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Putting Education in "Educational" Apps: Lessons From the Science of Learning

Kathy Hirsh-Pasek[1], Jennifer M. Zosh[2], Roberta Michnick Golinkoff[3], James H. Gray[4], Michael B. Robb[5], and Jordy Kaufman[6]

[1]Department of Psychology, Temple University; [2]Department of Human Development and Family Studies, Penn State University, Brandywine; [3]School of Education, University of Delaware; [4]Sesame Workshop, New York, NY; [5]Fred Rogers Center for Early Learning and Children's Media at Saint Vincent College; and [6]Brain and Psychological Sciences Research Centre, Swinburne University of Technology

Summary

Children are in the midst of a vast, unplanned experiment, surrounded by digital technologies that were not available but 5 years ago. At the apex of this boom is the introduction of applications ("apps") for tablets and smartphones. However, there is simply not the time, money, or resources available to evaluate each app as it enters the market. Thus, "educational" apps—the number of which, as of January 2015, stood at 80,000 in Apple's App Store (Apple, 2015)—are largely unregulated and untested. This article offers a way to define the potential educational impact of current and future apps. We build upon decades of work on the Science of Learning, which has examined how children learn best. From this work, we abstract a set of principles for two ultimate goals. First, we aim to guide researchers, educators, and designers in evidence-based app development. Second, by creating an evidence-based guide, we hope to set a new standard for evaluating and selecting the most effective existing children's apps. In short, we will show how the design and use of educational apps aligns with known processes of children's learning and development and offer a framework that can be used by parents and designers alike. Apps designed to promote active, engaged, meaningful, and socially interactive learning—four "pillars" of learning—within the context of a supported learning goal are considered educational.

Keywords

media, apps, Science of Learning, education, digital, early childhood education

Introduction

Over 56% of all Americans (A. Smith, 2013) own a smartphone. More than a third of these also include tablets (34%; Rainie, 2012; Zickuhr, 2013) in their cache of digital personal items. These handheld devices allow us to do everything from the privacy of our portable offices. They help us manage our vacations, update our calendars, and give us immediate access to the Internet, all through the power of "apps" (applications) or computer programs. Remarkably, a decade ago, apps were not part of the e-landscape. Yet just 3 years after the popular iPad was introduced on July 26, 2010 (Apple, 2010), Apple proclaimed that iTunes had achieved its 50 billionth download (Apple, 2013b). Indeed, in December 2013 alone, consumers downloaded almost 3 billion apps (Apple, 2014), with more than 500,000 apps developed for iPhone, iPad, and iPod touch users alone (Apple, 2014).

The numbers tell the story. Apps are not just ubiquitous, but also big business: Over $10 billion was spent in the App Store in 2013 (Apple, 2014). By 2015, revenue from apps is predicted to triple to $38 billion (Shuler, 2012). Technology is rapidly changing the nature of adults' day-to-day and even minute-to-minute experiences. We have not begun to understand the impact of the app explosion on our economy and society.

While this sweeping change has had significant effects on the daily lives of adults, its ultimate impact may be even more significant for the children, toddlers, and even infants for whom apps are designed and marketed. Over

Corresponding Author:
Kathy Hirsh-Pasek, Department of Psychology, Temple University, Philadelphia, PA 19122
E-mail: khirshpa@temple.edu

80,000 apps are classified as education- and learning-based (Apple, 2015). In 2013, 58% of parents in the United States reported that they had downloaded apps for their children (Common Sense Media, 2013). Indeed, the Preschool/Toddler category is the most popular category of apps in the App Store, accounting for 72% of the top paid apps (Shuler, 2012). The near-instantaneous delivery of new apps prevents scientists from evaluating specific apps as they are introduced into the marketplace.

This article focuses on "educational" apps that have been developed for touch-screen tablets and phones and marketed to young children ages 0 to 8. We concentrate on the use of apps by this age bracket for four reasons. First, intuitive interactions afforded by touch-screen devices make app content potentially accessible to very young prereaders—even babies. Indeed, there are so many apps targeted toward young children that parents and educators do not know how to navigate the marketplace of possibilities (Guernsey, 2014; Rideout, 2014). Second, a large number of schools throughout the nation have integrated the use of tablets into their curriculum (Apple, 2013a), despite the absence of research to support this change. Third, less than 20% of a child's waking time is spent in school (LIFE Center: Learning in Informal and Formal Environments, 2005). The amount of time that children spend with digital media and the surge in educational apps' popularity suggest that at least some apps are being used in an attempt to supplement learning outside of school. Apps present a significant opportunity for out-of-school, informal learning when designed in educationally appropriate ways. Fourth, school readiness is predictive of later achievement (Duncan et al., 2007). If apps can improve young children's skills, school readiness, or executive-function capabilities, then early learning with apps might have long-term impacts (Goldin et al., 2014).

In this article, we use data from decades of research in the Science of Learning to illustrate how the development and evaluation of apps could embrace an evidence-based stance. Importantly, there are a number of theoretical positions on the ways in which children learn (Bransford, Brown, & Cocking, 1999), ranging from direct instruction (Kirschner, Sweller, & Clark, 2006) to free play (P. Gray, 2013). Our goal in this article is not to choose among theories of learning or even to craft our own theory of learning. Rather, we attempt to highlight areas of convergence among the theories from this relatively new, amalgamated research area dubbed the Science of Learning. We also do not endorse or evaluate any particular apps, but rather use targeted apps as illustrations of four psychological principles (or pillars) that can be derived from the scientific literature. We suggest that if we want to put the "education" back in educational apps, we will need to design and evaluate them in ways that promote the best learning. Research suggests that children learn best when they are cognitively active and engaged, when learning experiences are meaningful and socially interactive, and when learning is guided by a specific goal. This should not suggest that learning cannot take place outside of these conditions, only that the research literature suggests that these conditions often set the stage for effective learning. Therefore, apps that recruit some or all of these pillars within a learning context are more likely to result in effective learning than those that do not. This conclusion is warranted by the literature and deserves to be further refined through additional empirical research.

It is important to clarify what is meant by "active," "engaged," "meaningful," "socially interactive," and "in the service of a learning goal." These pillars represent areas of convergence from the newly amalgamated field of the Science of Learning. "Active" learning implies minds-on involvement during the learning experience, in addition to any physical activity that may be occurring, such as swipes and taps. Children's engagement—that is, their ability to stay on task and undistracted—also supports learning. Meaningful learning goes beyond simple memorization, and occurs when children find the meaning in what they are learning and are able to not only connect new material to existing knowledge but expand their current knowledge to create new conceptual understanding. Social interaction revolves around high-quality interactions (e.g., those with knowledgeable social partners or in collaborative learning situations) that are contingent and adaptable to the child (Tamis-LeMonda, Kuchirko, & Song, 2014). Finally, and importantly, we will argue that "educational" apps are those that support a learning goal, be it in the learning of shapes or the mastery of new vocabulary words. There exist whole categories of very good apps that are fun to play with but that have no real educational goals. These might be highly engaging, but they are beyond the purview of what we consider "educational."

We review the literature supporting each of these pillars and the rationale for the educational focus below.

The Importance of Considering the Development of Principles for App Use

Designers of child-focused apps do not begin with a blank slate. Instead, they are influenced by current trends in technology and design, their own interactions with technology, and their experiences and intuitive sense of how learning happens or what children will find enjoyable. While this is understandable, this approach is often tainted by misconceptions about learning and education, as exemplified by the success of the Baby Genius video series and related "educational" television in the early 2000s. Despite marketers' explicit and implicit claims of effectiveness, scientific study (e.g., DeLoache et al., 2010; Richert, Robb, Fender, & Wartella, 2010; Robb, Richert, & Wartella, 2009; Zimmerman, Christakis, & Meltzoff, 2007) revealed that young children were not learning effectively from these television programs and DVDs.

Only a handful of apps are designed with an eye toward how children actually learn. A small number of developers at both small start-ups and bigger toy/media companies have used research-based approaches with preliminary results of research. For example, a recent study found that interacting with a vocabulary-focused app increased young low-income children's vocabulary by up to 31% in just a 2-week period (Chiong & Shuler, 2010; Corporation for Public Broadcasting, 2011). While this may sound encouraging to app developers and users, little detail was offered about the study design, making it difficult to evaluate its scientific impact. Given a very limited precedent of effective app use, there is a need to propose principles for the design of appropriate apps that will offer a greater likelihood of educational benefits.

Riding the First Wave and Propelling the Second Wave of Apps for Use By Children

The majority of apps in today's marketplace can be considered part of the "first wave" of the digital revolution. In this wave, apps are simply digital worksheets, games, and puzzles that have been reproduced in an e-format without any explicit consideration of how children learn or how the unique affordances of electronic media can be harnessed to support learning. We must find ways to help parents assess apps that exist in this first wave (Kucirkova, 2014). While there is no way to scientifically study every app on the market, a set of principles based on science can be developed and used to evaluate the current crop of apps. Some preliminary steps have already been taken with the introduction of rating systems by Children's Technology Review, Common Sense Media, and a handful of parent-oriented app services. For example, Common Sense Media (https://www.commonsensemedia.org/) uses 5-point scales to rate individual pieces of media for "ease of play," "violence & scariness," "sexy stuff," "language," "consumerism," "drinking, drugs, & smoking," and "privacy & safety." Reviewers also give an overall rating for "quality" and "learning" and select the age of children for whom the app is appropriate. While these rating systems have not been scientifically evaluated, they are widely used in the field.

In this article, we hope to join those ushering in a second wave of app development—the wave just beginning to take shape—that harnesses guidelines from the Science of Learning. If researchers and developers work together, they might develop well-designed apps that could be fun for all users and provide augmented experiences to low-socioeconomic-status children, helping to reduce the long-standing achievement gap. This effort is already underway in New York City, where a massive investment in technology is being heralded as a key ingredient for narrowing the gap (City of New York, Office of the Mayor, 2014). This idea has some currency. The One Laptop per Child program was used in a poor rural area of Argentina to demonstrate how the availability of well-crafted educational games on an accessible laptop can promote school readiness in both learning processes such as attention and problem solving and academic outcomes such as reading (Goldin et al., 2014). Indeed, the scientists in the Argentine program collaborated with top researchers in the United States to craft and design computerized games that stimulated learning. The Plan Ceibal (http://www.ceibal.edu.uy/) in Uruguay represents a government initiative to offer all children in the country access to materials and curricular digital opportunities. Analyses of this program are underway.

We are at a unique and important time in the development of apps. They are ever present—in schools, in homes, and even in the crib. At the same time, the past few decades of research in the Science of Learning have transformed the way we think about learning and teaching. By melding these parallel threads, media developers can have access to knowledge that allows them to create better educational apps, and parents can evaluate apps' learning potential for their children.

The Science of Learning as a Guide for Educational Principles

How might we evaluate "educational" apps to determine their educational value? In the last 20 years, a potential answer has come from a new field dubbed the Science of Learning. The term "Science of Learning" was first used in the early 1990s with the creation of the *Journal of Learning Science*. In 1999, the publication of *How People Learn*, a report from the National Research Council (Bransford et al., 1999), secured its place at the juncture of psychology and education. The field has prospered since 1999, when the authors of this key volume wrote,

> The new Science of Learning is beginning to provide knowledge to improve significantly people's abilities to become active learners who seek to understand complex subject matter and are better prepared to transfer what they have learned to new problems and settings (p. 13).

