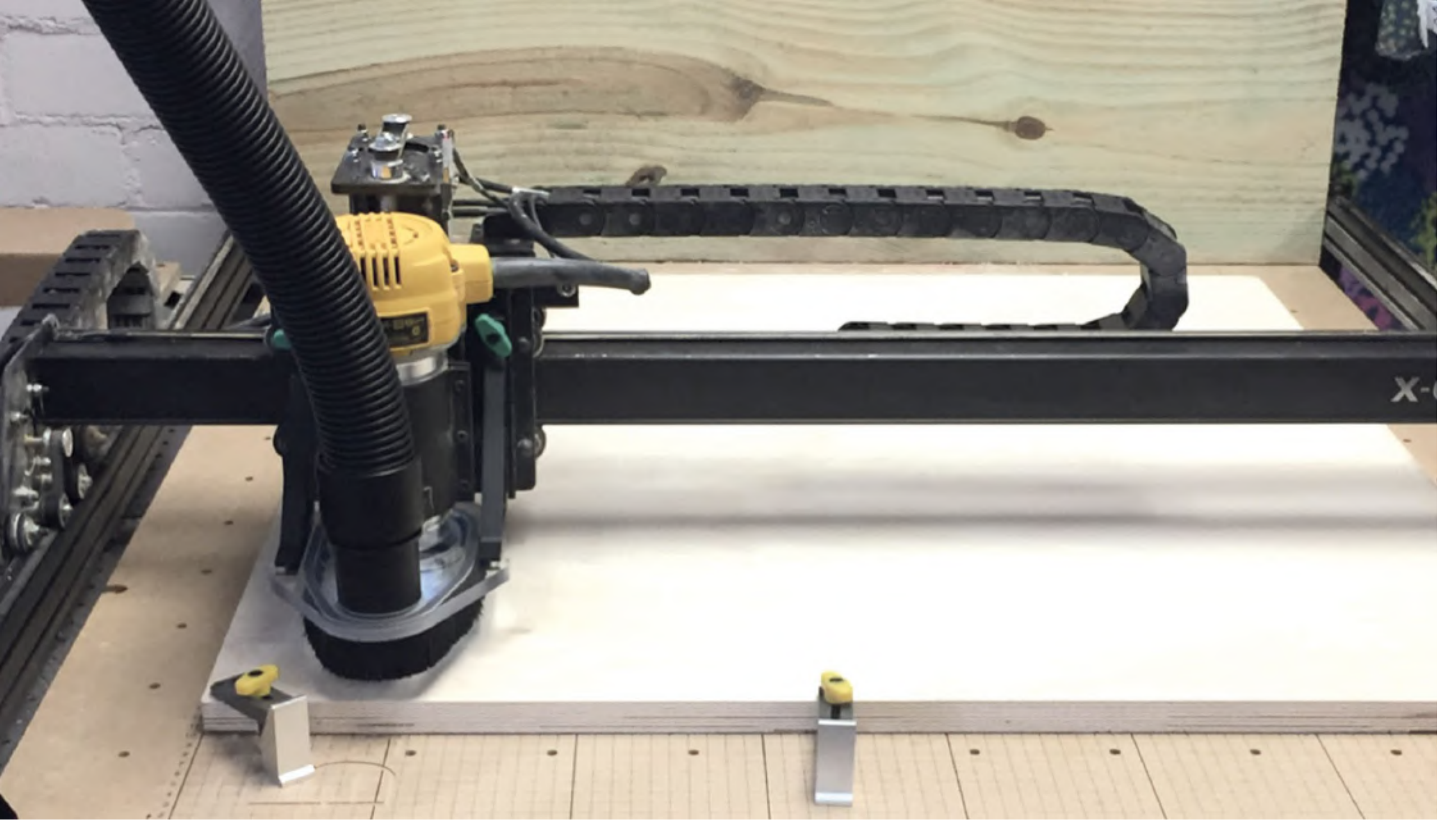
My goal for this second trip was to think specifically about how to inspire more engineering and intentional design in the space, in contrast with improvised crafting and tinkering. I first encouraged facilitators in the space to provide provocations, an idea borrowed from the Reggio tradition, for open-ended making activities. While this idea allows teachers to share what is personally meaningful to them and enables peer-to-peer learning as students make within the constrained challenge, it is very difficult to find provocations that are engaging to all students. By the end of my time, I had imposed a rule that students had to submit a labeled drawing in order to get materials from the candy wall, a practice shown to supports students' reflections on their thinking, processes, and choices. The drawings are essentially a medium for thinking about what you want to do, for being intentional, and for providing space to think about the materials and decisions that are important to you as a maker.

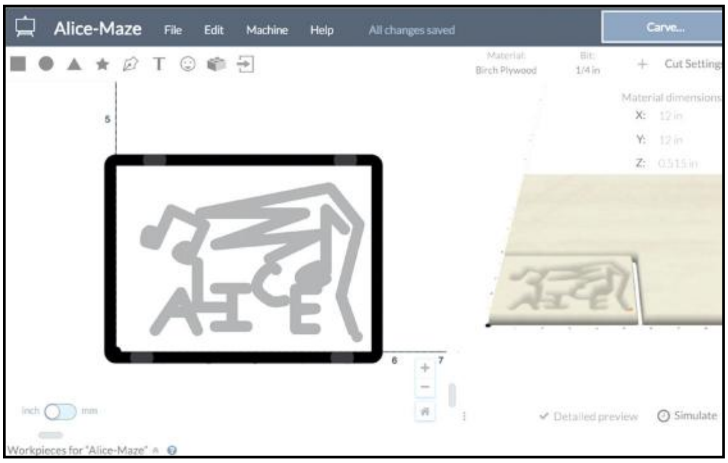
When I returned to ISB in January of 2018, I found a Creator Space that was starting to hit its stride as both teachers and students seemed more comfortable navigating the tools and materials. Classes were using the space during the day for various projects that fit in with their curriculum, and teachers were coming up with engaging activities that allowed students to engage with engineering design practices in the after school club. Middle school students were designing machines to sort LEGO bricks out of cardboard and Mindstorms, and elementary students were iterating on flying contraptions to make them float in a wind tube.

Computer Aided Design for Kids

Computer Aided Design (CAD) is a skill used in nearly every technical field for prototyping ideas and designing for manufacturing. It is similar to computer coding in a few ways; there are many different software interfaces (like the many different coding languages), you can just create designs on a computer (like coding a website), or you can test your design in the physical world by 3D printing it (like controlling a robot). CAD can also teach many computational thinking practices such as abstracting shapes, planning the order of operations, and recognizing patterns as you try to model an idea with the available tools. Similar to a number of "learn-to-code" type experiences, many intro CAD software wraps up functionality into modular tools and exists as a web-browser application.

The first step for using almost any of these interfaces is to log into an account, which requires an email address and a parent's permission to create. At ISB, I would typically have to walk around to all of the students and log them in using my account, then have them each create a new project to work in. This process becomes especially difficult to sustain when





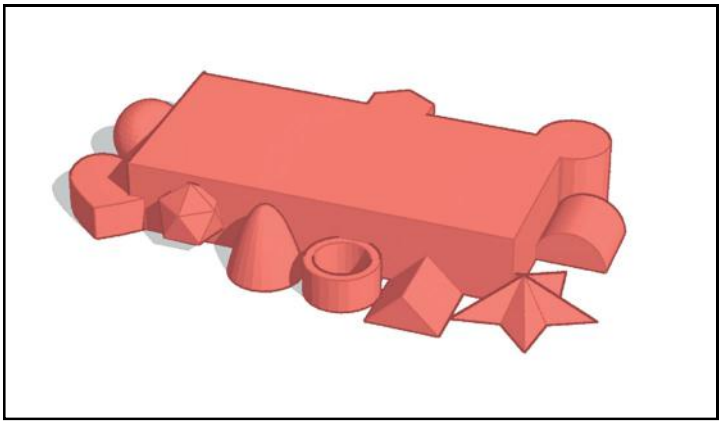


Figure 3
A Tinkercad creation made by a student at ISB (bottom), a screenshot of Easel (middle), the CAD interface for designing for and controlling a CNC machine (top)

teachers do not have the time or interest to create an account and learn the tool on their own. While the prospect of introducing students to CAD can be intimidating, simplified interfaces and extensive support materials have made it much easier to get started.

Tinkercad, one of the most ubiquitous beginner CAD interfaces, is a great "getting started" experience because it adds simple geometries to the workspace with just one click. This geometric modeling experience allows people who have never used CAD before to create with a very low barrier to entry. Some of the shapes you can add to the workspace have controllable parameters that allow users to get a glimpse of the programmatic process that goes into generating the geometries. However, there are limited dimensioning features and no way to model directly in 2D like more advanced interfaces. The un-packable modularity of this interface is great for getting started, but does not teach students many basic terms or skills necessary once they go onto a more advanced interface.

Although there is a high ceiling when it comes to the capabilities of some CAD software, there is no reason that a facilitator needs to be proficient in the interface to use it with students. Getting started programs like Tinkercad are often intuitive enough for students as young as second or third grade to figure out on their own. There are countless interfaces available, as iPad apps, web-browser, or computer programs, and more keep being developed. My main recommendation to teachers would be to pick whatever they or someone in their class is most comfortable with and get started. You will only learn by using the software, but introducing it before you are proficient provides a unique opportunity to model how to use google to answer questions students have. And once one student figures something out, they become the expert who can teach their friends, cultivating an ecosystem of peer-to-peer learning that is one of the richest facets of makerspaces.

3D Digital Fabrication Tools with Beginners

The first thing that anybody who has some experience with a 3D printer will tell you is how slow it is. Even the smallest objects that are an inch or two cubed in volume can take hours to print. This makes them not particularly conducive to iterative design in a school context - by the time one iteration is done, nearly all students will have lost interest or forgotten the details of their creative process. My recommendation to new spaces looking to buy a 3D printer is to go for quantity over quality; buying a few 3D printers that cost less than $200 will be much more useful than one nicer one that costs $600 and a beginner would hardly notice the difference. With the right settings and sizing, full designs can be built in 20 minutes or less.

My personal favorite tools for creating in 3D are desktop CNC machines (figure 3 above). Although it is more difficult to create models with intricate detail as compared to a 3D printer, CNC's are capable of producing more robust parts in a fraction of the time. They are similarly powerful to laser cutters in their ability to both decorate (etching or engraving) and cut out wood and plastic pieces, but they can go through much thicker materials and cost less than half the price. I purchased and built an X-Carve for the creator space during my last visit to ISB and introduce it to some teachers and students. While the subtractive manufacturing process introduces a number of complexities, the Easel design interface allowed them to design their ideas quickly and easily.

Laser Cutter at ISB

In the winter of 2017, the laser cutter arrived a few weeks into my residency, and it provided a number of interesting glimpses into the getting started experience. A couple of teaching aides were the members of the ISB community responsible for becoming residential experts in using the laser cutter. They spent their first twenty hours or so using the machine to etch pictures of the staff into cardboard and wood (figure 4). While they were barely scratching the surface of the machine's capabilities, this project allowed them to play with the speed and power settings in a way they otherwise would not have been able to. Particularly when trying to etch a picture of a member of the staff with a darker skin tone and struggling to get enough contrast for a nice picture, one of the teaching aides was able to bring in his expertise with photo editing to try and achieve the best picture.

As students saw all of these pictures, they of course wanted to print their own. Rather than simply etch the Nyan Cat or Roblox pictures they asked for and cut out a rectangle, I was able to use the promise of a high quality final product as inspiration to get the students to do some designing. I decided to implement a rule that before etching a picture, students had to design the outline of a shape to put the picture on using Tinkercad. Throughout my time, I kept encouraging the students and teachers to use the laser cutter to connect the 2D shapes cut out of the laser cutter into 3D shapes. Even as I started creating examples of the things you could make with finger joints and interlocking slots, it was difficult to get them to move on from the etched pictures because the mental model had been set that the laser cutter was meant to burn pictures into wood. Just before I left, I instituted a "no picture etching" rule in after school to try and push their creativity and use of the machine.


s300p15
s200p15
Please use extreme caution when cutting flammable materials such as wood and acrylic.
A CO2 fire extinguisher MUST be kept near this machine at all times.
Periodically remove the work bed and extraction hose from the back of the machine and make sure all debris are cleaned from the table and exhaust port.
REFER TO THE USER MANUAL OR RING RADECAL FOR HELP ON 0191 417 6285.
DANGER
FIRE HAZARD

Figure 4
Some of the many photos etched by teachers, an example I made of how to use interlocking slits to make something stand up, and a box that was co-created with students who did the math and dimensions.

Similar to using the high quality picture as the motivation for learning about designing shapes in Tinkercad, I was able to use the promise of a laser cut box to get students to do math. With small groups at a time, I would have them measure the thickness of the wood being cut, determine the length of the finger joints, and tell me all the dimensions to put into the laser cutter design software. Each student in the group would then be able to cut out a copy of the box and etch in a small image onto theirs.

This model of co-creating with students is great for introducing them to interfaces and tools that may be too complicated for them as is, and the high-quality product can serve as motivation for learning more deeply about the tool. The "shiny object" effect of everyone wanting to use the new, expensive machine may not be sufficient to generate sustained, meaningful participation, but this initial excitement can be harnessed to teach design skills that opens up the power of the tools, empowering them to continue as makers with the skills to use the tool for other projects.

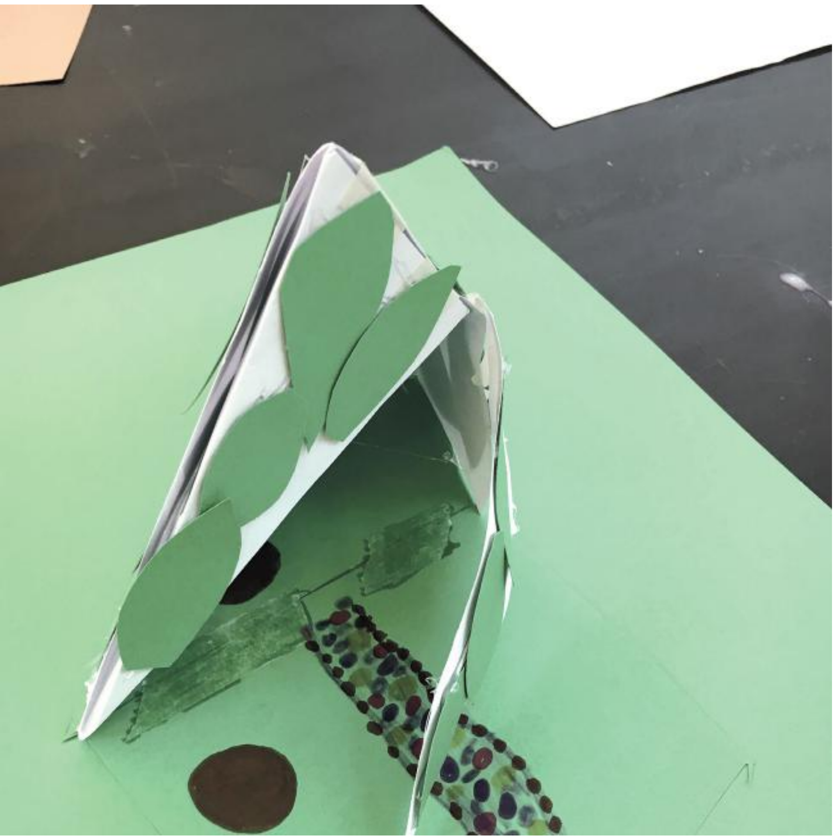
Summary

Considering how varying levels of technology can be used in meaningful, iterative design processes have lead to our theorizing about trajectories through making that capitalize on a young student's familiarity with craft materials and builds toward more complex digital practices and technologies. For example, we can start by challenge children to fold a 3-dimensional letter using the very familiar scissors and paper. We then introduce X-acto knives and straight edges, to teach them about more precise cutting and paper manipulation. We then show them a tool like Inkscape, or some other vector-based drawing software and tell them we can use this to teach a machine to cut the paper for us. They design a letter and we cut it on the vinyl cutter or paper cutter. From there, we think about moving away from paper. Should we want to use wood, we turn to the CNC mill. If we want to use plastics, we could use the laser cutter or 3D printer. But all along, we're building on that initial familiarity with the material and processes - cutting paper with scissors - adding knowledge and experience to that familiar foundation as ways of building up new skills and techniques.

