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# ScratchJr Bots: Maker Literacies for the Hearts and Minds of Young Children

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**Abstract**

This paper describes the ScratchJr Bots project aimed at helping young children develop maker literacies, which is the ability to design, program, and build technology-rich projects with developmentally appropriate tools to express themselves. Maker literacies can involve hands-on learning, collaborative experimentation, critical thinking, and problem-solving, as well as the development of socio-emotional skills. By engaging with the design process, children become active creators rather than passive consumers—brainstorming ideas, prototyping, testing, and making improvements toward sharing a final project. Maker literacies engage children in Positive Technological Development in the form of six behaviors—content creation, creativity, choices of conduct, communication, collaboration, and community building. Additionally, children develop character strengths, or virtues, such as patience, generosity, and forgiveness while making. This paper will first introduce the concept of maker literacies as it applies to early childhood and the theoretical background supporting this work. Then, it will introduce the ScratchJr Bots project developed by the DevTech Research Group, a new technology and curriculum that affords the development of maker literacies. Finally, by using design-based research as the methodological approach, two pilot projects are described, including children's learning experiences, to illustrate the positive behaviors and character strengths that children can exhibit while engaging with ScratchJr Bots.

**Keywords:** robotics; early childhood education; maker literacies; computer science; humanistic education; character development

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## 1. Introduction

There are both developmental and economic benefits to beginning computing education in early childhood. Computing education encompasses computer science and robotics, both of which aim to strengthen children's computational thinking. Computational thinking (CT) is a term coined by researchers to refer to an analytical process rooted in the discipline of computer science. It involves thinking recursively, applying abstraction, breaking up a complex problem into smaller tasks, and using heuristic reasoning to discover a solution (Wing, 2006, 2011, 2017). The term CT is still evolving, but for present purposes, we will define CT as the set of higher-order thought processes that allows framing and solving problems using computers, robots, and other computational devices (Bers, 2020). Mastery of CT requires a broad set of cognitive abilities, including but not limited to pattern recognition, conceptualization, sequencing, planning, and problem-solving. Computing education has also been found to strengthen critical thinking, a higher-order skill closely related to CT (Moraiti et al., 2022). Such skills can help prepare children for active and engaged learning when introduced at an early age (O'Reilly et al., 2022). Furthermore, as children work with technology, they can also develop their creativity as innovators who can think in new ways (Papert, 1980; Resnick, 2018).

Research shows that educational interventions beginning in early childhood in general are associated with lower costs and more durable effects than interventions that begin later on (e.g., Bustamante et al., 2023; Cunha & Heckman, 2007; Heckman & Masterov, 2007). A report from the National Academies of Sciences, Engineering, and Medicine (2024) stresses that an enriching and effective preschool education can allow all children, specifically those from marginalized populations, realize their full potential. Other science, technology, engineering, and mathematics (STEM) education researchers have found that children who are exposed to STEM curriculum and activities at an early age demonstrate fewer gender-based stereotypes regarding STEM careers and an increased interest in engineering and computer science (Sullivan & Bers, 2018; Metz, 2007; Steele, 1997) and fewer obstacles to entering these fields later in life (Madill et al., 2007; Markert, 1996).

However, if computing education is to start in the early years—when children are just starting to develop literacy and numeracy skills and are adjusting to formal schooling for the first time—there is a need for pedagogical approaches, curricula, and programming languages that are developmentally appropriate for young children (Bers, 2019, 2022). There have been numerous efforts to develop such tools and pedagogical approaches (Macrides et al., 2022; Yu & Roque, 2019), many of which draw upon play- and project-based learning. Research in the learning sciences documents how STEM activities, when embedded in playful experiences, can provide rich contexts for children to understand the relevance of STEM to their daily lives, develop a STEM identity and a long-term interest in STEM, and provide opportunities to understand the wide applications of STEM skills (Ahn et al., 2018; Azevedo, 2011; Azevedo & Mann, 2021; Clegg & Kolonder, 2013).

There is also an emerging body of research on socio-emotional learning and the development of character strengths that occur in STEM interventions (Bers, 2021, 2022; Dumitrache et al., 2023; Garner et al., 2017). Socio-emotional learning includes understanding and regulating emotions, understanding and empathizing with others, positive decision making, and navigating interpersonal challenges (Elias et al., 1997). Computing education, like many educational settings, offers a rich landscape for exploring both interpersonal and intrapersonal challenges. In a computer science class, children may work together on a project in which they must communicate their ideas and settle disputes amongst one another, or they might encounter errors or bugs in their code, forcing them to overcome frustrations and practice flexibility when exploring different solutions. Frameworks such as Positive Technological Development (PTD) (Bers, 2012), discussed more in-depth below, point to ways in which technology education can and should be shaped to cater to a child's positive development.

Computer programming initiatives are growing in popularity amongst early childhood researchers and educators, and results seem promising regarding children in K-2 mastering coding, which in turn might support learning of problem-solving, foundational programming, and discipline-specific content in mathematics and literacy (Bers, 2018; Hallström et al., 2014; Werner et al., 2014). However, while CT and coding are important skills, these activities do not capture the full potential of what children can learn with new technologies. This paper explores the concept of maker literacies that can have an impact on the heart and minds of young children, that is, on both socio-emotional and character strengths, as well as cognitive learning. The development of maker literacies can support the teaching of computer science as a humanistic endeavor (Bers, 2025).