Several new efforts have popularized this idea for formal schooling (Brown, Roediger, & McDaniel, 2014;

Mayer, 2011) and for college teaching (Ambrose, Bridges, DiPietro, Lovett, & Norman, 2010), among other areas. Notably, this approach has been taken in the field of computer-based games (Honey & Hilton, 2011; Mayer, 2014a, 2014b; O'Neil & Perez, 2008; Tobias & Fletcher, 2011), but rarely has the Science of Learning been used to design apps for young children (notable exceptions include DreamBox Learning, Kidaptive, Motion Math, and Next Generation Preschool Math). However, to our knowledge, this is the first time anyone has derived a relatively simple set of principles from the Science of Learning that can be applied to the design and evaluation of apps for young children.

Knitted together from psychology, linguistics, computer science, animal behavior, machine learning, brain imaging, neurobiology, and other areas, this newly minted field asks not merely what we should teach children—that is, what content—but also *how* children best learn the strategies they will need to cope flexibly and creatively in a 21st-century world (e.g., Benassi, Overson, & Hakala, 2014; Golinkoff & Hirsh-Pasek, in press; Pellegrino, 2012; Pellegrino & Hilton, 2013; Sawyer, 2006). To date, researchers have cast a wide net over the Science of Learning, and this approach includes a wealth of topics, from navigation and robotics to language learning by man, machine, and animals to early understanding of mathematics and mastery of literacy, among others. The National Science Foundation jump-started conversations among these interdisciplinary fields and topic areas to form a more coherent understanding of how people learn (see LIFE Center: Learning in Informal and Formal Environments, n.d., and the Center for Innovative Learning Technologies, n.d.). Indeed, a similar effort has been made to specifically yoke the Science of Learning with education for older children in formal school settings (Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013).

The impetus for this new area comes not only from advances in basic brain science and computer science but also from problems in our current educational system, which is based on what Papert (1993) identified as *instructionism*. In the introductory chapter to *The Cambridge Handbook of the Learning Sciences*, Sawyer (2006) suggested that "instructionism is an anachronism . . . students cannot learn deeper conceptual understanding simply from teachers instructing them better . . . learners are not empty vessels waiting to be filled" (p. 2). Indeed, Mayer conceptualized how we have moved from instructionism (what Mayer called "response acquisition") to a more constructivist and active view of the learner over the last 100 years (Mayer, 1992).

The study of learning and the melding of research psychology and educational practice is not new. For centuries, the view that learning was synonymous with conditioning was the prevailing viewpoint, a dominant theory originating from Plato and Aristotle and espoused by John Locke and David Hume. In this view, the environment plays a key role in building associations and is solely responsible for learning. Behaviorism reflects a refinement of these views and emphasizes how children learn via conditioning. But by the mid-20th century, a cognitive revolution had taken hold. Instead of an emphasis on how behaviors are brought about by conditioning or building associations, the "black box" of the mind began to play a key role in our understanding of learning. From Miller's (1956) study of memory to Chomsky's (1965) view of language learning via the brain's "Language Acquisition Device," the middle of the last century marked a turning point (Gardner, 1985): Implicit learning processes were posited, and equating psychology with the science of behavior lost ground.

This same change characterized the study of children and reinvigorated interest in early experience and the works of Jean Piaget, who had been writing since the 1920s (Flavell, 1963). The father of constructivism, Piaget (1923/1965) heralded the idea that children are "little scientists" and actively construct their knowledge of the world—from relying on sensorimotor schema to remember and find hidden objects as infants (i.e., object permanence) to gaining symbolic understanding and more complex thinking throughout childhood (Gopnik, Meltzoff, & Kuhl, 1999). Urie Bronfenbrenner (1979) added to these theories by focusing the field on the importance of the context, culture, and environment. He also bolstered awareness of the need for a forum that would include education and public policy. This renewed interest in child development and the linking of education and public policy helped to set the stage for the cross-disciplinary approach espoused by the Science of Learning.

The efficacy of this approach is impressive. The study of dead reckoning in ants and animal species has taught us about the basics of human navigation and spatial learning (Cheng & Gallistel, 1984). The vast advances and remaining challenges in machine learning have taught us about the intricacy of human thinking (e.g., Kotsiantis, Zaharakis, & Pinelas, 2006). Statistical models have revolutionized the way we think about how children and adults learn to make sense of a world full of data (e.g., Brady, Konkle, & Alvarez, 2009; Buchsbaum, Gopnik, Griffiths, & Shafto, 2011; Munakata & McClelland, 2003; Xu & Garcia, 2008). In this article, we ask what the Science of Learning has taught us about how humans (particularly children)—rather than machines, neural networks, or animals—learn.

The Four Pillars: Where the Science of Learning Meets App Development and Design

A few well-agreed-upon pillars of learning at the core of the learning sciences have remained steady through the decades. Humans learn best when they are *actively* involved ("minds-on"), *engaged* with the learning materials and undistracted by peripheral elements, have *meaningful* experiences that relate to their lives, and *socially interact* with others in high-quality ways around new material, within a context that provides a clear learning goal. The pedagogical structure of the environment determines what kind of learning will result. For example, drill and practice may foster rote learning of facts, but it is not likely to promote deeper conceptual understanding (see Ravitch, 2010). Similarly, exploration and discovery without any guidance or scaffolding may not provide enough support for learning (Mayer, 2004). Effective learning is facilitated in a flexible context that supports scaffolded exploration, questioning, and discovery as children work toward well-defined learning goals (Darling-Hammond, 2008).

When apps instantiate the pillars within the context of scaffolded exploration, their use contrasts sharply with the instructionism that many schools still use to educate children. The "modern" classroom of 2015 may not differ much from a classroom from earlier generations: desks in rows, children listening in their seats or on a rug, and teachers transmitting well-worn knowledge that students regurgitate to get their grade. These images were reinforced by the No Child Left Behind (NCLB) Act, which was passed in 2001 and in effect until 2012. While noble in its aim to provide a quality education to all children regardless of age, race, socioeconomic status, or location, the implementation of NCLB has resulted in a test-focused system that emphasizes teaching to the test and drilling students for factoids (Darling-Hammond & Adamson, 2014; Ravitch, 2010) and has been ineffective at closing the achievement gap (Dillon, 2009). Critics worry that despite efforts to remedy the situation with the Common Core, a test-conscious education system might inadvertently emphasize a teach-to-the-test mentality and result in less effective learning overall (Roediger, 2014).

Findings from the Science of Learning suggest an alternative approach to supporting educational experiences, including the four evidence-based pillars of learning that provide a starting foundation for the next wave of educational apps. These are not novel ideas; our application of these ideas to app creation is. For instance, Chi (2009) has provided a taxonomy for learning that includes three levels: active, constructive, and interactive learning. As she interprets the psychological literature, socially interactive learning with another person is better than constructive learning, in which the child goes beyond a presented problem to generate a new understanding. In Chi's taxonomy, socially interactive and constructive learning trump active learning, in which a child does something such as manipulate objects or rehearse material; in turn, active learning is better than learning through listening in the absence of activity.

Although our focus on cognitive activity and social interaction overlap with Chi's approach, our goals are different from hers. Whereas Chi's taxonomy provides a testable hypothesis intended to advance learning theory, our four pillars are meant to inform the design and evaluation of a particular class of learning environments—namely, touch-screen apps. We recognize that learning need not always be active or social (Dunn et al., 1990), as research has suggested that direct instruction methods in which the impetus is on the teacher to present material can be effective, even for young children or those with intellectual disabilities (Przychodzin-Havis et al., 2005). Yet active involvement in a task and social interaction both appear to be potent ingredients that stimulate learning (Meltzoff, Kuhl, Movellan, & Sejnowski, 2009; Okumura, Kanakogi, Kanda, Ishiguro, & Itakura, 2013).

These pillars, which will be described in greater detail below, are child-centric, meaning that they apply to how children are involved (or not) in the learning experience. Is the child active and minds-on (Duckworth, Easley, Hawkins, & Henriques, 1990)? Is the child engaged in the learning experience and remaining on task? Is the child finding meaning that goes beyond the app? Is the child engaged in high-quality social interaction with others while playing with the screen? And does the app provide a learning goal?

Much like the producers and developers of television, games, and other digital media, some developers have clear learning goals in mind when designing and marketing an app (e.g., to teach children about numeracy), and others have no clear learning goals for their apps and design them only to be entertaining. One popular children's app developer, Toca Boca, has apps that are often at the top of the "education" category in the App Store. However, Toca Boca's CEO, Björn Jeffrey, recently stated (Banville, 2014):

> My argument would be: Education is great and it has its place, but there are other things we can do for children other than just educate them. Just looking at learning from a broader sense, there are things you can learn . . . that are not from a strict curriculum perspective—things like collaborating or using your imagination or being creative. There's a place for that in an educational context, but they are also things that can be just learned from doing completely different things. . . . I don't see us as an

> educational company. I see us as a company that makes apps for children or digital toys for children or, more simply, products for children, but it is about the children first. If they can be used in an educational context, great, but that's not the intent.

This quote highlights a distinction that is critical when thinking about "educational" apps. Throughout this piece, we use "learning" and "education" interchangeably to refer to learning in a general sense. This is important to clarify, because the term "educational" may be interpreted as describing a formal learning context such as school-based instruction or tutoring. As decades of research have shown, learning and education occur in both formal (i.e., school) and informal (e.g., museums, the playground, home) settings. When the term "educational" is thought about broadly as inspiring "learning," we begin to more clearly define what we mean by educational apps.

As a starting point, our pillars are applied to another medium that has featured a torrent of "educational" programming that preceded scientific research. Indeed, 40 years of studies on educational television programming have helped to document the effectiveness of quality viewing experiences on a range of academic subjects, including reading, math, science, and other content areas (see Fisch, 2004; Fisch & Truglio, 2001, for reviews). These studies offer a window into many of the developmental challenges, limitations, and opportunities for using screen media as a learning tool with young children.

To make the case for a new conceptualization of "educational" apps, we will (a) describe and operationalize each pillar in depth, (b) ask how the pillar applies to television research, and (c) describe the ways in which the pillar could apply to the evaluation, development, and design of apps for young children.

Active learning

Evidence from the Science of Learning. The idea that children play an active role in their own learning has been reinforced since the days of Piaget and Vygotsky. Piaget and other constructivists suggested that children are active knowledge builders—they do not simply observe what is going on around them and copy it or wait for others to teach them.

When it comes to apps, we need to draw a distinction between being *physically* active and *mentally* active, because access to every app demands at least some physical activity. To qualify as active in our pillar, children cannot simply tap or swipe, but rather must be minds-on. We use the term "minds-on" to distinguish between physical activities that can be done with relatively little mental effort and those activities that require thinking and intellectual manipulation. Tapping in a response to something on a screen to make it rise is "minds-off," but activities such as purposefully figuring out where a puzzle piece goes or learning about abstract concepts such as cardinality or addition are minds-on.

The literature amply demonstrates the importance of active or minds-on learning. Grabinger and Dunlap (1995), for example, described rich environments for active learning (REALs) as "[providing] learning activities that engage students in a continuous collaborative process of building and reshaping understanding as a natural consequence of their experiences and interactions within learning environments that authentically reflect the world around them" (p. 5). This is the type of active learning that is critical for fueling children's knowledge.