My first recommendation to new makerspaces in schools would be to start with low-tech construction materials such as hot glue guns, cardboard, recyclables, wood scraps, and hand tools. There is little need to invest resources in getting high quality craft materials unless there is a teacher excited about using them with students. As the space starts investing in high-tech tools and materials, it is important to make sure there is a facilitator with time to be a creator themselves and support the students in their making. It is important that spaces are willing to continually adapt and play around with different layouts or organization structures, especially in the first few years as a community is forming. New technologies and methods for using them are constantly being developed, and while there is no one right answer for any makerspace, the quality of learning and making will only continue to get more awesome.

Chapter 4: Shelters Curriculum

David Alsdorf



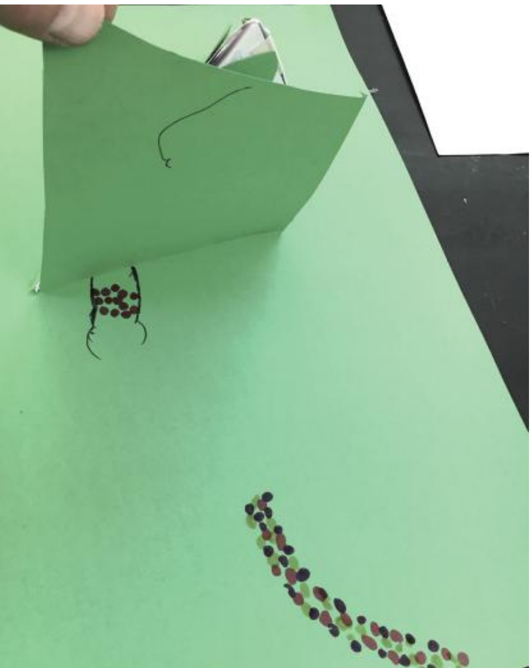


Figure 1
Mia's paper shelter.

In my two teaching residencies at ISB, I developed a maker-centered curriculum that would allow us to take advantage of the school's making space. In each case the occasion was a "Creativity" unit of inquiry—one of six segments in the program for International Baccalaureate (see Table 1)—for 9-10 year olds. This is a description of the curriculum.

Each child begins by building, from a single sheet of paper, a model of shelter, and by narrating an accompanying story. No other constraints are specified; students can interpret the task in whatever ways they would like. For example, Mia wrote a story about a mouse who was afraid of the light, whose human friend provided berries and hid them in a tunnel. Mia's paper shelter included folds and a drawing to suggest the affordance of an underground tunnel.

Once upon a time there was a mouse it was called Jerry. Jerry lived in a little shelter. The problem was that Jerry was afraid of light. Jerry really likes berries and you can only pick berries on the day. Not in the night because in the night the eagle and the wolfs come out to hunt. One day a little girl called Lina came into the woods. After a little time Lina found the shelter where Jerry was living in. On that second they knew that they would be friends. As she wanted him to be safe she helped him to make the shelter strong with leafs and wood. When they were finished she dig a hole in to the shelter where Lina could put berries for Jerry so he did not have to go outside when it was light.

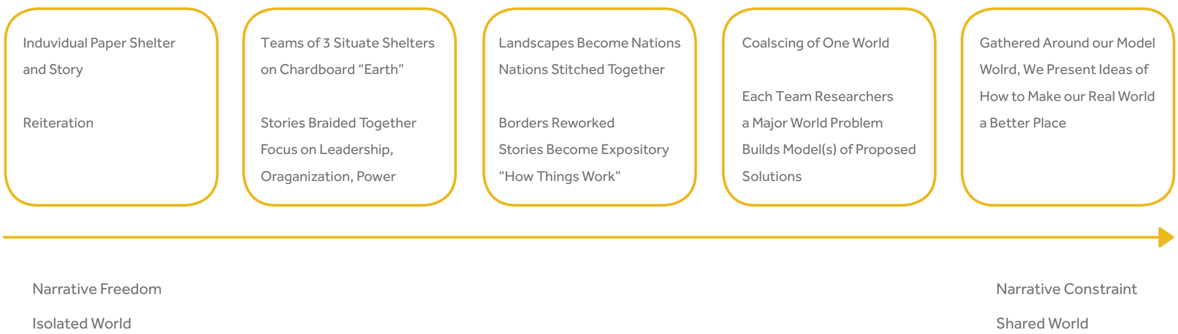
Table 1
ISB's academic program for ages 9-10 ("P4"), 2016-2017, with ideas for connecting each unit to the activity of building a self-authored, shared, make-believe world. Would such a world be valuable if made at the beginning of the school year, and sustained throughout the year for assessments?

P4 Units & Central Ideas	Storytelling Activities	Making Activities	Problem Solving Tasks
Personal Histories: Reflecting on personal histories allows us to celebrate who we are and where we have come from.	Include personal biography among narrative iterations.	Make **river of life** collages; model one's own shelter / landscape.	Relate world problems to concerns of one's own family.
Energy: energy exists in a number of forms and can be transferred and stored.	Narrate the story of a character who needs energy in some form.	Represent a power grid on each landscape.	Investigate dependence on non-renewable energy resources.
Beliefs and Values: Differences in beliefs and values are factors leading to disagreements.	Weave one's story into a narrative shared with other classmates and with other points of view.	Build a peacefully shared landscape. Make structures of care.	Recognize that all people are impacted by global problems. Investigate causes of war.
Leaders: Leaders in all areas of human society bring about change.	Experience leadership through authorial agency. Assign leadership roles for characters in one's narratives.	Practice leadership, or being led, by working with classmates on shared land. Play make-believe games of leadership in self-authored landscape.	Recognize importance of leadership in tackling global problems.
Organizations: People create organizations to solve problems and support human endeavor and enterprise.	Solve problems by working in tandem with teammates and classmates. Author organizations to solve problems.	Represent organizations as economic entities in the world.	Use organizations to improve life (e.g., to enforce laws, distribute wealth).
Creativity: Through the arts we express our emotions and show creativity.	Let children make mistakes and test ideas instead of correcting		

Students are invited to share these stories, and engage in several cycles of re-iteration to both their shelters and their stories. Following this, students form groups of three, and are asked to weave their stories together — into a kind of braid, each narrative standing on its own but as part of a whole as well. Accompanying this combined narrative, each team builds a shared landscape for their shelters. Children are at this point somewhat constrained in their storytelling by the small community of shelters and narratives around them; at the same time, their worlds are becoming larger and more complex. For the next several days, teams focus developing their landscapes, inspired by the notion that there should be no blank cardboard, just as on earth there is no “space in general”; every space has some kind of story.

Then, teams are tasked with stitching their landscapes together, creating a single World out of many landscapes (which we have now shifted to calling “nations”). Children are now constrained by the many different stories and geographical realities that comprise their one shared World. On the other hand, each child now participates in a very large and diverse community. The individual experience of storytelling, with which this project began, has evolved into a social experience of narrating and making.

Figure 2
Progression of the curriculum.



This protocol is designed to create a "playful making" experience that is pedagogically advantageous. At the forefront, children are engaged in a self-authored, make-believe framework; we expect this to be highly engaging for children, in contrast to frameworks that are not self-authored and based in make-believe. Self-authorship by children allows teachers to find out what interests, concerns, and joys the children may authentically bring to a conversation; children establish ownership and pride in their making and storytelling from the first step; community, and each child's place in community, develops over time, mirroring what one hopes will happen in the child's life experience outside of school; within the children's self-authored frameworks, teachers can stage critical pedagogy and situate academic content. These are some of the motivations behind the protocol's design.

During my first ISB residency, April-May 2016, I experimented with ways to encourage iteration and an economy for using new materials. We established that making materials (e.g., glitter and popsicle sticks) could be "purchased" with new narrative. The more children developed their stories, the more materials they could gather to build and extend their shelters, lands, and Worlds. Students became more sensitive to the value of limited resources — as evidenced by their bargaining with one another for even small scraps of leftover materials — and more attuned to the effort involved in constructing story (as literary gatekeepers, we rejected children's efforts to purchase new building materials by simply appending to their stories tidbits of "and then . . . and then . . . and then . . .") Throughout, we witnessed **making material becoming media** ("materials become media when they mediate . . . and to convert a material into a medium is an achievement" (Eisner, 2002, p. 80, cited in Halverson, 2013, p. 124). The materials mediated the construction of the accompanying narratives, and evolving stories became media too: they accompanied physical artifacts and were themselves also artifacts. To provide alternative inroads for children, we adapted Vivian Paley's story-telling and story-acting protocols, and enacted some of the children's stories as theater. Paley claims that the opportunity to tell a story is the greatest gift one can be given. I shared this idea with the children, and mentioned that in Paley's classrooms, story-telling was limited to one page **except on a child's birthday**, when the story could be as long as the child wished. Our narrative based economy developed. Everyone told stories, and no one was poor.

During the second residency, April-May 2017, when the children got into trios and were given cardboard "earth" to develop, I asked them to specifically focus on **leadership, organizations**, and **energy**, each a Unit of Inquiry from earlier in the IB curriculum. As a result, teams built power grids, solar farms, utility poles, and other infrastructure into their landscapes, referencing things that they had learned earlier in the year. For example, one team remembered their teacher's lesson that solar cells do not work optimally in high temperatures. This influenced their decision about where and how to situate a solar farm in their landscape. Many teams also represented civic organizations, such as hospitals and schools, in their lands. The stories retold during this phase of the project mentioned presidents, labor, and taxes.

As landscape development neared its completion, at the end of our second week of making, I made a deliberate shift in language, referring to each landscape as a nation. This allowed for a subsequent shift to the language of worldhood when, over the next few days, we stitched the nations together into one large world. (We had eight nations to stitch together, but to create a perfect rectangle, we added a ninth land, and enigmatically called it "Zone 9". Zone 9 was eventually given to the children as additional space for meeting the needs of the public. The children built a water treatment facility.)

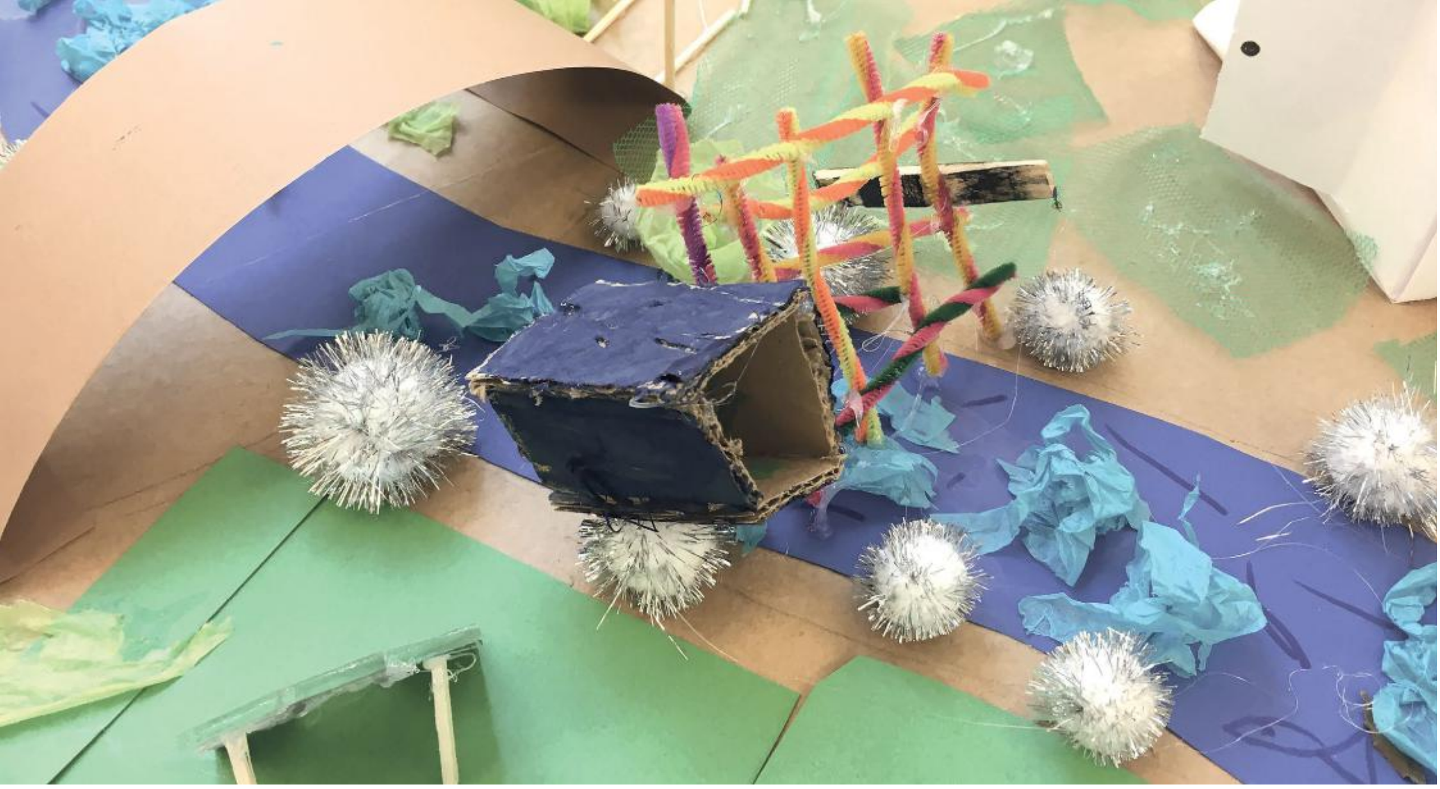


Figure 3
Joseph's fishing net.

Students' responses to the curriculum

During the small team phase of the project, there were varying levels of engagement. For example, Mia enjoyed her first round of making and narrating, but did not want to rewrite her story, nor did she want to consider her paper shelter a prototype. Joseph enjoyed physical making, but not storytelling, as evidenced by his single-sentence-stories. He became more engaged toward the end of the curriculum, when he was asked to defend his engineering ideas about removing pollutants from water. Joseph had proposed netting in the river that ran through his land. When I asked about potential problems in his proposed solution — specifically, whether fish might get caught up the net —he eagerly added, alongside the net, a tube featuring "worms and [some kind of system of] suction" which would lure fish into the tube, so that they would not get caught in the net.

Emil, another student, was not enjoying school at the start of our project, and resisted the first round of storytelling and making. When presenting his paper shelter to the class, he received some rough questioning from his peers, and nearly started crying. When asked in a feedback form how he had felt about making a shelter and telling a story, Emil wrote "Mad". And yet, he began to feel empowered during our after-school Mindstorms club, where I suggested he work on infrastructure for his team's landscape. He built a motorized crane to lift and lower objects. No other team could boast of such an artifact. Then, by participating in make-believe play with his teammates, Emil became more involved in our activities. When asked on his second feedback form how he had recently felt about making and narrating, he wrote "It was so fun!" Emil went on to be one of the most outspoken inventors during the final phase of our project.

Table 2.
Teachers discussed major world problems and created a lottery through which the teams were randomly assigned a problem to research and upon which to ideate, invent, and engineer. Given more time, we would involve students in the process of choosing the world problems they would then investigate. We would have also allocated additional time to more rigorous engineering and testing of proposed solutions.

Team Name	World Problem	Sample Solution
DJ Mali	Water and land pollution	Factories should have filters; government enforcement of environmental laws; net to catch garbage in the river, with tube letting fish bypass the net (this involves suction & worms); government funding to organic farms; "treat sewers fairly"; filter factory waste; quadcopter to carry organic produce from farm.
Nature Town	Homelessness	More jobs; more health organizations; free hospitals; more shops & jobs for the shops; houses should be cheaper; free healthcare.
Tomato Otto	Refugees	"We are going to make an apartment'; a shop that donates to refugees; tree houses for children refugees.
Creative World	Earthquakes & Hurricanes	Hurricane & earthquake detector and alert system; a boat that's a house that can go away from storms; a dome that covers city; a sphere that people get into and it floats up into the sky above a storm.
Bad City	Drought	Store the water when it rains; create laws to make people save water.
Farmcity	Dependence on non-renewable energy resources	Watermills; solar cells on windmills.
Shock	Accessibility to buildings for people with disabilities	Bus with lift; building with ramp; single story house with no stairs, waterproof chair in shower, "low kitchen and lower toilet".
Team Nice	War	Beacon in the sky to help dispersed people find one another (for displaced families and communities).