## 2. Literature Review

### 2.1. The Maker Movement

The concept of maker literacies emerged from the broader maker movement, a movement that emphasizes hands-on, project-based learning and a shift from passive consumption to active creation. The growing maker community is characterized by its do-it-yourself ethos and commitment to a fluid design cycle in which discovery and experimentation are valued and produced artifacts are shared, continuously remixed and reinvented, and often co-created through collaboration and distributed expertise (Halverson & Sheridan, 2014; Martinez & Stager, 2013).

Within the maker movement, craft, tinkering, and "messing about" (Hawkins, 1965) are just as important as mastering STEM content knowledge. In fact, these practices can also enhance one's understanding of STEM principles. For instance, Peppler et al. (2018) found that, through hands-on exploration, preschool-aged children were able to understand challenging circuitry topics, like the concept of current, when exploring and creating physical circuits made out of conductive clay. The maker movement highlights the ways in which physical artifacts can serve as a link between embodied experiences and abstract concepts (Horn & Bers, 2019), an approach to learning that aligns with a constructionist perspective (Papert, 1980). This theory holds that, through building and sharing objects, learners produce, articulate, and refine their understandings.

In addition to facilitating learning, maker activities also have the potential to democratize learning (Blikstein, 2013). Maker activities can transform typical learning environments by bringing learners' everyday practices into the classroom and inviting learners to creatively solve problems that are important to them and their communities (Vossoughi et al., 2016). They also play a role in the very formation of maker's identities. As McLean and Rowsell (2021) mention, making provides an opportunity to "learn about ourselves and others through materials" (p. 1). The process of making invites learners to make use of space, time, and materials, not only to tinker and problem-solve, but also to relate to others and grow, discover, and express themselves.

### 2.2. Maker Literacies

By tacking "literacies" on to this idea of making, we align our work with others who have highlighted the semiotic meaning-making practices involved when engaging with technologies, materials, and other people during maker activities (Kumpulainen et al., 2020; Marsh et al., 2018; Roswell et al., 2024; Wohlwend et al., 2018). Learners leverage literacy skills as they engage with and create digital and non-digital artifacts throughout all steps of the design process (Marsh et al., 2018). As such, makerspaces can act as sites of "multimodal meaning-making" (p. 5). Further, making provides a learning environment in which literacies can be developed alongside content knowledge, demonstrating the utility of maker activities in blurring boundaries between disciplines (Blikstein, 2013) and concretizing abstract STEM concepts (Peppler et al., 2018).

Maker literacies have been conceptualized across the same integrated elements as conventional literacy (Green, 1988; Kumpulainen et al., 2020; Marsh et al., 2018). These include the operational, cultural, and critical dimensions of literacy. When applied to the context of making, these elements align with technical skills and knowledge (operational literacy), the ability to leverage sociocultural signs and participate with others (cultural literacy), and the ability to reflect on the power dynamics and larger contextual forces at play (critical literacy) that can arise when engaging in maker activities. This three-part maker literacy framework highlights the capacity of making beyond developing technical skills, although this aspect is often the apparent component of making activities (Blikstein, 2013; Kumpulainen et al., 2020). Making is also a social, relational, affective, critical, and cultural endeavor (Roswell et al., 2024).

### 2.3. Robotics as a Means of Developing Maker Literacies

The integration of robotics, a particular form of physical computing, into education aligns naturally with the principles of maker literacies. Both emphasize a hands-on, student-driven learning approach where failure is seen as a valuable part of the process. Robotics, and physical computing more broadly, provides a means for learners to encounter powerful ideas from computer science while creating something tangible and purposeful (Horn & Bers, 2019).

When building a robot, the learner must constantly shift between the technical, functional, and esthetic aspects as well as between the two-dimensional plan and the three-dimensional reality of their project (Peppler, 2016). Furthermore, educational robotics kits encourage students to think critically and creatively as they troubleshoot design flaws, optimize performance, and adapt to constraints (Blikstein, 2013; Peppler, 2016). The collaborative nature of many robotics challenges also fosters communication and teamwork, the key elements of maker literacies. As such, robotics education not only supports content mastery but also cultivates the maker mindset needed for innovation in modern society (Martinez & Stager, 2013).

There exists a growing suite of commercially available robotics kits, making it possible for physical computing technologies to enter schools and classrooms. Organizations such as the Raspberry Pi Foundation (https://www.raspberrypi.org/, accessed on 1 June 2025) and the Micro:bit Educational Foundation (https://microbit.org/, accessed on 1 June 2025) are among those developing such kits. Through activities that leverage maker literacies, students can combine the sensors, actuators, and programmable microcontrollers from these kits to construct small articulated robots. In addition to promoting maker cultures, educational robotics systems can also facilitate cognitive, motor, and social skill development (Ali et al., 2019; Dorouka et al., 2020). These technologies also serve as hands-on entries to applied mathematical concepts, the scientific method, and problem-solving (Karim et al., 2015).

Many educational robots with tangible interfaces allow students to engage in screen-free programming (Hamilton et al., 2020), a feature aligned with calls to limit screen use among young children (American Academy of Pediatrics' Council on Communications and Media, 2016). However, some of these kits are not appropriate for use in early childhood contexts. For instance, some kits are based on programming languages, such as C++, that are commonly taught in introductory undergraduate courses (Gao, 2014), or are based on Scratch, a block-based language created for students aged eight and up (Maloney et al., 2010). Even when kits are designed to be developmentally appropriate for young learners, such as the KIBO robotics kit, they are often expensive, limiting their presence in under-resourced classrooms (Sullivan & Bers, 2015).

