Digital Technology and Child Development

A Literature Review

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Special thanks to our advisors:

Alicia Blum-Ross, Ph.D., Chip Donohue, Ph.D.,
Elizabeth Rood, Ed.D., and Lori Takeuchi, Ph.D.

This research was made possible by generous support of:

The Thomas P. Murphy Fund at the San Diego Foundation
The Walt Disney Company

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Introduction

Today's children are growing up in a technology-rich world. They use technology both in their homes and at school, and often carry devices in their pockets wherever they go. As a result, the topic of "screen time" has already attracted a great deal of attention as it relates to children and technology. It has been covered quite thoroughly, with experts writing at length about children's exposure to screen-based media such as television (e.g., Barr, McClure, & Parlakian, 2018; Chassiakos, Radesky, Christakis, Moreno, & Cross, 2016; Council on Communications and Media, 2016; Donohue, 2014; Guernsey & Levine, 2017; Hirsh-Pasek, Evans, & Golinkoff, 2019; Livingstone & Franklin, 2018; NAEYC & Fred Rogers Center, 2012; Paciga & Donohue, 2017; Rideout, 2014; Rideout, 2017; Stephen & Edwards, 2017; Viner, Davie, & Firth, 2019). According to an extensive study by Rideout (2017), on an average day, children 0 to 8 years of age spend approximately 2 hours and 19 minutes engaged with screens. Ultimately (and not surprisingly) it seems that there are both potential costs and benefits for children engaging with screens (e.g., Chassiakos et al., 2016).

While the topic of screen time likely conjures up mental images of televisions, computer screens, or mobile phones, the types of technology that children are interacting with today are far more diverse than traditional screen time alone. Given the omnipresence of digital devices, parents, caregivers, and educators today are faced with new challenges compared to generations past. For example, they must try to identify which types of technology experiences are most beneficial, attempt to balance children's "technology time" with other activities, and navigate how to talk with children about appropriate use of digital products and devices. Further, there is a multitude of information, all of which provide slightly different ideas about how, when, and where to use digital technology.

Additionally, digital technologies are being introduced at a fast rate, and being adopted by the public very quickly. Sometimes there is little chance to critically evaluate the pros and cons of digital technologies before they become a common part of our homes and schools. Because of this,

parents, caregivers, and educators are understandably eager for guidance. In response, scientists are attempting to provide answers, although this can be challenging considering how quickly the landscape is changing.

The present publication bridges research and practice with a focus on digital technology in early childhood. We use the term digital technology to denote both a range of digital devices (e.g., computers, gaming consoles, tablets), as well as products that are meant to be consumed on such devices (e.g., apps, games) (Plowman, 2016). More specifically, we reviewed research primarily focused on individuals in early to middle childhood and their interactions with the following: (1) digital gaming; (2) coding; (3) augmented reality and virtual reality; (4) digital fabrication; and (5) social robots and conversational agents. This selection provides a look at both the more established (i.e., digital gaming, coding) as well as the emerging (i.e., augmented/virtual reality, digital fabrication, social robots and conversational agents).

Because digital technology is relevant to multiple disciplines, the pieces reviewed here come from a variety of fields including psychology, education, technology, and media/communication studies. However, due to the relative novelty of research on many of these topics, there were limited published journal articles. This led us to broaden our review to include sources such as conference proceedings and reputable online news sources. In addition, despite our efforts to highlight work with young children, there was not always relevant research for this age group. Therefore, we have included studies with individuals beyond middle childhood. These modifications allowed us to create a more thorough review in a field of work where empirical research with young children is still emerging.

It is important to note that there are equity issues with regard to technology access in early childhood. When considering how emerging technologies will impact the lives of children, we need to acknowledge the "digital divide," or gap in digital technology access and use based on income or availability of resources (e.g., Warschauer, Knowbel, & Stone, 2004; Warschauer & Matuchniak, 2010). According to Rideout and Katz (2016), certain segments of the population—especially Hispanic immigrants and those living in poverty—are not fully included in the digital revolution or are "under-connected." For children, this means that their, "opportunities to develop creative projects, take advantage of educational media, explore extracurricular programs, and complete homework, are limited" (Rideout & Katz, 2016, p. 40).

Ultimately, despite inequalities in access to and use of technology, as well as limited information regarding the effects of technology on early childhood development, it is still essential that we utilize the information that is currently available. We know that many children are using technology, and frequently. Thus, high-quality research should be used to inform the decisions of those developing technology for young children as well as parents, educators, and other adults faced with making decisions about adopting these technologies for children's use.

The CREATE Framework

A unique contribution of this review is the use of BADM's CREATE Framework (Bay Area Discovery Museum, 2017). This research-backed framework serves as a guide to design and evaluate quality learning environments for children that develop creative problem-solving skills. There are six CREATE components: (1) Child-directed; (2) Risk-friendly; (3) Exploratory; (4) Active; (5) Time for imagination; and (6) Exchange of ideas. For additional information, see graphic on pg. 5.

In the present review, we use the components of the CREATE framework as a lens to evaluate research studies of five types of digital technology: digital gaming, augmented reality/virtual reality, coding, digital fabrication, and conversational agents/social robots. In this way, we highlight the potential developmental benefits offered by different types of digital technology. Ultimately, we believe that the CREATE components can help identify ways digital technology can be used as a part of a positive learning environment for young children.

C	Child-Directed	Intrinsic Motivation State of Flow Guided Play Planning & Reflection
R	Risk-Friendly	Positive Emotions Appropriate Challenge Novel Experiences Growth Mindset
E	Exploratory	Playful Experimentation Hands-on Learning Open-ended Divergent & Convergent Thinking
A	Active	Opportunities for Movement Physical Development Brain Breaks
T	Time for Imagination	Pretend Play Imaginary Worlds Daydreaming Explicit Instructions to be Creative
E	Exchange of Ideas	Conversation Connections & Combinations Collaboration

Learn more about the CREATE framework **here**.

Digital Gaming

Video games are a prevalent part of the lives of many young people today. In this review, we use the terms digital gaming and video games interchangeably to include both games downloaded to computers and mobile devices as well as games played on physical game consoles (either personal or connected to a TV). Although youth do not spend as much time playing video games as they do watching TV or listening to music, video game use by 8- to 18-year-olds has increased, particularly in terms of gaming on mobile devices (Rideout, Foehr, & Roberts, 2010). In a recent large-scale study, Rideout (2017) found that on average, 2- to 4-year-olds play video games for 21 minutes/day, and 5- to 8-year-olds play video games for 42 minutes/day.

Digital games are highly accessible and hugely engaging, providing a unique opportunity for entertainment, and in some cases, education. To that point, the Joan Ganz Cooney Center surveyed close to 700 K-8 teachers from across the United States and found that a large percentage (74%) of teachers reported using digital games for instruction in their classrooms (Takeuchi & Vaala, 2014). And with the increasing ease of access to video games through mobile devices such as cell phones and tablets, researchers have investigated some of the potential effects of video games on children's development (see Gorman & Green, 2017 for an additional review).

It is essential to remember that "not all games are created equal" (Gorman & Green, 2017, p. 122). There are multiple categories of games (e.g., games designed for educational purposes, for commercial sale, or to encourage physical movement), and also subcategories of games (e.g., puzzles, strategy, action) (Fietzer & Chin, 2017). While a single video game can involve more than one of these "categories," each has a different goal for the user and involves a different type of gameplay. Put simply, if two children each spend an hour playing video games, but each child is playing a different game, they are likely to have very different experiences. For this reason, it is important to be careful when drawing conclusions about video games as a whole because there is a large amount of variability across the market. With respect to research, action games (see Fietzer & Chin, 2017) and educational games (e.g., Riconscente, 2013) have received substantial attention because of their potential associations with important developmental gains.

Learning and Motivation

Although video games are a commonly used means of recreation (e.g., Gorman & Green, 2017), people have become interested in investigating whether digital games also offer any educational benefits (e.g., Chiong & Shuler, 2010; Egenfeldt-Nielsen, 2006; Mishra & Foster, 2007). Researchers have looked at both popular recreational games as well as games created specifically for educational use.

In one study, Herodotou (2018) was interested in examining whether the popular game Angry Birds (a mobile game in which players use slingshot devices to shoot birds into pigs) has the potential to teach 4- and 5-year-olds about physics. To investigate this, preschoolers spent approximately 50 minutes total playing Angry Birds over several days. Both before and after this gameplay period, children completed a series of assessments to record their game preferences and their understanding of projectile motion. Additionally, screen-recordings were used to document children's success in the game, and teachers rated the children's general performance. They found that in contrast to younger children, older children showed a greater intuitive understanding of force dynamics. Following the gaming experience, 5-year-olds (but not 4-year-olds) demonstrated improved understanding of projectile motion and were better at playing the game. Additionally, only children who were originally low-performing showed improvements over time (although Herodotou suggests this finding may be due to the low-performers actually not being that "low" in their understanding and/or the high-performers hitting ceiling levels of performance). It seems that the older children (5-year-olds) particularly benefited from this experience, and were able to learn a significant amount about physics from a small amount of time playing this game.

Scientists have also found ways to gamify educational experiences (see Dicheva, Dichev, Agre, & Angelova, 2015 for a thematic analysis of gamification). Gamification is defined as the application of game-like components to something that is not a game (Deterding, Dixon, Khaled, & Nacke, 2011; van Roy & Zaman, 2017). These game-like components include features such as points, levels, badges/rewards, scoreboards, storylines, and challenges. Experts have suggested that gamifying one's life can provide benefits such as greater satisfaction and productivity (see McGonigal, 2011 for more information).

Sandberg, Maris, and Hoogendoorn (2014) conducted a study in which they compared learning from a standard educational app to one with more game-like elements. In this work, 8- to 9-year-olds first completed a pre-test on vocabulary for the target topics: zoo animals and neighborhood (things that could be found in the areas surrounding the school). Next, children spent two weeks attending in-class lessons on these topics and using a Mobile English Learning (MEL) game which was either (1) standard (presented information and quizzes), or (2) enhanced (presented information, but including adaptive quizzes and additional game-like features such as rewards and storyline). Following this, children completed a post-test on relevant vocabulary. Sandberg et al. (2014) found that children who used the enhanced MEL application learned a greater amount than children who used the standard version. In this case, the application with added game features seemed to provide benefits over the standard edition.

Chuang and Chen (2007) also looked at whether children would learn more from a computer-game based curriculum than a traditional computer-based curriculum (without any gaming elements). The experimenters had third graders engage in two approximately 40-minute sessions of either: (1) playing "Fire Department 2: Fire Captain," a 3D computer game in which players use strategic thinking to complete fire-fighting tasks, or (2) viewing a webpage about firefighting. After this, children completed a battery of measures asking about their understanding of fire-fighting details, concepts, and applications. The researchers found that children who had completed the video game version of the fire-fighting training performed better than children in the standard computer-based education group. From this, we can conclude that at least in certain cases, there seem to be benefits to game-based, minds-on, highly engaging learning over traditional computer-based methods.