Another study examined college students who were instructed to learn material with the expectation of teaching it to another student. These students learned the material better than students who just thought they would be tested (Benware & Deci, 1984). Having to teach puts students in a more active, minds-on mind-set for learning the material. The authors stated that "subjects who learned in order to teach were more intrinsically motivated, had higher conceptual learning scores, and . . . were more actively engaged . . . than subjects who learned in order to be examined" (p. 755). Further, recent experiments involving the teaching of physics have illustrated that college students learn more by actively constructing their knowledge with others than by listening to lectures (Mazur, 2009).

If adults are presented with a word pair in which one of the words has a few letters missing and are asked to generate the full word, they will remember the pair better than if they passively read it (Hirshman & Bjork, 1988). The benefit of generating responses is not even limited to accuracy. When adults generate an incorrect response and are then given feedback, they show better retention than if they either were provided with or chose a correct answer (Potts & Shanks, 2014). When adults were tasked with learning how to tie a nautical knot via video, they performed better when they were allowed to actively manipulate the video (e.g., to pause or rewind it) than when they were permitted only to watch it (Schwan & Riempp, 2004). Adults show better problem solving and learning when they are allowed to take notes than when they are not (Trafton & Trickett, 2001). Taking notes by hand versus on a laptop results in better conceptual understanding, despite the fact that students take a greater quantity of notes when typing, possibly because the slower process of handwriting requires them to select and synthesize information (Mueller & Oppenheimer, 2014). Medical residents who were instructed to mentally practice before performing surgery in a virtual-reality environment showed better performance than those who watched an online lecture (Arora et al., 2011). College students asked to use mental imagery when reading about a topic remembered more and transferred this knowledge more than a group that simply read the text (Leopold & Mayer, 2014).

These results are not confined to adult learning. Active learning also boosts academic and social outcomes for children. Middle schoolers asked to actively draw chemical reactions rather than just explore them with dynamic visualization had a better understanding of the underlying mechanisms (Zhang & Linn, 2011). At science museums, children who are active in their experience (e.g., those who ask or answer questions, comment on what they see, etc.) learn more than those who are not (Borun, Chambers, & Cleghorn, 1996; see Haden, 2002, for a review). Ninth graders who generated drawings when reading about chemical processes outperformed those who only read (Schwamborn, Mayer, Thillmann, Leopold, & Leutner, 2010). Finally, high school students involved in an active-learning lesson about chemistry had fewer misconceptions and a more positive attitude compared to those who learned in a more traditional format (Sesen & Tarhan, 2010).

Recent work has suggested that there might even be neural differences when children are active versus passive during a learning experience. When 5- to 6-year-old children actively manipulated an object while hearing a new label and then heard that label again, motor areas of their brains were more likely to be activated upon subsequent viewing compared with when they were only allowed to passively watch an experimenter manipulate an object (James & Swain, 2011). Furthermore, motor areas are activated to a greater extent when objects are learned actively versus passively. Similar increased recruitment of sensorimotor brain areas occurs when children write letters versus when they watch an experimenter write (Kersey & James, 2013).

One study used a presented storybook reading with preschool children who had low expressive vocabularies. The researchers found that "dialogic reading," in which the adult involves the child in the story by prompting him or her and soliciting talk about the content, resulted in higher vocabulary gains than traditional storybook reading in which the child listened silently (Hargrave & Sénéchal, 2000). Similarly, children who ask more questions and label objects during storybook reading comprehend more novel words than those who passively listen to the same story (Sénéchal, Thomas, & Monker, 1995).

Active learning also benefits vocabulary learning. When 3-year-old children figured out the referent of a novel label through a process of elimination, they showed better retention of that label than children who were explicitly and directly told the label (Zosh, Brinster, & Halberda, 2013). Impressively, in the Zosh et al. (2013) study, children learned more in the active-learning condition even though they spent less time looking at the target object.

Active manipulation appears to be key for supporting minds-on learning, even for infants. When 3-month-old infants were outfitted with mittens that had Velcro that stuck to objects, they learned about having a goal and reaching to achieve it. This, in turn, made them more likely to interpret the actions of others as goal-directed (Sommerville, Woodward, & Needham, 2005). Similarly, this active experience appears to help "jump-start" infants' own reaching behaviors (Libertus & Needham, 2010). This effect holds throughout infancy, with action production helping 12-month-old infants interpret the goal of another's action (Cannon, Woodward, Gredebäck, von Hofsten, & Turek, 2013).

The results of these studies are clear: Learning is not simply a passive registration of information, nor is it simply a result of any type of physical activity. Learning that "sticks" requires active, minds-on learning.

Active, "minds-on" learning in television. Research also suggests that as viewers, children learn best when they are not passive, but rather active and engaged. Children make decisions about what, when, and how much television they view based on ongoing sophisticated decision-making processes. Huston and Wright (1983) suggested that children watching a television program are actually sampling small parts of the program by glancing quickly at the screen or monitoring the audio, and making ongoing judgments about the content. If children judge the program to be understandable and interesting, it is more likely that they will keep viewing (Anderson & Lorch, 1983). Anderson, Choi, and Lorch (1987) also observed that a child is more likely to continue looking at the television if he or she has already been looking for a period of time. In other words, when a child first looks at a screen, the chance that he or she will look away is at its highest; however, as the child continues viewing, the chances that he or she will look away go down. This phenomenon is called *attentional inertia*, and it has been documented with children watching *Sesame Street* (Anderson et al., 1987; Anderson & Lorch, 1983). When children actively make decisions to watch and to stay on task, they learn more from educational programming (Lorch, Anderson, & Levin, 1979).

Formal features of television—such as cuts, movement, sound effects, music, montage, visual effects, and so on—are modified by producers based on a program's content and viewing audience. Features such as the use of animation or child-directed speech may serve as instant markers of programming that is interesting or relevant to a child. The child may be more likely to form an immediate expectation that the program will be comprehensible and worthy of attention (Huston, Bickham, Lee, & Wright, 2007). Children's television producers may also use formal features to direct attention to important concepts or ideas, such as a sound effect to cue children to pay attention to the appearance of a character. These methods are designed to promote minds-on thinking.

Studies of *Sesame Street*, which incorporates child-development research into production, have shown that children ages 3 to 5 can effectively learn vocabulary, body parts, numbers, initial sounds, decoding, and counting strategies after viewing (Bogartz & Ball, 1971; Rice, Huston, Truglio, & Wright, 1990). Programs such as *Mister Rogers' Neighborhood*, in which Fred Rogers directly addressed children, or *Barney & Friends*, which incorporated music into its plotlines, have been found to have positive effects on social-emotional outcomes (Coates, Pusser, & Goodman, 1976; Singer & Singer, 1998).

Applying active, minds-on learning to apps. Activity in the context of apps can take a number of forms. For example, children can touch the screen (e.g., poke, swipe, pinch), move the device (e.g., shake, tilt, point), talk or sing into the microphone, listen to music through speakers or headphones, and wave for a camera connected to gesture-recognition software. But merely tapping a finger or swiping a screen does not qualify as the kinds of minds-on activity that underpins learning. These behaviors require little mental attention. For cognitively active learning to occur, there must be more than mindless, stimulus-response reactions to on-screen actions. For example, swiping diagonally across a screen can be a strategic move for a child solving a navigation problem in a mapping game or simply a superficial response to moving objects in an arcade-style spaceship game. A child can move her arm to mindlessly blow out a "candle" on an app or, in a collaborative music activity using two wirelessly connected mobile devices with motion sensors, a more experienced child can guide the learning of a novice peer by changing the tempo of her arm movements to establish a new rhythm to imitate. Likewise, in a host of other ways, apps can be designed around the affordances of mobile devices to incorporate physical activity and other experiences to spur children's minds-on engagement with app content.

The level of mental involvement for children increases when apps include symbolic systems that promote learning potential. Consider the range of cognitive activities involved in learning to understand oral language, written language, number lines, musical scales, geographic maps, visual icons, and so forth. When young children first encounter these various forms of representation, apps can provide many opportunities for active cognition—interpretation, translation from words to mental images, and manipulation of symbolic material. To the extent that children proactively engage with representations, they are likely to learn lessons afforded by the particular symbolic system involved. For example, a mathematics app designed to build skills at understanding quantity may usefully present analog representations of physical objects (e.g., photos of red rubber balls) while supporting direct manipulation of these virtual objects, together with verbal labeling of quantities ("You found 5 balls!") and numerical representations ("5"). Similarly, literacy apps can guide children to form letters into words or arrange words into sentences with the aim of communicating with another person. In music apps, children can touch notes to hear corresponding sounds or arrange them on a staff before playing a completed melody.

This flexibility lets designers arrange symbolic material to support active cognition and minds-on behavior at various levels of expertise in a domain. Newer apps just entering the marketplace even allow children to jump from the screen to manipulables and back again. An app called Words for Osmo allows players to look at a picture on the screen showing an object (e.g., a bear) and a series of spaces that represent the letters in the word for that object (in this example, four letters). Using real tiles, children try to guess the word and align the manipulable tiles to spell that word. The app diagnoses progress through what is called *reflective artificial intelligence* using a built-in mirror. When children guess the word and spell it correctly, they are rewarded with on-screen feedback.

Finally, parents and children can be actively involved with an app when they use it as a platform to discover new information about a content area. For example, "interactive" book apps can encourage parent-child dialog that stimulates children's understanding of story content. An app that promotes mental activity might require children to choose among story characters or objects that further the story line. An app that allows children to build musical compositions actively supports discovery of chord progressions and aspects of melody.

Control has been cited as a factor in why apps capture attention, especially as it pertains to interactions with software. Well-designed software affords children an appropriate level of control and agency depending on their age and experience, allowing them to proceed at their own pace and sustain their interest. For example, children who read computer e-books with adults paid more attention to the story when they controlled the computer mouse than when the adult controlled the mouse (Calvert, Strong, & Gallagher, 2005). When adults controlled the mouse, children's attention waned over multiple readings. This is an especially important point to consider, because many preschool-aged children lack the skills to effectively control a mouse or keyboard (Revelle

& Strommen, 1990). Touch-screen apps, in contrast, may be controllable by children of almost any age, depending on how they are designed.

Research has demonstrated that children must be minds-on in a task to maximize learning. But being minds-on is not enough—children also need to stay on-task and engage in the learning process. If a child is active and asking questions while reading a story and then a fire alarm goes off, the child's learning is disrupted. Similarly, if a child is reading a story in an app and there are pop-up features and distracting information that take away from the story line, his or her learning may be compromised.

Next, we turn our attention to children's engagement—that is, their staying focused and on task.

Engagement in the learning process

Evidence from the Science of Learning. The study of engagement often centers on the idea of student engagement in the classroom. In a review of the literature, Fredricks, Blumenfeld, and Paris (2004) suggested three kinds of engagement: *behavioral* engagement (i.e., rule-following, effort, persistence, participation in programs), *emotional* engagement (i.e., affective reactions), and *cognitive* engagement (i.e., investment in learning, flexibility in problem solving). Each type of engagement is critical for learning because they all foster staying on task. The Science of Learning has highlighted the importance of focused engagement in learning in early childhood. Engagement and distraction have also been extensively studied in the context of executive functions—an umbrella term that covers flexibility in thinking, problem solving, inhibition of behavior, and attention (see Zelazo, Muller, Frye, & Marcovitch, 2003, for a review).