### 2.4. Positive Technological Development

The concept of maker literacies challenges us to consider learning beyond screens, involving embodied experiences that engage, alongside cognitive aspects, emotional, physical, and moral dimensions. McLean and Rowsell (2021) frame making as a process of becoming in which learners come across materials that draw on their senses and motivate them to make meaning. As such, technological competencies and character development intersect through the process of making. Noting this intersection, the PTD framework (Bers, 2006, 2012) offers a useful lens toward understanding the socio-emotional components of maker activities. PTD extends the holistic approach of the positive youth development field (Benson et al., 2011; Damon, 2004; Lerner et al., 2005) to the process of youth development in technologically rich settings. PTD introduces three intrapersonal behaviors (i.e., content creation, creativity, and choices of conduct) alongside three interpersonal behaviors (i.e., communication, collaboration, and community building) that typically arise when youth interact with technology and with each other.

Making activities can promote all six of these behaviors, which are well aligned with the operational, cultural, and critical dimensions of maker literacies (Kumpulainen et al., 2020; Marsh et al., 2018). For instance, content creation is the main goal of the making process, prompting learners to shift from consumers to creators with agency as they make purposeful and meaningful projects. Throughout this process, learners leverage their creativity as they imagine and transcend traditional ideas. Choices of conduct arise as learners experience and reflect on the outcomes of their actions and are supported in acting in better alignment with their values and intentions. As will be described in more detail below, these choices serve as opportunities for learners to develop their character strengths.

Maker literacies are often salient in the ways in which learners communicate ideas and express themselves during the making activities. Importantly, maker activities uplift many modes of communication, especially non-verbal forms such as gestures, visuals, sounds, and movements (Roswell et al., 2024). Collaboration is present in many maker activities as learners share their expertise, advice, and experiences in both individual and group learning structures (Bevan et al., 2017). By articulating and refining their understandings, maker activities create a space in which learners can deepen their learning through collaborative knowledge sharing (Peppler et al., 2018). Lastly, community building can occur both through the culture cultivated in the makerspace (Halverson & Sheridan, 2014) and students' ideas about solving real-world problems (Vossoughi et al., 2016). To these ends, the PTD framework guided the development of the project presented in this paper.

## 3. ScratchJr Bots

The ScratchJr Bots project focused on making low-cost, developmentally appropriate tangible computing experiences for young children to develop maker literacies, grapple with CT concepts, and foster social-emotional growth. ScratchJr Bots are a physical computing extension of ScratchJr (Bers & Resnick, 2015), a popular and freely accessible block-based programming language designed for 5- to 7-year-old children. With ScratchJr Bots, students can design and build their own robot with off-the-shelf, low-cost electronics components. Then, the ScratchJr Bots codebase can be downloaded onto the robot's microcontroller. Finally, the Bot can be connected to a device with ScratchJr, over Bluetooth, making it possible to digitally program the Bot.

Beyond the physical designs of the technology, we sought to design a full learning experience for ScratchJr Bots, given the necessity of pedagogical and curricular support when introducing any technology into a classroom. The intervention follows an adapted version of the Coding as Another Language Curriculum (CAL; Bers et al., 2023). In addition to curricular support, we also sought to implement a learning dynamic shift from that of a typical classroom in the United States to a multi-age learning experience. The ScratchJr Bots intervention, as currently designed, partners children from early childhood (ages 5–8) with children from older elementary classrooms or middle school grades (ages 11–15) to create and program ScratchJr Bots as a multi-age team.

A set of design values guided the development of ScratchJr Bots such that both the hardware and software elements as well as the curricular design supported learners' holistic development. These values reflect a commitment to (1) accessibility and cost-effectiveness, (2) play and exploration, (3) coding and maker literacies, and (4) character development. Each design value is described in detail below.

### *3.1. Accessible and Cost-Effective*

One goal behind the ScratchJr Bots project was to be economically accessible to classrooms around the world. To achieve this, we committed to using low-cost, easily acquired tools that could be used in any classroom, especially in communities with fewer resources. Our hope is that such an approach would counter the "digital divide" in which access to digital technologies is linked to families' socioeconomic status and impacts students' academic outcomes (Pierce & Cleary, 2024).

Constructed from affordable materials, ScratchJr Bots can be quickly assembled and integrated seamlessly into various educational settings. To maximize accessibility and cost-effectiveness, ScratchJr Bots' hardware consists of components that are available at many electronics stores and online retailers. These include breadboards, servo motors, resistors, light-emitting diodes (LEDs), AA batteries, battery packs, and various breadboard jumper cables (Figure 1). At the time of this publication, one ScratchJr Bot can be created for less than USD 21.00 in hardware-related materials. We deliberately designed the Bots so that substitutions could be made with similarly compatible components and that new components could be added once the supporting software is available.

