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The design of early childhood makerspaces to support positive technological development: Two case studies

Marina Umaschi Bers, Amanda Strawhacker, Miki Vizner,

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# The design of early childhood makerspaces to support positive technological development

## Two case studies



Marina Umaschi Bers, Amanda Strawhacker and Miki Vizner
*Child Study and Human Development, Tufts University, Medford, Massachusetts, USA*

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### Abstract

**Purpose** – With the advent of the maker movement, there has been a new push to explore how spaces of learning ought to be designed. The purpose of this paper is to integrate three approaches for thinking about the role of design of the learning environment: the makerspace movement, Reggio Emilia's Third Teacher approach, and the positive technological development (PTD) framework.

**Design/methodology/approach** – This paper describes two case studies that involved the design of two different early childhood makerspaces (ECMSs) through a co-participatory design experience: the Kindergarten Creator Space at the International School of Billund in Denmark; and the ECMS at (removed for blind review), a resource library in Medford, MA.

**Findings** – Based on the foundational education framework of PTD, and ideas from the field of interior design, this paper describes the design principles of several successful makerspaces, and case examples of children who use them.

**Originality/value** – By grounding the theoretical discussion in three approaches, the authors aim to suggest design elements of physical spaces in schools and libraries that can promote young children's learning through making. Recommendations are discussed for practitioners and researchers interested in ECMSs.

**Keywords** Design and development, Case studies, Denmark, Makerspaces, Early childhood education, Positive technological development

**Paper type** Case study



## Theoretical foundations

This section will present three foundations for designing makerspaces for early childhood education: the makerspace movement, Reggio Emilia's Third Teacher approach, and the positive technological development (PTD) framework.

### *The maker movement*

The educational maker movement is a grassroots global culture shift toward physical, interactive, and design-based learning models that include, but are not limited to, the use of novel technologies (Blikstein, 2013). Makerspaces, which are designed to foster a "process of inspiration, creativity, frustration, and breakthrough" (Petrich *et al.*, 2013, p. 56), are growing in popularity across the USA (Deloitte and Maker Media, 2014) and the world (Burke, 2014; Chang *et al.*, 2015). Within this approach, the concept of "making" emphasizes the learners as makers of their own projects by experimenting with "powerful ideas, tools, and literacies" (Blikstein, 2013, p. 2).

In an educational makerspace you might see children engaged in activities such as designing a table-top rollercoaster, building light-up sculptures using LED-lights and play doh, or creating a pinball machine out of recyclable materials (Blikstein, 2013; Thomas, 2013; Vossoughi *et al.*, 2013). The maker movement has rapidly gained national and international attention. For example, in the USA, the White House has instituted an annual National Week of Making, and worldwide Maker Faires have hosted over 1.4 million attendees (Deloitte and Maker Media, 2014; Maker Media, 2017).

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Often when people refer to makerspaces, they are actually thinking of the fabrication and high-tech tools within them (Meehan *et al.*, 2014). However, the project-based learning and community building activities that these spaces foster are critical to the essence of the space.

Peer-supported making and tinkering activities have been shown to have a positive effect on youth because of the potential for "feedback-in-practice," which contributes to deep and transformative learning (DiGiacomo and Gutiérrez, 2016). These learning experiences, which leverage distributed knowledge, collaborative design processes, and constructionist "learning-by-making" pedagogies, may be particularly relevant for learners with historically marginalized identities, who are typically not provided access to mainstream entry points to STEM education, or for learners who thrive with idiosyncratic practices that allow for personal motivation to drive learning (Azevedo, 2011; Honey and Kanter, 2013; Martin *et al.*, 2014; Papert and Harel, 1991; Vossoughi *et al.*, 2013).

The maker educational environment is characterized by a blend of project-based pedagogical practices alongside informal "ways of seeing, valuing, thinking, and doing found in participatory cultures," which contributes to participant reports of makerspaces "feeling like a family or a group of friends" (Sheridan *et al.*, 2014, pp. 527-528). All of these cultural elements contribute to young makers who develop cognition, character, and social skills, as well as technical and professional attitudes (Agency by Design, 2015). By intentionally designing an environment rich with technologies, tools, resources, and community values, makerspaces can provide makers with opportunities to develop identities as individuals and community members, uniquely poised to engage with and impact their world. In the early childhood context, the Reggio Emilia approach has long focused on these issues.

### *Reggio Emilia and the Third Teacher approach*

The maker movement pays special attention to the social practices, technology use, and peer-mentorship that characterizes a collaborative project-based learning environment, in addition to studying the kinds of tools and technologies that are needed to include in the space itself. This approach is consistent with the emphasis in early childhood education on promoting social learning (and not only academic skills) through designing the classroom environment as a "third teacher." Loris Malaguzzi coined the concept of the environment as a "third teacher" to capture the profound role that he believed environment plays in children's development, along with the "first" teachers, the child's caregivers, and the "second" teachers, the classroom educators (Biermeier, 2015).

Malaguzzi was the founder of the influential Reggio Emilia approach, a pedagogical framework for municipal preschools, which emerged shortly after the Second World War in war-torn Reggio Emilia, Italy. The Reggio approach is rooted in a deep respect for all community members, including very young children, and recognizes children's competency and contribution to the community (Gandini, 2011). The physical Reggio space is distinctive in its focus on natural materials, beautiful colors and textures, and loose, open-ended materials (2011). Reggio positions classroom educators as "researchers alongside the children" (Gandini, 2011, p. 3), who must actively listen and follow the interests of the children in order to structure curricular activities, rather than relying on a predetermined standardized lesson plan (Biermeier, 2015). In this way, the learning environment and its constantly evolving "provocations," (Biermeier, 2015, p. 74) or material offerings, provide the children a renewable source of collaborative investigation.

The Reggio Emilia approach and the maker movement share a similar philosophy and provide a foundation for understanding how a learning environment can be set up to improve and support an authentic teaching and learning process. The research presented in this paper, which focuses on early childhood makerspaces (ECMS), is grounded in this work and also integrates a third line of research: PTD, which provides guidelines for the kind of learning experiences children can have in the space.