Gamification of learning is a relatively controversial topic, with researchers divided on whether it is beneficial or not (see van Roy & Zaman, 2017). Some of the concerns raised around gamification of learning have to do with motivation. An extensive body of work by Deci and Ryan has shown that motivation is a hugely influential force in

our lives and highly predictive of actions (see Deci & Ryan, 1985). Thus, in order to anticipate or alter what people are likely to act on, it is important to first understand their motivation. Relatedly, we know from years of research that providing external rewards (i.e. extrinsic motivation) for an activity that one was already motivated to do (i.e. intrinsic motivation) can undermine that natural interest (e.g., Lepper, Greene, & Nisbett, 1973). Therefore, it may be the case that adding external rewards in the form of gamification components (e.g., points, badges) to educational experiences could actually unintentionally lead to decreases in children's natural desire to learn.

In a study of gamified learning and motivation, Su and Cheng (2015) explored 10- to 11-year-olds' learning outcomes as a consequence of varied instructional approaches. First, children attended a series of standard classes focused on insect identification. Following this, children engaged in one of the following educational approaches across three weeks: (1) traditional natural science classes, (2) smartphone-assisted exploration of insects, or (3) mobile gamification learning system (MGLS) exploration of insects. The MGLS included gamification features such as leaderboards and quests to engage students and QR code capabilities to provide students with easy access to additional information. Su and Cheng (2015) had children complete a series of assessments before and after completing the insect curriculum (e.g., knowledge of insects, motivation). Children who completed the MGLS experience demonstrated greater expertise compared to either of the other groups. Furthermore, children who reported higher learning motivation (especially attention) scored higher on their insect knowledge tasks. This shows that gamified learning provided educational benefits for these students, and further, that children who were most motivated to learn were most likely to succeed on the assessments.

Collaboration

Minecraft is a hugely popular game among children of all ages. Although Minecraft includes a survival mode of gameplay, it is probably most well-known for its construction features. Players work to build structures out of gathered materials, and these structures can be as elaborate as their imaginations allow. Teachers and researchers alike are recognizing that this game appears to have educational potential (e.g., Brand & Kinash, 2013; Lane & Yi, 2017). In fact, Karsenti, Bugmann, and Gros (2017) found that playing Minecraft across an extended period of time resulted in significant benefits for elementary schoolers across several cognitive domains (e.g., motivation, collaboration, understanding of computer science).

One of the reasons that Minecraft is seen as having such great educational potential is the focus on collaboration (e.g., Marklund, Backlund, & Johannesson, 2013; Zolyomi & Schmalz, 2017). As stated by Lane and Yi (2017), "How we leverage this powerful tool and merge it with education to promote learning, engagement, interest, and in developmentally sound ways are all open questions" (p. 164). Given this, many educators are excited by the opportunity to use Minecraft for encouraging skills like engineering, collaboration, and creativity among their students (see Nebel, Schneider, & Rey, 2016 for a review of pros and cons).

In one study addressing the collaborative component of digital games, Garzotto (2007) investigated the effects of a Massively Multiplayer Online game (or MMO) on children's learning. Seven- to 10-year-old children were divided into groups of 2-3 individuals who completed four sessions of playing a 3D computer game called "Pirates Treasure Hunt." In this game, children work in small groups to explore new lands and learn about other cultures. The goal is to work with your own group to collect a set of treasures and correctly answer questions about the objects found from various nations. The game includes both competitive components (e.g., players want their group to find all the treasures first) and collaborative components (e.g., chat functions to communicate with other groups). For each session, all children first spent a bit of time becoming familiar with the game before playing two rounds. Both before and after having experience with the game, children were tested on their knowledge about a set of items from a variety of cultures (i.e., children were shown a photo and asked to label/categorize it). After all the sessions were complete, children were asked about their experience with the game (e.g., game preferences).

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Garzotto (2007) found that children performed better on the cultural knowledge assessment following the gameplay sessions. Children reported greatly enjoying the game experience, finding objects, and learning about other cultures. Participants also worked together successfully to achieve their goals; however, some did struggle to collaborate with other players. Garzotto (2007) also reported that in particular, the 9- to 10-year-old children were excited by the ability to communicate with players who were not co-located. This work provides evidence that children can demonstrate basic knowledge regarding academic content from a game, and also, that games are able to provide opportunities for social interaction and collaboration.

It is worth noting that beyond the games mentioned above, other popular video games are also well-known for their collaborative and social components. For instance, individuals playing games like Fortnite, or using gaming websites such as Neopets, can communicate with each other in real time. Additionally, platforms such as YouTube and Twitch allow gamers to extensively interact with one another, resulting in gaming communities. As more research on the learning potential of video games is conducted, it will be informative to see how such activities may provide social learning opportunities for individuals (see Shaffer, Squire, Halverson, & Gee, 2005).

Executive Function

Given the skills that many video games require (e.g., shifting attention, attending to many pieces of information at once, planning subsequent moves), it is thought that there may be a meaningful connection between executive function (EF) and video gameplay (see Fietzer & Chin, 2017). EF is generally conceptualized as a set of cognitive skills used for planning and problem solving (e.g. inhibitory control, verbal working memory) (Zelazo & Müller, 2011; Zelazo, Müller, Frye, & Marcovitch, 2003). Action games, or games "that require quick reflexes in the navigation of the game space," (Fietzer & Chin, 2017, p. 168) include such hits as Fortnite, Marvel's Spider-Man, Dragon Chase, and Subway Surfers.

One study conducted by Trick, Jaspers-Fayer, and Sethi (2005), explored the potential impact of action games on executive function development (namely, tracking and working memory). First, information was gathered to determine whether the 6- to 19-year-old participants had any prior experience with action-video games or action-sports. Next, all participants completed a computerized "Catch the Spies" task. To begin, individuals were shown a screen display of 10 happy-faces. Then, a subset of 1-4 faces began to blink back-and-forth to spies. After the blinking stopped, the faces moved around the screen, and participants were asked to report which faces were really spies before finding out the correct answers.

Not surprisingly, Trick et al. (2005) found that older participants outperformed their younger counterparts, particularly when there were more "spies" on the screen. The researchers also found that individuals who had experience playing action video games performed better on the spies task (and those with real-life action-sports experience did as well, albeit to a smaller degree). It seems that the experience children and young adults had with tracking multiple objects in action video games transferred to their greater ability to succeed in a complex object tracking computer task (see Achtman, Green, & Bavelier, 2008 for more on ways in which action video games affect adults' cognition).

In an investigation of the connection between more general video gameplay and executive function, Swing, Gentile, Anderson, and Walsh (2010) investigated potential associations between screen media use and attention issues, more specifically, time spent with television and video games. In their work, Swing et al. (2010) gathered information about two groups of individuals. First, parents of third-fifth grade students were asked to report on the average amount of time their child spends watching television and playing video games at two time points approximately 13 months apart. The children's teachers also reported on the child's level of attentional issues. Second, a sample of undergraduates self-reported on their screen media exposure (television + video games) and attention problems. Ultimately, the researchers found that for both third-fifth grade students and undergraduates, there was a positive correlation between screen time (television and video games separately, as well as television + video games combined) and attentional issues which were teacher-reported for the children and self-reported by the undergrads. Of particular importance to this literature review is that individuals who spent more than two hours per day playing video games and watching television demonstrated a greater number of attentional problems. It is essential to acknowledge, however, that as commonly stated, correlation does not equal causation, therefore, these findings should be interpreted with caution.

What Makes a Game Educational?

Given the ubiquitous nature of digital games, it becomes critical to think about the ways in which we can evaluate the quality of games for educational purposes. Several researchers have come forward with recommendations regarding which features define a "good" educational game. For one, Garzotto (2007) argues that for MMOs in particular to be successfully educational, they must excel in terms of usability (e.g., manageable controls), content (e.g., goal appropriateness, scaffolding), enjoyment (e.g., clear goals, challenge, feedback), and social interaction (e.g., cooperation, competition).

Similarly, Hirsh-Pasek et al. (2015) argue that there are four pillars for determining whether an app is likely to facilitate learning. First, the app must encourage users to be actively involved (i.e., foster minds-on engagement rather than passive observation). Second, users should be engaged with the central content (i.e., compel the user to stay focused on the task at hand). Third, the app needs to provide users with meaningful experiences (i.e., tie the app content to topics that are relevant to one's own life). Fourth, the app should encourage social interaction (i.e., encourage users to talk about the content with those around them or interact with characters). Additionally, Hirsh-Pasek et al. (2015) state that in order for an app to be educational, it needs to function within an educational context (i.e., it must be designed to highlight a learning goal). The authors suggest that by using these criteria as a starting point, one may be able to begin assessing whether an app should be considered truly "educational." (see Hirsh-Pasek et al., 2015 for examples of how particular apps rank when compared to these criteria).

Recently, Callaghan and Reich (2018) conducted an analysis of the top educational apps (both paid and free) on the market for preschoolers. These researchers evaluated a collection of 171 math and literacy apps designed for use by children under 5-years-old across several months. They argued that the key components of a useful educational app for young children are: clear and simple goals, high quality feedback and appropriate rewards, scaffolded challenge, and the incorporation of a physical component afforded by technology. Unfortunately, Callaghan and Reich (2018) concluded that it was uncommon for the apps to be deemed fully developmentally appropriate across all four criteria.

Opportunities for Movement

Unlike playing traditional computer games which is a rather sedentary activity, some digital games today are designed to get players moving (e.g., acting out a tennis match in Wii Sports, completing a routine in Dance Dance Revolution). In one study, Wuang, Chiang, Su, and Wang (2011) investigated the benefits of physically active games for children with Down syndrome. They posited that while traditional occupational therapy intended to improve the sensorimotor deficits associated with Down syndrome, it may become redundant and disengaging, and a game-based intervention involving physical movement could provide greater variety and motivation. In their work, 7- to 12-year-olds with Down syndrome completed about 48 total hours of either: (1) traditional occupational therapy, (2) physically active game-based therapy using the Wii, or (3) no therapy. Both before and after the treatment period, participants completed assessments focused on an assortment of coordination, motor control, and sensory skills. The researchers found that those in the therapy groups outperformed children who received no treatment.

Critically, overall, children who completed the physically active game-based sessions demonstrated the most improvement on measures of motor proficiency, visual integration, and sensory integration. This research suggests that providing the opportunity to engage in fun gameplay while moving around (and to watch an avatar simultaneously do the same), may be an effective tool for children who face sensorimotor challenges.