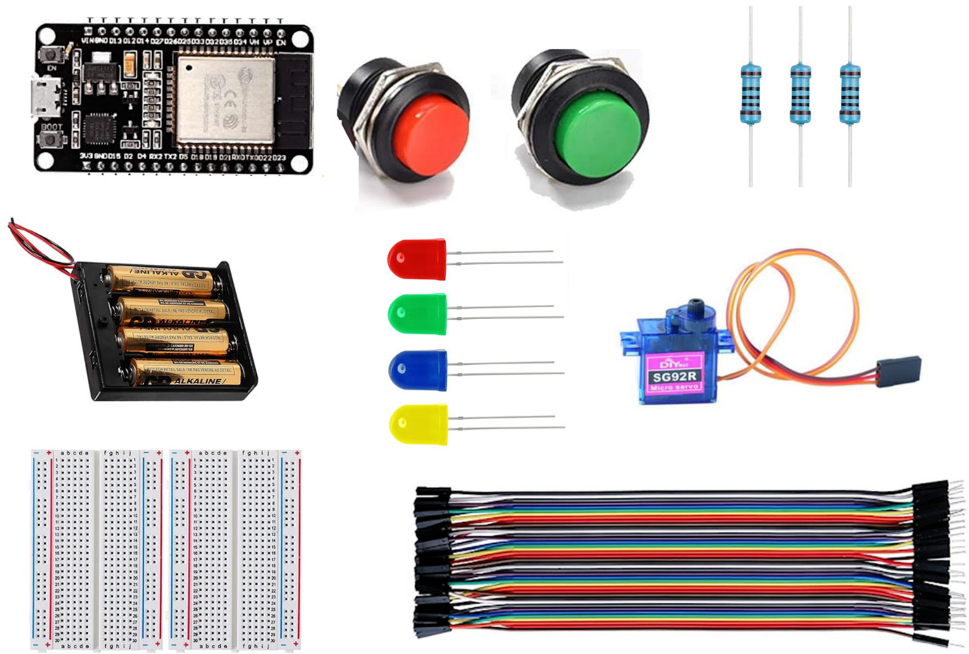


**Figure 1.** Sample hardware parts used in a ScratchJr Bot.

In the process of developing ScratchJr Bots, we have had to balance cost-effectiveness with developmental appropriateness. The version of ScratchJr Bots described here utilizes an ESP32 microcontroller, an inexpensive board that supports Wi-Fi and Bluetooth and is compatible with many kinds of sensor and actuator interfaces, including the one we use, the Arduino Integrated Development Environment (https://www.arduino.cc/en/software/, accessed on 1 June 2025). However, the 38-pin board can make wiring challenging. As an alternative, in collaboration with Plan Ceibal in Uruguay, we are in the process of adapting ScratchJr Bots to be compatible with micro:bit. Micro:bit offers a 5-pin board, making the wiring more accessible to young students without sacrificing functionality. Despite these developmental affordances, the board is slightly more expensive than an ESP32, demonstrating small tensions that we have encountered, and are working to overcome, between cost and developmental considerations. As for the esthetic dimensions of the robot, as previously mentioned, we have seen robots come to life with recycled cardboard, construction paper, and other crafting materials that are common in most early childhood classrooms (Figure 2).

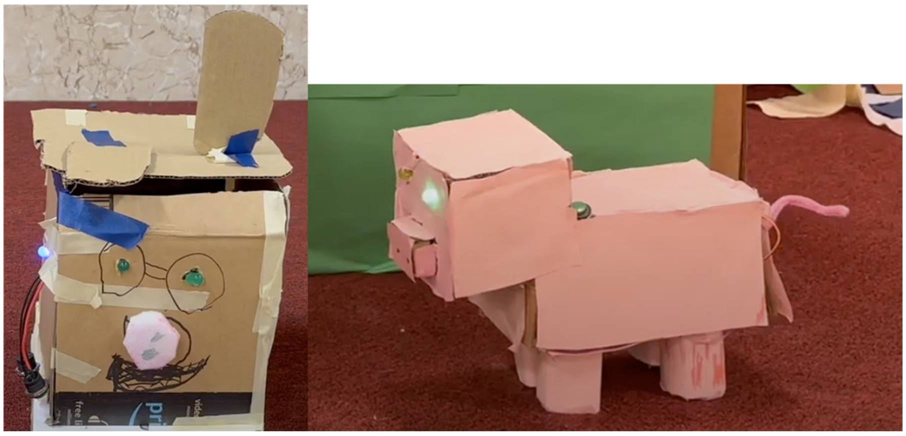

**Figure 2.** ScratchJr Bots made from recycled cardboard.

To keep costs limited to basic materials, we plan to make all wiring designs, the hardware code, the ScratchJr Bots app, and the accompanying curriculum materials freely available for the public. These resources are currently being revised based on findings of the two pilot studies described below and will be made available online following the completion of this development stage. Once available, they will enable researchers and educators to replicate these interventions and adapt them for use in their own contexts.

*3.2. Playful and Explorative*

In designing the ScratchJr Bots learning experience, we drew upon our pedagogical goal of creating coding playgrounds (Bers, 2020), playful learning environments where learners can explore technologies in ways that promote PTD behaviors. By extending the ScratchJr experience into the physical world, ScratchJr Bots empower children to explore and engage with CT as they witness their digital code come to life beyond the screen. The debugging process becomes more active and complex as students learn to systematically check both their software and hardware for errors. This feature invites both tinkering and exploration in the process of problem-solving and innovation. Furthermore, by extending the off-screen experience, ScratchJr Bots invite a social experience. Rather than working individually on screens, the physicality of the Bot allows for shared attention, collaboration, and/or group work, and consequently more playful interactions between peers.

Additionally, ScratchJr Bots leverage children's creativity in both the digital and physical realms as they code their robot's behavior and customize its esthetic appearance using low-tech arts and crafts materials. Programmed robots can represent characters in a story, facilitate newly invented games, or help solve real-world problems. This aspect of the Bots experience requires students to transform their robots into the objects they imagine using the physical materials available to them (Figure 3).