When the landscapes — now called "nations" — were stitched together, each group's nation now bordering another nation, each team was asked to perform "diplomacy" with representatives from other nations. There were many problems to solve. For example, six of the eight nations had a river running from one border to another. With the nations stitched together, these rivers did not all align. Children worked with their new neighbors to decide which way the water flowed and to re-build landscapes so that water, roadways and paths were coherent; they negotiated with one another (we called it diplomacy) to create a cohesive design and one shared narrative between the groups.

Each nation was also assigned a major world problem — for example, war, land and water pollution, drought, homelessness, refugee crises — to research and solve through invention, engineering, and fabrication (see Table 2). Each student authored a solution to her group's assigned problem, built a model or representation of the solution, installed it in one or more places in the shared world, and made a presentation to the class. Some solutions were relatively practical (e.g., Joseph's net to catch pollutants in a river), some hopeful (e.g., Daniel's beacon of light to reunite families displaced by war), while other ideas (e.g., solar panels on windmills) made the teachers ask:

"Why **don't** we do that?"

In the problem solving phase of our project, many early stories were abandoned in favor of expository narratives, simple explanations of how things work. While children were welcomed to continue telling fictions, they were more specifically tasked with explaining the shared world they were constructing.

There is strong evidence that the self-authored make-believe aspect of this curriculum was engaging to children. Prior research has already shown that students involved in pretense play have improved concentration, memory formation and recall, and emotional regulation. One delightful study describes "David", a kindergartener, who could not sit attentively for two minutes of circle time in school; however, when researchers created a game of make-believe school, the same child sat attentively for ten minutes (Choi & Anderson, 1991; Ruff & Capozzoli, 2003; Singer, Golinkoff, & Hirsh-Pasek, 2006). Solid evidence that children were highly engaged with the shelter curricula is found in written narratives (see Chapter 5, Table 2) and in the children's drawings of maps (see Chapter 6, Table 1). Further, because shelter is a universal human concern, the topic offers multiple inroads, or entry points, to teachers and children alike. Shelters are at the same time familiar, simple, complex, and multilayered; as we learned in other settings, "shelters" range from tents, to houses, to refuge from oppression, to a place where a homeless youth may stay for a while. Within this broad and inviting, yet potentially complex theme of shelter, one can integrate nearly any content. The subject offers what Mitchell Resnick (2017) describes as "low floors, wide walls, high ceilings"; in other words, easy access, potentially great depth, and wide ranging possibilities for exploration. I suggest that the activity of shared, make-believe world building would be most valuable at the start of an academic year (again, see Table 2). Given additional time, children could have carried their problem solving ideas through an iterative engineering design process across multiple units of the yearlong program.

At the end of our time together, we — the students and teachers — gathered in a circle around our shared world for final thoughts. Each team presented their portion of the global landscape, and shared part of their research and problem-solving invention. Children also talked about their fabrications as beautiful works of art.

As we prepared to say goodbye, I offered two analogies about the children's river. There was now one large river that flowed logically, in one direction, through six lands. Its water was filtered for pollution, it irrigated farmland, powered a mill, was traversed by countless bridges, fished in by fictive characters, and so on. I compared the river to creativity itself: a force more powerful than any one individual, yet

Figure 4
The children's combined World.

significant because of the individuals who turn to it and who it sustains. Any one of us might hope to harness its power. Then I made a quite different comparison: the river is similar to our individual lives. We are constrained by pasts that cannot be changed and have, along with a certainty that our decisions and activity shape our futures, an uncertainty about what lies ahead. The children agreed that living life is similar to writing a story. We likened both to the wending of a river.

There was one more thing. Each of us has been given something that we had yet to give to our river. Almost all rivers in the world have this thing too. "What is it?" several children asked. I called on Alexandre, a Parisian, and asked him to tell us everything he knew about the Seine. I shared a few facts about the Charles River near my home. I asked the Ella, from the UK, to speak about the Thames. Finally, Laura and Clara realized what we had to do for our river.

"We have to give it a name."

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Chapter 5: Narrative Assessments & Theory Building

David Alsdorf & Brian E. Gravel

Our ideas take form in narratives—stories, interactions, and conversations we have with ourselves, others, materials, tools, and histories (Ochs, 1997). The narratives of children provide access to their thinking and development. This fact is so obvious that perhaps we do not always recognize it. When we give children worksheets, homework, quizzes and tests, we are actually asking them to create concise narratives, through which we hope to assess their understanding. But narratives come in many forms, and they can show us far more than the mere crude possession of knowledge; they give us access to the **substance** and the **form** of a child's understanding. To assess such subtleties in narrative, we must with open minds braille the many narrative forms available to us: neither quiz answers nor filled-in worksheets alone, but also stories, essays, doodles, sketches, photographs, curated portfolios. The many forms of narrative are revelations of the child's thinking and identity. We can understand the child through these forms. We must also consider data gathered in the name of **documentation** (another narrative activity), whereby a child produces commentaries on — rather than mere records of — more primordial production; documentation can be an iterative story form. Our central conjecture is that by nurturing narrative making in these many forms, and cultivating respect for child-authored playful making, we create more opportunities for assessment, more opportunities to understand the child's ideas, brilliance, and knowledge.

During David's second residency at ISB (Spring 2017), he led a curriculum that asked students to iteratively construct and reconstruct stories about shelter. We analyzed the content of these stories for ideas, themes, and markers of what children were choosing to include in their narratives. We were particularly interested in what shifts occurred in the ways their stories evolved over the course of the curriculum. We counted the number of times certain phrases and plot details appeared in the first and then the third drafts of each child's story (see Table 1). At this point in the analysis, we were simply trying to get a feel for various focal points and how these shifted through the process. The interestingness that emerged, which was admittedly unexpected, was a dramatic shift in the ways children involved themselves in the stories they wrote. In the first draft stories, zero children appeared as characters in a story or stood-in as narrators; the authors were largely absent from the stories they wrote. In the third draft stories, written one week after the first draft stories, following a period of make-believe landscape development, 7 children (out of 22, or roughly 1/3) appeared in their stories either as a first person narrator or as a third person character. In other words, something about our make-believe activities had led many children to write themselves into their stories. Many others, who did not write themselves into their stories as characters, had nevertheless transformed their relationships to the play frame by taking on and imagining more agentive roles for themselves and for their characters. Several examples of students placing themselves into their stories, as agents, or adding agentive roles for other characters illuminate this phenomenon.

Table 1
Somewhere between drafts one and three, the children wrote themselves into their stories.

Appearances in 1st & 3rd drafts of stories	1st Draft	3rd Draft
1st person / 3rd about self		7
Work/Employment	3	11
Farm	0	3
Forest	9	4
Storm	9	4
"Once upon a time . . ."	8	9
". . . happily ever after."	2	1
Named protagonist	10	8
Family	5	3
Friends	5	9
Animals	7	4
Food	7	8
Money	3	3
Fire	2	3
War	2	1
Rescue / help	4	3
LEGO Mini Fig (LMF)	3	
Gender assignment to LMF	1	
Death/murder of Humans	4	1
Death/murder of Animals	1	
Real world setting (named)	4	1
Shelter material(s) specified	5	3
Total number of stories	22	22

For example, Joseph became a farmer in his third draft story:

One day at DJ land Joseph wakes up and goes to the farm. He grabs a rake and starts working. After he's done he goes fishing.

Lev's story hints at work and wonder:

I live in an observatory. When I wake up I polish the lens of my telescope. I look through it and see outer space. I can see R136Al, and Detel-Guze Alpha Proktamus, T5a4, and 8A32 . . .

Lev's teammate Sonia writes about a girl:

who owns [a] shop [that] has materials from her grand mother who died in a war. They lived in a dangerous place before they moved to Nature Town. But when they moved she wanted to use the materials and at the same time she thought my grandmother died to save other people & that makes other people happy too. So she looked around and saw her dress! Perfect! She said I will make people happy by making a dress shop!

Noah writes of god-like characters who, in his narratives, create by divine fiat the landscape which Noah and his teammates were actually making by hand. His make-believe gods, one of whom is named after Noah:

used all their power and energy to make the rest of the land.

Isabella writes his leadership role in the fictitious world:

my neighbor is the leader of the kingdom and I am the president. I'm making the roles and I'm leading the school, kindergarten and more. One role I have made is that you have to give tax. I love to be the president.

Oscar, who co-constructed a landscape with Isabella, wrote about waking up:

early every morning to go out and pick the apples or carrots. Then I go out selling the food to people that live in the city or drives through the city. Then in the middle of the day I go over to the kindergarten and training football with the small kids. In the evening I cook the apples and carrots and drink some water.

Their teammate Emil made himself into a Scout leader, writing:

I was chopping wood then I saw smoke. I went over and it was just a grill and I forgot to do my daily chore . . . I saw a bear cub alone with a baby fox so I sent a letter with a picture to my friend the farmer using my hawk. Then I went to the school to pick up the Scouts. We are going to practice carving.

Laura wrote about David and Alisha, who built a house before a storm, but had so much fun building that:

they were still building when the storm was over. Then their Mum and Dad came and saw what Alisha and David had built. Some years later David and Alisha made a company [that] made small houses and it got so popular that there were a whole village with that kind of houses.

These are examples of employment or labor appearing in third draft stories. In their first drafts, the students had written stories in a manner familiar from children's books—stories about things that happen to other people. But in their third drafts, we see an evolution of the kinds of content in these stories. Story arcs evolved from "forest . . . storm . . . shelter", a most popular arc in first drafts stories, to arcs that involved employment, labor, farmlands, money and even taxes. Indeed, **forest + storm** appeared nine times in first drafts, but only four times in third drafts; meanwhile, third draft stories included **three mentions of farmlands** (up from zero), **and eleven instances of work or employment** (up from three). We will revisit this trend in a moment.

An important aspect of narrative is that it is a theory building activity (Ochs et al., 1992). As we make sense of the world, we do not build theory formlessly and without context, first, and then shape it into a narrative form before, as it were, publishing it to our conscious minds; rather, we build theory in the process of struggling to produce external representations of the things that we think. We make sense of the world, and construct understandings and knowledge, through the production of representations, whether these are oral or written stories, playful acts, physical artifacts, drawings, spaces that we curate, or any other externalized manifestation of an idea. This is why when one writes a paper the ideas are developed through, by, and during — rather than wholly in advance of — the process of writing, rewriting, and sharing that writing with others. As we construct narratives, we also construct understandings or theories about how the world works; this is similar to Vygotksy's description of what happens during play (Vygoskty, 1978), e.g. because many play forms, such as the creation and sustainment of make-believe premises, are narrative acts.

In the stories written by the P4s at ISB, children also built theories about how the world works. The world that each team designed and made became an apparatus to support their process of building theory about the larger world, the "real" world. Issues of energy production, protection against natural disasters, poverty, migration, and economies were present in their stories. They were engaging with large-scale, very important and acute issues of the world around them through the construction of their make-believe worlds, and the coupled narratives that co-evolved with their imaginations. As the stories of their worlds developed—from the first drafts to the third drafts, co-constructed alongside the physical artifacts of their make-believe landscapes — so too did their thinking about being a citizen in the world. They thought about the needs and systems that promote civil and equitable lives, and their own roles and positions in those stories. The narratives they constructed were about a "make believe" world that addressed issues pertinent to life in contemporary times.

Further evidence of this immersion into the worlds and narratives they constructed was gathered when they were asked to stitch together their make-believe landscapes into one large world. We share a story of two groups negotiating how their landscapes would fit together, and analyze not only how the narrative apparatus supported this moment's occurrence, but also gives a window into particular kinds of academic skills they are exhibiting and refining through the work.

Stitching Together Lands, Blending Narratives, Building Worlds

The students of P4 gathered in the Creator Space, with their landscapes arranged outside in the hallway. David announced that they were to combine their individual group landscapes into one large world, organized as one large grid. David provided a map of each landscape's location. The grid thus indicated which lands would be neighbors. The students rushed into the hallway to grab their landscapes and bring them back into the Creator Space to begin their work. In the hallway, two of the groups noticed their landscapes were to be located next to each other, and they needed to reconcile some discontinuities between the two lands.

Mikhail: Guys, we're connected! We're three, and you guys are six. Look, one, two, three, four, five, six.

Paul: How should we get the rivers together?

Ella: See, look, their river is in a really different place, so maybe, what we could do, is we could have some river here... and suddenly the water just gets darker. Maybe it's just **more shady** in your city.

The task of stitching together their work presented some tensions for the students—moments for negotiation and diplomacy—in which individual designs, in order to work harmoniously with other designs, required revisions. These students immediately recognized a problem with their rivers: when they lined up the corners of their worlds, the rivers did not align. They began solving this issue immediately, and without the intervention of a teacher. They embraced the opportunity to negotiate with each other, and generated more narrative in the process. For example, the river was a different shade of blue in world three and world six. Ella, part storyteller and part diplomat, suggested "Maybe it's just more shady in your city." Each such addition to narrative suggested new opportunities for physical fabrication. The new constraints that emerged as the children's worlds expanded became occasions for more making and story.

Back inside the classroom, three landscapes were placed together. Interestingly, they were not in the exact arrangement that David had suggested, but were askew because, for example, one or more landscapes had been "rotated" by 90 degrees and pushed this way or that; these adjustments had been made by the students so that their roads and rivers in one land lined up with those in the next land. They had generated a level of coherence in the stitching together of their lands. The students leveraged elements of their designs as points to connect their worlds. They were negotiating the constraints of the challenge based on issues germane to their make-believe worlds. As more groups
combined their landscapes, and encountered discontinuities between them, many more examples of this kind of cooperative negotiation emerged.

Lucas: "Guys, we have to connect these somehow!"

Emma: "Maybe it's a bridge, or a road."

Kristof: "I think we could go through our river, we can connect it."

In this culminating activity — the simultaneous merging of land and narrative — each group developed both physical fabrications and expository narratives to account for their make-believe worlds. As make-believe worlds grew, new constraints helped the children to refine their thinking. In this, there were contradictory vectors between expanding narrative fields and growing physical constraints. Within this context, the children's ability to cooperate, negotiate, and propose viable solutions that satisfied each of the parties involved demonstrated a growing skillset of tactics needed to negotiate even larger complexities in the real world. From an academic standpoint, this is a form of the kind of critical, situated, and reasoned thinking for which we strive. Solving problems using features of a context — the constraints of their growing world —by negotiating and persuading each of reasonable and achievable solutions are the kinds of meta-practices that benefit the learner in engineering, mathematics, history, civics, etcetera. This is not new content they learned, but rather a kind of learning and practice that is very difficult to achieve in schools, and is often intangible. Problem-based learning is popular for just these reasons, because there is a higher potential for students to develop and refine problem-solving skills. Here, we see narrative as a central feature of both supporting students to develop these problem-solving skills, and as a medium through which we can assess and understand the child's thinking.

Through their making, their narratives, and their negotiations with one another, these students were exhibiting regional and global thinking in ways that situated their work as real, meaningful, and impactful; they were addressing authentic issues facing the world at large, through the make-believe stories and landscapes of their imagination.

Understanding Sense-Making through Narrative

Shared narrative—whether in scientific discourse, idle chatter, or family dinner conversations—helps participants develop social skills and special skills as theorists, such as the ability to consider multiple perspectives while thinking critically. For example, at a dinner table a storyteller might present a theory of events that contain an explanation; this theory may then be challenged directly or indirectly by listeners or co-narrators. Familiarity of co-narrators may make more complex theory building possible (Ochs et al., 1992).