*PTD*

The PTD developed by Bers (2012) informs the design of learning environments that promote good, developmentally appropriate experiences with technology. The focus of PTD is on how to design learning environments that promote positive behaviors through the use of technology. Bers (2012) describes how this quest "is inspired by an old question: 'How should we live?' The pressing issue is not what kind of digital landscapes we will build, but what kind of people we will become as we inhabit those spaces" (Bers 2012). Building on this, PTD challenges us to design spaces by asking questions such as: What kind of learners do we want our young children to become? Curious innovators? Creative problem solvers? Critical thinkers? Caring collaborators? Active citizens?

The PTD framework invites us to think about these questions by providing a model for how development can be supported through the use of new technologies (Bers, 2012), as well as guidelines for evaluation (Sullivan and Bers, 2017). As a theoretical approach, PTD grew from integrating constructionist theories of learning with and about technology (Bers, 2018; Papert, 1980) with applied developmental science, most specifically Positive Youth Development (PYD) (Lerner *et al.*, 2002; Benson, 2006; Damon, 2004). PYD explores the pathways of thriving individuals in the first two decades of their lives. The use of the term positive in both PYD and PTD connotes the goal of engaging a young person in a good, healthy, and productive developmental trajectory (i.e. development toward improvement of one's self and society).

PYD researchers use six C's to refer to developmental assets: competence (cognitive abilities and behavioral dispositions for being healthy), connection (positive bonds with people and institutions), character (integrity and moral centeredness), confidence (positive self-regard, a sense of self-efficacy), caring (human values, empathy, and a sense of social justice), and contribution (orientation to contribute to civil society (Lerner *et al.*, 2002, 2005). Taken together, these characteristics reflect a growing consensus about what is involved in healthy and positive development among people in the first two decades of their lives and the promotion of healthy communities (Scales *et al.*, 2000).

While PYD is a theory that explains positive behavior, it does not take an interventionist perspective, a design approach. PTD brings design into the discussion and focuses on technologies as tools to promote change. PYD describes a naturally occurring phenomenon (i.e. positive development), while PTD provides methods and tools for designing experiences where positive development is more likely to happen. Some of the questions answered by the PTD framework are: How can the learning experience and the learning space be designed to support cognitive, personal, social, and moral development? How can these designed experiences promote developmental milestones for healthy and productive psychosocial growth at each stage of growing up?

The PTD framework builds on the PYD's six developmental characteristics or assets (e.g. competence, connection, character, confidence, caring, and contribution to civil society) but focuses on behaviors. Specifically, on positive behaviors expressed through the use of technology. These behaviors also start with the letter C: content creation, creativity, choice of conduct, communication, collaboration, and community building. This second set of C's focusses on positive behaviors supported by technology.

Figure 1 shows the PTD theoretical framework composed of 12 C's: six assets derived from PYD, and six behaviors from PTD.

Our actions in the world change who we are, and who we are changes our actions in the world. There is a bidirectional relationship between developmental assets and technology-supported behaviors. The PTD behaviors that learners can engage in through the design affordances of a makerspace are:

- Content creation. The opportunity to engage children in computer programming or maker activities that engage them in working with different materials. In the process

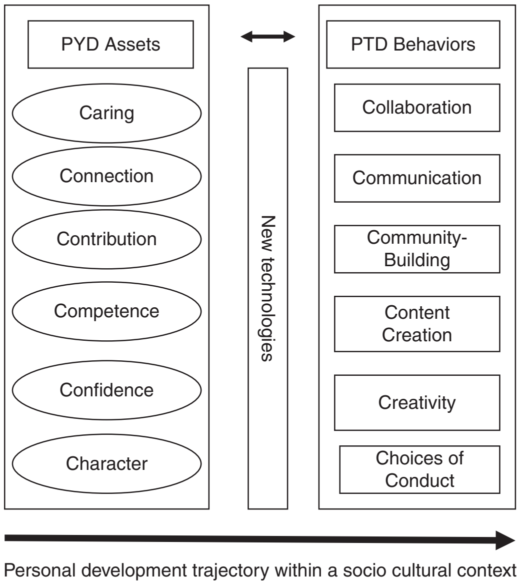


**Figure 1.**
PTD framework



of creating content, children also develop technological fluency. There is a strong relationship between content creation and competence. A sense of competence in the technological domain is displayed by the ability to use diverse computer applications to create content, to debug projects, and to problem-solve.

- Creativity. The ability to transcend traditional ideas, rules, patterns, relationships, or interpretations, and to create and imagine original new ideas, forms, and methods for using new technologies. Most constructionist tools that support content creation also support creativity. There is a strong relationship between creativity and a sense of confidence, which is further promoted when one can use technology in creative ways.
- Choices of conduct. The opportunity to make choices about our behaviors, explore "what if" situations, take action in the digital world, and experience the consequences. There is a relationship between choices of conduct and character. The moral compass that guides the use of technology in responsible ways is built upon having choices of conduct, the freedom to evaluate consequences of different "what if" situations and develop a sense of character.
- Communication. The process of interchanging thoughts, opinions, or information by using technologies. When the mechanisms for supporting communication are established, it is possible to envision ways of using technology to connect with others. New developments in the technologically rich world promote new ways of communication.
- Collaboration. The opportunity to work with others and to willingly cooperate toward a shared task. There is a strong bidirectional relationship between collaboration and caring. In order to collaborate we need to care about each other's ideas and needs. The more we establish and maintain positive bonds and relationships, the better we are also able to collaborate. Most technologies that support collaboration also provide ways for people to connect and communicate.

- Community building. An active stance toward using technology to form and enhance the community and the quality of relationships among the people of that community. Engaging in community building has a strong relationship with an orientation to contribute to society by using and inventing new digital tools to solve social problems.