**Figure 3.** A ScratchJr Bot transformed with common craft supplies.

### 3.3. Coding and Maker Literacies

Our third commitment in developing the ScratchJr Bots was to create a learning experience that promotes various forms of literacy. For instance, the ScratchJr Bots activities were created by adapting the Coding as Another Language (CAL) curriculum (Bers, 2019; Bers et al., 2023). This freely available coding curriculum for grades K-2 explicitly links the development of coding and CT skills with foundational literacy skills. CAL is based on the premise that computer code and other artificial languages are systems of symbolic representation, just like any natural language.

By extension, code can be utilized for more than just problem-solving but also as a medium for creative expression. Prior research has shown that incorporating storytelling and narrative into coding can enhance the acquisition of coding CT skills (Metin et al., 2024; Yang et al., 2023). When applied to ScratchJr, CAL highlights the potential of embedding storytelling practices into creative coding as a means to enhance both coding and literacy skills. Similarly, maker literacies highlight the same potential for physical computing. In the ScratchJr Bots curriculum, all of these forms of literacy are promoted in the final project in which students Bots become characters in a retelling of a familiar story (Figure 4).

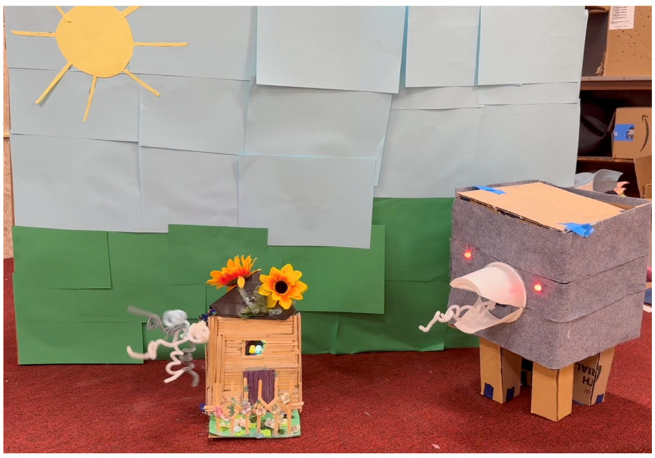

**Figure 4.** The Three Little Pigs, as performed by ScratchJr Bots.

While children engage in creative expression through storytelling and building characters, they practice CT skills in both stages as well. For example, sequencing is required as students build the Bot to ensure that essential steps, such as connecting the battery to the microcontroller, are completed first, since powering the system is necessary to test each additional component as they are added. Once building is complete and students can code the Bots, sequencing is practiced again as the user determines the correct order of programming blocks to make their Bots move and light up in sync with a story. Debugging also happens in both stages as students test their Bots, observe when they do not behave as expected, and revise either the wiring or the code accordingly. Together, these activities illustrate how maker literacies provide an integrated learning experience in which they can code, engage in CT, and express themselves creatively through both digital and physical media.

### *3.4. Character Development*

Finally, we wanted interactions with ScratchJr Bots to also provide opportunities for character development based on the assumption that creative coding and hands-on making activities can serve as gateways to learning human values (Bers, 2022). Bers uses the metaphor of a palette of virtues to highlight how technical knowledge and skills and character can be cultivated in parallel (Bers, 2021). This metaphor points to the intentionality behind the human values practiced throughout the creative coding process, an intentionality that reflects choices of conduct from PTD. Although the content of any individual's palette of virtues can vary, ten virtues commonly arise during the creative coding process: curiosity, fairness, forgiveness, generosity, gratitude, honesty, open-mindedness, optimism, patience, and perseverance. These virtues point to the potential of creative coding and physical computing projects as pathways to explore the socio-emotional dimensions of learning and to engage the whole learner.

In the case of ScratchJr Bots, we highlighted opportunities for character development in our pedagogical approach to teaching, learning, and using the technology. Because the process of wiring, coding, and putting a ScratchJr Bot to meaningful use requires a variety of skill sets, we saw this as a feature that afforded intergenerational learning (Figure 5). In the vignettes that follow, older and younger students were paired to build their ScratchJr Bot together. The older children focused on the circuitry aspects of the Bot, whereas the younger students focused on the digital coding aspects. Within each pair, their respective technical knowledge was shared, but together they learned to persist in the face of challenge, show humility in asking for help, and welcome other's ideas and contributions.

**Figure 5.** An older and younger student collaborating on ScratchJr Bots.

## 4. Methodology

In order to understand the feasibility of the ScratchJr Bots project, as well as to understand if and how our design goals were being met, we followed a design-based research

(DBR) approach in which we conducted our investigations through an iterative collaboration between researchers, designers, and participants (Brown, 1992; Collins, 1992; Wang & Hannafin, 2005). Design-based research within the learning sciences acknowledges that learning is contextual; thus, DBR posits that research for and about learning must take place in the learning environment (Brown & Campione, 1996; Collins, 1999). Thus, we integrated our ScratchJr Bots prototype and early lesson plans into classroom settings. Furthermore, in order to gain thorough insights from the design experiment, we positioned ourselves as both researchers and teachers throughout the experience. By being the primary actors in a classroom set up, leading lessons, and assisting children with various difficulties, we were able to conduct a thorough investigation of the full learning experience (Kelly, 2003; Wang & Hannafin, 2005).

Because DBR positioned us in a real-world setting, we were both able to understand the practical implications of our designs. Due to the grounded nature of DBR, however, there is also a need for flexibility and iteration, given the challenges that a real-world context can pose (Collins, 1992, 1999). Flexibility and iteration are also key elements of DBR (Wang & Hannafin, 2005). For example, despite beginning with a set lesson plan, we quickly had to adapt to the needs of the students, expanding foundational learning time for the older children in our second pilot, and creating extra time for building and debugging. Through introducing our initial designs into two classroom settings as both teachers and design-researchers, we were able to build strong collaborative relationships with participants, discover areas for improvement first-hand, examine the effects of our iterations in real-time, and understand the feasibility of our work in a real-world setting.