Way-finding and sense-making are forms of theory building, and we find these present in the fictitious stories that children tell as well. From the stories collected during David's 2016 ISB residency, consider one girl's story of a woman [in a house] who "had two faces, and one was a girl, and the other was a boy." The topic of shelter led this student to construct a frame through which she could examine human identity and (dis)integration. This frame could help her **make-sense**, or build a theory of individuation. Or consider her classmate, whose family was moving to Japan because of a change in a parent's employment. In his shelter story, a "family moved to a new house in a faraway land . . . because there's problems with the father's job." Here too, the storyteller used the story activity to make sense and, as it were, work through a personal challenge.

Discourse transcription — even mere **listening** — is also theory building. For example, in deciding where, when, and how to annotate pauses in a transcribed dialogue, an ethnographer performs assessments, determines what was and was not spoken, interprets and recreates emphases, and makes determinations about a speaker's intentions.

These many dimensions of narrative and transcription as theory building can be seen in dialogue that David witnessed and recorded at a Reggio inspired preschool in Massachusetts. While not at ISB, this small independent school shares many of the same characteristics and pedagogical values of ISB. It was the source of much inspiration for the design of curriculum and the development of the ideas in this chapter. We hope you find it as interesting and charming as we did.

A small group of three and four year olds was gathered around a table of kinetic sand. They were equipped with spoons and small plastic cups.

"I'm making ice cream"
"I'm making a potion."
"Are you making a special potion?"
"No I'm making ice cream."
"I'm making ice cream too."

"They're not melting."
"They're not melting cause it's cold outside."
"They're not melting cause it's kinetic sand. Kinetic sand does not melt."

[Teacher] "What kind of ice cream is that?"
"This is never melt."
[Teacher] "Is there an ingredient that makes it not melt?"

"Special water from the river. And lavender."

"Ice cream will never melt."
"Ice cream is supposed to be cold."
"It melts in summer."
"No, that's why it's supposed to be cold."

[To the teacher] "If ice cream is cold, will it melt?"
[Teacher] "Well, if it's in the freezer it won't, but if you take it outside and it's warm, then it will."
"When I eat ice cream from the ice cream store, it isn't cold and it doesn't melt."
[Teacher] "Well maybe you eat it quickly."

Table 2

Narrative Assessments: children build theory while playing make-believe (**"making sense"** or **sense-making** and **way-finding**); the teacher builds theory while listening (**formative assessment**); the ethnographer builds theory while transcribing (**primordial assessment**) and subsequently (**reflective-assessment**). This table is the ethnographer's primordial and reflective assessment. It includes surmise about the students' and the teacher's thinking.

Narrative	Children's sense-making	Teacher's Formative Assessment
"I'm making ice cream too"	pretense (make believe) established	
"They're not melting cause it's cold outside"	ice cream durability does relate to temperature, and may relate to weather	Child relates outdoor temperature to indoor objects
"They are not melting cause it's kinetic sand. Kinetic sand does not melt"	reminder that we are playing make believe with kinetic sand, to which we ascribe the property of not melting	
"Special water from the river"	reality constraints may be overcome (in play) via "magic"	
"Ice cream is supposed to be cold"	dogma about the world	One child has "self evident" knowledge that another lacks
"No, that's **why** it's supposed to be cold"	a causal theory made explicit	This "**Why**" is close to the center of the kids' epistemological confusion
"When I eat ice cream from the ice cream store, it isn't cold and it doesn't melt"	teacher's claim regarding ice cream stability is rejected	New scaffold will be needed for this child to reach understanding about ice cream, temperature, melt, etc.

The children's storytelling accompanies make-believe, symbolic, and dramatic play. Their story allows for scientific theory building: hypotheses are postulated, challenged, revised, shared, and so on. Notice the supporting role of the teacher, who does not disrupt the children's play frame, but nevertheless remains close to their activity so that she can gently contribute her knowledge **after** the students have provided evidence of what they do and do not understand. Notice also that in transcribing the event, we clustered speech to indicate several basic but important pauses in the conversation. This is a simple illustration of the ethnographer's own theory building as manifest in the interpretive acts of transcription. Writ large, we propose that several kinds of theory building are occurring through these layered events: the children are **making-sense**, the teacher is performing **formative assessment**, and the ethnographer is performing a **primordial assessment** (e.g., forming a base level theory of what words were spoken) and a **reflective assessment** (e.g., a high level theory about the understanding of the various actors engaged in the observed scene). See Table 2.

This example serves as evidence of how within instances of playful making, where children are immersed in their worlds, real or imaginary, constructing things with objects and materials at their disposal, the narratives that emerge are theory building. These "theories" are the sense the child is making of the narrative, of the materials, of social performances and cooperation, and of a myriad other things that we would consider to be powerful features of learning. Furthermore, as we tap these narratives—having students write stories, draw and sketch, take pictures, present their work, combine their work, etcetera—we are assessing their thinking; we are gathering a record of their thinking that can be examined for evidence of shifts, evidence of the rich learning happening in playful making. We have chosen to highlight the narrative qualities of making, and the possibilities for narrative assessments that we observed at ISB. Through this work, we have learned that making is not only a form of and an accompaniment to narrative, but that all the complimentary forms taken together are evidence of children's theory production, sense-making, and learning. If a goal for our schools is to create meaningful opportunities for children to center themselves in their learning, to grapple with contradictions and tensions, and to produce records of their thinking, then we would argue that playful narrating and making must be central to the pedagogical practices and aims of the school.

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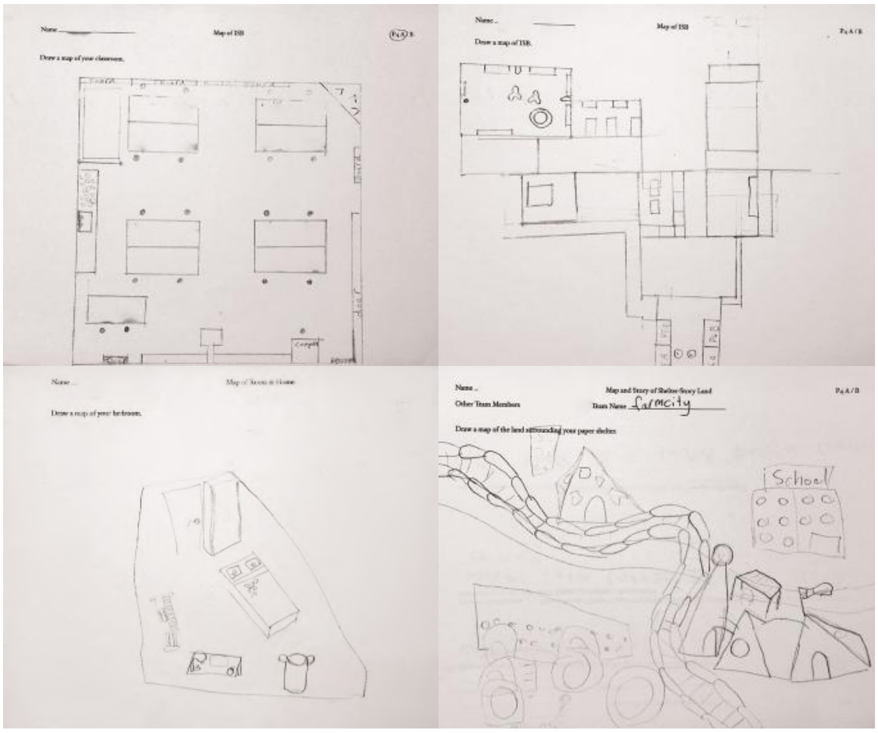
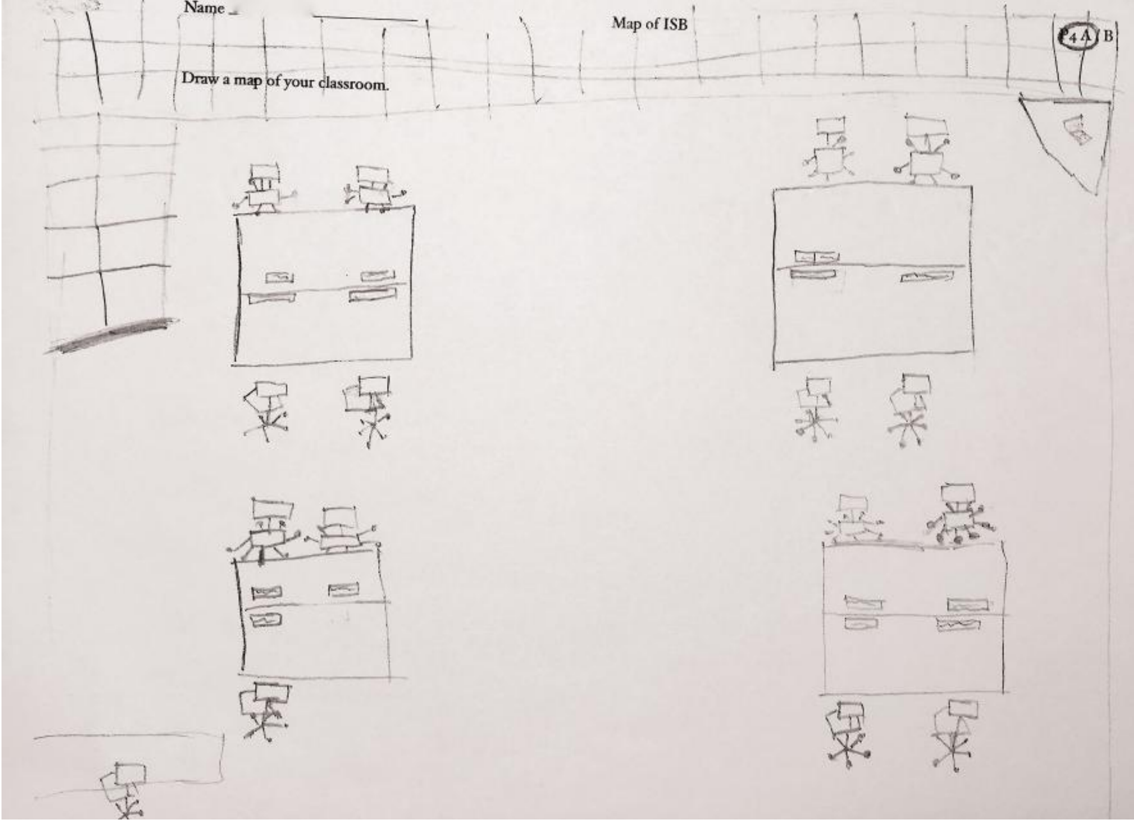
Chapter 6: Representational Praxes

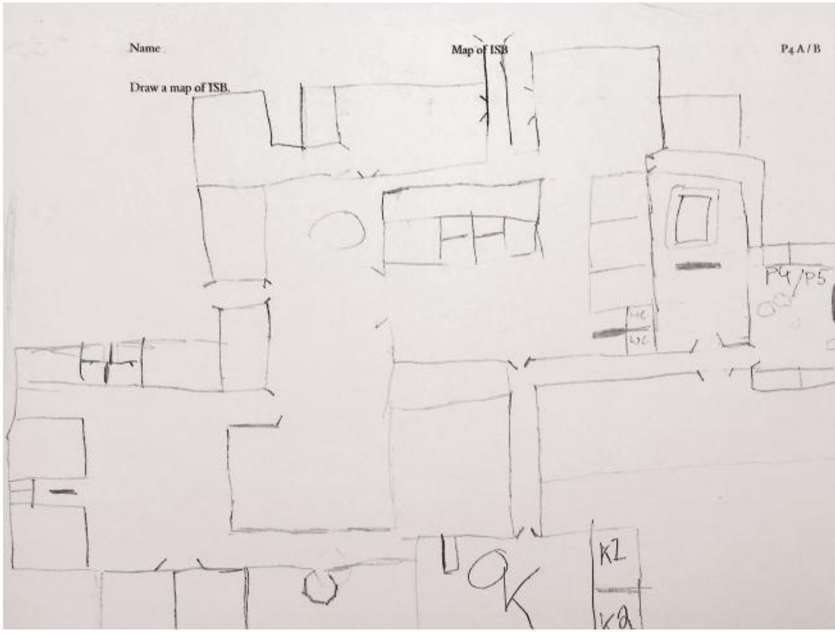
David Alsdorf & Brian E. Gravel

We consider visual representations to be narrative forms. The production and interpretation of drawings, photographs, diagrams, and other visual forms are features of narrative processes. Thus, we argue these representations should be understood as theory building tools, and as artifacts that provide insight into children's development, self-understanding, and making and storytelling skills. During David's second residency at ISB, he incorporated a map drawing component into the shelters-based curriculum. This involved asking the students to construct maps of different kinds of environments—those they inhabit, and those they imagined—as a means for assessing the thinking and reasoning students exhibited in their drawings. Each map that a child drew was an additional external document that could be mined for theory and assessed from various perspectives. Children drew maps on two separate occasions. On both occasions, we asked, first, how are spatial concepts expressed in a two dimensional field? What perspective(s) are taken? What was included, or excluded, in a map, and where or what was the center of attention?



One child's map of the school classroom, the school campus, her bedroom, and her make-believe landscape.





One child's maps of the classroom and of the school campus

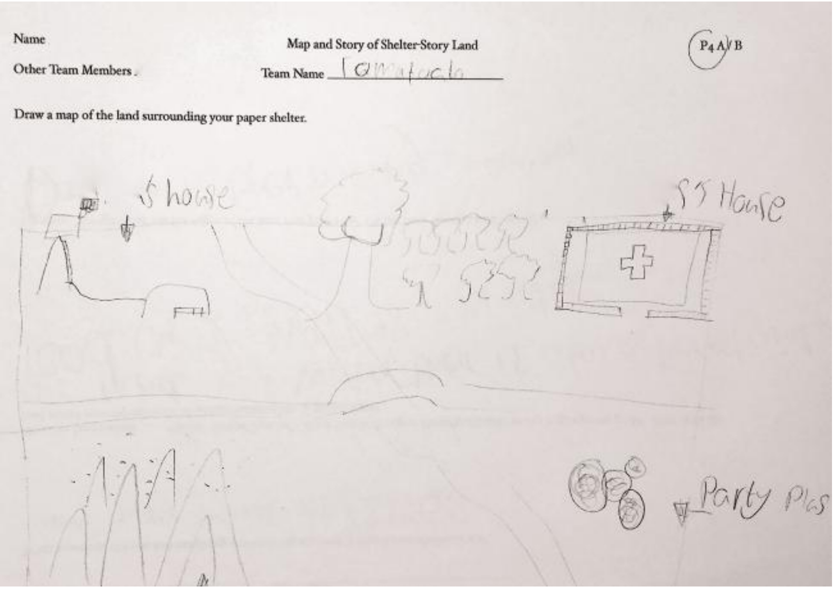
Because the curriculum focused on constructed physical worlds, David wanted to see how children expressed spatiality when drawing familiar places from daily life (school, classroom, and home, for example). Secondly, the maps provided a way to examine this spatial thinking over time, particularly as the making activities led us from individual storytelling to shared make-believe, landscape construction and curatorship, and eventually into world building. Our analysis of the students' work uncovered some interesting patterns, some that confirm other research in this area (e.g., Bárbara Brizuela's work on young children and mapping; Brizuela & Cayton-Hodges, 2013; David Uttal's work on mapping practices, Uttal, 2000), and other patterns that seem directly related to the curricular intervention. One specific finding was that students' spatial conceptions following their authorship of shared, make-believe landscapes were profoundly different than their spatial conceptions about the school environment prior to playful make-believing, making, and storytelling. Initially, we asked children to draw maps of their classrooms. The classrooms were familiar spaces (children spent a large part of each day there) and, moreover, the children were in their classroom during this exercise, and so they were able to look around the room to verify details. They could count the number of chairs, they could see how the desks were arranged, and they could reproduce these arrangements as they understood them on paper in their maps. Next, we asked children to draw maps of ISB, the whole school building, the entirety of the school campus. Parts of the building were very familiar to many students, like their classrooms, the cafeteria, the Creator Space, while other parts were unfamiliar. For example, there might be a wing of the school for older children, for teachers, or for maintenance that the students had never explored; perhaps they knew only the perimeter of these parts of the building from playing outside around the school building. There also exist detailed maps posted within the building which may have influenced how the children understood the space.