## The learning environment is the message

Marshall McLuhan, the world-renowned scholar on media theory, popularized (amongst many other things) the phrase, "the medium is the message" (McLuhan, 1964). He was referring to the realization that the form of a medium embeds itself in any message. Thus, the medium influences how the message is perceived.

In this paper, we propose that the learning environment is the message. The design of the learning space (e.g. the ECMS) conveys the kind of learning we are promoting and what is most valuable in this educational process. Rosan Bosch, principal of an international design studio focused on designing the schools of the future, talks about how people need access to six basic "learning spaces" in which to operate in order to learn effectively. She created a typology of these spaces and labeled them metaphorically as the Campfire, the Watering Hole, the Mountain, the Cave, the Hands On and the Movement environments (Bosch, 2013). Each of these spaces carries its own set of design principles to support learning in its different forms. For example, while the mountain top is typically for one-way, broadcast communication such as lectures (but also for displaying work on walls), the cave supports concentration and focus, where individual learning is enabled; the watering hole is where fast informal knowledge exchange happens, for example, in a corridor or circulation area. It is where people meet occasionally and often randomly in a space with high levels of movement and disturbance, and high levels of knowledge exchange.

Bosch's discussion of learning spaces implicitly supports the Reggio Emilia philosophy, that environments themselves have educational value. However, Louis Malaguzzi focused on the nature and location of a space's materials which can serve as "provocations." Bosch takes this logic a step further, positing that the organization of the space itself – the seating, window features, the width, and depth of the room – contribute certain provocations of their own. For example, a narrow hallway provokes transit and thus, brief and fluid exchanges, whereas a recessed low-ceilinged area invites reflection and solitude.

Although Bosch and the Third Teacher approach focus on pre-designed spaces, the Maker Movement represents an educational agenda. Makerspace theorists argue that makers should be exploring digital competency, self-expression, and community formation through the creation of artifacts. The movement pays little attention to how these goals are met – indeed, some might argue that it is up to the makers themselves to determine how to cultivate their own learning experience. This presents a challenge to early childhood spaces, where children are too young to physically or philosophically create a collaborative space without some assistance from adults. The PTD framework provides a lens into these issues and engages in the investigation of questions that require the re-thinking of space and behaviors such as: How can educators and librarians create a space with enough structure to foster certain types of behaviors, while also inviting children's creativity and ownership of the space?

Bosch's typology of six learning spaces is in alignment with the PTD framework that also proposes six elements that inform not only the physical location of walls and lighting, structures and windows, hallways and open areas, but also the kinds of experiences and behaviors that we want learners to have inside them. Because of this focus on design as an avenue to cultivating learning experiences, the PTD framework is a useful guideline for shaping a makerspace as well as the activity within it.

The defining characteristic of any makerspace is the community of makers who use it and the kind of behaviors they engage in. Makerspaces offer a unique context to support

PTD behaviors. Table I describes how elements of a makerspace can be designed to promote each of the 6C behaviors.

By focusing on the 6Cs of PTD when thinking about the design of the makerspace, we highlight the importance of the behaviors that will be supported in the learning environment, and not only the kinds of tools that can be found. Thus, the learning environment becomes the message. Providing opportunities for children to engage in positive making behaviors, becomes the pedagogy of choice.

## Case studies of two ECMSs

The next sections of the paper present two case studies of a co-participatory design experience in the creation of two ECMSs built upon the foundations presented earlier: the Kindergarten Creator Space at the International School of Billund (ISB) in Denmark; and the ECMS at Tufts University in Medford, MA in the USA. Both spaces were designed as open-ended learning environments for young children to explore, design, and make, while promoting the six positive behaviors indicated by the PTD framework, but they each have unique institutional contexts and goals.

The Billund space, in Denmark, was envisioned as a shared resource room for the school's six Kindergarten classrooms (age three to six years) to use as part of their regular weekly activities. It is physically situated within a much larger makerspace that serves the whole school. The Medford space in the USA is designed for children ages four to seven, and serves as a research site for students in the Eliot-Pearson Department of Child Study and Human Development, as well as local pre-service and in-service teachers, to explore theory and practice related to making in early childhood.

The co-participatory design process used to develop both spaces involved semi-structured interviews, making sessions, and collaborative design experiences with teachers and children. In the Billund context, Kindergarten teachers and children were focused on developing ownership of the space, and differentiating makerspace activities from activities in their



| PTD behavior | Application to makerspaces |
|---|---|
| Content creation | Many people think of specific tools like 3D printers or laser cutters when they think of makerspaces. However, the tool itself is less important than the experience of building something, making a project |
| Creativity | Offering a variety of materials with different properties promotes diverse solutions and mixed-media projects. Different tools serve a variety of purposes and settings: cutting and connecting, large and small, physical and digital, crafting and experimenting |
| Communication | The physical design of the makerspace can promote different forms of communication (one-to-one, small groups, etc.). Additionally, areas that allow a moderate level of noise and group play can promote conversations and questions about each other's work |
| Collaboration | Large work stations (e.g. round tables, floor space) and materials that are large enough to require many children to use them (e.g. large foam building blocks) allow children to work together on projects and children to be inspired by others' work |
| Choices of conduct | A variety of tools and materials, some of which are more delicate or present extra safety requirements, can present opportunities for children to reflect on their actions to preserve the space, its tools, and materials. Facilitation is also key, as children will have socio-emotional challenges that they will need help coping with in order to continue making their projects. Quiet spaces for reflection can support the development of this behavior |
| Community building | A makerspace should reflect the community of children who use it. Posting images, quotes, and finished projects of children at a low height allows them to recognize themselves and their friends in this community. Additionally, maps and objects that represent the local neighborhood, town, or country can help to contextualize the community for children, and may inspire them to make projects that serve their community in a meaningful way |

**Table I.**
PTD Behaviors and applications to makerspace contexts

regular classrooms. In contrast, the Medford space was designed through a combination of research and outreach efforts with a broad range of Medford community members, including parents, teachers, university professors, and non-profits groups. The space continues to be iteratively developed with the Kindergarten community from the Eliot-Pearson Children's School, as well as other children and community members who enter the space.