Indeed, engagement is evidenced from the earliest ages. When a child looks at a toy and a parent zooms in on the child's focus of attention and talks about the focus of the child's gaze, that child is already engaged. When a child insists that a parent read the same book over and over during the bedtime routine, the child is engaged. At its foundation, engagement in all of its forms is predicated on an individual's ability to stay on task and not be distracted. In a recent article, Mayer (2014c) came to a similar conclusion. He spoke of the "coherence" principle, noting both that people learn more deeply when extraneous material is excluded and that extraneous processing can "drain limited cognitive processing capacity" (p. 61).

Distraction is becoming a key area of research in the study of engagement, as children's normal environments seem to require constant multitasking. Research on adult multitasking in the context of texting and driving has suggested that only 2% of adults are "super taskers" who can effectively multitask without cognitive overload (Watson & Strayer, 2010). Research on children has shown much the same. Background television serves to distract young children. Even if they spend only a few seconds looking at the screen, their play is disrupted: The length of time they play with a toy is decreased, as is their level of focused attention (Schmidt, Pempek, Kirkorian, Lund, & Anderson, 2008). Similarly, the quality and quantity of parent-child interaction decreases when a television is on in the background (Kirkorian, Pempek, Murphy, Schmidt, & Anderson, 2009), and parents are more likely to talk to and play with their infants when background television is off than when it is on (Courage, Murphy, Goulding, & Setliff, 2010; Pempek, Kirkorian, & Anderson, 2014). Despite these findings, Masur and Flynn (2008) have reported that television is on at least half the time during children's solo play and dyadic play in 44% and 53% of households, respectively.

Children's engagement during learning can be disrupted in other ways. Tare, Chiong, Ganea, and DeLoache (2010), for example, found that children learned fewer novel words and fewer facts from a pop-up book relative to a simpler, unenhanced storybook. Even when extra features were designed to call attention to a specific learning goal (e.g., letters in an alphabet book), children learned best when they were able to stay on task using a simpler version of the book (Chiong & DeLoache, 2012). Barr, Shuck, Salerno, Atkinson, and Linebarger (2010) noted that even background instrumental music can distract infants from learning a new action. Parish-Morris, Mahajan, Hirsh-Pasek, Golinkoff, and Collins (2013) found that the "bells and whistles" embedded in an e-book often distracted 3-year-olds from understanding and remembering the story. In research on textbooks, entertaining content or information that is not relevant to the author's intended theme are known as "seductive details" (Garner, Brown, Sanders, & Menke, 1992), which interfere with the retention of the target information.

Preschoolers are particularly susceptible to distraction, not having much ability to inhibit attention to extraneous information. Kannass and Colombo (2007) examined the task performance of 3.5- and 4-year-old children under conditions of no distractions, continuous distractions, and intermittent distractions. For the younger children, any type of distraction resulted in impaired task performance, whereas for the 4-year-old children, only continuous distraction impaired performance. Individual differences also exist in children's susceptibility to distractions (Choudhury & Gorman, 2000; Dixon, Salley, & Clements, 2006). Sustained attention at age 5 (measured by lack of impulsivity and focused attention) negatively predicts attention problems at age 9 (Martin, Razza, & Brooks-Gunn, 2012), and research with an at-risk sample suggested that these two factors are associated with specific outcomes: Focused attention at age 5 predicts achievement outcomes at age 9, whereas increased impulsivity predicts more negative behavioral outcomes (Razza, Martin, & Brooks-Gunn, 2012). Kindergartners in a highly decorated classroom who have not yet mastered the ability to regulate their attention are more distracted, spend more time off-task, and have fewer subsequent learning gains than those in a less distracting environment (A. V. Fisher, Godwin, & Seltman, 2014). However, susceptibility to distraction is malleable for children and adults (Kannass, Colombo, & Wyss, 2010; Neville et al., 2013), which suggests that the environment can help, or hinder, one's ability to stay engaged.

The danger of distraction is apparent throughout childhood and adulthood. When college students multitasked on a laptop during a lecture, not only did they score lower on a test, but so did others in direct view of that laptop (Sana, Weston, & Cepeda, 2013). Further evidence to this point is the finding that texting during class results in decreased performance (Dietz & Henrich, 2014).

Engaged learning in television. To promote engagement, we must maximize strategies that help the learner stay on task and reduce impediments that distract learners and sap needed cognitive resources (Benassi et al., 2014). Television research suggests that one way to accomplish this goal is to ensure that the challenge presented in a medium—whether television or an app—hits the "sweet spot." As with Goldilocks, a program must be "just right," presenting material that strikes an optimum balance between being challenging and accessible. If content is too easy or too familiar, children may stop watching. Conversely, content that is too challenging or unfamiliar may also turn children away from viewing. However, when a program falls in between, children are more likely to pay attention and demonstrate interest. This is known as the *traveling lens model* of viewing (Wright & Huston, 1983). What is interesting or challenging to children changes with their age and familiarity with the content. Judicious use of formal features, such as cuts, audio cues, visual cues, and other aspects of production, may also direct children's attention to important content and keep them engaged, or re-recruit attention if it has been lost (Calvert, 1999; Huston & Wright, 1983; Huston et al., 1981). With the advent of eye tracking technology, researchers are in a position with television—and apps—to begin to probe where children look and for how long during a show or game. Research of this nature should assist in determining the location of the "sweet spot" as well as elements that are needlessly distracting.

Applying engaged learning to apps. The educational quality of apps depends on their ability to support children's engagement with the learning process. This means avoiding the myriad distractions potentially available on-screen and allowing for sustained engagement sufficient to meet the learning goals. Extraneous animations, sound effects, and tangential games might be appealing to a child when activated but not add to the child's understanding of the primary content because they disrupt the coherence of the learning experience and the child's engagement.

We next examine three elements of app design that can afford this kind of deep engagement in learning. Notably, evidence for the effectiveness of many of these design characteristics has been found in work done more generally on multimedia learning (Mayer, 2014a).

Contingent interactions. When contingent interactions occur between children and their caregivers, as in video chats (Roseberry, Hirsh-Pasek, & Golinkoff, 2014), even 24- to 30-month-olds can learn new words that they cannot learn when presented noncontingently by a person on television. The contingent interactions that apps afford are perhaps the most basic element of engagement with a touch screen. When each touch or swipe is met with an immediate response, children feel in control, maintain their focus, and continue the interaction. This sort of responsiveness is a core element of user-interface design in the field of human-computer interaction (Nielsen, 1993/2014). It is also a growing subject of investigation among researchers interested in educational media (Lauricella, Pempek, Barr, & Calvert, 2010). For example, experimental manipulations that required children to use a computer to move the story of *Dora the Explorer* forward at preselected points were linked to children's increased understanding of story content (Calvert, Strong, Jacobs, & Conger, 2007).

Extrinsic motivation and feedback. Engagement—and its potential to foster learning—is deepened when an app responds to children's activities with meaningful feedback. Apps with an explicit question-answer format typically provide differential responses to children's answers. These responses may include labels of "correct" or "incorrect," motivational messages (e.g., "Great work!" and "Try again"), parasocial displays (e.g., of a crowd cheering or an animated monkey jumping with joy), points or badges, and access to additional meaningful content that progresses the game. By carefully structuring the feedback as well as allowing progressive access to content (e.g., presenting more advanced content through a series of game levels or adaptively, based on user profiles), apps can focus children's attention on the app experience and extend engagement for a long time.

Children's engagement in this structured system of learning and feedback is typically driven by extrinsic motivation (Ryan & Deci, 2000). Players want to achieve external rewards and avoid the opposite—typically, the absence of rewards. However, extrinsic reinforcements are not limited to question-answer formats but may also be embedded in a more naturalistic context. For example, on-screen environments that let children search for hidden objects may provide a kind of hide-and-seek game in which discovering objects is its own reward.

Importantly, praise by an adult or by an app can have differential effects depending on what is praised. A significant body of research conducted by Dweck and colleagues (Dweck, 1999, 2006; Gunderson et al., 2013) has shown that praising children's intelligence leads them to avoid the inevitable risks of learning for fear of appearing stupid and losing face. Alternatively, praising children for their efforts and hard work helps them understand that learning is not often instantaneous and motivates them to persevere through the difficulties they may encounter and, ultimately, succeed more often. This approach helps children develop a *growth mind-set* in which they feel a sense of control over their own capacity to think and learn. With this research in mind, the praise offered through apps should be mindful of praising children for their effort rather than for their intelligence. The former can cultivate a growth mind-set, motivating children to tackle and stay engaged in difficult tasks.

Intrinsic motivation. A driver of app engagement perhaps most valuable to children's long-term development is their intrinsic motivation. Open-ended "sandbox" apps, which are structured to be as open-ended as play in a real sandbox, can evoke a player's unique abilities and personal passions and create new interests. For instance, an app like *Morton Subotnick's Pitch Painter*, which lets children place and play musical notes, might awaken an interest in music. With a poke of their finger, children can engage in musical play akin to drawing with crayons on paper. These kinds of user-driven, intrinsically motivating experiences are known to be deeply engaging for children and adults alike, as in the experience of "flow," in which a person loses his or her sense of time while engaged in an activity (Csikszentmihalyi, & Csikszentmihalyi, 1992).

The type of feedback and rewards offered by apps should also account for the fact that young children are intrinsically motivated to learn and solve problems. Recent work in the classroom has shown that, despite their widespread use, stickers handed out as rewards actually dilute children's internally generated feelings of accomplishment. Instead of offering stickers or causally weak information as task-unrelated rewards, research shows that it is better to reward success with causally rich information (e.g., about how an object might be used to achieve a goal; Alvarez & Booth, 2014).

A final consideration for app developers, parents, and researchers is distraction. Some apps enable children to tap and swipe the screen in the middle of an ongoing narrative. These behaviors may activate a new screen, sound effects, or animations that take the child off-task. By way of example, in many current storybook apps, children can activate features that bring them to new activities during a story reading. An app that focused on the giant dog Clifford illustrates this problem. The app began by reading the story to the child, and the narrative was progressing naturally with an introduction of the main characters and a story arc when buttons were suddenly displayed on the screen and children were asked to find things that "begin with the letter C." Breaking the narrative in this way disrupts learning. Indeed, in an empirical study, the "bells and whistles" placed within a story presented on an electronic console interfered with 3-year-olds' understanding of story elements such as the plot (Parish-Morris et al., 2013).

Some children are more susceptible to distraction than others (Choudhury & Gorman, 2000; Dixon et al., 2006). While one child may be distracted by an "enhancement" in an app, another may not. Similarly, as the research shows, distraction is more damaging to younger (3.5 years) than older children (4 years; Kannass & Colombo, 2007). These findings highlight the importance of creating interfaces that enable parents to turn off distracting options.

Using the Science of Learning for guidance, then, we can conclude that both minds-on learning and sustained engagement are key factors for successful learning. Learning may be enhanced when it is made meaningful as well.

Meaningful learning

Evidence from the Science of Learning. Sustainable and useful learning comes from experiences that connect to our existing knowledge. Cramming for a final might help get us a passing grade, but we will be unable to remember or use that same information the next week. Indeed, Brown et al. (2014) stated that "people who learn to extract the key ideas from new material and organize them into a mental model and connect that model to prior knowledge show an advantage in learning complex mastery" (p. 6). Meaningful learning takes many forms, including learning with a purpose, learning new material that is personally relevant, and linking new learning to preexisting knowledge. Decades of research in the Science of Learning attest to these facts. Bransford et al. (1999) wrote that if students are to develop competence in an area, they need to have factual knowledge, but "a large set of disconnected facts is not sufficient" (p. 16). Students also need a conceptual framework to house these facts and to organize their knowledge in a way that allows them to apply what they have learned.