Sobel et al. (2017) were interested in examining parents' views on video games, and more specifically, joint media engagement, or using media with other people rather than on one's own (see Stevens & Penuel, 2010 for more on joint media engagement). Although the purpose of their study was to investigate joint media engagement in general, the game Pokémon GO (a mobile gaming app in which players walk around in real space to catch and battle fictional creatures known as Pokémon) served as the focus of this study. The researchers gathered information regarding parents' thoughts on Pokémon GO both by: (1) having parents who play Pokémon GO with their children complete an online survey; and (2) having parents who were playing Pokémon GO in the park with their children complete a brief semi-structured interview. Sobel et al. (2017) found that parents and children often played Pokémon GO together, allowing for family bonding both during and surrounding play time. Additionally, parents liked the physical, social, and exploratory components to the game. Respondents noted that gameplay often involved turn-taking/role differentiation, and the game provided opportunities to enjoy a shared interest/reminisce. Parents saw this active gameplay as different from other forms of "screen time" and expressed concerns primarily around children's physical safety. This is in contrast to parental concerns around children's well-being generally raised around more sedentary games.

Children's Well-Being

Although research does show evidence of positive outcomes for children, there is still great debate with regard to how video game features (e.g., time spent playing video games, type of game content, social interactions involved while playing a video game) may affect whether the experience is helpful or harmful to children. While some researchers argue that there are a number of cognitive, motivational, emotional, and social benefits to playing video games (e.g., Granic, Lobel, & Engels, 2014), others raise concerns regarding such issues as the development of a hostile attribution bias (tendency to expect that others acted with negative intentions) and gaming addiction among children and teenagers (e.g., Kirsh, 1998; Kuss & Griffiths, 2012).

The primary concerns are with regard to the constructs of violence, aggression, and desensitization. Researchers Funk, Buchman, Jenks, and Bechtoldt (2003) explored this topic in their study of video gameplay and socio-emotional well-being with 5- to 12-year-old children. First, children completed a series of measures to record their gaming habits at home, attitudes towards violence, and empathy. Pulse rate was also measured as an index of arousal. Following this, children were assigned to play a computer game for 15 minutes that was either: (1) non-violent, or (2) violent. Lastly, all children were asked to rate their frustration with the game, to complete an additional task in which they were shown images of characters engaged in an action, and asked a variety of questions about the depicted scene (e.g., one child taking a toy truck from another).

The researchers found that the short-term experience of video game play during the experiment did not lead to any differences in aggression or empathy for children who played the non-violent versus violent video game in the lab. However, they did find that children who reported playing more violent video games at home had lower levels of empathy. Funk et al. (2003) concluded that although long term exposure to violent video games may have had a desensitization effect on children, brief amounts of exposure to violent video games did not. They also noted that it is important to investigate whether there are some children who are more susceptible to the effects of violent video games than others.

Ferguson (2015) completed an additional exploration of the potential negative effects video games may have on young children. In this work, researchers completed an extensive meta-analysis of 101 studies looking at the influences of video games on children's development. Ferguson (2015) found that in the studies of 5- to 17-year-olds reviewed, associations between video game exposure and many metrics of poor well-being (e.g., low academic success, aggressive behavior, low prosociality) are typically very small if they exist at all. Interestingly, this lack of relation was most apparent when looking at high quality research (e.g., studies that used standardized measures and appropriate controls). Although it is of course important to be sure that the activities children are engaging in are well-suited to facilitate healthy development, a synthesized look at a large body of research indicates that in the majority of cases reviewed, video games are not cause for major concern.

In an illustration of work that demonstrates certain benefits of playing video games, Kovess-Masfety et al. (2016) conducted an analysis of research gathered on a sample of over 3,000 children from six countries to examine whether playing video games is helping or harming youth. Researchers collected survey data from 6- to 11-year-olds, their mothers, and their teachers on a variety of topics surrounding video game use and child well-being (e.g., time spent playing video games, mental health status, academic performance). Analyses revealed that high video game usage (spending over five hours per week playing video games) was positively associated with academic performance. Furthermore, the researchers found that children who were considered high video game users were actually less likely to have issues with both peer relationships and mental health problems.

Similarly, Pujol et al. (2016) investigated the influence of gaming on a variety of outcomes among 7- to 11-year-olds. The researchers had parents and children complete a set of assessments to record how much time the child typically spends playing video games, the child's cognitive capabilities, the child's psychological well-being, and brain development. They found that children who played video games for at least one hour per week ("gamers") had faster motor response times and better academic achievement. Additionally, gamers were found to have increased white matter volume and higher functional connectivity in certain brain areas (e.g., basal ganglia circuits). The study found no differences in social and behavioral problems between gamers and non-gamers, however, the gamers who spent more time playing video games (more than nine hours per week) were reported to have more social and behavioral issues.

Developmental Concepts and Future Directions

Although digital gaming is arguably older than some other types of digital technology reviewed here (e.g., voice assistant technology/conversational agents), there is still a great deal left to be known about the impact of its use. Many findings are mixed and an understanding of best practices for young children remains somewhat unclear.

- **Correlation vs. Causation.** Some research on video gameplay in children has been experimental in nature (e.g., Funk et al., 2003; Garzotto, 2007), however, in many cases, these studies are largely correlational (e.g., Pujol et al., 2016). While correlational studies reveal interesting and informative findings, we must acknowledge that the direction of effects is not entirely clear (e.g., does playing video games lead to certain levels of well-being, or does a certain level of wellbeing lead to playing video games?).
- **Transfer of Knowledge.** It is also worth considering how "real" the lessons learned from digital games are. For instance, in Minecraft, one is able to violate certain laws of physics to achieve their building goals. Do the physics concepts learned in Angry Birds apply to activities in the real world? Do the engineering skills practiced in The Sims hold true in reality? It would be informative to see which concepts learned in game-play apply to the real world, and which may lead to misconceptions (e.g., how well does in-game learning transfer to out-of-game problem solving?).
- **Motivation.** It is important to be sensitive to the potential risks of providing external rewards for learning and possibly undermining children's natural interest. On the other hand, sometimes an external reward may be necessary to serve as a "jumping off point" which may hook children on learning. Although researchers have begun to investigate differences between intrinsic and extrinsic motivation in games (e.g., Habgood & Ainsworth, 2011), more work needs to be conducted to identify the best ways to both motivate young learners and sustain their interest in learning.
- **Flow.** Another relevant concept is that of flow, a psychological state in which one is entirely absorbed by their current activity, or "in the zone" (see Csikszentmihalyi, 1997; Csikszentmihalyi, Abuhamdeh, & Nakamura, 2014). Digital games can be very captivating, so much so that people may lose track of time. Given this, it becomes important to think about the line between positive engagement and addiction. When does joyful engagement become an unhealthy dependence? (For more on gaming addiction, see: Gentile et al., 2017; Kuss, 2013; Kuss & Griffiths, 2012.)

It is no secret that masses of children love playing video games. And from the work described in this section, we can see that certain themes are beginning to emerge around the importance of such features as scaffolding/feedback, appropriate challenge, and straight-forward goals. Ideally, additional research analyzing qualities of digital games for young children will further clarify which components are most important for an effective educational game and for a particular developmental stage. As these findings emerge, they should be used to inform appropriate policy and design decisions (see Blumberg et al., 2019; Peirce, 2013).

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Coding

Coding and programming are two highly related constructs garnering a great deal of attention from parents and educators alike. While the term coding is typically used to mean the process of selecting appropriate symbols to get a computer to complete a particular task, programming is more complex and can involve the actual creation of rules to direct a computer's actions (Morgado, Cruz, & Kahn, 2010; Pila, Aladé, Sheehan, Lauricella, & Wartella, 2019). Despite these intricacies, and because the terms are closely associated and frequently used interchangeably (Duncan, Bell, & Tanimoto, 2014), in this paper we discuss coding and programming together.

Both coding and programming put individuals in control by allowing them to identify and arrange commands, and become digital creators. As coding/programming is becoming a more common field of practice for adults, particularly with the booming tech industry, this domain is simultaneously becoming a part of the lives of many children (e.g., Leidl, Bers, & Mihm, 2017; see Duncan et al., 2014 for a review of potential pros and cons). Several educational initiatives around coding and computer science access for children have become very popular. One of the most well-known is Code.org, a nonprofit whose mission is to provide high-quality computer science curriculum to K-12 students around the world (Partovi, 2014). Code.org has been incredibly successful in reaching the public, and is possibly best known for its Hour of Code campaign, in which one day a year, students and teachers around the world are encouraged to spend one hour engaged in coding exercises. In fact, over 740 million individuals have participated in Hour of Code to date (see Code.org, 2019).

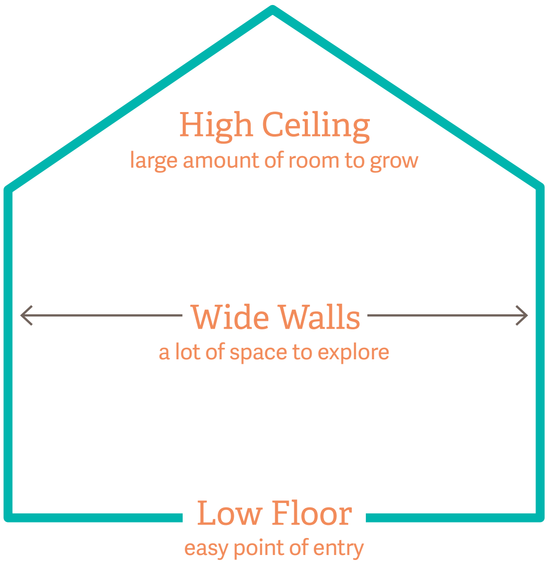
Appropriate Challenge

There are a variety of computer programming languages designed specifically for use with children [e.g., Scratch (Resnick et al., 2009); ScratchJr (Bers & Resnick, 2015); Logo (Papert, 1999)]. Among the most popular, Scratch is a free website that gives individuals 8 years of age and older the opportunity to practice coding by using digital blocks to program their own stories and games (Resnick et al., 2009). ScratchJr is specifically modified for use by younger children, 5- to 7-year-olds (Bers & Resnick, 2015).

In an investigation of user data for ScratchJr conducted by Leidl et al. (2017), Google Analytics (Google Inc., 2016) revealed that this program is flourishing. Not only did the number of users increase, but the number of sessions completed by each user did as well, indicating repeat visitation. The program was used across the globe, and impressively, "The year 2016 saw over 7.5 million projects created in ScratchJr. Furthermore, there were over 9 million existing projects edited" (Leidl et al., 2017, p. 5).