In both case studies, through the co-design process, researchers, educators, and community members utilized different tools. They participated in focus groups and structured interviews, design reviews, explorations of potential tools to include in the makerspace, and small-scale projects. Researchers incorporated Reggio Emilia and Maker Movement principles into each space's design, and they also utilized the PTD Environment Checklist, developed by the DevTech Research Group (DevTech, 2017) to determine the extent to which each space could promote the six positive behaviors of the PTD framework for young children (Bers, 2012).

The PTD Environment Checklist is derived from the PTD Engagement Checklist, which is designed to provide a lens into how children are engaging with the behaviors described by the PTD framework in a particular context (Sullivan and Bers, 2017). While the PTD Engagement Checklist focuses on the children's activity, the Environments Checklist focuses on the setting and facilitation. It is divided into six sections (each one representing a behavior described in the PTD framework) and measured using a five-point Likert scale. For example, in the Choices of Conduct section, one item reads, "Tools/materials are offered that require children to use with care, such as materials and containers that are breakable or delicate, tools that have sharp edges, or tools that require focused attention to use." The item can be marked with the following choices: 1, never; 2, almost never; 3, sometimes; 4, often; 5, always; or 6, N/A or not observable. This item does not measure how much children display good conduct, but rather whether a space offers chances for children to exercise their judgment and caution. This version of the checklist is used to evaluate the affordances of the learning space to promote PTD.

The next sections present both case studies, by addressing their uniqueness and similarities in their implementation of the PTD-based design guidelines and the co-participatory design process. All names of children and teachers are pseudonyms, to protect their privacy.

## Case study: Billund, Denmark

The ISB, an English-instruction International Baccalaureate World School, is located in the municipality of Billund, Denmark – headquarters of the LEGO company, and self-declared Capital of Children (www.capitalofchildren.com). The ISB has a commitment to innovative education techniques, such as making. Their Creator Space is a multi-room makerspace at the center of the school that offers a wood shop, LEGO robotics lab, clay and paint studios, a textile workshop, and more. Despite the Creator Space's rich resources, the school's early childhood educators felt that it was missing key design elements that would allow them to invite their three- to six-year-old children to the environment. This need led to a co-design collaboration among the Tufts University research team, the ISB Kindergarten teaching team, and the Kindergarten children themselves.

As a part of the co-design collaboration, teachers participated in semi-structured interviews and focus group discussions to discover their teaching values around makerspaces. For example, Kindergarten teacher Marcia wanted children to learn responsibility and safe handling of "grown-up" tools like X-Acto knives. Pre-school teacher Emma wanted her children to develop their collaboration and cooperation skills. Kindergarten teacher Danielle wanted children to explore their creative sides. As you can see from these teacher's perspectives, the design of the space was less about having the latest, coolest technologies and more about creating spaces for positive behaviors to emerge.

Researchers collected teacher's thoughts and also made observations of children in various spaces around the school. Children were aware of their role as co-designers of the

Kindergarten Creator Space and were happy to test it and provide feedback and ideas. Teachers drew on their classroom experiences to identify needs and goals for this new space. This co-design process resulted in a shared environment that gained support from all levels of school administration and is personally meaningful to the children and educators who use it.

When you walk into the Kindergarten Creator Space at the ISB, the first thing you might notice is the carpet (see Plate 1). Here, you might observe three-year-olds building animals with DUPLO LEGO bricks, five-year-olds having a conversation about new parts of the KIBO robot that they've learned, or six-year-olds discussing the properties of hot and cold water (see Plate 2). Children may be sitting on low "bubble" stools, lying on cushions to read a book, or crouched next to the bookshelf examining pictures and artifacts from other children who used the space before them.

All of the activity that occurs here is purposefully crafted to engage children and adults in two behaviors specified in the PTD framework: communication and community building. When sitting for a focused discussion, children are communicating by listening to others, explaining ideas, and asking questions. Children can communicate in this space in

**Plate 1.**
The Kindergarten Creator Space at the International School of Billund

**Note:** This image was taken after the space was redesigned to foster PTD behaviors

**Plate 2.**
Three-year-old children in the carpet area work together with their teacher, following step-by-step instructions to build animals using DUPLO LEGO bricks

extroverted ways, such as chatting and relaxing with friends, or introspective ways, such as observing the class activity or quietly reflecting on a discussion. Developing community and civic connectedness is also a hallmark of the Reggio Emilia tradition. Reggio Emilia educators position themselves as researchers alongside the children they work with, to position all children on equal footing with adults in the classroom community. Circular spaces that promote group discussion allow for mutually respectful conversation and idea exchange. Designers of this space felt that the two Cs of communication and community building were essential for the young child's developing identity as a valued member of her classroom and school. Therefore, they chose to devote much cherished space to set up an environment that would promote them.

Before the co-design of the space, which is described in this case study, this area contained an open tile floor and a "tech center" (an audio-visual hookup for projecting onto the white board). The area was infrequently used, and the environment fostered a didactic, instructionist style of interaction, with one person teaching and others sitting and observing (Papert and Harel, 1991). By adding a soft, round carpet, and displays at a low height, the area was transformed into a child-friendly sitting space. More importantly, it invited group engagement by allowing children to sit in a semi-circle looking at each other rather than the wall; it encouraged open-ended discussion by providing interesting display objects to look at and wonder about (Curtis and Carter, 2014; Martinez and Stager, 2013). Using Rosan Bosch's typology, the space was transformed from a mountain to a campfire. This design choice was directly impacted by the need to foster community building and communication.

Next to the carpet, there is a low worktable large enough to seat 10 children. The table is a place that promotes hands-on exploration, where children can manipulate clay and glue, explore sensors and motors, compare beautiful objects, and build experiments (see Plate 3). The table is low enough for children to stand or sit, and wide enough for plenty of room to work on. The table promotes PTD's content creation and creativity. These two C's are directly aligned with Maker Movement values of agency, self-expression, and tool mastery. Children have ample room and materials to begin making their own projects through the use of a variety of low-tech and high-tech objects. At the same time, the height and size of the table allow children to see each other's and invite opportunities for creative interpretation and idea sharing.