The widely cited scholar David Ausubel (1968) theorized that true learning occurs when we make connections between new material and related content we already know. He distinguished *meaningful learning* from *rote learning*. Rote learning occurs when new information does not link to previously learned content in any substantial way. In other words, the new information has no existing information to be "hooked" onto. This is why rote learning often does not "stick" but fades from memory. It often lacks meaningful connection to what we already know.

Shuell (1990) forwarded a similar argument. He held that rote learning is a precursor to "real" learning, which takes place only when we develop new understanding by incorporating newly learned facts into our current understanding. When we learn the multiplication tables, for example, we do not yet know division. However, the multiplication tables gain new importance and meaning when we begin doing division problems—they become automatized and serve as the base for the next round of learning. In other words, complex learning and expertise are built on having a base of knowledge and skills that can be fluently retrieved. New mental models and conceptual frameworks are constructed on this base.

In Chi's (2009) framework, constructive learning is meaningful when it relies on the active construction of a mental model of the newly learned material. When meaning is added to rote learning, it propels the change to true conceptual understanding (Novak, 2002). But this does not imply that all learning starts out as rote learning; to the contrary, learning can be meaningful from the start. Though rote learning may be useful in some situations, it can often be very shallow. For example, we can imagine children in the fifth grade working with an app that makes a game of memorizing the names of the presidents in order. While children can do this, if they have no idea that the United States is a democracy and that the presidents are elected rather than chosen by a king, their understanding of "presidents" is limited. Until children learn about the United States' system of government, the names of the presidents are just that—names memorized in a vague context.

No doubt, the original "base of knowledge and skills" upon which more meaningful learning is established will need to be built. Acquisition of such a base seems to depend at least in part on drill and practice. For example, learning the multiplication tables is needed for doing mathematics; learning the meaning of many vocabulary words is needed for apprehending school content in reading, science, and social studies. Judging from existing work on middle school children, this may be where the use of apps will shine. Apps offer tremendous potential to support this kind of practice. When computer tutors—which could be instantiated as apps—have been compared with self-study, they have been shown to produce greater gains in learning and retention (e.g., Metcalfe, Kornell, & Son, 2007). Such apps could be invaluable, making it possible for many more students to profit from the higher-order conceptual learning advanced in school. And even more to the point is an article by Walker, Mickes, Bajic, Nailon, and Rickard (2013) that reported that old-fashioned drill and practice with the multiplication tables leads to more fluent learning of these basic facts than does instruction with a more conceptually oriented "fact triangle" approach. Thus, the story on meaningful learning is nuanced: Sometimes apps that invite drill and practice and are instantiated in a game-like framework can be educational and effective for building up the base on which meaningful learning rests.

Sometimes, however, promoting meaningful learning depends on contexts that stimulate greater motivation. A child may be more motivated to learn fractions, for example, by dividing Halloween candy among siblings than by answering problems posed on a worksheet. Similarly, playing a game in which math skills are embedded within a story line of feeding a school of fish or serving people in a pizzeria allows children to see potential real-world applications of mathematical concepts. The benefit of context and meaning is apparent even in infancy. By 14 months of age, learning about the function of a novel object helps infants categorize objects (Booth & Waxman, 2002). Further, early word learning is "smart," such that infants will only extend a novel label to an appropriate object based on what they know about that kind of object. For example, children are likely to extend their new word "chair" to other artifacts with roughly the same shape (Landau, Smith, & Jones, 1998).

When words were embedded in a written passage, middle school children showed vocabulary gains (Nagy, Herman, & Anderson, 1985) relative to a control group that did not see the passage. This effect is probably due to the fact that the words were couched in a narrative that exemplified their meaning. Learning meaningful information motivates children to stay engaged and on-task. If children are given causally rich information about a novel object, they will stay engaged in a boring task that rewards them with this information. For example, children were more likely to continue with placing pegs in a board if they were prompted with a picture of a novel object and given new, meaningful information about that object. These children were more likely to continue with the boring task than children who received less rich information or even tangible rewards (stickers; Alvarez & Booth, 2014). Finally, meaning is invoked when learning contexts are familiar. Hudson and Nelson (1983) found that children 4 to 7 years of age are likely to remember more story events when the narrative they are hearing is familiar (e.g., about a birthday party) versus unfamiliar (e.g., about baking cookies).

Meaningful learning also produces effects for adults. In a health care context, learning within the context of a narrative helps both patients and doctors. For instance, Hinyard and Kreuter (2007) stated:

> To date, the dominant paradigm in health communication has involved using statistical evidence, probability, and appeals to logic and reason to persuade and motivate people to adopt behavioral changes. Increasingly, however, health communication developers are turning to narrative forms of communication like entertainment education, storytelling, and testimonials to help achieve those same objectives (p. 777).

When health information is embedded within a meaningful context, outcomes improve. For example, doctors who are told a narrative about a patient are more likely to remember the guidelines for prescribing opioids than are those who are simply told the guidelines (Kilaru et al., 2014). The latter are likely to forget the guidelines quickly and even make up guidelines that do not exist.

For college students, taking longhand notes results in better learning, likely because students are looking for meaning and more deeply processing the lecture material than when they type verbatim notes (Mueller & Oppenheimer, 2014). Indeed, the brain processes familiar and novel information differently. Presenting adults with familiar faces that are meaningful to them recruits a broader network of brain regions than does presenting novel faces (Heisz, Shedden, & McIntosh, 2012). When adults are presented with novel shapes but find meaning in those shapes (i.e., a potato chip that looks like Elvis), their pattern of brain activation differs from when they do not find additional meaning (Voss, Federmeier, & Paller, 2012). Thus, and this may be the key, when we process information that is more meaningful, we often (though not always) are more mentally active, making more connections across brain areas.

How is newly learned information meaningfully encoded to form new memories? Levels-of-processing theory suggests that the depth at which an item is mentally processed, or elaborated on, determines the strength of memory for that item (Craik & Tulving, 1975). The durability of a memory trace is related to the semantic depth at which it is processed. Deeper processing, such as accessing the semantic meaning of a word, produces a stronger memory trace than processing that same word at a more shallow level, such as noting its orthography or phonemic features. Although its main application has been in verbal learning, this framework closely resembles the theory proposed by Ausubel (1968). In this way, phonetic processing parallels rote learning, as they both incur a less durable memory trace. Meaningful learning that is connected to prior knowledge allows us to tap into deeper semantic levels of processing.

Another indicator that meaningful learning has occurred is in problem solving and cognitive flexibility. If learners have truly created a new understanding of a concept, they should be able to use that information to solve novel problems and flexibly transfer that knowledge to other problems (Goldstone & Day, 2012). If, for example, a child knows what "half" means only when asked about a cookie split between two siblings, learning is not complete. Similarly, a toddler's having memorized that 2 plus 2 equals 4 but not knowing that 2 plus 1 equals 3 suggests that the numbers do not have meaning for him or her.

Meaningful learning in television. Several studies have demonstrated that children better learn educational content from television when it is "on the plotline." Children are better able to recall educational content that is directly tied to the narrative of a program (Fisch, 2004; Hall & Williams, 1993). For example, when children watch a character in a show solve a mystery by figuring out the missing letters in a written clue (Fisch, 2004), they are more likely to remember the spelling of the word than when the word is just repeated. Characters who advance the plot by using targeted educational concepts or content lead to more retention of those concepts by children. Educational content that is irrelevant or tangential to the plotline is less likely to be recalled.

Applying meaningful learning to apps. How can an app be assessed for something as complex and unobservable as "meaning"? A reasonable proxy might be to consider the quantity and quality of connections between the app experience and the wider circles of a child's life. For example, one might ask: Does the app ask the child to go beyond rote learning? Does the app experience tap into the child's personal history, activate prior knowledge of a subject, or build a rich narrative? Does it extend important interpersonal experiences with parents, siblings, or peers? How does it connect to the child's role in his or her school community and, ultimately, to related domains of knowledge, such as science, mathematics, or history (cf. Rogoff, 1995)?

Similar to television content created to be on the plotline, apps that require children to solve problems or demonstrate proficiency in a content area in the service of a larger game narrative may be more successful than apps in which challenges are not integrated into the game's narrative or context. For example, the game *Motion Math: Pizza!* embeds math concepts into the running of a pizzeria. Children must understand money concepts and how to complete specific mathematical operations in order to run a successful pizza parlor.

A number of apps in the marketplace require shallow, rote memorization. For example, an app that asks a child to touch a triangle and then showers the child with applause before it moves on to asking about a blue square is hardly meaningful. Contrast that with an app that explains and demonstrates that “a triangle has three sides,” shows the three sides with colorful accents, and then asks the child to “find the triangles” in an everyday, meaningful scene in a hidden-pictures task.

Other apps might make connections with the child’s home environment. Consider an app that engages children and parents in mathematics activities around the home using the device’s camera. The child is asked to take a photo of something square or of a group of three things, for example. As children examine and photograph familiar objects in their home, they connect previous personal experiences to the app activity—for example, grouping three favorite dolls for a group portrait brings a personal meaning to the quantity involved, especially when the fourth favorite one is necessarily left out. Children next show the photograph to a parent to assess the quantity it shows, which builds links between the app experience and an essential interpersonal relationship. If the child does the same thing with the other parent and an older sibling, these meaningful connections grow threefold. Finally, children can connect this home experience with classroom mathematics activities, by engaging in other activities that involve grouping quantities in a meaningful new way.

Thus, when thinking about apps, it is important to promote meaningful learning that goes beyond just learning that the letter *A* is made with two long lines with a short line in between them. *A* has various sounds; when followed by an *E* after a consonant, it sounds like its name (as in *ape*); and it also stands for a job well done. There is no denying that apps can teach children isolated facts, but meaningful interactions with the content that link to children’s lives will lead to greater retention and spur conceptual change.

Active, engaged, and meaningful experiences are three of the pillars that move deftly from the Science of Learning into app design. The final pillar is social interaction. At first glance, this pillar might seem in opposition to the quiet absorption of a child playing alone with a device in the back of an SUV during a long road trip. Yet research suggests that high-quality social interaction can be a key component of learning, especially for younger children. More digital experiences need to reflect the idea that social interactions between children, between children and adults, and even between on-screen characters like Elmo and viewers or users spur interest and learning (Calvert & Richards, 2014).

Social interaction

Evidence from the Science of Learning. Csibra and Gergely (2009) suggested that the transmission of information between individuals acts as a kind of “natural pedagogy” (p. 148). From within an hour of birth, infants will imitate a social partner’s tongue protrusion (Meltzoff & Moore, 1983), and by 12 to 21 days, they can imitate both facial expressions and manual gestures (Meltzoff & Moore, 1977). By 6 months of age, infants initiate more looks toward a caregiver when they are shown something that violates their expectation than when something expected happens (Walden, Kim, McCoy, & Karrass, 2007).