In a paper describing the development of ScratchJr, Flannery et al. (2013) state that this program is designed to be accessible to those with little or no prior knowledge, but also provides room for users to explore once they are more advanced. This means that anyone can feel comfortable starting to use it, and that there is an appropriate level of challenge provided to facilitate learning. Put simply, digital experiences should have a "low floor" (easy point of entry), "high ceiling" (room for growth in skills), and "wide walls" (space to explore). These ideas are championed by many as attributes of good design as they provide an appropriate level of challenge and accessibility during learning (e.g., Papert, 1980; Resnick & Silverman, 2005).

Accessibility During Learning



Learning and Motivation

Recently, Pila et al. (2019) published work looking at children's potential learning gains as a result of coding experience. In this research, 4- to 6-year-olds who were considered gifted and talented completed a week-long class using two drag and drop coding apps, Daisy the Dinosaur and Kodable. These programs challenge children to practice coding by helping characters complete various tasks and navigate mazes. Both before and after the coding classes, all children completed an interview and a gameplay observation. During the interview, children were asked about their knowledge of digital devices, interest in coding apps, and understanding of coding. Gameplay was observed to assess children's understanding of important coding concepts (e.g., sequencing, conditions, loops). The researchers found that children demonstrated gains in their coding knowledge, especially related to the games they practiced playing. In contrast, children had a difficult time verbally expressing their understanding of coding concepts. The authors explained that this may be due to a lack of knowledge or vocabulary to express their ideas.

As with many areas of STEM, parents, educators, and researchers have expressed interest in investigating gender-based differences in coding/computer science interest and abilities. Studies on this topic have been conducted with both adults (see Margolis & Fisher, 2003; Margolis, Fisher, & Miller, 2000) and young children (e.g., Martinez, Gomez, & Benotti, 2015). For one, Martinez et al. (2015) wanted to examine whether there may be meaningful differences by age and sex in computer programming understanding across early childhood. In their research, 3- to 6-year-old preschoolers completed a series of three lessons in which they practiced choosing appropriate programming commands and observing the outcomes. They first acted out programming sequences with their classmates (e.g., laid arrows on the floor to direct their peer to a goal end point) before repeating this activity with toy robots. Then, they actually programmed an N6 robot using UNC++Duino (a programming system which allows students to drag and drop symbols on the computer screen to code their robot's actions). In parallel, 8- to 11-year-old elementary schoolers completed a set of three lessons as well. These lessons included spending time working with Code.org (Partovi, 2014), the program Alice (a syntax-free drag-and-drop programming system [Dann, Cooper, & Pausch, 2008]), and, like the preschoolers, programming a N6 robot using UNC++Duino.

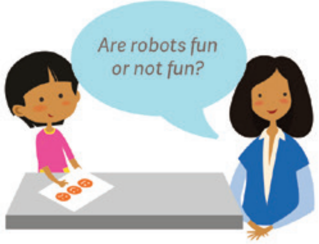
Following each lesson, children completed a multiple-choice assessment including a variety of programming challenges. These tasks ranged in difficulty, and required an understanding of programming concepts (i.e., sequences, conditionals, loops, parameters). Martinez et al. (2015) observed that overall, children of all ages were able to understand the targeted concepts to some degree. The researchers also documented important developmental changes. Namely, the youngest preschoolers struggled to understand that the programmed commands would dictate the robot's actions. In contrast, older students were able to complete complex tasks which required an understanding of multiple concepts. Despite some variation in depth of understanding by age, all students seemed highly engaged by the programming activities. The elementary schoolers even spontaneously explored more complex computer science concepts during their coding sessions. Interestingly, girls tended to outperform boys on the more complex tasks. Martinez et al. (2015) concluded that these findings provide some justification for the inclusion of computer science-based classes in schools starting from an early age.

Additionally, Master, Cheryan, Moscatelli, and Meltzoff (2017) conducted research on children's ideas about programming before and after a short intervention. In this study, a sample of 6-year-old children completed measures of both technology motivation (interest and self-efficacy with regard to programming and robots) and STEM-gender stereotypes (perceived gender-based differences in robotics, programming, math, and science capabilities). Next, based on a randomly assigned condition, children spent 20 minutes either: (1) using a drag-and-drop programming system to code a robot's movements such that the robot would follow a particular path (robot/experimental condition), (2) playing a storytelling card game (storytelling/control condition), or (3) playing no games (no activity/control condition). Lastly, all children completed assessments mirroring those at pre-test. Master et al. (2017) found that among those in the control conditions, boys reported greater technology motivation (interest and self-efficacy) than did girls, however, for children in the robotics intervention group, there was no gender difference in motivation.

The brief positive robotics programming experience boosted girls' technology motivation such that there was no longer any gender difference in programming and robotics motivation.

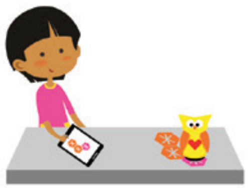
Promoting early programming motivation via coding experience

Pre-test and Post-test


Are robots fun or not fun?

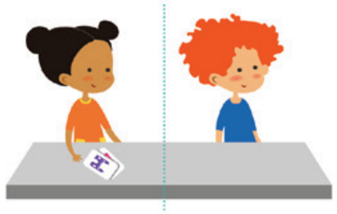
Six year old children completed measures of technology motivation (interest and self-efficacy with regard to programming and robots) before and after the intervention.

Robot (experimental condition)



Children used a drag-and-drop programming system to code a robot's movements to navigate several different paths. Children could program the robot to move forward, make left and right turns, and create loops to repeat moves.

Control conditions



1. Storytelling condition: Children played a storytelling card game.

2. No activity condition: Children did not play any games.

Results: For children in the robotics intervention group, there was no gender difference in motivation. In contrast, boys reported greater technology motivation (interest and self-efficacy) than did girls in the two control conditions.

Conclusion: The brief robotics programming experience boosted girls' technology motivation such that there was no longer any gender difference in programming and robotics motivation.

Master, Cheryone, Moscatelli, and Meltzoff (2017)

Computational Thinking

A theoretically related "hot topic" in education today is computational thinking, an array of skills rooted in computer science and centered around problem solving and analytical thinking (e.g., Grover & Pea, 2013; Wing, 2006). While computational thinking concepts are traditionally thought of in terms of computer science, many are relevant to success in life in general (e.g., creative problem solving, engaging in trial-and error processes). In fact, experts have argued that an understanding of computational thinking is important to all individuals, regardless of career (e.g., Wing, 2006).

Researchers have become interested in studying the ways children learn about computational thinking (see Shute, Sun, & Asbell-Clarke, 2017), and of particular relevance to the current review, how their understanding of computational thinking and programming may be associated. For one, Bers, Flannery, Kazakoff, and Sullivan (2014) investigated children's developing understanding of the TangibleK curriculum (see Bers, 2010 for more on TangibleK). Across a series of six increasingly challenging lessons and a final project, children spent approximately 20 hours working to program a vehicle. Lessons focused on programming, robotics, and computational thinking through activities on such topics as sequencing and looping (or getting their robot to repeat an action). At the end of each lesson, a researcher evaluated each child's success in that day's tasks, with a particular focus on their understanding of debugging (trouble-shooting/problem solving), correspondence (matching a symbol to its action), sequencing (planning the correct order of actions), and control flow (recognition that they decide what order the actions take place).

The researchers found that kindergarteners' scores were higher for the final project vs. lessons 2, 3, 4, 5, and 6 on measures of sequencing and correctly choosing programming instructions. The authors posit that this is because children had more autonomy over their final project compared to the prior lessons. This likely led children to be more motivated and for the task to be at an appropriate difficulty level for their skills. It seems that the unique opportunity to take control of their experience and execute a project based on their own desires led to the best outcomes.

Sáez-López, Román-González, and Vázquez-Cano (2016) conducted associated research which took place across two years with students in fifth and then sixth grade. The students involved first took a pre-test to measure their

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initial understanding of computer programming (e.g., sequencing, loops, experimenting, and revising ideas). Next, students in the computer programming condition completed 20 one-hour computer programming lessons centered around Scratch, and integrated into their normal coursework. Throughout the classes, students were observed. Those in the programming group also completed a questionnaire about their attitudes regarding the classes after completing them. Students in the control condition did not get any computer programming lessons. All participating students then completed a post-test on computer programming.

Results indicated that students who took these classes did demonstrate a meaningful improvement in their comprehension of computer programming constructs and logic, as well as coding skills. Those who received the programming training significantly outperformed those in the control group. Students also reported positive attitudes towards the programming activities, finding them fun and motivating, and were actively involved, committed, and enthusiastic about participation.

Integration in school curriculum

There is already a framework for including computer science in K-12 education (see Creative Commons, n.d., https://k12cs.org/), and an increasing number of states have standards around this (e.g. California State Board of Education, www.cde.ca.gov/be/st/ss/computerscicontentstds.asp). Many schools are now providing (or even requiring) classes on computer science/coding for students (Wing, 2016). And great efforts are being made to ensure that computer science becomes a valued part of the education system which is accessible to all individuals (see Xavier et al., 2019). Part of the emphasis stems from the idea that coding is a type of literacy (e.g., Bers, 2017; Hutchinson, Nadolny, & Estapa, 2016). Some researchers have argued that coding shares many similarities with traditional language (e.g., involves the use of tools and symbols, requires revision), and thus, should be conceptualized as a form of literacy as well (Bers, 2017). Taken literally, computer programming requires writing script, or text, and is thus analogous to what we think of as traditional written language. Beyond this, some have asserted that more abstractly, coding is a form of literacy because it is a socially-valued means of organizing and communicating information (see Vee, 2017).

Despite its presence in schools across the country, there are surprisingly few educators specializing in computer science, a problem that Code.org (among others) is working to ameliorate by providing computer science training for teachers (see 60 Minutes, 2019).

Developmental Concepts and Future Directions

Since coding is becoming increasingly more prevalent as part of the formal education of children, it is important to recognize how and what very young children can gain from these experiences.

- **Sequencing.** Sequencing, or logical ordering of a series of objects or events (Kazakoff & Bers, 2012; Zelazo, Carter, Reznick, & Frye, 1997) is a skill that is important for succeeding in everyday life (e.g., realizing that it is important to get out a cup before beginning to pour orange juice, or put toothpaste on the toothbrush before brushing one's teeth). Sequencing is also a focal concept for coding and computational thinking; in order to create a successful program, one must recognize that they are in charge of directing the computer (e.g. robot, digital character) and be able to give it a set of correctly ordered commands to achieve their goal. Although findings have been somewhat mixed with regard to programming and some cognitive skills (see Clements, 1986), evidence strongly suggests that programming is positively associated with greater understanding of sequencing (e.g., Kazakoff & Bers, 2014; Kazakoff, Sullivan, & Bers, 2013).
- **Executive Function.** Executive function is a battery of cognitive capabilities (see digital gaming section for description) that are used in many areas of life, and coding is no exception. Specifically, such executive function components as effective planning (e.g., "What is the goal?"), problem solving (e.g., "How can I get this to do what I want?"), and working memory (e.g., "What did I try last time?") are all useful (if not essential) to successfully completing a coding exercise. It may be enlightening for future research to investigate connections between executive function and coding among young children.