**Plate 3.**
Children explore clay at the low worktable using a variety of decorations and tools, including sequins, buttons, and putty knives

Prior to the co-design experience, the art classes occasionally (e.g. perhaps eight weeks out of the school year) used the high table space and adult-sized rolling chairs for clay work. More often, though, the table was used for older children in language classes to come and take practice tests or study vocabulary. This was because the room felt "unused" and so invited a library-like study atmosphere.

This layout of the Creator Space was not conducive to more than traditional, independent work. By lowering the height of the table, children were able to actually use the table, see across to other children's work and other parts of the room, and to reach objects in the center of the tabletop (Burke, 2014). Various seating options (different height stools, adjustable chairs, even the option to stand) provided children different ways to orient their bodies, as they worked with their hands and minds (Curtis and Carter, 2014).

Past the worktable is a wide-open area with floor mats, a low bench, and an upright mirror (see Plate 4). This is the workshop area. Here, you might see children building blanket forts, testing on the floor a new robotic program that repeats forever the same action, or painting huge sheets of paper with their feet and hands. The workshop area is a whole-body area for testing, trying, and figuring things out. When children have room to play, they are able to work together in large groups to build large structures.

This wide-open area provides opportunities to negotiate the developmentally appropriate social challenges of working on a shared task, and engages children in collaboration and choices of conduct. For example, Mads, Vincent, and Rukti are all exploring the KIBO robot in the workshop area (see Plate 5). They are sharing a few pieces of equipment at the same time. Vincent says, "Mads, your turn is over! Someone else needs a turn now." Mads exclaims, "No, it's not! I still can't make the light work." Rukti says, "I want to try the light also!" Vincent holds up a "Light On" programming block and says, "Wait I know! You need this block. We only have one, Mads, so we need to share." Mads thinks a moment "Ok, Vincent builds the program and Rukti can scan it, and I can press the button." The children all agree, and busily work on their light-up robot. The affordances of the space and tools motivated the children to work together to come up with their own solution to this disagreement. Here again is the influence of the environment as a Third Teacher, promoting a spirit of community involvement and conflict resolution among children. They are developing technical and collaborative skills with the KIBO robot, but more importantly, they are also strengthening their sense of character through their actions and choices.

**Plate 4.**
The workshop area provides a venue for children to test creations and collaborate with other children self-motivated projects

**Plate 5.**
Kindergarten children program a robot in the workshop area of the creator space



Previously, this area of the room was a storage area for drying paintings and sculptures, and for extra art supplies. Although the large corner offers a bulletin board and a window, it was an open-access closet. The choice to add low storage around the walls encourages children move around while they make, and take only what they need from shelves (Bers, 2012). The mirror and peripheral seating allow children to watch each other while they work. Because of the open floor, children can fluidly join groups or separate to work alone on projects as their design process ebbs and flows (DiGiacomo and Gutiérrez, 2016). These behaviors are characteristic of the PTD's collaboration and choices of conduct, which the area was designed to support.

## Case study: Medford, USA

The ECMS is located at the Eliot-Pearson Department of Child Study and Human Development (see Plate 6). The ECMS is housed in the Evelyn G. Pitcher Curriculum Resource Laboratory, and shares the Curriculum Lab's goal of presenting a space for developmental researchers, pre-service teachers, and education professionals to gain hands-on experience with current trends and best practices in the field of Child Development. The ECMS was created to foster and serve an active making community of children, educators, and families, and to provide a venue for the DevTech Research Group and students at the Eliot-Pearson Department to research novel tools and practices related to making in the early childhood context.

Plate 6.
Children and adults engage in making at the early childhood makerspace



The Evelyn G. Pitcher Curriculum Resource Lab is a resource library with a stated mission to provide "scholarly resources, classroom teaching materials, and professional development workshops" to Eliot-Pearson community members working with young children and their families (Johnson, 2017). The area of the Lab chosen to become the ECMS was previously a "computer lab," with a bank of desktop computers and two printers. Researchers and teachers were coming to the Curriculum Lab with questions about technology, engineering, and the maker movement, and the resources needed an update. Two graduate researchers from the DevTech Research Group worked with the Curriculum Lab coordinator to design a space that incorporates maker tools and STEAM content into a developmentally appropriate space for young children. The research team held brainstorming events with local educators, engineers, artists, parents, and others involved in the maker movement to generate ideas. The ECMS was launched based on these ideas. Currently, the space continues to grow and change as children from the Eliot-Pearson Children's School and surrounding area schools, as well as researchers and community members from Tufts University, explore making in this new setting.

One of the first things you might notice about the ECMS is the wide-open floor with neutral-colored foam tiles. Throughout the room, there are comfortable bean-bag chairs, over-sized pillows, and a round table with several child-height chairs. This comfortable expanse is designed to allow children to build and play. The various work spaces and seating options encourage children to fluidly shift between group-work and independent play, or between large building on the floor or focused, hand-held work at the table. A row of shelves on one side of the room offers large construction kits, including the Rig-a-majig (a wooden block kit with simple machines like levers and screws), and a prototype of the Curious Construction Kit (a cardboard building kit with digital outputs) (see Plate 7) (Vizner and Strawhacker, 2016). Many of these parts are so heavy or long that two children must work together to use them, which fosters conversation and planning throughout the building process.

If you visit the space when children are here, you will hear ongoing conversation, with many children participating in projects in different ways. The open work area promotes cross-pollination of ideas and communication, but also presents opportunities for children to hone their collaboration skills. For example, Jon and George are both working with the Rig-a-majig kit to build an "elevator" (see Plate 8). Jon says, "George, we need to make it sturdy. How do we get the top part [pulley wheel] to stay on?" George replies,

**Plate 7.**
Large building materials line one wall of the makerspace

**Plate 8.**
Kindergarteners Jon and George use the Rig-a-majig to build a working pulley system

"I know! We need a bolt and screw. Watch me do it." Jon watches, and then announces, "I'm going to try that. Can you hold the bottom for me?" Jon and George are learning how to collaborate and work together on projects by splitting up work. They are also practicing how to communicate their building instructions to each other, both verbally and through demonstration. The wide work area and large-scale building tools allow them to work together, and to engage in the C's of collaboration and communication.