Infants’ use of social cues occurs across many contexts. The mere presence of a social partner promoted infant learning of the properties of novel objects: Nine-month-old infants succeeded in learning only when this task included the presentation of a face looking at the stimuli to be learned and a voice saying, “Hi, baby, look at this!” They failed at the same task without this support (Wu, Gopnik, Richardson, & Kirkham, 2011). Infants also readily distinguish between communicative and noncommunicative contexts, an ability that has far-reaching consequences for learning (Yoon, Johnson, and Csibra, 2008). Simply put, social interaction itself enables learning. And while the evidence that infants use statistical reasoning across a variety of domains is clear (Saffran, Aslin, & Newport, 1996; Saffran & Wilson, 2003; L. Smith & Yu, 2008; Xu & Garcia, 2008; Yu & Smith, 2007; Yurovsky, Yu, & Smith, 2012), other research has shown that when social cues are provided, infants perform even better in complex situations than if they are provided only with statistical information (Wu et al., 2011; Yu & Ballard, 2007).

One domain that appears to particularly benefit from social learning is language. The positive effect of social interaction is apparent even at the level of infants’ ability to discriminate between the phonemes of a new language (Kuhl, Tsao, & Liu, 2003). Infants typically lose the ability to discriminate between phonemes that are not used in their native language between 6 and 12 months of age; however, experience with a live speaker talking in Chinese, but not a video recording of that same speaker, was enough to allow English-reared infants to maintain phonemes from Chinese that they would ordinarily have lost. Kuhl (2007) suggested that not only is social interaction important for this type of early language learning, but it may act as a gate that is necessary for language learning:

> I advance the hypothesis that the earliest phases of language acquisition—the developmental transition from an initial universal state of language processing to one that is language specific—requires social interaction. . . . I argue that the social brain "gates" the computational mechanisms involved in human language learning (p. 110).

The importance of social interaction for language learning does not end with phonemic discrimination. By 5 months of age, infants have learned that their vocalizations impact social partners. They stop vocalizing if their social partner stops responding to them (i.e., by displaying a still face). The magnitude of their response to a still face predicts their language development 8 months later (Goldstein, Schwade, & Bornstein, 2009). The responsiveness of a caregiver to an infant's vocalization predicts that infant's subsequent vocalizations in general (Dunst, Gorman, & Hamby, 2010; Tamis-LeMonda et al., 2014) and the frequency of vocalizations directed toward the caregiver in the following months (Gros-Louis, West, & King, 2014). When a parent responds to an infant's babbling in a contingent way, the infant is more likely to pick up on phonological patterns and generalize these forms to his or her own vocalizations (Goldstein & Schwade, 2008). Infants' ability to gaze follow and point at 10 to 11 months of age predicts their vocabulary at age 2 (Brooks & Meltzoff, 2008). By 12 months of age, infants will follow the gaze of either a human or a robot, but they will show increased object learning only when following the human gaze (Okumura et al., 2013), a finding consistent with the results of the Wu et al. (2011) study described above.

Throughout the preschool years, children learn much from their peers and from other adults. Sawyer (2006) noted that "outside of formal schooling, almost all learning occurs in a complex social environment" (p. 9), and there is agreement that social interaction is central to learning. In fact, according to Vygotsky (1978), the social dialogs preschoolers engage in are crucial for advancing their cognitive development. Laura Berk (2003) described how her 21-month-old imitated her 4-year-old in pretending to bake a pineapple upside-down cake. The 4-year-old taught his younger sibling the steps—reinforcing his own knowledge—and several hours later, the 21-month-old engaged in many of behaviors he had been shown earlier—but in pretend play. Social interaction allows children to observe and imitate older siblings, peers, and their elders, and in doing so, they learn about how events in the world typically unfold. But young children can learn more than concrete actions from imitation. Thirty-six-month-olds can even learn rules by imitating adults, such as by sorting objects by both visible (color) and nonvisible properties (object noises; Williamson, Jaswal, & Meltzoff, 2010). Further, preschool children use statistical information differently if they perceive the demonstrator to be naïve versus knowledgeable (Buchsbaum et al., 2011). By the age of 4, children are able to use the pedagogical intent of a speaker to guide their inductive generalizations (Butler & Markman, 2012). Thus, when an adult speaker acting as a teacher said "Watch this!" while showing children that a (secretly magnetized) block could pick up paper clips, children made a generic inference that other identical blocks should also pick up paper clips and were surprised when that did not happen. However, when they were given this information as if by accident, they did not make that generalization and did not continue exploring the blocks' properties.

Social interaction also impacts children's understanding in school. The benefits of collaborative learning, in which students work together toward a common learning goal rather than in solo learning environments, have been known for decades (see Johnson, Maruyama, Johnson, Nelson, & Skon, 1981, for a review). It appears that one specific type of learning might particularly benefit from collaborative learning: critical thinking skills. Gokhale (1995) directly compared students' learning of rote drill-and-practice skills and critical thinking skills when working alone or working with groups. While students in both conditions performed the same on the rote learning material, those working collaboratively showed better critical thinking skills. Having to explain one's reasoning to another and think through an argument deepens one's understanding of the problem at hand.

Ironically, even computer-based learning environments are capitalizing on social interaction for maximizing learning. The computer program *Betty's Brain* has students teach a character called a Teachable Agent (TA) or just learn the material by themselves (not from a teacher). The use of a TA has paradoxical effects. When students think they are teaching the TA, they spend more time learning the material and actually learn more than when they are learning for themselves. Interestingly, the effect is strongest for weaker students. Clearly, having a sense of responsibility to teach another increases children's motivation to learn (Chase, Chin, Oppezzo, & Schwartz, 2009). Further, when interaction with an avatar is controlled by a real person rather than a computer, people experience higher levels of arousal, learn more, and pay more attention (Okita, Bailenson, & Schwartz, 2008).

Research shows that *social contingency* in particular is a key factor in learning. That is, when a back-and-forth cycle is established between two speakers, in which the reaction of one speaker is in response to the other, powerful learning can occur. While evidence suggests limited learning of new words from screen media in the first

3 years of life (Barr & Wyss, 2008; Krcmar, Grela, & Lin, 2007; Scofield & Williams, 2009), a phenomenon sometimes referred to as a *video deficit* (Anderson & Pempek, 2005; Robb et al., 2009; Zimmerman et al., 2007), the undisputed finding is that human interaction trumps electronic "interaction" (Krcmar et al., 2007; Kuhl et al., 2003; Reiser, Tessmer, & Phelps, 1984; Roseberry, Hirsh-Pasek, Parish-Morris, & Golinkoff, 2009). Recent work has pointed to the natural give-and-take that happens in face-to-face interaction. In fact, when social contingency was established in an electronic format (i.e., via Skype or a similar live video chat program), children learned equally well from a real person and a "digitally live" on-screen interaction (Roseberry et al., 2014). They did not learn from watching a digital interaction between the adult and another child.

This raises an important point: For social interaction to benefit learning, it must be high quality. One can easily imagine how a child may be distracted in the classroom by other children screaming or playing games. Similarly, one could imagine a child using an educational app being distracted by another child (or sibling, or parent) making off-topic comments. Simply having a social partner is not enough. The social interaction has to be of a high enough quality that it does not detract from the learning situation. Overwhelmingly, research in education has found that cooperative and collaborative learning environments are optimal (see Johnson & Johnson, 2009, for a review).

Socially interactive learning in television. Several authors have pointed out that it makes conceptual sense to investigate interactivity (and media generally) through a social lens (Luckin, Connolly, Plowman, & Airey, 2003; Reeves & Nass, 1996; Richert, Robb, & Smith, 2011; Strommen, 2003). Given that media in all forms is overwhelmingly populated by humans and human-like characters, viewers are really sharing a type of interaction with another social partner (Reeves & Nass, 1996; Richert et al., 2011; Strommen, 2003). If media are perceived as providing social partners, even two-dimensional representations of puppets, it will impact how children react to them. Improving learning from media requires sensitivity to children's social expectations and might be achieved through a variety of means, including contingent feedback or a character with whom the child has an emotional relationship (e.g., Elmo from *Sesame Street* or Dora from *Dora the Explorer*; Strommen, 2000). In this context, parasocial features of television are relevant for children's learning from the medium.

Many television studies have supported this notion. For example, 2-year-olds who had an extended socially contingent interaction (playing games, answering questions, etc.) with a person through a television screen were more likely to successfully complete a search-and-retrieval task using information provided by the on-screen person than children who only saw a noncontingent, prerecorded video of the person (Troseth, Saylor, & Archer, 2006). Experience successfully interacting with an on-screen partner may contribute to the perception that on-screen events provide information. Similarly, O'Doherty et al. (2011) found that when 30-month-old children either observed or participated in a socially reciprocal interactive exchange, they showed increased word learning relative to when they engaged in a nonsocial interaction, such as with a person on television who was unresponsive to either the child or someone else. Contingent social responding is important for learning—especially for younger children.

Coviewing. Though television is not inherently social, it morphs into a social activity through *coviewing*, the act of watching television with children. Coviewing has been linked to how well children learn educational content. Teachers, siblings, peers, and others in a child's environment can be coviewers, but most research to date has focused on parental coviewing. Coviewing involves a spectrum of behaviors, from a child and parent quietly watching a program together to parents actively engaging children to make televised material more accessible. Effective coviewing behaviors are sensitive to individual children's developmental levels and include techniques such as asking children questions about what they are seeing or hearing, prompting children to imitate songs or movements, and pointing out or labeling objects or actions on screen (Valkenburg, Krcmar, Peeters, & Marseille, 1999).

Coviewing can affect children's viewing in a number of ways. For example, Demers, Hanson, Kirkorian, Pempek, and Anderson (2013) reported that infants were more likely to look at a television right after a parent looked toward the screen and to look for a longer period of time when they switched gaze in response to a parent's gaze. Parents can also intervene in television viewing, adding a social dimension to the experience. Children watching *Sesame Street* learned numbers and letters better when their parents asked them to name numbers and letters during a viewing, but not when the parents themselves named them (Reiser et al., 1984; Reiser, Williamson, & Suzuki, 1988; Rice et al., 1990). Children also understood televised stories better and learned more vocabulary when parents used techniques similar to effective shared book-reading behaviors, including asking open-ended questions and having children recall stories after viewing (Strouse, O'Doherty, & Troseth, 2013). However, a study by DeLoache et al. (2010) using videos designed to teach vocabulary showed that toddlers did not learn new words from the videos even when parents coviewed with them. Children showed word learning only when their parents interacted with them around the new words without the video.

Importance of parasocial factors. Finally, relatively recent research has suggested that children receive educational benefits when viewing programs with familiar characters. Children may have parasocial relationships with on-screen characters, in which children perceive themselves to be meaningfully interacting with a character even though the character cannot actually respond. In the television show *Dora the Explorer*, Dora asks questions or gives a prompt, waits for a response, looks directly at the camera, and pauses for a few seconds as if waiting for the child to reply. The program has been linked to educational gains, including improved expressive vocabulary (Linebarger & Walker, 2005). Characters with which 2-year-olds have parasocial relationships can also help teach them early math skills (Lauricella, Gola, & Calvert, 2011) better than a video of an unfamiliar figure. Parasocial relationships can also help children make healthier food choices (Kotler, Schiffman, & Hanson, 2012).