To maximize the learning benefits, it will be essential for more coding languages and curriculum to be accessible (low floor, high ceiling, wide walls) to both children and the adults who are facilitating these experiences. It will be interesting to see to what degree educators embrace these experiences and incorporate coding into their coursework, and how research will inform those decisions.

Augmented Reality & Virtual Reality

From medical school classrooms to libraries, and from military training sessions to apps, virtual reality (VR) and augmented reality (AR) experiences are becoming rapidly more present in our everyday lives. In AR, the user's view of the real world is modified such that elements are added or changed via digital means (Bacca, Baldiris, Fabregat, Graf, & Kinshuk, 2014). For example, when individuals play the AR game Pokémon GO, images of Pokémon are visible overtop the player's normal surroundings (e.g., they may see a Pikachu sitting on a real bench in their local park). On the other hand, VR is meant to be a fully immersive experience that takes an individual out of their current existence and into another world (e.g., Oculus Rift) (Yamada-Rice & Marsh, 2018). When players put on a VR headset, their vision is entirely occupied by the VR display (often a game/eSport, movie, or setting/scene which completely occupies their field of vision). These forms of technology alter (AR) or entirely replace (VR) one's view of reality, and often encourage physical activity on the part of the user. Although these are different forms of technology, due to their similarities and the overlap in their applications, we present a review of the current state of the literature on AR and VR use with children together below.

Learning and Motivation

It seems that AR and VR have the potential to provide children with engaging, beneficial learning experiences. Dalgarno and Lee (2010) succinctly identified what they believe are the primary affordances of 3-dimensional virtual learning environments (3-D VLEs). They asserted that 3-D VLEs: (1) facilitate spatial learning, (2) provide learning opportunities that would otherwise not be feasible, (3) can be intrinsically motivating and engaging, (4) aid in the transfer of knowledge from the context in which learning originally occurred to the real world, and (5) enable collaborative learning opportunities.

One relatively common application of AR technology is integration into children's book reading experiences. These technologically advanced books allow readers to use additional digital devices (e.g., computers, phones) to experience further content and engage with that content in novel ways (e.g., games, videos). This provides a unique means of book reading for children both while in school and at home. (See Billinghurst, Kato, & Poupyrev, 2001 for a discussion of MagicBook, a mixed reality book.)

Tobar-Muñoz, Baldiris, and Fabregat (2017) created an AR game designed to aid reading comprehension. The researchers had pairs of 8- to 12-year-olds either: (1) read a traditional book, or (2) read an AR book with game components (the games required successful comprehension of the story for children to succeed). They found that although children in the two groups did not differ in terms of reading comprehension, the children who completed the AR book task were more motivated to engage in the reading activity. Some enjoyed it so much that they restarted the book from the beginning.

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This indicates that although AR may not always improve learning outcomes, there could be other benefits to this technology (i.e., increased motivation and interest). It is imperative to highlight this finding given that research has long shown motivation and interest aid in successful learning (e.g., Deci, Vallerand, Pelletier, & Ryan, 1991).

Additionally, Enyedy, Danish, Delacruz, and Kumar (2012) conducted research looking at 6- to 8-year-olds' understanding of physics, and how that may be shaped by AR experiences. Across 15 weeks, children completed a variety of activities including AR exercises designed to educate them about a set of physics concepts (i.e., force/speed, net force, friction, and two-dimensional motion). Researchers found that children did in fact demonstrate improvements in their understanding of the physics concepts following interaction with the technology (i.e., gains between pre- and post-tests).

Although in some situations, both AR and VR technologies provide educational benefits for children, it is also important to consider whether they may be capable of misinforming children. Segovia and Bailenson (2009) looked at this concept by first reading children (4- to 5-year-olds and 6- to 7-year-olds) a narrative about an unusual event (a time the child swam with whales or shrunk to dance with his/her toy mouse) that they were told their parent had confirmed. Next, children completed one of four different memory prompt interventions: sitting idle, imagining experiencing the event, using VR to see someone else do the activity, or using VR to see a simulation of themselves doing the event. Both before and after the memory prompt, children were asked to report whether they remembered having gone through this event (the process was repeated for the second event; children were eventually told both scenarios). Several days later, children returned to the lab and were asked again whether they remembered having experienced the events.

This work found that preschoolers had higher false memory scores immediately following the intervention (as compared to beforehand), but the type of memory prompt did not affect their reports. In contrast, elementary-school aged children reported more false memories immediately following the intervention (compared to beforehand or after the delay), and the type of intervention mattered. Specifically, elementary-schoolers in the mental imagery and virtual reality-self conditions reported more false memories than those in the idle condition. This work provides insight regarding the powerfully rich nature of VR to make experiences feel incredibly real, so much so that it can shape memory recall. This also serves as a reminder that young children's memories are vulnerable to suggestion (Bruck & Ceci, 1991).

Clinical Applications

One area where VR is being innovatively applied is in work with clinical populations, such as with individuals with autism. Studies have shown that children with autism are able to successfully use VR technology, and further, that VR experiences can meaningfully improve their performance on tasks (e.g., social skills; see Bellani, Fornasari, Chittaro, & Brambilla, 2011 for a review). Due to the playful nature, realism, and flexibility of VR, it may provide unique benefits when compared to other educational approaches, and thus could facilitate useful learning opportunities for special populations.

For example, Didehbani, Allen, Kandalaft, Krawczyk, and Chapman (2016) researched the effectiveness of a VR-based intervention for 7- to 16-year-olds with diagnosed Autism Spectrum Disorder. First, these children completed a battery of pre-tests designed to measure facial affect recognition, theory of mind (understanding others' mental states), attention, and executive function/analogical reasoning. After this, all children completed 10 one-hour long sessions in which they played Second Life, a VR game displayed on a computer wherein individuals controlled an avatar of themselves going about a multitude of activities on an island (e.g., engaging in small talk in the school yard). Second Life scenarios involved the child, another participant, a confederate (someone who was, unbeknownst to the children, part of the research staff), and a "coach" (a researcher who prompted the children to complete certain actions, asked questions, and provided feedback). Following this intervention, participants completed the same set of assessments once again. Compared to task performance before the VR intervention, children demonstrated advances in

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facial affect recognition, theory of mind, and analogical reasoning. This shows there may be ways of using VR to improve components of social-emotional understanding and executive function among children with autism.

VR is also being used as a means of pain management for individuals suffering from such diseases as cancer (e.g., Gershon, Zimand, Pickering, Rothbaum, & Hodges, 2004). Gershon et al. (2004) investigated this concept among a group of 7- to 19-year-olds diagnosed with pediatric cancer. As a standard part of their cancer treatment process, these patients needed to have a port access procedure completed (insertion of a port to allow for easy access to the patient's veins for such purposes as administering chemotherapy injections). To study the possible effect of a VR intervention on the patients' experience, during this procedure the researchers had children engage in either: (1) a VR distraction (playing a zoo-themed game using VR), (2) a non-VR distraction (playing a zoo-themed game without VR), or (3) no distraction while the port was being placed. The researchers measured patients' pulse, distress, and pain before, during, and after the procedure.

They found that children who completed the VR distraction had lower pulse rates than individuals who had no distraction, and individuals who completed a distraction (VR or non-VR) were rated as being in less pain and generally appeared to be less tense than those who experienced no distraction. This suggests that VR-assisted distraction serves as a useful aid to reduce negative experiences associated with medical procedures. It should be noted that while this medical procedure can be uncomfortable, it is not considered particularly severe. Findings regarding a similar intervention for a more painful procedure could have different results.

Children's Well Being

An additional theme in work on AR and VR is an attempt to assess parental views and potential concerns associated with the use of this technology (e.g., Aubrey, Robb, Bailey, & Bailenson, 2018; Cheng, 2017; Yamada-Rice et al., 2017). Given the novelty of AR and VR, it is not surprising that parents may be a bit cautious about embracing it, but researchers are working to identify what particular issues parents are wary of and whether there is reason to be concerned.

Yamada-Rice and colleagues (2017) conducted a study which surveyed parents' and children's views on VR, and additionally, assessed some of the physical risk factors associated with VR use. More specifically, they first analyzed data from an online survey of parents and their 2- to 15-year-old children asking about technology in general, and VR in particular. The researchers then recruited 8- to 12-year-olds to come to the lab with a parent to play a VR game, answer a set of interview questions centered on VR, and complete a physical exam of their vision and balance. Among their findings, Yamada-Rice et al. (2017) found that after seeing and using VR in the lab, both parents and children were excited about VR, and children enjoyed interacting with VR to the point that they did not want to stop. Moreover, while a few children experienced short-term physical side effects after VR engagement (issues with vision and/or balance), the vast majority of individuals did not.

While additional work is necessary to further examine the safety risks that could result from the use of this technology, the work by Yamada-Rice et al. (2017) suggests that there may be less for parents to be concerned about when it comes to the physical risks associated with VR than once thought. It is still reasonable, however, to proceed with caution. For instance, even if we learn that there are not substantial physical risks to using these devices (e.g., VR headsets), it will still be important to critically evaluate which software is appropriate for children.

Developmental Concepts and Future Directions

An extensive review of the literature has revealed that although AR and VR frequently offer a number of benefits (e.g., increased content understanding, long-term memory retention, and collaboration), there are also limitations (e.g., attention tunneling, usability difficulties) (Radu, 2014). Because most AR and VR experiences were originally designed for teens and adults, a more thorough risk-benefit analysis is needed in order for adults to make informed choices about their use with children. As these technologies become more commonplace, it is important to consider the following aspects concerning the use of the devices themselves as well as the software children engage with while using them.

- **Imaginary worlds.** One concept of principal importance here is children's developing understanding of the distinction between fantasy and reality. Although children are in some circumstances better at identifying the division than was once thought (e.g., Sharon & Woolley, 2004), the goal with AR and VR is for users to have an immersive experience that makes a digital experience feel real. This means that at times, it may be challenging for children to distinguish between what is actual and what is digitally imagined. For instance, Yilmaz, Kucuk, and Goktas (2017) found that children reported believing that AR books were magic. Moreover, Aubrey et al. (2018) stated that, "Virtual reality (VR) is likely to have powerful effects on children because it can provoke a response to virtual experiences similar to a response to actual experiences" (p. 2). This area is deserving of additional investigation to better determine how children's understanding of the fantasy-reality distinction may affect their AR and VR experiences, and further, what sorts of conversations educators and caregivers may be able to have with children to assist their learning.
- **Safety Concerns.** As described previously, there is some concern regarding the safety of AR and VR devices, especially for use with young children. For instance, according to a recent paper by Won et al. (2017), the majority of VR head-mounted displays are recommended for use with children at least 13 years of age. Despite this, we know that younger children are interested in using this technology (Yamada-Rice et al., 2017). Given this disjoint, it is critical that additional research is conducted to identify what is safe and developmentally appropriate for children, in order to inform future development and use (see Sobel, 2019).