## 5. Two Pilot Projects

### *5.1. Pilot 1*

#### 5.1.1. Research Goal

As part of the ScratchJr Bots project, two pilot projects were conducted. The first pilot explored the feasibility of integrating the Bots technology with early programming and literacy education. Specifically, we sought to investigate whether the use of low-cost robotics materials could support playful, explorative learning while remaining accessible and cost-effective for educational settings.

#### 5.1.2. Setting

This pilot took place weekly between October and November 2024 at the DevTech workshop space in four 90 min sessions. Participants included nine children from third, sixth, and seventh grades, who had different levels of prior experience with robotics and/or programming. The design and facilitation team, made up of DevTech members, led all sessions.

#### 5.1.3. Curriculum

The curriculum implemented during this pilot included a series of newly developed lessons that introduced foundational concepts in robotics, coding, and literacy through a creative, play-based approach. The program promoted active learning through tasking a pair of a third grader and a sixth or seventh grader to construct a robot and learn to program it with ScratchJr. This then culminated in a collective storytelling project making use of each pair's robot. Instructional materials included visual placemats, written guides, and teacher-led demonstrations. Lessons were grounded in interdisciplinary learning goals and informed by the original CAL curriculum and PTD.

#### 5.1.4. Methodology

We followed a DBR approach to iteratively refine our materials and evaluate the feasibility of our design goals in a classroom-like setting. Researchers acted as facilitators, supporting students through each lesson of building, coding, or storytelling while also collecting data through video recording, field notes, and student interviews. Pre- and post-interviews were conducted with all nine students. Interviews were semi-structured and aimed to assess students' attitudes toward robotics and programming, their understanding of key concepts, and their reflections on collaboration and creative expression. Pre-interviews were structured around ten questions focusing on prior experience and initial interest while post-interviews asked ten questions about perceived difficulty, enjoyment, collaboration, and learning outcomes. Observational data focused on student engagement, collaboration styles, and general ease of use of the technology. The research team focused on both the hardware and programming interface to determine whether it was developmentally appropriate for the participating age groups. Researchers paid close attention to moments of confusion, successful use independent of facilitators, and how students interpreted the visual instructions and coding tasks. In line with our DBR approach, we also documented the necessary adaptations made to lesson plans and materials as we tried to respond flexibly to students' needs.

#### 5.1.5. Results

Our analysis of observational notes and interviews revealed promising findings as well as areas for improvement. Observation notes from this pilot revealed that, while students were initially hesitant to engage verbally, they demonstrated strong attentiveness and task execution, with collaboration emerging naturally through peer interaction and shared problem-solving strategies. Feedback gathered through the interviews indicated that students appreciated the availability of visual materials but desired better guidance for wiring, including labels or even a combination of visual and written instructions on the same placemats. Additionally, researchers observed the need for an anticipated introduction of the final product to better guide students in their creative processes. The pilot emphasized the importance of balancing challenge with support, and new questions surfaced about equitable access to supplementary resources, informing iterative lesson redesign and underscoring the potential of creative, interdisciplinary robotics and programming education to support both technical and expressive learning in early and middle childhood.

The final project involved creating four distinct characters, each designed with specific physical features and codes, such as activating a motor, lighting LEDs, or playing a sound. These characters showcased students' ability to connect hardware components with digital coding, demonstrating both technical and creative thinking. However, due to time constraints, students could not collaboratively develop a cohesive narrative that integrated all the characters into a shared story. Instead, each pair presented their creations, highlighting the unique design and function of their Bots without weaving them into a collective plot. While this limited the storytelling aspect initially envisioned for the showcase, it allowed students to reflect on their design choices, demonstrate their programming logic, and celebrate their work. The experience underscored the need for additional time and scaffolding in future iterations to fully realize the potential of collaborative storytelling through expressive robotics.

Most importantly, this pilot also affirmed the feasibility of using ScratchJr Bots as a cost-effective and developmentally appropriate tool for learning. The low-cost materials that were used enabled students to build and program functional robots. Even with minimal exposure to similar technology, students could meaningfully engage with all aspects of the project. Additionally, the playful and exploratory nature of the experience shone through in the characters the students designed, the way they experimented with different hardware features, and the excitement they showed when making their Bots come to life through successfully programmed motors and lights.

### *5.2. Pilot 2*

#### 5.2.1. Research Goal

The second pilot project built upon the lessons learned from the first experience as we shifted our focus to two central research goals: to investigate how the integration of coding and maker literacies supported student learning, and to examine whether and in what ways the experience fostered character development.

#### 5.2.2. Setting

This pilot was conducted in partnership with a private K-8 school in Boston between February and May 2025, involving 45 min sessions with 8 first graders and 10 eighth graders. All sessions took place in the students' school with the supervision of their technology director. For the first session, we combined the groups to introduce the overall project, showcase various robot prototypes, and establish buddy pairs between younger and older students. We then moved to separate sessions and then gradually transitioned into collaborative buddy pairs.