Before the floor was transformed into a work area with foam tiles, it was purely a work station for college students, with rolling chairs, computers on desks, and cold laminate tiles. Although the room had expensive technological equipment, the college students rarely used it, choosing instead to work in cozy library corners and on couches around the rest of the building. The positioning of the chairs did not promote communication, and instead functioned more like a series of individual work cubicles. The space was clearly designed to promote a quiet, library-like atmosphere, but the sterile furnishings resulted in an empty work area. Now, the ECMS floor area serves as a watering hole in Bosch's typology, encouraging communication and collaboration, two important aspects of PTD.

As you walk through the room, you might begin to touch and play with some of the other building and prototyping tools around the space. Along the walls of the room, you will find robotic kits, circuitry materials, and digital fabrication equipment, including a vinyl cutter, powered hand tools, and several robotics kits for young children, such as KIBO (www.kinderlab.com), BeeBot (www.bee-bot.us), Code-a-Pillar (www.fisher-price.com), Ozobot (www.ozobot.com), and more. These high-tech tools are interspersed alongside traditional building tools, including packing foam, cardboard, clay, scissors, tape, and metal brads. Children using the space are adept at mixing materials to create inventive designs, such as castles made of wood blocks and LEGOs, with electric lights and a doorbell. Mixing media is not only a fun way to engage in the creative process, but it also allows children to develop mastery of their tools and materials as they stretch the limits of their use (Matthews, 2003). In this way, the space fosters creativity and content creation.

The availability of diverse materials and tools allows children to extend ideas from their imagination into making an object in the real world. For example, 2nd grader Nate and his Kindergarten brother, Joseph, have been designing imaginary teams for their favorite sport, football. Nate says, "I want to play for the Dover Dragons! What would their jerseys look like?" The boys draw different dragons and lizards on paper and talk about jersey colors. When they tell the makerspace facilitator, Melissa, they want to make t-shirts, she shows them the vinyl cutter connected to the computer. Together, they load up the software, type their names and team numbers onto the jersey, and then find pictures of dragons to paste onto the other side of the shirt (see Plate 9). Nate carefully places the blade into the vinyl cutter, Joseph selects the

**Plate 9.**
Children used the computer and vinyl cutter to create their jerseys for an imaginary sports team

iron-on vinyl, and within seconds they have an outline for their shirts. While they help Melissa to iron their designs onto red shirts, Joseph exclaims, "When we play football it will look like we're really on the Dover Dragons! I bet other kids will ask where we got these shirts, they look like they're from the store!" The pride these boys take in their professional-looking creation is evident. This is the kind of scene that the Maker Movement promotes: inventive, personally meaningful projects that are technically challenging to implement but promote perseverance and even collaboration to see through to completion.

Before the ECMS came to exist, the computers in this corner of the room were only used for printing, researching, and reading articles. The computers were not positioned alongside crafting or building materials, but were lined up for individual use. Because of the variety of tools, technologies, and techniques on display at the makerspace, the same computers were transformed from digital textbooks into artistic instruments.

Finally, you might notice the walls and decorations around the space. The walls display pictures and drawings created by children who use the space. This helps contextualize for the children the other makers who use the space, and also allows them to "see themselves" in the room. For example, six-year-old Sophie is looking at all the drawings on the wall and suddenly reaches out to one. "Julia," she says, "did you make this picture?" Julia looks up from the beads bracelet she is working on and says, "Oh yeah, I did. Isn't it cool? I tried really hard on the cat part." Sophie and Julia have a conversation about drawing animals, and Julia offers tips about drawing fur. This is a common example of how the displays in the room are chosen to foster community building and choices of conduct.

The ECMS reading nook has several bean-bag chairs, pillows of different textures, and a basket of books. A child sitting on the bean-bags can look up to see the "shelves of wonder," a set of clear plastic shelves that allow children to examine unique objects from the bottom (see Plate 10). The reading nook is a place for children to sit quietly and plan or reflect without being disturbed by others. This space is also heavily infused with natural materials, from the wooden blocks and logs surrounding the bean-bags to the vining plant draped across the shelves of wonder. Reggio Emilia philosophy prizes beautiful, organic materials as critical for a child's ability to relax and concentrate. Similarly, in Bosch's typology this nook is a cave, a place for deep thinking and concentration, because of its isolation and

**Plate 10.**
The shelves of wonder allow teachers to provide children with new provocations and promote a new perspective of objects

uniqueness in the space. Although makerspaces are environments designed for collaboration, in early childhood it is crucial to carve out a place for children to take time out and disengage from a busy place.

Four-year-old Jamey and six-year-old Eric are working on building a huge robotic chinchilla. Jamey is attaching a two-foot chinchilla head that she constructed onto a big robot (see Plate 11) that Eric has just finished programming. The robot, called "Big KIBO," is a prototype built by one of the authors that is heavy (150 lbs) and large enough for up to two children to ride (22″ wide by 30″ long by 10″ tall). Suddenly Jamey erupts into tears – her chinchilla head has fallen apart. She runs over to the reading nook to take a break away from the frustrating robot. Eventually Jamey returns to find Eric trying to repair her head. "I don't need your help," Jamey tells Eric, to which he replies "but that's what friends are for!" She thinks for a moment, nods, and then the two of them work to re-attach the new head.

During their work on this project Jamey and Eric engage in a "process of inspiration, creativity, frustration, and breakthrough" typical of makerspaces designed for older populations (Petrich *et al.*, 2013). For young children, the frustration inherent in this process can be overwhelming as they are still learning to manage their emotions. However, the reading nook at the ECMS was explicitly designed to address this developmental need, providing a place to "cool down" while remaining in the periphery of the work area. Eric was also able to continue working on their project, and to exercise how to build community through shared construction.