While questions about developmentally appropriate use of AR and VR remain, it is important to acknowledge that these technologies are still developing and much will change as the software and devices evolve. Right now, much of this technology is quite expensive to own, however, over time, we can expect that prices will drop making it much easier for families and classrooms to acquire such devices. With that in mind, it is important for research to stay ahead of their integration into home and educational settings.

Digital Fabrication

Technology exists today that allows users to generate an idea, draw it on a tablet or computer, and then, minutes later, hold it in their own hands. This method of using a computer to create a design which is then transformed into a real object is known as digital fabrication (Gershenfeld, 2005), and is taking place in makerspaces and Fabrication Laboratories (Fab Labs; Mikhak et al., 2002) across the world. The "Maker Movement" has generated much excitement for people of all ages. As stated by Holbert (2016): "Makerspaces and fabrication labs have become an international phenomenon in recent years" (p.1.; for a review of the literature on young individuals and makerspaces, see Marsh et al., 2017).

This technology distinctively provides an experience which is both digital and physical, and has been popping up in schools, libraries, summer camps, and community spaces as a way to provide more hands-on opportunities for child-directed learning. In a Fab Lab or makerspace where digital fabrication often takes place, it is likely that there will be other people working side-by-side, providing the optimal opportunity for collective discussions and joint work efforts. For example, Bar-El and Zuckerman (2016) discussed how one of their primary goals for their digital fabrication makerspace was to encourage socialization between co-participants. Additionally, unlike some other forms of technology that appear relatively intuitive for young users (e.g., children often begin playing a mobile game without getting instructions on how to do so from a parent), digital fabrication is an area where children rely more on adults' assistance for various reasons (e.g., the tools are quite complex, concerns regarding physical safety).

Some of the most common digital fabrication tools are the 3D printer, vinyl cutter, and laser cutter. A 3D printer melts plastic at a very high temperature and pushes it through a nozzle in very thin layers to create an object one layer at a time. A vinyl cutter uses a thin blade driven by motors to make precise cuts through paper, fabric, and vinyl—a thin plastic that can be sticky on one side. A laser cutter uses a very bright light to cut through different materials such as cardboard, wood, or even plastic. It can also be used to engrave, or make deep marks, on different types of materials like glass or certain types of metal.

Learning and Motivation

Motivation is a key construct when it comes to understanding how children interact with and learn from technology. Because digital fabrication tools are less well known and accessible to many children, there are questions that remain about children's interest in experiencing digital fabrication tools in a makerspace. For example, what do children think of these spaces, what do they want to create with the tools, what age are children able to understand the advantages these fabrication tools have over more traditional tools (e.g., saw, scissors, chisel), and are there any educational benefits to working with these tools?

In one examination of this topic, Holbert (2016) conducted a study where a small group of 9- to 10-year-old children (notably, primarily girls) attended a five-day "Bots for Tots" workshop in which they were tasked with designing toys for 3- to 4-year-olds using digital fabrication tools. The participants completed a pre-test which assessed their interest in STEM (science, technology, engineering, and math), their prior experiences with technology, and their self-efficacy with regard to digital fabrication. On day one of the workshop, children worked with a tablet and laser cutter to create plywood animals. Next, they met with preschoolers and asked them about their ideal toy. The fourth graders then broke up into small groups and worked to both prototype and create these toys. Finally, the older and younger children met up to play with the new toys. In a post-test, participants were asked to report on their self-efficacy, impressions of the workshop, and their potential interest in participating in a similar workshop in the future.

Holbert (2016) documented that the majority of participants were excited about and believed they were good at working with technology, even before the workshop began. Children reported continuing to feel this way following the classes, and some individuals who were more doubtful at first became increasingly confident over time. The researchers were also interested in seeing whether emphasizing how the children's work could help/be gifted to others would increase engagement in making activities. Notably, they found that it did. The authors posit that these findings may inform approaches to get girls excited about making.

Finding ways to motivate and encourage children to persist through challenges related to new technologies or unfamiliar STEM concepts will be important as our world becomes increasingly STEM-driven. Given the recent decline in the number of students who pursue careers in STEM in Europe, the EU Horizon 2020 funded a project, NEWTON, through which ultimately over 1,000 students will participate in student-centered learning approaches to education (Togou, Lorenzo, Lorenzo, Cornetta, & Muntean, 2018). As part of this project, Togou et al. (2018) conducted a pilot study on NEWTON Fab Lab STEM, a digital fabrication program, to investigate the effects of this workshop on children's knowledge and motivation regarding 3D printing. In these classes, pairs of 9- to 10-year-old students each spent a total of six hours across two days creating vases with 3D printing technology.

Using pre- and post-program assessments, observations, and interviews, Togou et al. (2018) found that although, overall, children were not familiar with 3D printing technology before the program, they demonstrated gains in their knowledge of 3D printing following the classes. The majority of students reported finding the classes useful, fun, and worth recommending to a friend. In general, students seemed to have greatly enjoyed their experience in the NEWTON Fab Lab STEM 3D printing program, with the exception being that a few students became frustrated when faced with difficulties getting the technology to work as they expected. This suggests that such 3D printing classes could provide a fun and useful learning opportunity to engage students in a way that standard classes sometimes do not, especially for individuals who are willing to work through some challenges, or who have a supportive adult to help guide and scaffold the experience.

In parallel work by Posch and Fitzpatrick (2012), 10- to 14-year-olds attended a Fab Lab workshop where they worked with a variety of digital fabrication tools and activities (e.g., 3D printer, vinyl cutter) for 10 hours across two days. The workshops focused on making sure that the projects were personally relevant, that products could be taken home by the students who created them, and that the skills learned could be applied outside the walls of the Fab Lab. Children's experiences in the Fab Lab were assessed via several means, including observations, interviews, questionnaires, and presentations. The vast majority of children reported liking the workshop and having learned something they did not know before, and all children reported wanting to return to the Fab Lab. Especially for vinyl cutting activities, children were able to successfully understand how to use the tools and create products that represented their personal interests (e.g.,

using a vinyl cutter to make a T-shirt with a picture of a game they like). Again, this work provides some evidence that children seem highly interested in digital fabrication activities, although there may be some digital fabrication tools that are more developmentally appropriate than others. The authors state that compared to 3D printing, other digital fabrication tools (e.g., vinyl cutters and laser cutters) may be easier to use and less time consuming, and thus most appropriate for working with younger children to maximize their enjoyment.

Bar-El and Zuckerman (2016) conducted work evaluating young individuals' perceptions of Maketec, a library makerspace in which teenagers serve as the program facilitators. In this small-scale study, the researchers conducted interviews with four 9- to 13-year-old children about their Maektec experience. Bar-El and Zuckerman (2016) found that children reported being able to successfully use the technology at the makerspace, craft personally-relevant products, and enjoy the exploratory nature of the makerspace environment. Children found the mentors to be helpful, however, there was some disagreement in how involved the teenagers should be, with some individuals requesting greater amounts of assistance and mentor involvement than others. Overall, children seemed pleased by the opportunity to create in a unique technology-laden environment.

Some researchers have also begun to look at whether children make educational gains from their hands-on experiences in digital fabrication makerspaces (see Blikstein, 2013). For instance, Smith, Iversen, and Hjorth (2015) conducted a pair of studies to examine connections between design thinking, or creative problem solving when faced with a complex design challenge, and digital fabrication (see Brown, 2008 for more on design thinking).

In their first study, Smith et al. (2015) completed extensive observations of fifth through ninth grade students in classes on digital fabrication and design. They reported that students struggled to understand the digital fabrication design process, or aspects of design thinking as applied to digital fabrication (e.g., found it difficult to collaborate with others and transform their conceptual ideas into real products). Next, Smith et al. (2015) conducted a second study designed based on the hurdles documented in their first project. The researchers created a six-week Fab Lab course for seventh graders on similar topics with a focus on design processes of digital fabrication. During this program, students were challenged to work in small groups to redesign an urban space. Students were encouraged to engage in such thought exercises as generating ideas, reflecting on their work, and drawing connections between their work and the real-world. Observations were taken for later analysis, and a small subset of students were interviewed during the Fab Lab classes. Following this course, students demonstrated a greater understanding of the digital fabrication process in contrast to those observed during the first study. These

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authors concluded that teaching digital fabrication and design thinking together is quite challenging, but that by adding a greater emphasis on the design process, educators may be able to better facilitate a deeper understanding of digital fabrication (Smith et al., 2015).

Designing Effective Experiences

Although research on digital fabrication and young children remains limited and leaves much to be understood, some scientists have started evaluating what features of makerspaces lead to the greatest success. Iivari, Molin-Juustila, and Kinnula (2016) conducted an extensive literature review and analysis of research on children and digital fabrication/making guided in part by Chawla and Heft's (2002) work, specifically their "effective participation framework," which proposes that children gain the most from experiences where they are actively involved and given a degree of autonomy. This review revealed that, overall, the literature on digital fabrication and making says activities should: (1) take place in familiar environments which are easily accessible for all individuals (e.g., libraries, schools, museums), (2) center around the child's personal interests, (3) foster collaboration, (4) often allow children to have a central role in their own learning (with possible adult guidance), and (5) result in tangible products.

Relatedly, Eriksson, Heath, Ljungstrand, and Parnes (2018) reported on findings from Makerspace in School, a large-scale, multi-year project in Sweden that was designed to investigate digital fabrication and making in schools. Work on this project resulted in a multitude of data from such sources as observations and interviews. Based on analyses from this study, Eriksson et al. (2018) suggest several lessons learned and challenges. First, schools find it difficult to acquire the necessary tools for digital fabrication classes and teachers lack knowledge regarding digital fabrication technology. Second, policy-makers need to be more involved in and informed about digital fabrication in education to make good public policy decisions. Third, opportunities to engage in digital fabrication activities should be made equal (and equally appealing) for all children. Finally, digital fabrication courses should help children to learn new information, rather than merely focusing on exposing them to the "hottest" new technology. These authors raise important points for parents, educators, and policy-makers to consider as advanced technology continues to become an ever-increasing part of our lives.