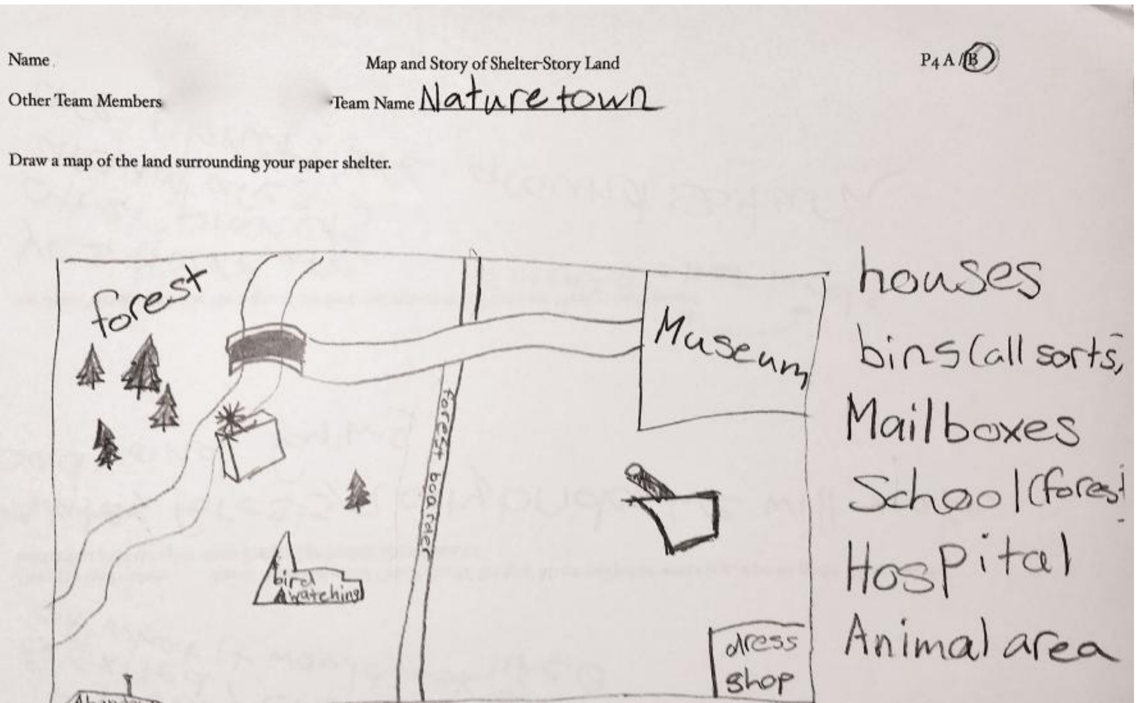
A week later, after the children had worked in small groups on shared, make-believe landscapes—the keystone of the shelters curriculum—we asked children to draw maps of the landscapes they had constructed. These maps had to be drawn from memory; the physical landscape models were purposefully placed out of sight so that, among other things, we could asses which details children did or did not recall, and so that children might become attuned by the memory challenge to various features of their evolving landscapes.

One of our conjectures was that there might be a relationship between the features of the representations included in each map and the (un) familiarity of the subject—the school grounds, their make-believe worlds—to the students.

The maps were coded using a scheme corresponding to the perspectives children took in drawing elements in them (see Brizuela & Cayton-Hodges, 2013; Uttal 2000). These perspectives included: (1) a "top down 2-d" flat perspective, e.g., the default Western perspective offered by Google maps (this is a perspective that many modern people consider "objective"); (2) a "2-d side profile" perspective, akin to the iconography one sees on park signs (e.g., slow children, picnic tables, etc.); and (3) "topographical / 3-d perspective" (or "bird's eye view"), e.g. 45-degree imagery, such as one sees from an airplane just before landing or just after take off. Each map was analyzed using this scheme, wherein a map could contain more than one perspective. Table 1 includes the results of the coding.

Almost all children used the first perspective, "top-down 2-d", as a primary vantage point for their maps of all three contexts: classroom, school, and make-believe landscapes. In some maps, children adopted additional perspectives for certain details. For example, in their classroom maps, three students also included "side profile" elements (drawing classroom chairs in profile), while seven children included three





Two samples of maps drawn of the children's make-believe landscapes.

dimensional "bird's eye" elements (drawing tables or chairs as three dimensional objects). Out of 23 classroom maps, six maps (26%) included two of the three possible perspectives, while two maps (8.7%) included all three perspectives.

Children's school maps universally adopted the "top-down" perspective as well, and only one map—out of 23—included an additional perspective: one child drew two doors in 2-d profile. In other words, out of 23 classroom map makers, 96% limited themselves to the top down perspective. We wonder what this suggests about the spatial familiarity of certain subjects (e.g., the classroom), and how that relates to the perspective(s) taken when children draw, inhabit, and learn within these places.

By contrast, the maps of students' make-believe landscapes often mixed several perspectives. Over 80% of them included 2-d profile elements, and nearly 55% of them included 3-d elements (see Table 1).

Table 1
When mapping their novel and self-authored make-believe landscapes, only 18% of students limited themselves to a simple "top down" perspective.

Perspectives taken (below) on map subjects (right)	Classroom	ISB (Whole School)	Make-Believe Landscape
Top-down 2-d	23	23	22
2-d Profile	3	1	18
Topographical / 3-d perspective	7		12
Map Included Just One Perspective	15	22	4
Map Included Two Perspectives	6	1	6
Map Included Three Perspectives	2		12
Classification of Subject	"Familiar"	"Un/Familiar"	"Self-Authored" & Brand New

What do these mapping perspectives suggest about the ways children represent their worlds in drawings or sketches, and what can we learn about making through the lens of representation to better understand what students may be learning? The increased use of multiple perspectives in constructing maps of the self-authored make-believe landscapes suggests students may be situating those worlds differently within a narrative structure than their everyday contexts, like the classroom or school building. In other words, because the students authored these worlds, their attempts to represent these worlds—in drawings as well as in stories—are access points to the artifacts and narratives they are constructing. Similar to how observational drawing or story-boarding have been shown to be powerful tools for assessing students' understandings (Hmelo-Silver, Duncan, Chinn, 2007), here maps serve as a way for the students to express multiple perspectives of their worlds. The maps are ways of understanding students' emerging narratives. Like all narrative, they are assessment opportunities, affording a window for us—teachers, facilitators, researchers—into the child's cares, values, and thoughts. Our interpretation of these data is that self authored make-believe landscapes can be dynamic, engaging and playful problem spaces for children to make these things accessible to us. When designing these landscapes, we can see what children care about, value, and are thinking. Therefore, it is advantageous to let children create such self-authored, make believe environments—albeit within the physical affordances of a familiar school environment—and use these as a problem-scape for situating academic content, for creating critical dialogues, for cultivating the development of narratives, and for sharing wonder. Below, we elaborate on these findings to explore current themes around representation and documentation in making, and make some recommendations for thinking about the role of documentation in how students share their learning, and how we can assess their thinking and narrative construction.

Representational Fidelity and Representational Acts

The benefits and value of time-intensive representational acts, such as map making or sketching, also alights several risks to which well-funded schools may be particularly subject. We are prone to valuing efficiency, speed, and—in the case of visual representations—image fidelity and fineness of detail. In many contexts, this means we value high-quality digital photographs and video over and against analogue, lower fidelity, and generally slower technologies, like sketching. However, as the above results help to illuminate, there are things we can see, and ideas students may be able to more fully express, when the modalities selected allow for slower, longer, and perhaps more deliberate processes of construction. To draw means taking care to construct lines and perspectives, and making decisions about what to include and what to omit. In other words, drawing the classroom may allow us to see aspects of students' thinking about that space that photographs taken by the students may miss. And yet, perhaps photographs—because they are fast, because they present ways to frame a view—offer a complimentary representation of children's thinking. This is all to say we encourage care and intention in the decisions around tools selected for curating the stories of making.

A question arises around the shared use of making tools:

How do we innovate if we also conform to socially shared and inherited conventions?

During Billund Builds Music, two six-year-old children illustrated this conundrum when they wished to cut a circle out of the lid of a large plastic bin in ISB's then-brand-new Creator Space. What tool is appropriate for this task? If one does not know, does one ask an expert? Where did the expert maker learn which tool is appropriate? Where did the person who taught the expert find out which equipment is best? As a backdrop to this story, we call upon a theoretical idea mentioned by Bernard Stiegler in **Technics and time** (1998): that the fabrication of tools **created history**. How could this be? Human memory, once confined to the span of a single life or generation, could build theory by reconstructing archaeological narratives—e.g., by studying the shape of an arrowhead, we can guess at the motivation underlying its creation. Again, we see narrative as theory building: a pulse of commentary interpretively answering iterative artifacts. When one less consciously references inherited norms and acts upon them—ask an expert maker how something is done—where are the occasions for innovation? Do grammars, conventions, rules, etc. of how things work or are put together circumscribe innovation? Does the "way things are" constrain innovation, creativity, and playful making?

Normalized, shared, and inherited ideas are delicate. We do well to consciously, at least as a thought exercise, handle such ideas slowly and deliberately, which may mean that we must at times de-value or de-emphasize efficiency and productivity. We must consciously bring more meditative and mindful practices into our making spaces.

Sitting poised in front of a computer is not the same act as thinking. Conference tables are efficient equipment for group meetings, but meditative thought may be best nurtured in an outdoor space, on an empty floor, through cat naps, or playful activities (e.g., Frisbee) not directly related to the goal of manufacturing some artifact.

In current educational settings, there are emphases on digital video and photography, both increasingly automated and effortless, to help create student portfolios and support teacher assessment. These are good practices. However, we recommend supplementing them with additional representational and narrative practices that go beyond (or stop before) the threshold of mechanized documentation. In particular, we recommend that children of all ages keep a **maker's journal**, akin to an art, design, or writing journal, and not necessarily one intended for consumption by peers or one's teacher, but rather for providing a space to make external representations of ideas, form observations, and otherwise work through problems related to one's own making experience. Journaling should be a practice that enhances consciousness in the making experience. Through meditative drawing—that is, where the goal of drawing is to help us see details we otherwise miss—writing, and making, we begin to change and shift what we are capable of seeing, imagining, and fabricating.

We also suggest building **storytelling stations** for age appropriate narration, play-acting, and presentations (e.g., a puppet theater configuration for early childhood and elementary aged children; a "news desk" configuration for middle school and older). These too afford opportunities for makers to create commentaries as part of a cycle of making and narrating. Encouraging multiple forms of narrative production, and the sharing of these narrative-based-artifacts, offers opportunities for narrative to become valued as part of the playful making process, and provides more opportunities for us to assess what our students are imagining, wondering, and thinking.

Finally, we recommend **representation stations** that promote attentiveness to detail—looking and seeing—and analogue forms of visual documentation: a physical location where multiple forms of representations are encouraged, many materials are present, and where students are asked to continually share their ideas and work in many different ways. This proposal is not intended to replace automated photographic "documentation stations," but to supplement the automized systems that already exist in our making spaces. We want to help makers reach other goals, and to create a balance against some of the risks that mechanized documentation poses to makers. The risks we refer to are evident in the language that we use when we speak vernacularly about photography as an activity that "captures" information. We overlook opportunities for more meaningful noticing practices when we allow ourselves to believe that photographic documentation is objective and sufficient. As a thought experiment, imagine what you would see if you were not permitted to photograph a LEGO Mindstorms configuration, but were instead allowed to sketch it; further, imagine what you would learn as an engineer, through such activity, in preparation for your next cycle of design and construction? We argue you would, through sketching, see new and previously unfamiliar details in both the design and in the raw materials included in a LEGO Technics kit. In particular, it would benefit the sketch artist to closely study pieces of a LEGO kit outside of the compartments LEGO offers, because these compartments (e.g., the red tray of a Mindstorms kit) suggests utility in a certain way, through organization, which may obscure alternative ideas about utility. For example, the red Mindstorms trays allocate three-holed beams to a separate compartment from all other beams. This encourages students to recognize the three holed beam as a "miscellaneous" piece, and to miss the fact that it is, other than in length, identical in structure and in many purposes to all other Mindstorms beams.

Drawing, sketching, mapping, and other manual representative practices heighten attention to detail and help us to see more clearly the objects around us. These practices are not only alternatives to photography, but stand in contrast to photography's typical impact on perception, where the photographic machine, in many if not most instances, distances the subject from the object under scrutiny: we tend to rely on a camera to do the seeing for us, at least in the present moment. Presumably we will do our seeing later, by scrutinizing the photographs, although that future never arrives, even more so in this digital age when we there are no functional limits to the quantity of records our machines will fabricate. This creates an alienating, non-spatial distance between subject and object. This and related phenomena have been well documented and discussed (Sontag, Barthes, Benjamin). To give an everyday example, we observe this phenomenon when a tourist approaches an awesome setting, and the sojourner—in what may be a deliberate effort to sidestep overwhelming existential experience—holds a camera between self and site. The camera at once obstructs the tourist's view and creates a documentary record that lures one into falsely thinking, first, that the spectacle has been seen (perhaps the tourist hasn't even looked) and that **this**, the record, **is** the spectacle (where in fact, the record is a derivative artifact). The photographic record represents only one of an infinite number of perspectives, rendered as an array of pixels, infinitely reproducible, and perhaps never looked upon by a human eye unencumbered by machine.

We argue for the centrality, power, and importance of representations as tools for building theory, as the products of practices rich in careful attention and inquiry, and as a means of assessing the thinking students are doing when engaged in playful making.

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Chapter 7: Core Principles for Making Engineering Playful

Brian E. Gravel and Chris Rogers

Introduction

In March 2016, following visits to ISB by Matt and Amanda, we had a conference call with Camilla Uhre Fog, Sue Oates, Per Havgaard, Brian Gravel, and Chris Rogers. We were reflecting on progress to date, and wondering about how to continually frame and refine the goals of the project to be most useful to both ISB and the researchers at Tufts. What were we trying to learn about the role of the Creator Space at ISB? How were the interventions, projects, and ideas Tufts researchers brought to ISB supposed to support the community in developing their own pedagogies of playful making?

In that conversation, Camilla and Sue reflected that many of the curricular activities, pedagogies, after-school offerings, professional development activities, and interactions with parents and the community involve some form of "making." The fabric of the school's culture, values, and ways of working were sewn with the threads of play and making; and yet, teachers and leaders alike knew they could do more. They wanted to learn how a major through-line of the work of ISB could be making, and they wanted to understand how that line moves in and out of classrooms, through the Creator Space, out to children's homes, museums, and the playground, and back to the classroom again.

Camilla suggested we ask:

How do we tell the story of making?

This question has occupied our attention, both in terms of producing this booklet, but also in terms of thinking about the activities we facilitate, and the evidence we collect of the learning at ISB.

In the Introduction to this booklet, we sketched out what "playful making" might entail. For children, it involves identifying problems that are challenging and interesting, framing and scoping those problems, playing with technologies and materials that could be used to solve those problems, learning new skills and processes, iterating frequently, engaging peers and mentors for support and assistance, and testing the solutions, over and over again, making revisions and refinements at every step. Erica Halverson, Kim Sheridan, and colleagues have argued that **making is learning**. When engaged in making, you are learning new practices and constructing new knowledge (see Halverson & Sheridan, 2014; Sheridan et al., 2014); and at the heart of this is the joy and satisfaction demonstrated by Owen and Yasmin in the Introduction.

And yet, the case-studies of learning in making are often focused on high-tech environments, where financial resources support access to technologies, materials, and supports (e.g., things as simple as a computer and Internet access) are core aspects of the learning environments described.

So, is playful making only for those in well-resourced situations? Is making only available to those with consistent Internet access and electricity? We would say no, of course not! At its core, playful making is something anyone can do, and many forms of making have always existed, in different ways, across a diversity of communities. At its core, playful making is a set of practices that people use to interrogate and understand the material world, and to make things in it. These practices can be fostered and developed in highly technical situations, but we argue they can also happen when the resources at hand are recycled, natural, and even scarce.