Before the ECMS redesign, there was almost nothing on the walls of the space. The concrete walls were blank except for a few posted notices about proper use of the computer equipment. The room could have been located in any museum, high school, or administrative building. Currently, the makerspace contains images made by the children who use the room, plants, and pine cones that are native to the local ecology, and projects that represent the children's local neighborhood and environment. These choices were

**Plate 11.**
Jamey and Eric attach a repaired part to their robotic chinchilla

specifically made to engage children in community building. The computer lab prior to the redesign only offered one type of activity: working independently on a computer. Now the makerspace offers many opportunities to learn technical and social skills alone, in small groups, or with a large cohort of peers. With this freedom often comes frustration and growing pains, so the design of this space also includes spaces to reflect and cope with choices of conduct that children will face, and learn how to make the right choice for themselves and their community (Bers, 2012).

**Discussion: from space to pedagogy**

Based on findings, the PTD framework is a useful guideline for designing makerspaces for this age group. Although the makerspaces were explicitly designed with PTD concepts in mind, both spaces were also inspired by the Maker Movement and the Reggio Emilia Third Teacher approach. In the following discussion, the influence of these elements is discussed, as well as the outcomes from children's activities that point to the success of the makerspaces. Finally, future directions for research and practice are outlined.

*Influences of the maker movement, the Third Teacher approach, and PTD on space design*

This study describes two multi-purpose spaces for older youth that were repurposed into makerspaces for young children. The influences of three foundational design philosophies show through in the design of each room.

The Third Teacher approach can be seen in decorative organic objects (e.g. plants, pinecones), wooden furniture, and visually interesting elements such as window hangings, mirrors, and soft textiles. The facilitators of both spaces work to document the activity in the room with pictures, quotes, and labels which are posted around the room near the finished and in-process child-made artifacts that they describe. This "museum style" approach to room cultivates a sense of community, as well as a respect for creative, original work. These values are at the heart of the Reggio Emilia philosophy.

Inspired by the Maker Movement, both spaces offer tools for open-ended physical construction, all appropriately sized for young children, and within easy reach of the average four-year-old child. Low-heat glue guns, KIBO robotics kits, and small hand tools allow children to create comfortably. Additionally, the Maker focus on agency comes through in mobility and modularity of many elements in both rooms, including light, moveable materials baskets, adjustable floor tiles, and rolling storage furniture.

The PTD framework has also influenced the tools and materials of both spaces. Novel technologies in both spaces offer opportunities for children to explore and create digital content. These tools include a range of robotic kits and programming environments, vinyl cutters, tablets and camera equipment, all modified or designed for children ages three to eight years. These tools are not important because they are advanced and challenging, but rather because they offer ways for children to design, build, and iterate on constructions quickly and meaningfully. This allows children to easily advance to using tools as media of expression, without getting stuck on difficult hurdles blocking the path to digital creation.

*Successful making in early childhood*

A measure of success for any makerspace is the frequency with which the space is used by its target audience. At both case sites, children regularly volunteer or request to work in their makerspace, and teachers actively schedule makerspace time, sometimes negotiating with many others for access to the popular rooms. In practice, children in both makerspaces engage in behaviors and experiences prized by all three foundational design philosophies.

During observations of children in both spaces, a few key findings suggest that the spaces are successful and the makers who use them are thriving.

*Finding 1: artifacts in the space stimulate community building*. Children in both spaces were regularly observed to initiate conversations and collaborative making activities with other children, and sometime even with children from outside of their classrooms. Often these connections were motivated by some artifact or picture that was on display in the space. Recall the example from the Billund space, in which several children were observing a sculpture and image when they recognized the child in the picture who made it. This led to a conversation about community connections (e.g. students identifying the child, relating him to his brother in their classroom, calling his attention to the sculpture) and also inspired these children to later request posted pictures of themselves and their own work. They wanted to be able to share the experience of familiarity and recognition in this new room with children from other classes. This kind of sharing occurred in the Medford space when two girls began to teach each other drawing techniques because one of them was inspired by a picture the other girl had drawn and put on the wall. Scenes like this frequently occur in the Medford space, with images and blueprints from one group influencing the work of later groups. For example, a girl who was curious about disabilities created several blueprints and constructions of crutches. This displayed work inspired later groups to explore other tools that aid healing and disabled people, and one group of children (who recognized the girl's name) spent an hour creating wheelchairs and elevators out of Rig-a-majig and KIBO robotics. They were excited to tell her about their work when they met her again back in the classroom. In both spaces, the choice of digital documentation, as well as the public display of documentation and projects at child's eye-level, contributed to a community spirit that includes children even when they are not physically in the room, adding to the rich culture of the makerspace.

*Finding 2: children explore new ideas and express themselves using novel tools and media*. Makerspaces are distinct from other learning spaces in part because of their unique equipment for inventing, designing, and tinkering. Children in the Medford space decorate and program moving robots the size of their own bodies with Big KIBO, design custom stickers, sport jerseys, and puppets with vinyl cutters and 3D milling machines, and film their own movies using video cameras and stop-motion animation apps on tablet devices. Children at the Billund space program KIBO robots complete with sensors and light outputs, and tell stories using tablet apps like Scratch Jr Children in both spaces make projects that are familiar in pre-school classes, such as modeling an animal, designing a dream room, or telling a story about their family. However, by exploring these classic creative experiences through the medium of completely novel tools, like computers and programmable robots, children also engage in character and community-building PTD behaviors.

### *Recommendations for libraries, centers, and schools*

In the makerspaces presented in these case studies, child makers engage in PTD-related behaviors and experiences, such as collaboration and communication with peers, and developing competence and confidence using digital tools. Children demonstrate Maker Movement values of agency and innovation, and demonstrate respect for others and their creative works that comes from the Reggio Emilia Third Teacher approach. Libraries and schools can use principles from these examples to enrich the learning in their own ECMSs.