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Developmental Concepts and Future Directions

Since digital fabrication tools and software were originally designed for adult use, they pose a series of cognitive challenges for young individuals that still need further investigation.

- **Scale & Proportion.** The Next Generation Science Standards (NGSS) outline seven crosscutting concepts that "unify the study of science and engineering through their common application across fields" (NGSS Lead States, 2013). One of these concepts is "scale, proportion, and quantity." While children are interacting with digital fabrication tools, they must particularly navigate the concepts of scale and proportion (e.g., "How does a 2-inch image on a tablet correspond to a 5-inch piece of wood?"). Knowledge of this concept is critical in understanding how their digital designs affect the final physical structure they create.
- **2D-3D Conversion.** Related, children need to comprehend the 2D-3D connection between the image they see on a screen (2D) and the resulting tangible product (3D). It may be difficult at times for young individuals to understand this digital fabrication modeling system in which 2-dimensional pictures "come to life" (see DeLoache, 1991 for relevant work on children's understanding of models/symbols). Impressively, recent research has shown that 4- to 6-year-olds are in some cases capable of transferring learned knowledge from a tablet to a puzzle in the real world (Huber et al., 2016). This indicates that even young children have some understanding of the connections between 2D and 3D, however, a great deal is left to be understood as it applies to digital fabrication.

To date, much of the research on digital fabrication tools has been with small samples and with older children or adults. Although preschool-aged children may have some difficulty navigating such advanced technology, researchers should explore what young individuals are capable of and what aspects might be too challenging due to subject complexity or children's developing fine motor skills. Since young children are interacting with digital fabrication tools in educational settings around the world, we hope that scientists will continue to investigate the ways in which children can successfully engage with these tools in meaningful and developmentally appropriate ways.

Case Study from the Bay Area Discovery Museum's Early Childhood Fab Lab

In 2016, the Bay Area Discovery Museum (BADM) in Sausalito, CA opened the world's first early childhood Fab Lab (now known as the Try It Studio), bringing digital fabrication (and making opportunities in general) to young children. In this facility, educators work with children as young as 3-years of age to engage in making activities utilizing both high- and low-tech tools.

In an effort to begin filling the gap in the literature on digital fabrication and young children, in 2018, BADM's Research and Evaluation Team conducted a study to explore the feasibility and effectiveness of digital fabrication classes for 4- to 10-year-olds. The research was primarily motivated by an interest in investigating potential age-based developmental differences in children's interest in and understanding of digital fabrication tools. The study included two groups of children: (1) 7- to 10-year-olds enrolled in a 4-day maker camp at BADM (n = 9), and (2) 4- to 5-year-olds enrolled in BADM's on-site preschool who completed a series of 10 maker classes (n = 11). The study was organized such that both groups of children first completed a series of pre-tests, then experienced working with the digital fabrication tools (camp or classes), and finally completed a parallel set of post-tests. Highly skilled educators facilitated all Fab Lab sessions to maximize learning and minimize frustration.

For each of the three digital fabrication tools (vinyl cutter, laser cutter, and 3D printer), children were asked a series of questions including: (1) did they knew what the picture of [tool] was, (2) did they think [tool] is primarily used for cutting vs. building, (3) did they think [tool] needs a computer to work, (4) how fun (or not fun) they thought playing with [tool] was, and (5) how good (or not good) they thought they were at playing with [tool] (self-efficacy). Children were also asked to provide explanations for their responses to some questions as a means of getting a deeper understanding of their ideas.

Analyses revealed that older children (vs. younger children) and children at post-test (vs. pre-test) more commonly reported knowing what the tools were. Additionally, 7- to 10-year-olds were better than 4- to 5-year-olds at correctly reporting which tools were primarily used for cutting vs. building, although there was no such difference by testing session. Children at both ages and test sessions typically reported knowing which tools needed a computer to work. Relatedly, children did not demonstrate a difference in how fun they thought the tools were across age or test session – on average, children thought the tools were a little to medium fun. Finally, children in both age groups reported being better at working with digital fabrication tools at post-test than pre-test, demonstrating an increase in self-efficacy over time.

Overall, it seems that experience working in the Fab Lab affected children's responses for certain measures but not others (i.e., knowing what tools were and increased self-efficacy). This work is an important initial contribution to the small but growing literature on digital fabrication in early childhood.

If you are interested in learning more about this research, please contact BADM at media@badm.org.

Social Robots & Conversational Agents

The concept of Artificial Intelligence (AI) may bring to mind strange images from futuristic science fiction films, but AI is already in the homes and lives of many. AI is a branch of computer science dedicated to studying agents that interact with the environment by taking in information and responding (Russell & Norvig, 2016). Two forms of AI that children are commonly interacting with today are social robots (robots intentionally designed to be social creatures; e.g., AIBO the robotic dog) and conversational agents (digital systems that allow people to use vocal commands to play games, listen to music, gain information, and more; e.g., Alexa, Siri). Because these forms of technology are voice-controlled, even young individuals can use them. Due to the similarities between these forms of technology, we discuss them sequentially within the section below.

Social Robots

Learning and Motivation

A leader in the field, Dr. Cynthia Breazeal defines social robots as, "autonomous robots...that people apply a social model to in order to interact with and to understand" (Breazeal, 2003, p. 168). Social robots vary in the degree of interaction they allow. For example, while some simply serve as a source of entertainment, others can hold a conversation and even learn from humans (see Breazeal, 2003 for a discussion of types of social robots).

Due to their novelty and the array of affordances social robots allow, researchers have become interested in learning how children engage with these distinctive devices. For one, are children able to learn just as effectively from a social robot as a human instructor? To address this question, Kory Westlund et al. (2017a) introduced 2- to 5-year-old children to one of two interlocutors: (1) a robot, or (2) a female experimenter (all children eventually worked with both interlocutors, each for half of the study). After the child and interlocutor became acquainted, the interlocutor and child looked together at a set of animal pictures on a digital tablet. Pairs of unknown animals were presented either close together or far apart. For half of the trials, the interlocutor provided uninformative remarks about an animal, whereas for the other half of trials, they labeled an animal. Following this, participants completed a series of test questions to see if they had learned the names of the animals.

Among many complex findings, this work revealed that there was no difference in how much children learned from the robot versus the human experimenter (Kory Westlund et al., 2017a). Additionally, children were much better at correctly identifying animals when their images had been presented further apart (rather than close together). The greater visual distance made it easier to decipher where the interlocutor's gaze was directed while they spoke.

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In another study, Kory Westlund and colleagues (2017b) examined the potential effects of a social robot's vocal intonation on learning outcomes. In this work, 4- to 7-year-old children completed a vocabulary assessment before sitting with a robot and a puppet to read a picture book displayed on a digital tablet. At some point during the reading activity, the puppet fell asleep. Critically, the robot either read the book in a flat tone or an expressive tone. After the story was complete, the puppet woke up and asked the child to recount the story. Children were then asked to complete another vocabulary assessment and answer a series of questions about the robot. Several weeks later, some of the children were asked to return to the lab to complete one more vocabulary task and reiterate the story again.

These researchers found that regardless of tone condition (flat vs. expressive), children showed similar levels of learned vocabulary and liking for the robot. That said, children who specifically listened to the robot tell the story in an expressive (rather than flat) tone used more similar phrases to those of the robot at both the immediate and delayed retelling, and were more likely to preserve the length of their story over the time delay, indicators of improved memory retention. This could in part be explained by the finding that children who listened to the expressive version of the story showed higher levels of concentration and engagement during the reading. Importantly, this work suggests that expressive language provides some learning benefits over flat language. Findings from these studies align with additional work by Breazeal et al. (2016) showing that children can use social robots as sources of information.

Growth Mindset

Beyond gaining content knowledge, children may be able to gain other types of knowledge from social robots. For instance, the concept of mindset has become incredibly popular with parents and educators alike. Dr. Carol Dweck is championed as the pioneer of this movement, encouraging people to foster a growth mindset (a belief that through effort, one can overcome challenges) rather than a fixed mindset (a belief that one has a set amount of ability, and there is nothing that can be done to change that) (see Dweck, 2008). Research has shown that individuals who hold a growth mindset tend to be more successful across a variety of domains including academic and social circumstances (e.g., Yeager & Dweck, 2012).

In connection to this work, Park, Rosenberg-Kima, Rosenberg, Gordon, and Breazeal (2017) conducted research to determine whether a brief interaction with a social robot who expressed growth mindset concepts could influence children's beliefs. Five- to 9-year-olds began by completing a set of pre-assessments including using a set of apps that children "played" on a tablet to assess their spatial skills and their current mindset. Next, children were introduced to a social robot, Tega (see Kory Westlund et al., 2016), and each child took turns playing a tangram puzzle game with Tega. For children in the growth mindset condition, Tega provided growth-oriented feedback (e.g., focused on praising effort and acknowledging challenge; "I will choose this one because it looks challenging!"), and the robot chose puzzles which became more difficult over time. For children in the neutral condition, Tega provided neutral feedback (e.g., focused on simply stating facts; "I will choose this one."), and selected puzzles which were of equal difficulty. Lastly, children completed additional spatial skills and mindset assessments via apps as in the pre-test and reported on their beliefs about Tega.

There were no differences between conditions in children's mindset at the start of the study, however, following their interactions with Tega, children in the growth mindset condition demonstrated greater alignment with growth mindset beliefs, more perseverance/resilience when faced with challenges, and stronger belief that Tega had a growth mindset. Additionally, all children demonstrated improved spatial skills over time. This work provides evidence that even a brief growth mindset oriented interaction with a peer-like social robot sufficiently boosted children's growth mindset. These findings also align with other research showing that parents have an important role in shaping children's mindsets from early on (e.g., Gunderson et al., 2013).

Animacy

In addition to examining what children can learn from social robots, it is also intriguing to consider how children conceptualize social robots. For example, Turkle, Breazeal, Dasté, and Scassellati (2006) conducted work to explore what children thought of two robots, Kismet (a robotic head with infant-like traits, capable of socializing through a variety of means including facial expressions and limited vocalizations) and Cog (a humanoid robotic torso, capable of such social tasks as visual detection and imitating actions). In this research, 5- to 13-year-olds spent approximately 50 minutes interacting with either Kismet or Cog. Part-way through this engagement period, children spoke with a researcher about their interaction experience. Children demonstrated a great desire to communicate successfully with the robots and (typically) to establish a positive social relationship with them. Additionally, children tended to see the robots as having some life-like qualities. This was actually so much the case that even when researchers explained to children that Cog had mechanical inner workings, they refused to see it as just a machine. This work shows that to children, Kismet and Cog were not simply seen as pieces of machinery, but as something more animated, capable of such things as sentience, feelings, and learning.