And, another powerful question that drives our thinking: is all making playful? Certainly there are particular tasks where safety concerns condition the potential for playful interactions (e.g., using a powerful saw, wiring high voltage systems like electric car batteries or solar panel arrays). And certainly there are forms of making that require a kind of precision and attention in ways that bend away from what we see as playful work (e.g., designing the Boeing 747, or the landing mechanisms for a Mars rover). Our vision of making is intentionally broad - from crafting, to electronic art, to engineering - as to expand our ideas about what **counts** as making, and what can be learned when one is engage in it.

In this chapter, we outline some core principles of "playful making" that we argue can be used to structure how making experiences are designed and offered to youth and adults alike in many different contexts. We discuss how play, tinkering, and engineering are related to this idea, and where they might differ, expand, or enhance the ways we think about making in schools. We do this to hopefully translate the wealth of interesting stories and findings from this project into ideas that will guide and shape how we continue to explore the role of "playful making" in schools. We present these ideas, in part, as our own contribution to Camilla's charge, by telling the story of playful making as we have come to understand it.

A Quick Review: Fostering Practices

Research on making has produced a few frameworks to support educators and children in thinking about the practices involved in making. We present two because they are useful ways of thinking about what kinds of activities support learning while making. These frameworks help to define some of boundaries of what makes learning through making, and playful making, unique and important to educational activities. The first comes from research conducted at MAKESHOP in the Pittsburgh Children's Museum. By watching children and families tinker, make, and engineer together in MAKESHOP, researchers were able to distill a set of core "learning practices" observed in that space. The second comes from the Tinkering Studio at the Exploratorium. Observing how visitors to the Tinkering Studio engaged in the various activities they had designed, researchers were able to identify key features of what makes tinkering powerful.

Learning Practices of Making - MAKESHOP @ the Pittsburgh Children's Museum
(Wardrip & Brahms, 2015)

Practices	Description	Example
Inquire	Pursuing questions and examining possibilities of materials.	Students building tracks for marbles with foam in the Creator Space at ISB.
Tinker	"Purposeful play" with materials to learn about them, their properties, and to possibly imagine them being used somewhere.	Exploring toothbrush robots to see what they draw and whether one can manipulate the artifact to draw concentric circles.
Seek & Share Resources	Identifying needed information, people who posses it, ways of asking about it, and ways of sharing one's own expertise.	While sewing, the maker asks the person next to him for help attaching two different materials.
Hack & Repurpose	Finding new ways to use old stuff, often not in the ways the manufacturers intended it.	CD-ROMs become wheels for a cart, or broken computer screens used in an interactive art display.
Express Intention	Personal identity and expression of personal meanings, goals, and questions through the work - either in the artifact, through the processes used, or in sharing one's work.	A youth maker designs a toy for children in hospitals to help them deal with their anxiety and nervousness.
Develop Fluency	Increasing comfort and capacity for working with new materials, processes, and ways of designing and making.	Practicing soldering by building a small LED cube requiring 128 different points of connection.
Simplify to Complexify	Entangling oneself in the processes and materials to connect them and combine them in new ways to make new meaning.	Choosing a complex project of interlocking gears to learn about how software helps render gears, and the realities of how they work in the physical world.

Learning Dimensions Framework - Tinkering Studio - Exploratorium
(Gutwill, Hido, & Sindorf, 2015)

Practices	Description	Example
Engagement	Spending time, paying attention, and demonstrating investment.	A child leans in closely to examine a toothpick structure. She is focused trying to connect two pieces. Her teacher tells her it is time to go, but she does not hear her and continues to work.
Initiative and intentionality	Goal setting, goal seeking, persisting, and taking intellectual risks.	Working on a marble run, the students decide they want the marble to do two loops and land in a bucket. They work to assemble the tubing this way, trying, adjusting, and trying again.
Social scaffolding	Seeking/offering help, "inspiring new ideas"	Those same students are struggling to get the marble to complete the loop. A teacher suggests they put the loop below where the balls start to see what happens.
Develop understanding	Striving to make sense and understand, expressing surprise or amazement by new connections or realizations.	"The ball can't go higher than is starts!" a girl exclaims after getting her marble run to perform perfectly.

When examining these frameworks, tinkering, making, and engineering are all ways we might describe the kind of work children are doing in MAKESHOP and at the Tinkering Studio. However, are they the all the same activity? We argue they are not, and that we prefer to think about the ways playful making, tinkering, and engineering are similar, and different, to begin providing ways of understanding work in makerspaces and how that contributes to student learning. For example, does engineering focus efforts on the needs of clients and bring in mathematics and science to help solve those needs? And if so, does it also fail to engage students more interested in play, or in exploring the materials for the sheer joy of understanding more about them? Does tinkering show us new ways of understanding circuits, that we might be able to apply in expanding our sense of how to solve an engineering problem? We do not answer these questions, but we want to encourage school communities and educators to think about how commonalities and differences can be useful in making decisions about making and makerspaces in schools. We believe playful making, tinkering, and engineering are complementary, and that many children may not see any differences at all, but that the work of giving each activity some definition can be useful for future decision making.

Playful Making, Tinkering, and Engineering: Commonalities and Differences

Playful making, as we defined in the Introduction to this booklet, involves engaging with materials to make things, express ideas, and to enjoy the act of making and learning with new materials and processes. It involves challenging oneself to take risks, and iterating on ideas and designs because we find them interesting and engaging. The end goals are not always well defined, but the ideas about what one wants to make are within sight—the child wants to build a house, but how that house will take shape and form is determined along the way. To complete the project, the child uses imagination, ideas from books or friends, and support from adults who may know particular processes or skills that they developed over time. At the core of this activity is learning, and thinking about ways to leverage and continually build new knowledge, skills, and practices.

Tinkering involves engaging with materials to understand them, processes for using them, and developing ideas and questions for further pursuit. One's goals may be less about solving a problem, or telling a story, or designing a solution for a particular situation as much as they are about quality and focused interactions with the objects at hand. From tinkering, problems emerge, stories unfold, and ideas for expression come into focus. This is a process used often **within** playful making and engineering, as it expands one's sense of tools, materials, and processes.

We consider **engineering** as the process of identifying a particular problem and leveraging what one knows, including known principles from mathematics, science, engineering, and the arts, to solve that relatively well-defined (even if ill-structured) problem. Engineering works toward a very particular goal by paying attention to trade-offs in design decisions, learning from failures, focusing on efficiency, considering economics, and striving for optimization. There is formality, an intentional use of one's existing understandings and ways of knowing, and a client or problem in mind when engineering is happening. This is a problem solving activity, that can be measured against whether or not the object created actually solves the problem at hand.

In considering these three activities, we see significant overlaps. Playful making incorporates elements of expression, and attention to aesthetics, in ways that engineering does not always foreground. Tinkering embodies play in the ways that play is generative, productive, and joyful, but does not always end in the production of some device or object like with engineering or making; similarly, defining what one learns while tinkering is challenging and often illusive in classroom settings. Engineering is often defined in formal terms, with an emphasis on technical ideas and practices, but sometimes misses how important aesthetics, social negotiations, and the importance of expression and message can be in a learner's experience. In all three activities, iteration and learning from repeated cycles of risk-taking, failure, and trying again are core to the work. And likely, in any one of these activities, moments exist where it would be nearly impossible to differentiate between playful making, tinkering, and engineering. **So, why create the distinction?** Why spend time articulating differences when for children do not experience these differences in their work? We offer these attempts at defining different activities with the intention of being provocative. We want to give some shape to each of these activities, not to suggest they are mutually exclusive, but to explore how each can be a lens for thinking about the role of making, and making spaces, in schools. Seeking clarity around what the activities are, what we are hoping students will gain from them, what forms of practice help students make progress on their own goals of learning and sense-making can support the case for making in schools.

In this work, are we fostering tinkering? Engineering? Playful making? We argue makerspaces **can** foster all three. But, it is important to be mindful and intentional about what we are hoping children will experience when we think about designing these spaces. The goals we set and the values that guide our work inform how we design learning activities, and the supports we offer students as they work in these spaces. Below we present Characteristics and Guiding Principles, derived from our findings, to support schools in thinking about makerspaces in their communities.

Characteristics and Guiding Principles

First, we offer some characteristics of makerspaces that we think support meaningful work and playful making in schools. These are organized as 7 key characteristics, with questions to help you think about whether your space is fostering playful making in ways that promote learning and productive engagements. We then offer some general principles for thinking about playful making, and how they might unfold in a variety of settings with different cultural and contextual features.

Characteristics of Making Spaces:

1. **Solution Diversity:** Excellent activities are characterized by a large diversity of excellent solutions (as opposed to one right answer). Makerspaces should both encourage this and monitor how well it is happening: when kids make, is creativity evident in the range of things they produce? Do even the most constrained systems, like toothbrush scribblers, offer space for solution diversity at more moderate scales?
2. **Distributed Expertise:** Making is a multidisciplinary activity - there is too much to know for any one person to master. Thus, learning comes from each other - with different members being masters of different subjects: does your space encourage people to share knowledge, skills, and expertise in different areas?
3. **Collaborative Learning:** Makerspaces should support peer-to-peer learning and teaming: are activities in the space build on the idea that collaboration supports learning?
4. **Access and Participation:** Makerspaces should accommodate work for the particular populations who visit them, and they should encourage participation in different ways - through provocations, through classes, through workshops, and with artists or makers in residence: are people welcomed into your makerspace, and do they feel supported to participate?
5. **Process Documentation:** Much of the learning in playful making comes in the failing and restarting of aspects of your design. Capturing these moments, so you can share progress and reflect on shifts in how things were designed and made can support learning. This should take many forms, including drawing, photographs, video, and writing stories: is documentation capturing the story of making in your space?
6. **Design and Engineering Design:** Making should promote the particular features of design and engineering. The spaces should combine activities that can be solved by tinkering and exploring, along with those that require math and science knowledge and prediction: are students learning to

become better designers through playful making?

7. **Inquiry and Action Research:** Makerspaces should center inquiry - everything that happens should be driven by the curiosity and questions of the maker. This may also come in the form of pre-determined problems that are structured in ways that allow the maker to find problems of interest through the process of engaging. This coupled with actively researching the learning happening in the space in order to modify policies and configurations in the learning environment (e.g., what tools and materials are available) keeps the space responsive to the needs of the community: is your makerspace able to grow and change as the community develops?
8. **Identity Development:** Being in the space, expressing yourself, and learning to make with others should help you see yourself as someone who is competent and empowered to design and engineer solutions in the world: are students' identities being expressed and are they seeing themselves as learners in your makerspace?

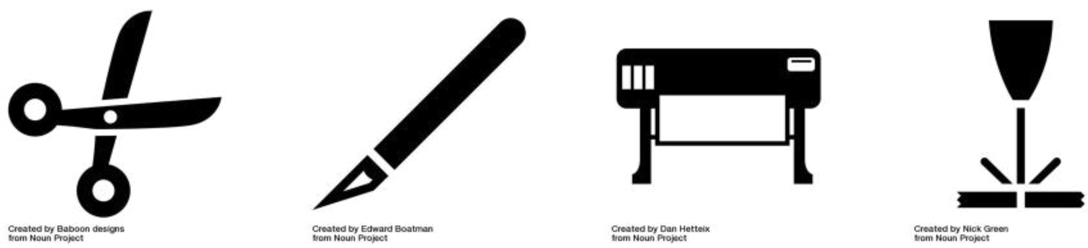
Guiding Principles for Playful Making in Makerspaces

Over two years of work with ISB, we have explored some ideas that we think contribute to playful making. We have organized these ideas into a short set of principals intended to guide future efforts to explore playful making in schools. These are not meant to be comprehensive, nor are they meant as a playbook or manual for doing this kind of work. Rather, they are meant as provocative ideas that we think can continue to advance conversations, and meaningful work, around making engineering playful in schools.

Material Familiarity

We have noticed that in the Creator Space at ISB, and in other makerspaces, children often gravitate to activities, processes, and materials with which they are familiar. We see a lot of crafting and simple manipulation of craft materials. This makes sense as these are places where children can feel immediately skilled and able to build, tell stories, and play with materials. We argue this phenomenon could lower barriers of entry into new forms of engineering and making. In other words, building from children's familiarity with materials, objects, processes, and technologies expands **access** to and **trajectories through** new forms of engineering and playful making.

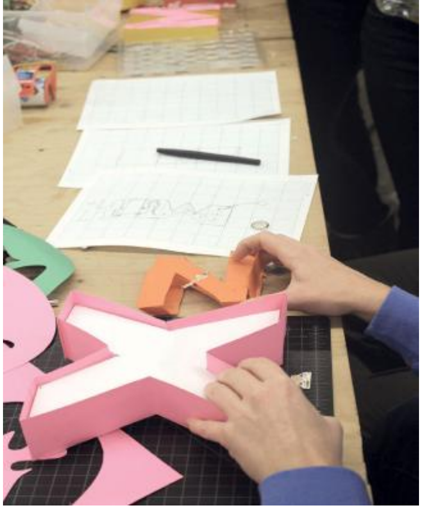
Take scissors and paper as an example. Many children are comfortable cutting paper with scissors at very young ages. They may begin haphazardly, not entirely in control of what is cut out of the paper, but they are practicing this process. They are learning about how the tool interacts with and manipulates the material. Before long, they can cut out shapes--circles, triangles, snowflakes, hearts. In doing so, they are also learning about the material itself—how it bends, folds, tears, and the shapes it can hold. Now, imagine we think about this familiarity as the beginnings of one's engagement with computer-controlled tools: my hands working the scissors as an analogy for how the computer tells a mill to move through wood, or how a laser should move across acrylic. How hard I squeeze the scissors is how "hard" the computer tells the laser to burn the objects. Following on with the paper example, we have explored the following trajectory to find that it supports makers (teachers and students

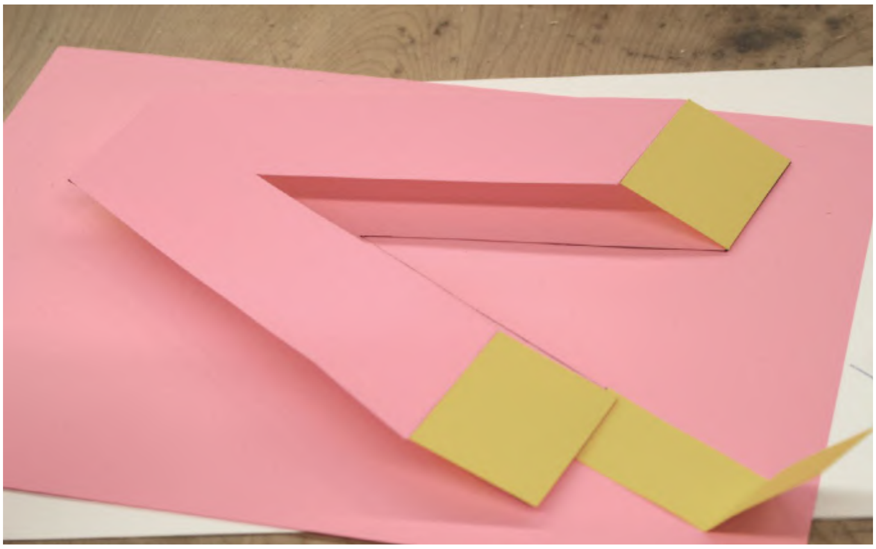


scissors and paper -> X-acto knife -> vinyl cutter -> laser cutter alike) in learning new technologies by seeing them as ways of doing familiar processes in different ways. These trajectories provide a structure for thinking about the dimensions of tools and materials for different kinds of tasks, and for opening up pathways for learners to experience manipulating materials to make things in different ways. We present one trajectory that we think is worth further consideration:

Each of these processes involves doing something to a 2-dimentional material. The first two being well-suited for work with paper, the vinyl cutter offering new possibilities for plastics and even thin metal, and a laser cutter expanding the options of both materials and thicknesses. Ultimately, these processes are about controlled cutting. We offer a comparison of these tools along three dimensions: precision and accuracy, skillful iteration (that is, how quickly can we iterate on a design using these tools), and applicability, safety, and cost.