#### 5.2.3. Curriculum

Based on feedback from the first pilot, where the older students asked for a more thorough exploration of the technology, the curriculum for the second pilot was intentionally differentiated by age group for the first four sessions. First graders engaged in foundational activities such as unplugged planning stories with ScratchJr blocks and digital storytelling using ScratchJr, while eighth graders undertook tasks involving hardware and electronics, by learning to wire and program the parts they would later use in the Bots. These age-specific sessions enabled researchers to scaffold learning effectively before gradually merging the two groups. By late March, the program transitioned to multi-age combined sessions where buddy pairs collaborated on final project development, integrating robotics hardware, ScratchJr programming, and creative storytelling. The culminating event was a final project showcase of the *Three Little Pigs* story, where students presented their completed work to peers, educators, and family members.

#### 5.2.4. Methodology

Like the first pilot, this study followed a DBR approach. Researchers took on multiple roles as designers, facilitators, and observers, allowing for the iterative refinement of lessons and materials in response to students' needs. The facilitation team provided consistent instructional support and maintained detailed documentation through field notes, dual-camera video recordings, and regular team reflections. Preliminary assessments were conducted to gauge prior experience and comfort with robotics and programming. Throughout the pilot, researchers used the PTD framework to guide observations of student behavior, particularly with regard to agency, collaboration, and creativity. Special attention was given to how children engaged in maker-centered learning, how they navigated mixed-age collaboration, and how the technical and narrative elements supported their sense of personal and collective investment in the project.

#### 5.2.5. Results

As students progressed from separate sessions to collaborative work, distinct learning trajectories emerged. The curriculum structure allowed older students to deepen their technical fluency while positioning younger students as creative storytellers. The research team observed that eighth graders displayed a strong desire to comprehend the underlying logic of their actions rather than merely following step-by-step instructions. This observation underscored the necessity of providing conceptual depth alongside technical guidance for older participants. The pilot also tested a novel method of visual instruction conveyed through a ScratchJr program. Although innovative, this approach produced mixed results: for some students, it was engaging and accessible, whereas for others, it turned out to be distracting or insufficiently clear, particularly among those who preferred to experiment and figure things out on their own. Over time, the experience prompted personal growth and new forms of participation from both age groups, as illustrated in the examples that follow.

Pedro (all names in this work are pseudonyms), an eighth grader in the second ScratchJr Bots pilot project, has always had an affinity for robotics. On the first day of class, when the project was announced, his face lit up and he proudly announced that he and his dad had worked with code and robotic kits for many years at home. While other students showed uncertainty at the mention of circuits and wiring, Pedro showed excitement and confidence: when questions were asked to the group, Pedro raised his hand and shared his answers with conviction, and he was the first to finish early circuit builds. His expertise distinguished him from his peers, and consequently, we were initially concerned that he may have difficulty working with others, given the discrepancy in knowledge and skills. Furthermore, in conversations with his teacher and general observations, we learned that social interactions do not come easily to Pedro and he often prefers to work alone on projects. Thus, as we introduced the multi-age, collaborative project, we were not certain how Pedro would react. While Pedro had a strong grasp on the content matter, this project introduced a greater challenge of working with others, specifically others that did not share his same expertise.

Despite these concerns, Pedro welcomed this challenge with grace. It was clear from his actions that he understood his advanced knowledge as something to be shared with others and stepped into a guidance role with many of his peers early on. When he finished his builds before others, he offered help to other students around him. In particular, Pedro consistently offered his help to Aaron, another eighth grader who struggled to keep up with the circuit lessons. Throughout the three first lessons with the eighth graders, Pedro demonstrated patience and generosity offering guidance and instruction to others in need.

Despite this success with peers of similar ages, we were still unsure of how Pedro would engage with younger students when the time came for the cross-grade collaboration. In the instances of working with Aaron, for example, he offered his help after completing his own circuit, demonstrating generosity with his time and knowledge, but not necessarily a capacity for true collaboration. In the next phase of this project, we were asking many things of the students: to build a robot, to build that robot collaboratively, and that the collaboration would be with a younger student. While Pedro's wealth of knowledge gave him an advantage in the project, he still found the robot building aspect to be challenging, and we were initially worried that the building challenge may outweigh the more social challenges of the project, resulting in him opting to work alone or isolating from his partner. This concern never materialized though. Pedro balanced the challenges at hand with grace.

Pedro was partnered with first grader, Emma, who was a bright and curious young student. Though Pedro and Emma shared the same explicit goal—creating the robot—Pedro took on a personal goal of ensuring that Emma learned. Pedro stepped into the role of educator through their collaboration. He demonstrated an incredible amount of care for Emma's learning; rather than feeding the instructions to her, he made sure that she really understood the process. As he read each instruction, he translated the steps into language and explanations he thought would work for Emma. He explained safety elements of circuits, for example, and allowed Emma to ask imaginative "what if…" questions about the robot they were building. Rather than handling the wires himself, he stepped back on many occasions to allow Emma to place the wires. At times, they encountered struggles together, but rather than turning within himself, Pedro put his role as a collaborator and a teacher first and stuck with Emma through the process, even if it meant sacrificing a speedy build or an extra feature on the robot. The project gave Pedro a chance to demonstrate generosity with his knowledge, instruction, and time, in ways that are not typical for him in other learning environments.

Through observation, researchers also noted the importance of giving these students opportunities to take the lead, especially in buddy work with younger peers, while preventing dominance in collaborative settings. While Pedro displayed consistency throughout the pilot, another student, Cam, had a more dynamic arc. Cam is a first grader who caught our attention on the very first day of the program; we knew we were asking a lot from these young students, welcoming strangers into their space and engaging with unfamiliar technology and terminology, but some eased into it more quickly than others. When we administered an informal formative assessment to gauge prior experience with robotics and programming, most of the first graders approached the task with a spirit of best guesses and exploration, despite having little to no background knowledge. Cam, however, quickly began to fall behind; it was not immediately clear whether this was due to a lack of knowledge, interest, or confidence, but it was clear that he was struggling. We had to assist him with nearly every question, and we made a note to keep an eye on him in the sessions to come.