Another interesting question inspected by Kahn, Friedman, Perez-Granados, and Freier (2006) is how children conceptualize robotic animals. In this work, 2- to 6-year old children spent time interacting with two different dogs: (1) a stuffed dog, and (2) AIBO, a popular robotic dog produced by Sony (see Pransky, 2001). Children spent time playing freely with one of the dogs before completing a semi-structured interview about the dog's biological properties, mental states, social rapport, moral standing, and animacy. Then, they completed the same process with the other dog. The final task was a card sort assessment where children were asked to state how similar AIBO was to a variety of other entities (i.e., stuffed dog, robot, desktop computer, real dog).

Findings indicated that children treated AIBO as an entity that is neither fully animate or inanimate. They reported believing that AIBO and the stuffed dog were approximately equivalent across many domains (e.g., animacy, biological properties, mental states), however, children's behavior indicated that they may have seen AIBO as slightly more life-like in some ways than the stuffed dog. For instance, the majority of children reported believing they had a positive relationship with AIBO, that it was not okay to mistreat AIBO, and that if AIBO was hurt, the experimenter should help. Compared to the stuffed dog, children were more likely to try to get AIBO to reciprocally interact with them, to act tentatively towards AIBO, and to use directive language towards AIBO, all indications that they thought AIBO may be able

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to act autonomously to a degree. In line with this, on the card task, children also reported that AIBO was least like a computer. Further, in contrast to AIBO, children were more likely to mistreat and animate the stuffed dog, likely indicating that they felt the stuffed dog was less "real." These findings indicate that even young children recognize there is something unique about AIBO, when compared to other inanimate objects.

Conversational Agents

Playful Experimentation

A related emerging form of interactive AI technology is conversational agents (e.g., Amazon's Alexa, Google Home, Apple's Siri) which are also designed to be highly social in nature (see Bickmore & Cassell, 2005; Cassell, Sullivan, Churchill, & Prevost, 2000 for more on embodied conversational agents). Such devices serve many purposes (e.g., play music, answer questions, enable gameplay; Rideout, 2017) and also go by many names (e.g., intelligent personal assistance technology, smart speakers, digital personal assistants, virtual agents, voice-activated assistants, voice input systems). Some of these technologies are audio-based only (e.g., just a voice coming from the phone), while others are "embodied," or represented by an image of a person or animal (e.g., an animated individual appears on a screen) (for more on embodied conversational agents, see Bickmore & Cassell, 2005; Cassell, Sullivan, Churchill, & Prevost, 2000).

Conversational agents are becoming an increasing presence in homes (Wiederhold, 2018) and according to a report by Rideout published in 2017, "9 percent of homes with children ages 0 to 8 now have such a device" (p. 35). It is important to recognize, however, that the majority of these tools were designed for use by adults (Yarosh et al., 2018). Given this, some researchers have set out to study children's use of these devices.

Druga, Williams, Breazeal, and Resnick (2017) explored how children conceptualize conversational agents. In their work, 3- to 10-year-olds spent time playing with a variety of agents: (1) Amazon's Alexa; (2) Google Home; (3) Anki's Cozmo (a small, intelligent, mobile robot which can be used for playing games and learning [e.g., coding activities]; Anki, 2019); and (4) Julie Chatbot (an app that allows individuals to chat with "Julie," a socially interactive 3-dimensional animated woman). After exploring each agent, children completed a brief questionnaire to assess their thoughts about each. Druga et al. (2017) found that overall, children greatly enjoyed spending time playing with each agent, although the younger children sometimes had more difficulty doing so than the older children. Observations indicated that children became familiar with how to use these tools, and that when faced with a challenge (e.g., if an agent did not understand their initial question), they made adjustments in hopes of getting a more satisfying response.

In associated work, Lovato and Piper (2015) explored the ways children use voice input technology using two different approaches. First, the researchers asked parents of children 7 years of age or younger to complete an online survey regarding their children's interactions with digital devices. The parent surveys revealed that the most common voice assistant technology used by young children was Apple's Siri. Second, these researchers examined a set of YouTube videos which showed children interacting with Siri. They found that it was common for children to ask exploratory questions to try to get to know the digital device better or to elicit silly responses. Additionally, children often used these tools to gain information and accomplish tasks (e.g., send a text message). These researchers saw that children often struggled to get the answers they desired (or answers in the format they desired, e.g., written text vs. an audio response), which sometimes led to frustration and even speaking unkindly towards the device.

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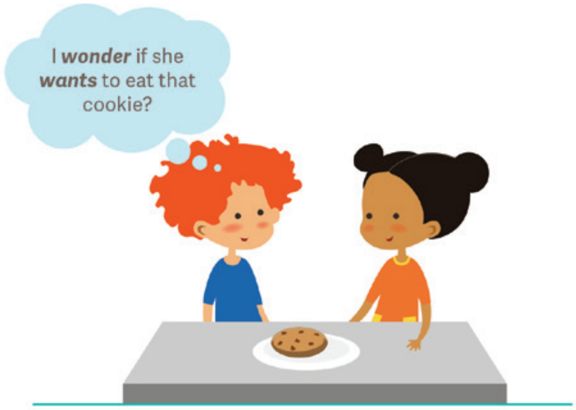
Developmental Concepts and Future Directions

Social robots and conversational agents seem to provide unique educational opportunities for young learners (and the research described prior shows children do indeed learn from these devices), however, this field is only just becoming established. As more of these devices are designed with children as the target audience, research can further establish how children conceptualize them and what they are able to gain from them.

- **Animacy.** It is important to contemplate children's understanding of animacy and whether or not children believe that these technological devices are alive. Many researchers have investigated what makes children categorize certain entities as alive versus not alive (e.g., Setoh, Wu, Baillargeon, & Gelman, 2013; Opfer & Gelman, 2011; Poulin-Dubois, Lepage, & Ferland, 1996). As stated by Opfer and Gelman (2011), "The animate-inanimate distinction is well in place in the first year of life...Infants make use of both featural information (e.g., faces, sounds) and dynamic information (e.g., biological and goal-directed movement) to determine which entities are animate vs. inanimate..." (p. 219). Despite this early-emerging basic understanding of what makes something "alive" children's comprehension of, and relationships with, technology are complex because these devices are designed to mimic features of living creatures, such as voice and sometimes physical features.
- **Theory of Mind.** Theory of Mind (ToM) is the understanding of mental states such as thoughts, desires, and beliefs (Wellman, 1992; Wellman & Lagattuta, 2004). This social-cognitive construct is heavily studied by developmental psychologists because understanding how children conceptualize mental states reveals a great deal about how children perceive and predict others' behaviors. When considering how a child interacts with a social robot or conversational agent, it becomes essential to understand whether they believe that it is capable of unique thoughts and emotions in the same way that they are. For example, do children think there is a real person named Siri in their phone who has beliefs and desires just as they do, or do they understand that Siri is connected to the internet and retrieves pre-existing information? These are important distinctions when considering how children can best learn from these tools, and how future devices can be designed to most greatly benefit young individuals.
- **Trust in Testimony.** This is an area wherein scientists study which factors individuals (of relevance here, children) weigh when determining whether they should accept information presented to them as true. This is of special importance as we discover whether children will assume what social robots and conversational agents state is true, or if they will be more selective in their trust of these devices. According to researchers, the issue of trust in testimony among young children is convoluted and two sided – children are both very open to accepting information provided by others and also quite selective in who they believe to be a trustworthy source of information (e.g., Harris, 2012; Robinson & Einav, 2014). When trying to determine whether or not to accept someone's testimony, children take into account a variety

Theory of Mind


I ***wonder*** if she ***wants*** to eat that cookie?

Theory of mind is the understanding of one's own and others' mental states (e.g., thoughts [***wonder***], emotions, beliefs, desires [***want***]).

of elements such as past accuracy, personality traits, and whether the individual is a real person or a fantasy character (e.g., Koenig & Harris, 2007; Lane, Wellman, & Gelman, 2013; Richert, Shawber, Hoffman, & Taylor, 2009). Some of these cues are more effective than others at leading children to acquire accurate information. As devices such as social robots and conversational agents become increasingly prevalent, work looking at children's acceptance of their statements as factual will be important.

- **Children with Special Needs.** Researchers are beginning to examine whether social robots and virtual agents like the Amazon Echo™ can be utilized to assist children with special needs, such as those with autism or cerebral palsy (e.g., Allen, Shane, & Schlosser, 2018; Cabibihan, Javed, Ang, & Aljunied, 2013; Kim et al., 2013; Kozyavkin, Kachmar, & Ablikova, 2014). These tools typically function using voice-activated controls and provide auditory information, enabling use by a broader population of individuals. It will be exciting to see how this work continues to evolve, and observe new discoveries for using this technology to better the lives of all children.

As social robots and conversational agents grow in popularity, it is worth noting that, in addition to the topics mentioned above, there are also concerns regarding safety and privacy surrounding this technology (see Chung, Iorga, Voas, & Lee, 2017). As research in this area continues to evolve, it will be important to address questions concerning children's interactions with these devices and what is appropriate for various developmental stages.

Conclusion

Children are exposed to technology in every aspect of their lives -- it is in their homes and in the homes of friends and family; it is in their schools and libraries; and it is in malls and other retail outlets. And the types of technologies children interact with are only becoming more diverse and sophisticated with time. Although research in this area is still trying to keep up with the rapid pace of technology adoption, it is important to look across disciplines to understand how children perceive and interact with technology as well as what impact it is having on them, both cognitively and socio-emotionally.

As an attempt to bridge research to practice in this realm, the articles reviewed here provide some interesting insights into both the more established (i.e., digital gaming, coding) as well as the emerging (i.e., augmented/virtual reality, digital fabrication, social robots and conversational agents) uses of technology in the lives of children today. These studies highlight how technology can be used to nurture some aspects of learning and healthy child development such as executive function, safe risk-taking, collaboration, and gross motor development. In addition, numerous studies across devices have shown that young children are capable of learning from technological devices and that technology in some cases can help motivate children or support those with cognitive differences.

Although the research has highlighted some academic and social benefits of using digital technology, questions around safety, addiction, developmentally-appropriate content, and childrens' well-being still exist. And, particularly for children in early childhood, we know that an interaction with a digital device should never replace interactions with human beings and the outdoors. So, where does that leave parents, caregivers and educators struggling with questions around appropriate technology use each day? We believe that utilizing a framework like CREATE, which is rooted in research for quality learning experiences, can serve as an evergreen guide for adults tasked with navigating the complexity of using technology with young children.

For more information on how the research discussed here can be translated into actionable recommendations for parents and caregivers using the CREATE framework, please refer to "Tech Time with Purpose: A Creative Approach to Using Digital Devices with Young Children" by visiting BADM.org/Tech.

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