Applying social interaction to apps. Apps allow for a remarkable degree of contingency—but only to a point. One strength of apps on touch screens is that they allow for an immediate response when a child makes a selection via a tap or swipe on the screen. However, apps are not fully socially interactive and adaptive. Imagine a child exploring a book via an app. One benefit is that when the child touches a picture of a cow, he or she will immediately see and hear a cow moo and perhaps even chomp on some grass. However, most apps cannot respond to a toddler saying the word "cow" or "moo" with praise and encouragement (but see progress on this front through apps like SpeakaZoo and Winston Show; Cha, 2013). This type of responsivity has been shown to be a key facilitator of language development in young children (Dunst et al., 2010; Goldstein & Schwade, 2008; Gros-Louis et al., 2014; Roseberry et al., 2014; Tamis-LeMonda et al., 2014). Responsivity is limited in apps compared to natural human interaction.

The app world invites a number of different social environments, each of which needs to be taken into account when we ask about the relationship between social interaction and learning. App design can incorporate the potential educational benefits of social interaction in three ways. First, multiple users may engage in face-to-face interactions around the screen, perhaps while competing in a game or collaborating on a project. That is, they can take turns. Or, an app may prompt these kinds of interactions further away from the screen, as when children search together for household objects during a treasure-hunt activity. In any case, apps may provide varying degrees of structure for these interactions. They may create a potentially social context in which two children may engage in a similar activity at the same time. Alternatively, they may provide well-defined roles with prompts for specific educational dialog, such as "scientists" pursuing the course of systematic inquiry.

Second, users may engage in mediated interactions through technologies such as video teleconferencing (e.g., Skype or FaceTime), voice over IP audio, or various types of screen-sharing apps that allow collaborative visual communication through typing, drawing, or interacting with virtual objects (e.g., Drawing Together!, Kindoma, Minecraft). The resulting social interactions parallel a great deal of what is possible in face-to-face interactions, with the obvious absence of direct physical contact between people. Research evidence suggests that these kinds of mediated social interactions have benefits for learning similar to those of face-to-face interactions (Roseberry et al., 2014). Existing research on this topic has focused on traditional video formats, but newer interactive media formats may provide similar effects, providing an incentive for media creators to design characters with whom children can relate.

Third, as with television, apps can support development of parasocial relations with on-screen characters. Characters presented on touch-screen devices, however, can be designed for more realistic two-way interactions with users. Companies are beginning to create apps with animated characters that respond to the content of children's speech. These kinds of parasocial interactions for entertainment and education are likely to expand in coming years.

Active, engaged, meaningful, and socially interactive experiences support learning, and if these concepts are harnessed within apps, the potential benefit for learning in early childhood is significant. Along with the four pillars, a final lesson from the Science of Learning literature involves the *context* for learning. Is the context one that promotes exploration toward a learning goal, or superficial rote learning? Apps that engage these pillars within the context of a learning goal are the most likely to be truly educational.

Scaffolded exploration toward a learning goal

Evidence from the Science of Learning. The four pillars of active, engaged, meaningful, and socially interactive experiences may be oriented toward entertainment or educational apps. Research in the Science of Learning suggests that they are more likely to result in significant learning if they are embedded in an educational context that supports scaffolded exploration, questioning, and discovery in relation to well-defined learning goals.

The importance of the learning situation itself cannot be understated. For apps, it is a primary concern. For instance, one can easily imagine a game in which a child is active and engaged but nothing is learned. Research in the Science of Learning suggests that the context itself can act as a scaffold, or support, for learning.

According to Sigel (1987), "the child as an active learner has to have opportunities for self-directed activities through play and other exploratory adventures as a means of self-stimulation and healthy development" (p. 214). Sigel and colleagues believed that the optimal early learning environment promotes physical and cognitive exploration (alone and with others) and a warm, encouraging atmosphere (Copple, Sigel, & Saunders, 1979). Sigel (1987) wrote,

> Children can learn anything if it is properly arranged; that appropriate structuring of the very young child's learning environment with accompanying, properly calibrated materials will enable that child to learn to read, to acquire an advanced vocabulary, and to do arithmetic calculations (p. 212).

Debates about the best learning contexts have been raging for decades (Hirsh-Pasek & Golinkoff, 2011). One end of the continuum supports free play, in which a play situation is not structured or designed in a purposeful way (P. Gray, 2013). At the other end of the continuum lies didactic learning, or direct instruction, in which adults explain to children how something works or what they need to know. There are merits to both approaches. A recent meta-analysis examining 164 studies, however, suggested that direct instruction resulted in better learning compared to free play in which no learning goal was defined, but that assisted discovery methods, in which an adult helped guide the child's experience but took a supportive rather than primary role, resulted in the best overall learning outcomes (Alfieri, Brooks, Aldrich, & Tenenbaum, 2011).

In education, the use of *manipulatives*—physical objects such as blocks that are designed to help children learn mathematical concepts through hands-on manipulation—is commonplace and has some empirical support (see Lillard, 2005; Pouw, van Gog, & Paas, 2014; and see Sowell, 1989, for a review; but see McNeil & Jarvin, 2007; Uttal, Scudder, & DeLoache, 1997). The key is that children are not just actively engaged in a situation but are given the appropriate tools that, when actively explored, allow them to acquire a new concept or understanding. When low-income children play linear board games in short interventions with an adult and other children, they gain significantly in their understanding of numbers (Ramani & Siegler, 2008, 2011; Siegler & Ramani, 2008, 2009). This same benefit has been shown in the use of dynamic visualizations, rather than static images, for enhancing student learning of scientific concepts, such as photosynthesis (Ryoo & Linn, 2012).

In the domain of spatial cognition, K. R. Fisher, Hirsh-Pasek, Newcombe, and Golinkoff (2013) directly compared learning about geometric knowledge through direct instruction, free play in which children could do whatever they wanted with geometric materials, and guided play in which a more experienced play partner scaffolded play and followed the child's lead. Only children who learned via guided play transferred their new understanding of shapes to noncanonical shapes (e.g., triangles with acute angles) immediately after training and 1 week later. In another study, this time focusing on reading outcomes, at-risk preschoolers showed greater literacy gains when their instruction was paired with guided play (Han, Moore, Vukelich, & Buell, 2010). Guided play (K. R. Fisher, Hirsh-Pasek, Golinkoff, Singer, & Berk, 2011; Hirsh-Pasek & Golinkoff, 2008) is child directed, builds upon children's interests, and entails interacting with an adult who has a learning goal in mind. In each of the above studies, playing alone did not generate as much learning as exploration with a learning objective in mind. Note also that these experiments using guided play sit midway between the two anchors of direct instruction and play in the educational debates (Hirsh-Pasek & Golinkoff, 2011; Weisberg, Hirsh-Pasek, & Golinkoff, 2013).

The same benefits of guided play and the importance of "setting the stage" for learning are seen when it comes to fostering language development and literacy. Preliminary evidence from a large-scale, ongoing intervention study with preschoolers in Head Start indicates that a guided, play-based vocabulary intervention in which children play with replicas that relate to a story works as well as an adult-led, more directed play context (Dickinson, Hirsh-Pasek, Golinkoff, Nicolopoulou, & Collins, 2013). Both of these focused, play-based contexts are equivalently successful, and both are superior to free play.

However, the Science of Learning does not suggest that there is no benefit of direct instruction. Direct instruction can work and in some cases has been found to be particularly effective (Klahr & Nigam, 2004). Work by David Klahr and his colleagues has suggested that more supported learning is the key to mastering second-grade science. In a comparison of directed learning versus discovery learning, Strand-Cary and Klahr (2008) found that children showed better mastery of the concept of experimental confounds in both the short term (1 week) and long term (3 years) when they had been more directly instructed on the content. A close inspection of Klahr's direct-instruction condition, however, renders it somewhat like the guided-play conditions discussed above (Chi, 2009).

The double-edged sword of a strict and nonresponsive direct instruction format is that it limits exploration and may prevent children from learning beyond exactly what they are taught (Alfieri et al., 2011; Bonawitz et al., 2011). Bonawitz and Schultz presented 4-year-olds with a toy that had four hidden functions. In one condition, children were told what the toy could do, shown one of its functions, and then left to explore the toy. In the other condition, an experimenter accidentally "tripped" on one of the functions (the same function demonstrated in the other condition) before the children were left to explore the toy. Children in the exploration condition were much more likely to discover all of the toy's remaining functions, whereas those in the directed condition seemed restricted to the function that had been shown to them. Pedagogy can be useful but seems to shortchange exploration and additional learning. In this case, it had the unanticipated outcome of implying that children had learned all they needed to know about the novel toy—otherwise, the "teacher" would have told them more.

Direct instruction coupled with exploration may be the more effective strategy. DeCaro and Rittle-Johnson (2012) presented second-, third-, and fourth-grade children with unfamiliar math problems and found that children who first had the opportunity to try to figure a problem out for themselves and explore possible solutions before receiving direct instruction showed better conceptual understanding than children who first received instruction and were then allowed to practice. These are exactly the benefits some of us experience when we teach: Figuring out content in a way that allows *us* to explain it makes the subject our own and deepens our understanding.

Research suggests that giving either complete free rein to children or using solely the contrasting method of direct instruction may not be optimal for learning. As Kagan and Lowenstein (2004) noted, "the literature is clear: Diverse strategies that combine play and more structured efforts are effective accelerators of children's readiness for school and long-term development" (p. 72). Guided play, with time for exploration, may increase learning gains. The main point is that the pedagogy used for promoting learning has consequences for what is learned and how long it is retained. With the right contexts that set up the learning pillars and that enable exploration toward a learning goal, we set the stage to create truly educational materials (Weisberg, Hirsh-Pasek, Golinkoff, & McCandliss, 2014).

Scaffolded exploration in television. The program *Blue's Clues* initially ran the same episode every day for a week based on research showing that children interacted more with the program as they mastered the content (Crawley et al., 2002). This finding echoes a parallel finding concerning reading books to young children: Children benefited from repeated readings of the same book rather than from being read a variety of books that presented the same information (Horst, Parsons, & Bryan, 2011). Viewing a show multiple times helps children learn content that they may not have fully understood during an initial viewing, as well as reinforcing mastery of content once it has become more familiar (Fisch & Truglio, 2001). However, once children begin to gain a greater understanding of a concept, encountering the same content repeatedly in different contexts may help them to generalize the content to new situations (Fisch & Truglio, 2001). For example, a *Sesame Street* episode teaching about the letter *B* may present *B* in the context of different words, such as *bed, bath*, or *bird*, and in different segments (animated vs. nonanimated, sung vs. spoken, etc.). In all of these cases, children were given the opportunity to explore within a context that supported learning—a context with a learning objective that was tailored to their understanding. In this sense, the television findings parallel those noted in guided play.

The same can be said of curricula that is specifically tied to television programming. PBS's *Ready to Learn*, with its accompanying materials and digital resources, offers one example of a way in which screen time can be infused with a learning goal. Neuman's (2010) work around the program *Super Why!* offers another prime example.

Applying scaffolded exploration in apps. In our analysis, the educational "context" of children's app experience includes both the external setting of use and the internal app design, in terms of how the app guides children's experience toward a learning goal. It encompasses concepts such as learning design in the field of human-computer interaction (J. H. Gray, Bulat, Jaynes, & Cunningham, 2009) and pedagogy in education.

Scaffolding is a pedagogical structure that helps children accomplish a task that they would not be able to accomplish by themselves and that is removed over time, allowing children to accomplish the same task independently (Wood, Bruner, & Ross, 1976). For certain types of apps, external scaffolding can transform children's experience from relatively haphazard poking and swiping to a guided exploration of age-appropriate content. For example, visual reference apps such as SoundTouch or The Human Body provide multimedia representations of animals, vehicles, instruments, the human circulatory system, and other highly engaging content through photographs, audio, video, and animations. Very young children exploring these apps alone may have relatively superficial sensory experiences, whereas, with the guidance of an educationally oriented adult, they could engage in a genuine inquiry about categories of animals or processes inside their own bodies.