During the early phase of the program, when the first graders and eighth graders were working in separate groups, Cam continued to have difficulty staying engaged. He often appeared to lose focus or drift away from activities that asked him to engage in content creation. This tendency changed when we introduced mixed-age pairs, assigning each first grader an eighth-grade partner. Once he realized his partner was not there to instruct him but was also a peer, someone who could be playful, encouraging, and collaborative, Cam's engagement grew. The sense of reliable companionship seemed to energize him, and the dynamic helped him feel more comfortable and capable.

From that point on, Cam's confidence and curiosity grew significantly. He appeared to immerse himself in all aspects of the project: carefully decorating and assembling the robot, experimenting with its code, and constantly testing new ideas to understand what was possible. When he completed his tasks, he looked for more to perform. His partner occasionally felt unsure how to keep up with Cam's pace, and other eighth graders even expressed envy at how motivated and productive he had become. It became common for the eighth graders with slower-moving projects to ask Cam for help when they ran into challenges.

This collaboration he experienced did not only boost his engagement, but also it sparked a full shift in how he approached the work and how others saw him in the classroom. By the end of the pilot, Cam had become one of the most productive students in the room, across both age groups. The combination of collaboration and creative freedom had transformed his experience. What started as quiet hesitation grew into a drive to explore, build, and contribute. Cam showed us how powerful it can be for young learners to collaborate with peers they both respect and feel comfortable with, partners who guide, support, and also have fun. This kind of cross-age collaboration had a clear impact on Cam's confidence and curiosity, leading to significant growth in both the quantity and quality of his content creation.

In the final example, we zoom out from specific students and examine the community that was built across the two and a half months of working together. Throughout the project, the pairs knew that their ultimate goal was to create a robot to be a part of the class story of the *Three Little Pigs*. The eight partnerships resulted in four pig characters, two house characters, and two wolf characters. While the story and characters were clear from the start, it was not until the final weeks that pigs began to take shape from pink paper and curly pipe cleaners, and houses were built from cardboard and popsicle sticks, and that students fully realized their robots were a part of something bigger. What began as eight separate partnerships, each focused on untangling wires and debugging breadboards, soon became eight parts of one classroom story.

In the final days of the project, with guidance from the teacher/researcher, children collaborated to imagine how each character would come to life in the scenes of the story. They began to think beyond their own projects and communicate across partnerships to create a story that incorporated all classroom voices and represented their collective work. Together, they negotiated which pig would live in which house, and how each robot would perform in each scene to advance the larger story. For the penultimate class, the children filmed each scene. For each scene, groups of four to six students of mixed ages placed their robots in front of the handmade backgrounds. Older students ensured the robot wiring was in place and the codes were run in a coordinated fashion, while younger students arranged the scene and verbally narrated the scene. With assistance from one of the teachers/researchers, 20 different scenes were filmed and edited into a movie of *The Three Little Pigs*.

For the final class, the students proudly showcased their work. Each partnership sat with their robot as their larger community, composed of parents, teachers, and other students from the school, packed into the classroom for the "Final Project Showcase". Guests first watched the movie and then circulated around the room to see each robot up close, ask questions to the creators, and see brief demonstrations of how to program the robots.

At the start of the project, the mixed-age partnerships felt exciting but also unfamiliar and, for some, intimidating. Children had to be reminded to sit with their partners instead of clustering with peers of their own age. By the time of the showcase, however, partners sat together naturally, welcoming the guests as a unified group and proudly presenting their project. Inviting in the larger community gave the children a tangible sense of pride in what they had accomplished together. In particular, younger students, who had at times taken a back seat during technical phases, stepped forward as confident programmers. As visitors moved from robot to robot, the older students took a step back and allowed the younger students to demonstrate their expertise: explaining how the robots worked, showing off the wiring, and programming different small actions on ScratchJr. While the older students had felt ownership and pride throughout, especially during the more challenging wiring and building stages, this final event gave the younger students their moment to shine and feel ownership over their contributions as well as they showcased their work to the school community.

Taken together, the findings from this second pilot suggest that the Bots activities successfully integrated coding and maker literacies in a developmentally meaningful way. Students engaged deeply with both the technical and creative aspects of the project, building and programming robots while also designing original characters and stories. Thus, they demonstrated growth not only in CT and hands-on making, but also in character development, expressing pride, confidence, patience, and a sense of ownership in their work.

## 6. Conclusions

The project described in this paper shows an example of how low-cost technologies that integrate creative learning by designing, making, and programming can foster not only maker literacies, but also socio-emotional growth and character development. As new technologies are rapidly entering early childhood education, opportunities to extend the range of creative activities off the screen, while promoting CT, are needed in the classroom. As shown in this paper, the ScratchJr Bots provided such an example, designed upon four guiding values: (1) to be accessible and cost-effective, (2) to be playful and explorative, (3) to strengthen students' coding and maker literacies, and (4) to promote character development.

Furthermore, the limitations of new technologies that are both low-cost and developmentally appropriate invite us to rethink the composition of learning teams. As shown in the Scratch Bots project described in this paper, mixing different age groups can be a solution. Furthermore, it can provide opportunities to explore the role of intergenerational mentorship and leadership. Future work will focus on these aspects.

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