	Precision/Accuracy	**Skillful Iteration**	**Applicability/Safety/Cost**
scissors and paper 	Dependent on the maker - youth hands cut in youth ways; adult hands can cut in adult ways. Accuracy is secondary to speed and familiarity.	New and young makers can build skill using paper and scissors, but there will always be a limit to how quickly one can repeat processes or tasks.	**$** Very familiar - both the process and the material. Relative safe for all ages.
X-acto knife 	Increasing precision, accuracy still driven by human hand.	With each iteration, skill and familiarity with technique, and with how materials react to tool improves. Slightly more repeatable than scissors, but still vulnerable to human hand errors.	**$** Familiar materials and processes, different opportunities for thinking about how cuts relate to 3D shapes. More planning required than with scissors, and slightly more dangerous.
vinyl cutter 	Motors take over for the hand, resolution is on-par with other knives, but tool paths are controlled by computers, not hands.	Lead times for designs - need a digital file to make first iteration increase, but they are easy to amend and iterate. Cuts are fast and cheap.	**$$** Materials are still familiar, process maybe less so, but cheap to iterate with paper and vinyl. Safe to use.
laser cutter 	Ultra-precise cutting, and intensity.	Great accuracy and repeatability. Machine runs quickly, so iteration can happen rapidly.	**$$$$** longer lead time to proficiency; once comfortable, cheap to iterate. Safe when used properly; training required.





We explored this particular trajectory with teachers in Nedlam's Workshop in Malden, Massachusetts. We asked them to start by constructing 3-dimensional letters from paper, with scissors[1]. Some opted to graduate to X-acto knives to make more precise cuts. Within minutes, they were making letters using ideas from geometry and physics to make them stand up and look interesting. Following on from this, we explored the vinyl cutter together, and eventually played with some tools for generating the parts for 3D letters on the laser cutter. The teachers reflected that doing these activities in this order, playing with familiar materials, introduced them to a new way of thinking about these relatively "scary" tools (e.g., the laser cutter), and that they could imagine doing similar things with their students.

We imagine another kind of trajectory, building from children's familiarity with construction tools like LEGO Bricks. As children build and imagine shapes and objects in the world, they are engaging in the beginnings of 3D design, a central and critical tool for engineering and making. What if we offered them clay to continue exploring how they go from idea to 3D part? The rigid angles and sharp features of LEGO now take on a different kind of possibility as those initial ideas are shaped and molded in clay. From there, we introduce Tinkercad, a relatively accessible (and free!) design tool where the children can make 3D shapes on the computer. Maybe they translate something they built using LEGO Bricks or clay into a 3D model. With a few button clicks, this 3D image can be printed on the 3D printer. Or, perhaps that object is sliced into different parts and cut out on the CNC mill (such as the X-Carve Mueller describes in Chapter 3). The idea is that materials and simple processes for manipulating them are familiar, long-standing traditions. They can be places to introduce new kinds of modeling, designing, engineering, and fabrication techniques and approaches. Ultimately, the perfect and most efficient machine is the right machine for the job, regardless of how fancy and new it is. Building from material familiarity to open pathways for children to learn about new tools, and new ways to make with those tools, can support the child in going from hammer and nail to more complex processes.

Build from Children's Stories and Questions

Beginning with the introduction, where we shared the story of Owen's pirate ship, we hope throughout this booklet we have made a compelling case that storytelling and narrative are part of the processes of making. Camilla's original question pushed us to think about **story**, and we have come to realize that powerful and meaningful making happens when there are also opportunities to explicitly connect that making to our own personal stories. Playful making opens up space to share, explore, and build from our stories. We argue that finding ways to anchor making in children's narratives and questions can lay an important foundation for learning through making. Furthermore, as Chapters 5 and 6 illustrate, continuing to connect the making children do to the stories they tell can have generative benefits. Within a school context, no matter the content the curriculum stipulates, children connect to and make sense of these ideas by relating them to what they know. Stories can become the vehicles on which their journey through making are mounted.

Low-to-High Tech

Children build familiarity with physical materials as they grow up in whatever context they live in, we made this argument above. They engage with natural materials, digging in dirt, gathering leaves, and they learn to put pen to paper. Growing up within particular cultures, children learn to use tools in the ways they are intended to be used. But, we see playful making a potential place where children can re-invent technological possibilities. Recall the boys in Billund Builds Music trying to cut a hole in a plastic lid for a bucket to make a drum (see Chapter 6). Without specific guidance from an adult, or a more knowledgeable peer, they grabbed a nail and a hammer. Noticing that when they drive a nail through an object it leaves a hole, they went about "punching" holes, one after another, next to each other in the lid to create a large, circular hole. While anyone with experience with making would notice that this is hardly the most effective, efficient, or even **safe** way to cut a hole, these two boys were inventing a way to use tools to achieve their goals. What have they noticed in their own, invented process? For one, they noticed that driving a nail through a material moves some material out of the way; it creates a void, which is an idea related to how saws work, only they are optimized to remove material rather than just push it out of the way. We might build on these noticings to help the students think about why a laser cutter, router, or even a saw might work better in this situation; we can work from these attempts to reinvent technological possibilities to show them how certain tools are designed to do certain things. Learning why a tool is designed to be used in a particular way, in context, enables newer ways of thinking about what technology can do to support us in our playful making and engineering. We ground this idea in a simple fact: The **expensive** tools of today are the **expected** tools of tomorrow. What is difficult to obtain, expensive to operate, yet powerful to use may be what is commonplace in the future. And we encourage the consideration of low-tech solutions in asking, how do we support students to explore both everyday technologies and future technologies to imagine the reinvention of technological possibilities for engaging in playful making?

Embrace Tensions

A central idea in social learning theories is that tensions drive our efforts to make sense of new things we encounter. When we see something that is confusing, contradictory, or that does not match our expectations, the tension that creates for us—between what we know, and what we are encountering—drives our attempts to make sense of things. The Introduction speaks of this as "the world pushing back on us." In making, tensions emerge all the time: I want to cut this thing, but the tools are not working for me; I think this circuit should work, but the LED is not lighting up; I expected this plastic to snap this way, but it snapped that way. These contradictions, or tensions, present rich opportunities for learning. It is in the negotiating and resolving of these tensions that we learn to think in new ways or to do new things. Shifts in our approaches are evidence of our learning, and shifting the ways we do things to resolve these tensions **is** learning.

Tensions are plentiful in playful making, and rather than think about how to smooth these over, or how to design for avoiding tension, we should think about when and where certain tensions could promote learning. A quick example of how we see this idea happening in practice is through the use of peer-to-peer critique. Often students will get frustrated if an aspect of their design is not working like they want. That frustration can be productive if the students are given ways to manage and explore the roots of that frustration. Asking peers to comment on, critique, or provide suggestions can be a way of working with that frustration to expand one's thinking about the problem. It can also reposition frustration as an opportunity to seek help and learn new ideas and approaches, which makes tensions productive for learning.

Cultivate Relationships

If there is one thing we learned in this project with the work at ISB, with work at the Cambridge Friends School, at Nedlam's Workshop, and in other making spaces: relationships are at the heart of doing good work. Spending time getting to know people, sharing your strengths and curiosities, learning about what drives and inspires people to make, and how you can work cooperatively is central to all forms of playful making. But, one particular thing we learned through the structure of the residencies is the power of sustained, long-term professional development for communities who want to learn and grow. This can take the form of protecting time and space for teachers to be makers themselves. Or, it can mean embedding "makers in residence" to support your school's use of a makerspace. Or, you could reach out to community artists, artisans, and designers to offer workshops and programs with children and families. Regardless of the form of collaboration, playful making is a social and communal activity, and it requires strong, sustained relationships to really make it sing. For these reasons, we recommend thinking broadly about **who** is in your making spaces, **why** they are there, and for **what** purposes they gather. Expanding our ways of connecting the work youth do in these spaces with the various aspects of their school, familial, religious, or social lives can only strengthen the ways these spaces help communities build and grow together.

Concluding Thoughts

It has been an incredible pleasure working closely with the amazing "play-makers" at ISB, members of the LEGO Foundation, Project Zero's Pedagogy of Play team, and the countless other individuals in making spaces around Boston. We are energized by the interest and passion in the current conversations around making in schools. We have learned that when a school is committed to having students learn with their hands through play and making throughout the school day, great things can happen. We have also come to see that this work is challenging, and not without its ups and downs. It turns out, being playful all the time is hard work! The big take away that we have is that a shared commitment—by teachers, families, students, administrators, and the community to playful making is an essential foundation from which we can learn more about the power of making in learning. In other words, a community committed to allowing students to dream, tell stories, make things, improve on them, and continually learn with their hands, is a place well-positioned to foster a culture of playful making.

We realize that not all school communities are at this place; not all schools currently share these kinds of commitments. However, in every school, there are adults who are committed to believing students are capable learners, that they are playful and creative, and that we can empower them to do great things if we give them the right opportunities. Beginning with a group of dedicated teachers, students, parents, and staff, and demonstrating the power of learning through making by giving students permission to try and to iterate can begin to shape a culture. It can begin to help the adults rekindle their own love of play and learning, and it can lead to an overall commitment to the power of making engineering playful in schools.

Notes

[1] This work with teachers in Nedlam's Workshop was conducted in collaboration with two additional research projects: (1) Engineering for All in Nedlam's Workshop, a project that brought the makerspace to Malden High School; and (2) Investigating STEM Literacy Practices in Maker Spaces, or STEMLiMS, which is a collaboration between TERC and Tufts to articulate a framework for STEM Literacy Practices in making (Gravel, Tucker-Raymond, Kohberger, & Browne, 2017; Tucker-Raymond, Gravel, Kohberger, 2017).

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Appendix: Examples of Practice: A Kindergarten Creator Space: Building a Space for 3- to 7-year-old Makers

NOTE: This "picture of practice" was produced by our partner in this work, Project Zero's Pedagogy of Play project, to illustrate how work with teachers came about in the conceptualization, design, and construction of an early childhood makerspace. Chapters 1 and 2 of this booklet describe findings from the research on the early childhood makerspace at ISB. This essay showcases how this work happened, as an illustration of the kinds of dedicated practice teachers, researchers, and children can engage in to make learning playful.

Background

The International School of Billund in Denmark has a multi-room Creator Space built at the heart of the school that contains a laser cutter, a 3D printer, a textile studio, woodworking equipment, clay and paint tools, LEGO robotics kits, and a wide variety of crafting materials. However, despite the plethora of tools available for making and designing, most of the early childhood classrooms stay away from the space during the school day. Because makerspaces are such a new idea, their success depends on teachers coming together and collaborating to figure out how to make it work for their context. In this picture of practice, we join the teachers in the Kindergarten Playful Environments Study Group at ISB as they ask, "How can we design a Creator Space for our young students?" The Kindergarten teachers decide to use Study Group as a forum to enact their changes, and leverage an existing partnership with Tufts University in Boston, inviting Amanda Strawhacker, a consulting researcher and Child Study Ph.D. student from Tufts who has experience designing developmentally appropriate spaces, tools, and technologies for young children, to help.

The Creator Space feels like a big-kids room

It is afterschool in the Creator Space. Four 10-year-old students are using the iPads to explore a tangram challenge on the Osmo app. An 8-year-old boy is navigating a Wonder Workshop robot to travel around the space and dodge under tables and chairs. Three girls from P4 are using beads and hot glue guns to make bracelets, and there is a steady stream of 6- and 7-year-olds building houses and rockets inside of the enclosed LEGO bench. With so many tools and materials to choose from, it is surprising that there are no children from the Kindergarten classrooms. Two 5-year-old girls from K3A walk through the space with Marina Benavente Barbon, their K3A teacher, on the way to the nurse. They look around and pause to ask older children what they are working on, but quickly lose interest and leave. Later, when asked why the Kindergarten classes don't use the space throughout the day, Marina replies "it feels like a big-kids room." She's not wrong. The layout and furnishings of the Creator Space can be daunting to Kindergarten children. The tables and chairs are so tall that the young students need help getting up and down. They aren't able to see the offerings above the lowest shelf of the "candy wall," an open storage area with dozens of craft and art material bins, with items ranging from cloth strips to beads and buttons.

The wide hallways that cross through the space can be overwhelming, with new people constantly walking through and loud noises echoing through the hall. Despite those issues, the hall and tables are the most young-child-friendly areas of the Creator Space, as most of the other rooms contain complex woodworking or textile machines, or complicated and expensive robotics and arts equipment.
The question of how to make the Creator Space more inviting and useful for Kindergarteners has come up before at the school. Although they had used parts of the main Creator Space in the past, schedule and time management became issues with older classrooms. Kindergarten teachers want a place where the smaller children can create and store large projects, without space being an issue. The idea of a Kindergarten Creator Space surfaced in Study Group, and left kindergarten teachers wondering how to make a space available for their children. The administration knows about the teachers' wish for a Creator Space that feels like a Kindergarten Space. They even have a room in mind to work on.

Converting the Clay Room

One room in the Creator Space is not used as much as the others. While the Clay room is occasionally used by 10- to 14-year-old students for art classes and language tutoring, often, the room is empty for the majority of the day. Amanda decides to collaborate with the Kindergarten Study Group, co-designing a space that works for them, and with Awanti Seth Rabenhøj, an art teacher, to help ensure that the needs of the arts students are still met. They will use Study Group to come up with a wish list for their dream space that will be welcoming to young children, and Amanda will coordinate and collaborate with these stakeholders to realize their new vision of a playful Kindergarten Creator Space.

View of the clay room.

Why a Kindergarten Creator Space?

For one week, Amanda observes several of the six Kindergarten classrooms as they work in their classroom, play on the playground, and even during meal times. The teachers share what making activities they already do in their classroom, such as painting and crafting, and which ones they need a separate space for. For example, children in Gaby Salas Davila's K3B classroom are very excited about paper airplanes this week. She offers to let them fold their airplanes in the classroom and test-fly them around the room. As free play ends and it is time to line up for lunch, Martin[1] , Casper, and Viva are still engrossed in flying the airplanes. Divani is curious about their airplanes and begins to make her own instead of lining up to wash her hands. Gaby mentions that if they had a place to do airplanes that wasn't in the middle of the classroom, it might help organize their day and make transitions like this easier for the children.

Co-design in the Study Group and Beyond

The next week, all of the Kindergarten teaching team gathers in the Clay room for their Study Group session. This session's focus is the Creator Space, and Amanda joins as a guest to help teachers brainstorm ideas and goals for the space. To support this brainstorm, the group engages in a values-identifying activity[2]. Teachers select cards that they feel resonate with their own teaching style and their goals for developing a KG Creator Space. Although the cards are useful, the important element of this activity is the conversation that it inspires among the teachers.

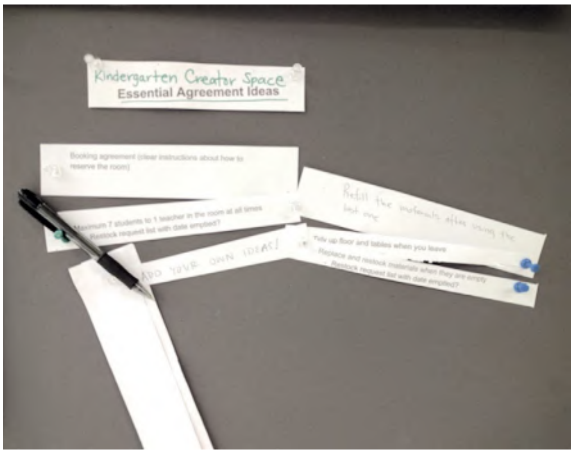
The group agrees on several learning goals that they believe are important for their Kindergarten Creator Space. These include: confidence, design thinking, problem solving, exploring sensory experiences, and feeling part of a community. The teachers refer back to themes that have surfaced throughout the year, such as designing a space that "says yes" to children.

Teachers choose cards to identify their favorite values that children can learn through making

The values cards chosen by the KG teaching team

In other words, teachers want to design a space where the furnishings and tools are invitations to play, and not temptations that teachers constantly need to monitor for safe use. A space that "says yes" implies that the environment evokes the freedom and creativity of a playground, rather than the strict rules of a museum. Teachers also mentioned striking a balance between rules of the space and the freedom to explore and make. By the end of the conversation, the teachers agree that they need to think about their needs and come up with a list of boundaries, or Essential Agreements, to govern the use of the space. They also have specific questions about materials, room layout, and scheduling that Amanda agrees to work on.