A key element in an ECMS is a selection of novel digital tools designed specifically for young children. High-tech tools such as 3D printers and laser cutters were purposefully not offered in the case spaces because they are prohibitively complicated and time consuming to use, and cannot sustain a child's focus. In contrast, robotics kits like KIBO, and programming environments such as ScratchJr, and rapid prototyping tools like vinyl cutters are fast enough to sustain a child's interest, and simple enough that they can use them without extensive adult guidance. These tools and experiences are critical for children to engage in PTD.

In order to achieve Maker movement goals of allowing makers to develop personal agency and expertise, spaces should offer a range of construction tools for different purposes. These should all be manageable by children (either working alone or collaborating in pairs or small groups), and should be appropriately sized and shaped for young children. Workspaces, storage, and other areas in the space should be sized to suit the average child using the space (e.g., for pre-school children, tabletops should not exceed 54″ tall, US General Services Administration Public Buildings Service, 1998). Tools that allow children to construct in a range of sizes should be offered, such as table top building kits (e.g. LEGO bricks) and large-scale building kits (e.g. Rig-a-majig). Additionally, tools and materials should be powerful enough for children to create lasting projects. Some suggestions include wood and screws, hand tools, and hot glue guns.

The Third Teacher approach allows librarians and educators to foster a sense of community using principles from space design. Spaces should offer documentation that tells a cohesive story about the children and adults who use it. This can take the form of written and picture guides, audio-recordings and video, or simply displayed work with images or captions about the maker. The documentation should be worded and positioned so that children as well as adults can engage in observation and wondering about the community. Additionally, facilitators should use details in the room as opportunities to bring in beautiful materials, natural objects, and esthetically and physical appealing experiences. Cushions for relaxing while reading wall documentation, large windows near work areas, and artifacts such as suncatchers or colored glass bottles offer ways to bring natural elements into the space, while simultaneously adding layers of interest for makers and visitors alike.

## Future directions and research

These findings are exciting for the burgeoning maker movement, but bring new questions for makerspace research and practice communities to address. Once libraries have active spaces, the logical question that facilitators and librarians may ask is how well their space is working toward their goals. In our research, qualitative depth observations and descriptions of activity have verified that children engage in the kind of activity the spaces were designed to foster. Specifically, children exhibited behaviors rooted in PTD, the Maker Movement, and the Third Teacher approach. Future work should explore assessment techniques, both clinical measures for researchers to replicate these findings, and practice-based rubrics for librarians and educators to efficiently gauge the success of their spaces. Additionally, the cases in this study involve typically developing children. A key area of focus for the Maker Movement is equity, access, and inclusion. Next steps can explore the developmental needs of unique populations of young children engaged in making, in order to create a more diverse set of makerspace recommendations. Finally, both case makerspaces represent formal education settings. Future work should integrate findings from formal and informal maker settings, in order to maximize children's engagement and internal motivation in formal makerspaces, and to characterize and evaluate the learning that takes place (but is not often assessed) in informal spaces.

## Conclusion

As shown through the two case studies presented earlier, the design of a physical space conveys a powerful message about the kinds of learning behaviors it can support and promote. Informed by the PTD framework, the ECMSs in Billund and Medford were carefully co-designed by a team of researchers, teachers, children, and community members to support the 6Cs: content creation, creativity, communication, collaboration, community building and choices of conduct. The goal of these makerspaces is not only to provide tools for making high-tech projects, but also to provide the needed scaffolds and supports to engage children in positive experiences that are developmentally appropriate. Furthermore, these spaces convey a strong message about the nature of teaching and learning. We learn best by doing, by making, by engaging in conversations and collaborative hands-on projects that integrate skills and disciplines (Bers, 2012). This emphasis on "project-based learning", "interdisciplinary learning," and "peer learning" as the pedagogies of choice for the ECMSs is mirrored in the way the learning environments were designed.

However, as any early childhood educator knows, this kind of learning cannot, and should not, be limited to only one room (e.g. a makerspace) in the school. Back in the 80's, when computers started to become popular and educators understood their teaching and learning potential, schools went ahead and heavily invested in building computer labs, with rows of fixed desktops facing a screen. As people understood the power of computers to not only to copy information, but for creating and making personally meaningful projects, the design of these computer labs became obsolete. The design of the space did not match the pedagogical goals. Furthermore, as the cost of the equipment became significantly reduced and the pedagogical understanding of how computers could be used to promote interdisciplinary, project-based learning advanced, many schools understood that the concept of a segregated computer lab also segregated this hands-on, constructionist pedagogical approach to just one room. Computers slowly left the computer lab and became available in every classroom, sometimes through rolling carts or through lending programs or BYO device initiatives.

Is this the future of makerspaces? Will the need and desired of schools to have a makerspace mirror what happened to computer labs? Nowadays, as 3D printers and other technologies become cheaper and more available, there are early signs that makerspaces might follow this trajectory. Projects such as Wendell's' Portable Maker Workshop initiative (Wendell, 2017) and Gierdowski and Reis' (2015) MobileMaker experiment both aim to develop approaches for bringing making into a variety of learning settings. For example, Wendell (2017) has developed a set of easily movable design kits on a rolling cart, which stores curated materials, lesson guides, and activity ideas. These kits are "small enough to fit in the back of a small car," and contain materials grouped by function (e.g. tools for fastening, measuring, or cutting) and learning content (e.g. electricity, water flow, sturdy structures) (Portable Maker Workshop, 2017).

In the future, every classroom in every school might become a makerspace where children are engaged in making to learn and learning to make. Will the design of the learning environments of the future match the desired pedagogical goals to promote learning by doing through interdisciplinary projects in a community setting? Our hope is that, as shown in this paper, the emphasis will not be limited to the technical tools available to support making, but will extend to the design choices that can support the kind of positive behaviors the overall experiences in the space can promote.

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**Corresponding author**
Amanda Strawhacker can be contacted at: amanda.strawhacker@tufts.edu