To continue the conversation begun in Study Group, many kindergarten teachers spend part of their team meetings or daily planning thinking about their goals for the Creator Space. For example, in the K3 team meeting, the teachers plan outreach to coordinate all of the kindergarten teaching team efforts. They discuss specific questions they have, like how to complete the list of Essential Agreements. Carolina Ayala (K3 assistant teacher) offers to coordinate with the Study Group to post their ideas for Essential Agreements on a bulletin board in the staff room. Marina also points out that materials ordering and management will become a consideration. Laura Tontsch (K3 assistant teacher) volunteers to assemble a list of materials requested from Study Group teachers, and to discuss the materials management and storage with the administration. Finally, Marina wonders about scheduling and sharing the space with Awanti's classes. Amanda takes this information to the administration, in order to work out an effective solution.



Teachers draft ideas for the Essential Agreements list, and post them on the Study Group board in the Staff Room

A few teachers also participate in one-on-one interviews with Amanda to further understand their Maker Values using the card sorting task. K1 teacher Ruth Baxter Hesseldal says that making something that "works" is not as important to her as letting children explore materials:

Ruth: "Instead of [the children] having a prearranged idea in their head of what they want to happen, it's more looking at what can I do with this thing, whatever it is in front of me. How does it feel? How does it look? How does it move? What can I make it do?"

She also touches on the art and craftsmanship, and the importance of offering opportunities for children to experiment and come to their own conclusions.

Gaby also talks about exploring with the materials:
Gaby: "Taking care of the materials is very important for us and we been trying to understand the way they use the material, and how they use it, and we've been giving them choices about how to use them, and examples."

She also speaks about the value of letting children develop their creativity through playful making:
Gaby: "you know, children are very creative, they really like to create, and it's always very important. You saw in our playing, it's very important for them to have that sense of personalization. And of course, the [...] pride that they feel when they make something."

A Gallery Walk of Documentation to Reflect on the New Space

It's April now, and the Creator Space has been used by the Kindergarten classes for the past few months. Children have explored such activities as foot-painting, KIBO robotics, building large models of houses, and investigations of materials using the light table. The Study Group has worked out a weekly schedule that allows everyone to access the space regularly. They can also make special arrangements to book the room after checking with the Study Group, Awanti, and the school administration. Laura continues to manage the materials and teacher requests for the room, volunteering part of her prep hours every week to as KG Creator Space Coordinator. She feels everyone is working together to keep the space warm and inviting for the children. The Essential Agreements that the group developed collaboratively are posted. Laura is pleased to find that classes adhere closely to the guidelines for number of children in the space, instructions to wear indoor shoes, and how to leave the room for the next group.

The Kindergarten Creator Space

Clockwise from top left: Two girls build a house out of bubbles; A KG class works on signs for the Creator Space; The KG candy wall offers a variety of materials; A boy explores colors on the light table

Today, the teachers are once again gathering in the Kindergarten Creator Space for Study Group, but this meeting feels different. They've organized a "gallery walk" of their work, with documentation posted on the walls. The guiding question teachers used to frame their documentation is, "How do children explore the Kindergarten Creator Space?". There are many different experiences, with some children diving right into exploration, and others feeling shy about the loose structure and freedom of the room. For example, when K3B children used the Kindergarten Creator Space to complete their unit on Communities, students were allowed free access to the candy wall to construct small buildings. Several girls hesitated and asked before taking items out of the bins, a few other students looked carefully into each bin before choosing the materials they wanted to use to build their house, and one student picked an excessive amount of items. The K3B teachers feel that it might have been a little overwhelming for one or two children in the class to have so much freedom in making, and this sparks a conversation within the Study Group about tailoring the presentation of materials to match teachers' knowledge of particular children.

As they reflect on the documentation, the teachers talk about how the work they are doing in the Pedagogy of Play Study Group feels more connected to the work they are doing in classes:

Ruth: "All that we've done is feeding into getting this space [the KG Creator Space] up and going, and we're using it"

Marina: "We've got a room! And it's not like yeah, we got a room and we're done – no, we're cat fighting for time in it!"

Group: "It's nice, yeah." "That's the best outcome I think."

Ruth: "Yeah, and we're using it. It's like it's real instead of just theory."

Andreia Adiaconiei (K2 teacher): "We have all this, like I can feel the pride that we are feeling and we feel like we've achieved something. The school and the parents should know about it, maybe more pictures on the boards and around the school. So when we have our Show and Tell for the parents, even though we haven't done much but it doesn't matter, just so that everyone can know what's going on and have a look at it."

Kindergarten teachers explore documentation during Gallery Walk. The guiding question was, "What do children do in the KG Creator Space?"

The teachers all feel a strong sense of community and ownership for all the work that they've put into the PoP meetings, the Kindergarten Playful Environments framework, and the Study Group. This Creator Space feels like a validation and a result of all that work; they know that the space has their unique fingerprint. Indeed, they're so proud of it that they're excited to share it with the rest of the school community.
The administration continues to be supportive of the project. In ISB's April Newsletter, the principal, Camilla Uhre Fog, writes:

The Kindergarten Creator Space (KGCS) is a hit! The Kindergarten Creator Space is working out so well, and it is positive how an idea, born in a study group, has become a reality. Laura Tontsch is contact-person for the space. The K teachers and children are working hard to care for and maintain the space, and we need everybody to support that.

This explicit support of the ideas and requests agreed upon by the Study Group shows how strongly the impact of the project has been felt throughout the school.
Now that the Kindergarten Creator Space is built, the Kindergarten Playful Environments Study Group is focusing on pedagogy and activities that support children's use of the space. For example, Laura invites families and children to collect items at home to bring in and donate to their new space. This home-school connection is meant to give the children a sense of ownership. Children are excited about the project, and want to know when they can take their found materials to the new Creator Space. Laura is pleased to see the children express so much joy and excitement about contributing to the new room.

As the co-design process shifts into the next phase, the teachers will continue to consider new questions that have emerged, such as: How can we iterate on the space to respond to children's needs for exploration and structure? How can we engage the broader ISB community in the activities that happen in the Kindergarten Creator Space? and How can we empower children to feel safe and confident in the space without overwhelming them? Additionally, since this project has been so successful, the teachers are excited to explore and redesign different spaces around the school that could be more playful for the children.

Makerspaces are exciting and full of potential, but this new style of learning requires careful and collective planning to fit into a school community. This picture of practice demonstrates one example of how teachers can come together and collaborate to design a space that suits their needs. When a new makerspace is being developed at a school, it is essential that teachers, staff, and administration all work together to realize their goals.

Notes

[1] When referring to children, pseudonyms are assigned throughout this paper

[2] The Maker Values Card Sorting task was initially developed by researchers at the Tufts Center for Engineering Education and Outreach to help teachers hone in on the specific areas of learning that they hope to see children develop in their maker space.

This picture of practice takes place at the International School of Billund (ISB) in Denmark, and is a product of the Pedagogy of Play (PoP) project, a participatory research collaboration between ISB and Project Zero, a research organization based at the Harvard Graduate School of Education. ISB serves approximately 320 children ages 3-14 from nearly 50 countries through a playful curriculum based on the International Baccalaureate framework. Supported by a generous grant from the LEGO Foundation, PoP seeks to better understand the relationship between play and learning in a school context, investigating what it means for playful learning to be at the heart of a school's culture and curriculum.

Author Bios – Alphabetical

David Alsdorf is an education researcher, curriculum developer, and teacher based in Cambridge, Massachusetts. He studied religion at Reed College, and first became involved in teaching as a volunteer in Cambridge Public Schools. His academic research is concerned with (among many things) narrative, make believe, and technology. He is also a self taught artist, and collaborated as an artist in residence on Project Zero's Pedagogy of Play project with The LEGO Foundation. Currently he teaches at the Acera School in Winchester, Massachusetts.

Marina Umaschi Bers is a professor at the Eliot-Pearson Department of Child Study and Human Development and an adjunct professor in the Computer Science Department at Tufts University, where she heads the interdisciplinary Developmental Technologies research group. Her research involves the design and study of innovative learning technologies to promote children's positive development, most specifically in early childhood She co-design the ScratchJr programming language with Mitch Resnick from the MIT Media Lab and she developed the KIBO robot kit for children 4 to 7 year old, that can be programmed with wooden blocks without using keyboards or screens old. Marina received a MEd from Boston University and an MS and PhD from the MIT Media Laboratory working with Seymour Papert.

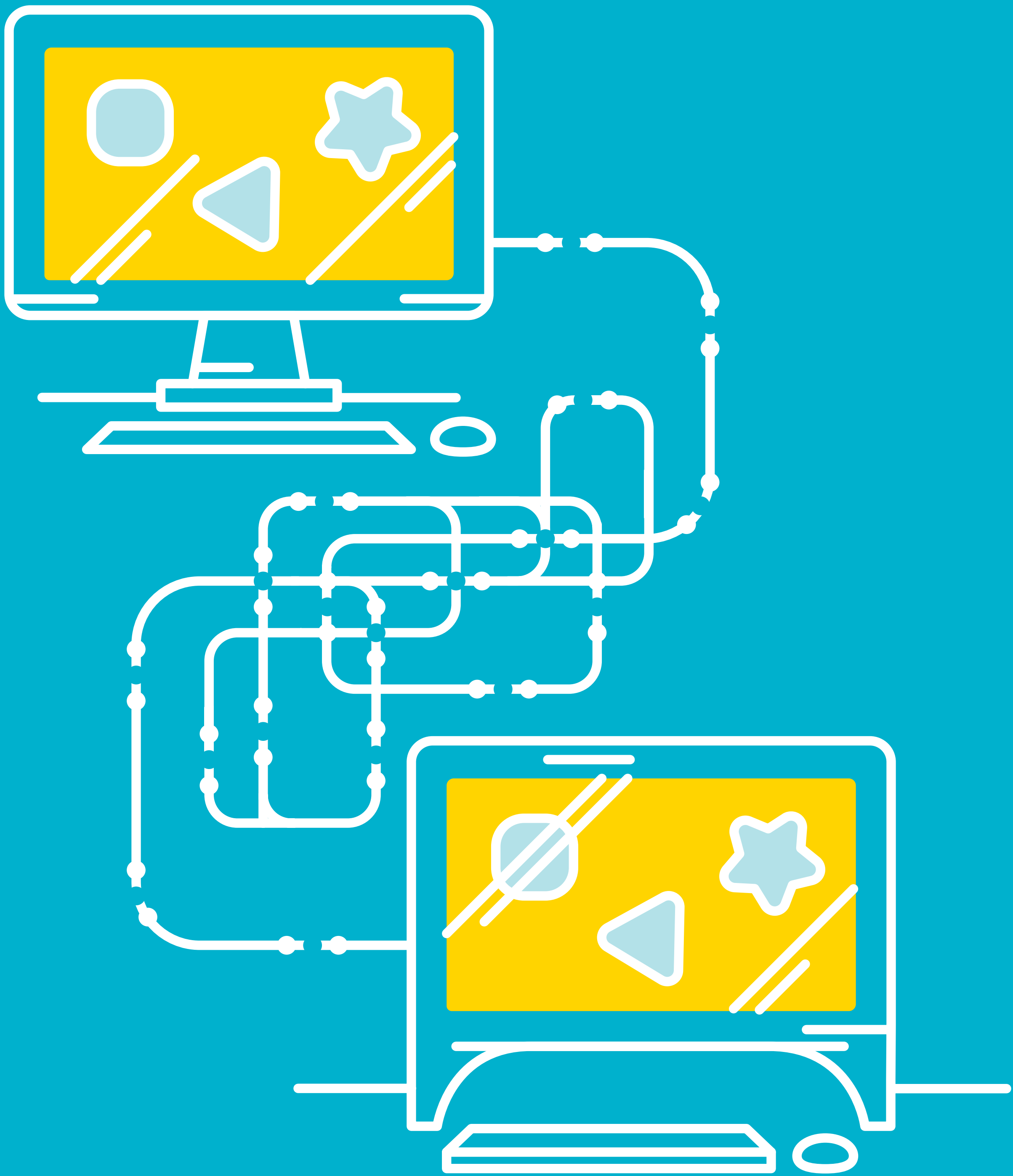
Dr. Ethan Danahy is a Research Assistant Professor at the Center for Engineering Education and Outreach (CEEO) with secondary appointment in the Department of Computer Science within the School of Engineering at Tufts University. Having received his graduate degrees in Computer Science and Electrical Engineering from Tufts University, he continues research in the design, implementation, and evaluation of different educational technologies. Ranging from software and hardware to interfaces and environments, Prof. Danahy explores how these tools can improve interactive educational pedagogies through supports aimed at learners in K-12 through university classrooms. With particular attention to engaging students in the STEAM content areas, he focuses his investigations on enhancing creativity and innovation, supporting better documentation, and encouraging collaborative learning.

Brian E. Gravel, Ph.D., is an Assistant Professor of education in the School of Arts and Sciences at Tufts University. He studies how people of all ages use representations to work and learn in STEM. As a former engineer and teacher, he has always loved building things and exploring how materials behave and interact. Brian's scholarship focuses on learning through inquiry with multiple representations, materials, and processes in making spaces and with expressive computational technologies. He was a developer of SAM Animation (now Hue Animation), SiMSAM, and participated in the formation of makerspaces in multiple schools. Through these strong partnerships with various communities, he grounds his design research in authentic contexts where, together, communities can build toward equity in STEM learning and participation. Brian holds a B.S. and M.S. in Mechanical Engineering, and his Ph.D. in Education all from Tufts University.

Matthew Mueller is a doctoral student in mechanical engineering and a research assistant at the Center for Engineering Education and Outreach at Tufts University, where he graduated in 2015 with a B.S. in mechanical engineering and a minor in engineering education. His research focuses on developing new interfaces for and ways to use digital fabrication machines and studying how students learn while using them. Matt's dissertation work focuses on musical acoustics, analyzing the quality of and building musical instruments, as well as studying how students engage in engineering practices while building their own.

Chris Rogers got all three of his degrees at Stanford University, where he worked with John Eaton on his thesis looking at particle motion in a boundary layer flow. From Stanford, he went to Tufts as a faculty member, where he has been for the last million years, with a few exceptions. His first sabbatical was spent at Harvard and a local kindergarten looking at methods of teaching engineering. He spent half a year in New Zealand on a Fulbright Scholarship looking at 3D reconstruction of flame fronts to estimate heat fluxes. In 2002-3 he was at Princeton as the Kenan Professor of Distinguished Teaching where he played with underwater robots, wind tunnels, and LEGO bricks. In 2006-7, he spent the year at ETH in Zurich playing with very very small robots and measuring the lift force on a fruit fly. He received the 2003 NSF Director's Distinguished Teaching Scholar Award for excellence in both teaching and research. Chris is involved in several different research areas: particle-laden flows (a continuation of his thesis), telerobotics and controls, slurry flows in chemical-mechanical planarization, the engineering of musical instruments, measuring flame shapes of couch fires, measuring fruit-fly locomotion, and in elementary school engineering education. His work has been funded by numerous government organizations and corporations, including the NSF, NASA, Intel, Boeing, Cabot, Steinway, Selmer, National Instruments, Raytheon, Fulbright, and the LEGO Corporation. His work in particle-laden flows led to the opportunity to fly aboard the NASA 0g experimental aircraft. He has flown over 700 parabolas without getting sick. Most importantly, he has three kids - all brilliant - who are responsible for most of his research interests and efforts.

Amanda Strawhacker is a Ph.D. student at the DevTech Research Group at Tufts University's Eliot Pearson Department of Child Study and Human Development. She completed her Master's in Child Development at Eliot-Pearson in 2013 and received the Eliot-Pearson Research-Practice Integration Award (2013) for her research with a Boston public school on robotic interfaces in kindergarten classrooms. Previously, she has served as the Project Coordinator of the ScratchJr Research Project, and the DevTech Lab Manager from 2013-2015. Currently, Amanda's research focuses on designing, implementing, and evaluating makerspaces, coding tools, and bioengineering learning experiences in early childhood education (K-2).



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