Built into the app design itself, scaffolding toward a learning goal can take various forms, ranging from hint systems that provide supportive background knowledge, to curriculum leveling strategies that provide more or less challenging options during a play session, to sophisticated adaptive learning systems that model relevant behavior, understanding, and opportunities for each child in order to prescribe personalized sequences of learning experiences. Examples in the latter category include apps from DreamBox Learning and Kidaptive, both of which adjust content for individual children with the goal of providing the most engaging and effective learning challenges at every moment. For example, a child struggling with the mathematical qualities of a 1-to-10 number line might be presented with additional conceptual support or a simpler 1-to-5 number line, depending on his or her patterns of performance after receiving similar help in the past.

App Analysis: Categories and Exemplars

Previously, we demonstrated how the four pillars from the Science of Learning can be operationalized to identify whether children are active, engaged, connecting to meaningful material, and socially interactive when working with apps. We also argued for the importance of context, such that true educational apps should support scaffolded exploration toward a learning goal. We suggest that this is a conceptual approach that will benefit various groups, including app developers—who endeavor to maximize the learning potential of their creations—and parents and early childhood educators, who can assess the learning potential of an app regardless of the intent of the designers or marketing claims. The extent to which this approach will benefit these groups depends on the ease with which it can be put into practice. Below, we offer a schematic framework with examples of how one could go about analyzing apps for their educational potential with respect to each pillar of learning. It is important to note that this evaluation framework is not intended as a strict set of guidelines for app analysis. Rather, it is meant to demonstrate that, regardless of one's expertise, it is possible to evaluate apps from a Science of Learning perspective.

Profiles and pedigrees

Using the four pillars within a context, as suggested by the Science of Learning, we can begin to analyze apps with respect to profiles—how they rate on the four pillars—and their *pedigree*, or whether they are for entertainment, education, or both. In what follows, we first examine the apps with respect to the profile analysis. Where might an app fall on each of the four pillars and the context when examined in the aggregate? We then supplement this analysis with talk about the apps' pedigree. In what cases might a profile signal that the app is truly educational at its core rather than merely using the label?

Exemplar analysis. We now look at a few exemplars to illustrate how the four pillars can be used to start an analysis of children's app experiences. Alien Assignment[1] is an app designed to encourage problem solving and discovery for young children by engaging them in a scavenger hunt with the device's camera and facilitating parent-child interactions that scaffold learning. It has a narrative structure involving a family of green aliens who get marooned on Earth and request help to fix their spaceship. The aliens ask children to take photos of household objects (e.g., "light switch") or categories of such objects (e.g., "something that turns") related to their spaceship repair needs (e.g., "The trunk is stuck. Take a picture of something you can open"). Children are prompted to show the photos to a "grown-up," who can evaluate the accuracy of each photo with a thumbs-up or -down and discuss related issues with the child. After all the child's photos have been approved, the alien family blasts off for home, only to have another collision that brings them back to Earth, which presents the child with the start menu again.

Active, minds-on learning. How might the app experience prompt minds-on activity in the service of literacy learning? Narrative is a virtually universal genre of human communication and thought (Bruner, 1990) that engages children's minds (Nicolopoulou & Ilgaz, 2013). Alien Assignment connects a series of vocabulary words and concepts at the center of each photographic quest. The parallel between plot points (e.g., aliens needing to open a trunk) and children's activity (evaluating familiar physical objects for their potential to help accomplish the task) prompts children to imagine themselves in the story and construct a more personal understanding of each word's meaning. Additionally, hearing and participating in a story is likely to bolster children's understanding of narrative structure, itself an important component of literacy learning.

Symbolic and sensory activity are notable in this app experience, which focuses on oral language and visual exploration of a physical setting. The narrative is told primarily through recorded voice, with supporting illustrations and some incidental on-screen text (e.g., a sign marked "Earth"). The finished photos provide a prompt for parent-child conversation. For example, when children take a picture of objects that open (e.g., drawers, doors, and covers), parents can expand the topic to include new vocabulary (e.g., *in, out, pull, push, hinge,* *lid*) or explore related concepts (e.g., the potentially useful or dangerous fact that objects placed near a door hinge can be bent or broken, and related physical forces of leverage and torque). Deciding on the subject of each photo involves thinking about the nearby physical environment, evaluating potential subjects, visually scanning, and ultimately framing and taking a photograph. This is likely to be a whole-body experience as children move through their homes (or another location) in search of suitable subjects, thinking about what to photograph that fits the task. A more advanced version of the app could also address literacy topics such as phonological awareness or word recognition in the context of the story; however, the current focus on oral language offers age-appropriate opportunities for learning vocabulary and story structure.

Engagement in the learning process. The focus and duration of children's attention while playing this app could vary tremendously, depending on the particular individuals and settings involved. The app affords both extrinsic and intrinsic motivations, offers explicit feedback, and allows for a host of highly responsive, contingent interactions with a parent. Ideally, children would be motivated by the extrinsic feedback from their parent and their own intrinsic motivation to creatively explore their environment. Unfortunately, children may also be distracted during the first photo quest and not return to the app, or fail to be engaged by the narrative in the first place. Realistically, most children's experiences will likely fall somewhere between these two extremes.

Perhaps most notable is that Alien Assignment attempts to create an educational context by prompting engagement with the physical and social setting. Although the app affords an educational experience, it cannot control it beyond prompting parents and children to take turns with the device and providing opportunities to discuss the photos. Depth of engagement will depend on children's ability to maintain their focus on quests, their parent's availability and pedagogical skills, and the presence of potential distractions in the immediate environment. By moving the user interaction well beyond the screen, the app affords opportunities for both deep, sustained learning and powerful distractions that compromise engagement. Therefore, we conclude that this open contextual learning design is both the app's strength and its weakness in terms of learning potential.

Meaningful learning. What meaning might the child get from engagement with an alien species? Ideally, players would construct significant personal meaning from their experience with each vocabulary word and concept as they find, photograph, and discuss objects in their own home. In the process, this learning would have interpersonal meaning as a shared parent-child experience, potentially connected to previous and subsequent family activities. In any case, the learning goals embodied in this app are an important part of young children's foundational knowledge in the domain of literacy. Although the app addresses only a very small segment of this foundation, the resulting learning experience is potentially meaningful to children on multiple levels.

To illustrate these levels of meaning, consider the example of "something you can open." Imagine a young child photographing a cardboard box that she has been playing with on her living room floor, focusing on the four overlapping flaps that open and close on top. She has a rich sensory understanding of how each one pivots, but is struggling with how to open all four together to create an imaginary boat that she can sit in and sail with her favorite animal toys. This *personal* meaning of "open" expands as she looks at the photo with her father and they discuss the box. Together, they devise a plan for experimenting with the flaps to see what will work best to keep them open. This interaction builds a deeper *interpersonal* meaning of "open" as a part of problem-solving and building activities with her dad. The meaning of "open" further expands when she explores a similar box with friends at preschool and her teacher documents their process with a photograph and a caption that says "opening and closing the boat hatch." The shared experience of reading the caption further deepens the meaning of "open" to include her school community and the wider domain of literacy.

Social interaction. Literacy learning with Alien Assignment is strongly supported through face-to-face social interactions between children and parents (or other adults). Not only does it afford a shared experience of viewing and discussing the photographs, it structures the interaction with prompts for sharing the device and assessing the accuracy of the photographs (with a thumbs-up or thumbs-down). While the parent-child interaction is guided toward this sort of assessment, the specifics of each conversation are up to the individuals involved. This flexibility allows parents to tailor their feedback based on their awareness of their child's knowledge, experience, and interests. Likewise, children can respond as they wish or remain silent while continuing to play the game.

Learning may also be supported indirectly through parasocial relationships with the story characters though the characters are largely unfamiliar. The alien children speak directly to the app users as they explain each repair needed and make a specific request for a photo to solve the problem. Indeed, the goal of participating in the story line is to help the family escape Earth and return

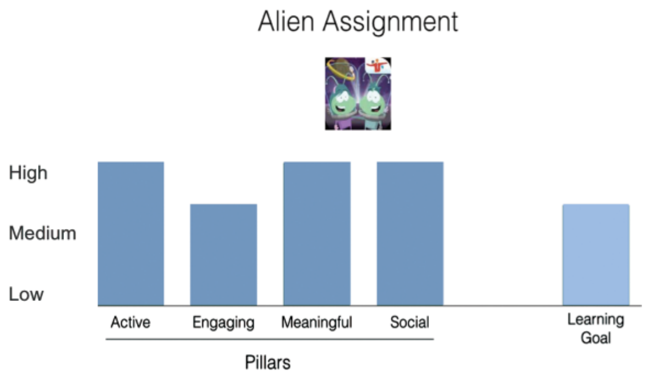

Fig. 1. A profile of Alien Assignment showing how the app rates on each of the four pillars from the Science of Learning and how it rates on furthering learning goals.

Fig. 2. A profile of Toca Hair Salon Me showing how the app rates on each of the four pillars from the Science of Learning and how it rates on furthering learning goals.

to their home planet. So, to the extent that the narrative compels children to photograph real objects and learn related vocabulary, it is because they accept the pretense of an alien family. Children help because they care about the characters.

Scaffolded exploration toward a learning goal. The learning goal for this activity is clear in that the designers hoped to have parents and children talking, thereby increasing vocabulary, language, and preliteracy skills. Because it relies on parents to achieve the goals, it is a heavily scaffolded program—assuming that the parents actually engage. The app itself does not allow for different levels of difficulty, other than adjustments to the number of clues to solve in a play session.

How might these analyses create a profile for Alien Assignment? We can graph the learning experience according to the four pillars and the context in which they are presented and can then create a visual of the attributes in a figurative profile like the one portrayed in Figure 1 by using a relative Likert scale to evaluate the app.

The profile for Alien Assignment would receive the highest score for providing a cognitively active, meaningful, and socially interactive experience but a slightly lower score for engagement because of the unknown qualities of the physical and social setting in which the app is played. Its literacy goals would give it a high score for context, but it would fall short of the highest score because of the same unknown aspects mentioned above.

Note that different apps will have very different profiles according to this schematic. For example, Toca Hair Salon Me, a game that allows children to cut and style virtual hair, is active, engaging, and meaningful, and it can be socially interactive, but it does not have an explicit learning goal. In contrast, an app like Toddler Teasers has a learning goal but is not very active, engaging, meaningful, or socially interactive and presents a very different profile than Alien Assignment. Children using Toddler Teasers merely point to squares and hexagons or to boxes of different colors and receive stock applause after correct responses. Figures 2 and 3 show profiles for Toca Hair Salon Me and Toddler Teasers, respectively.

These profiles provide an at-a-glance way of contrasting the educational potential of the various so-called "educational apps." This can be done across a range of app types.

Pedigrees: App categories

Finally, an alternative way to think about the educational value of the app is by looking at the qualitative category that it might fit into. Is it an entertaining or an educational app? We suggest a 2 × 2 grid that reflects whether an app has learning goals (yes or no) and whether the relative summation of the pillar scores yields a high or a low score (as shown in Fig. 4). Note that we are well aware that this schematic representation of the profiles and pedigree represents merely a starting point in what we hope will

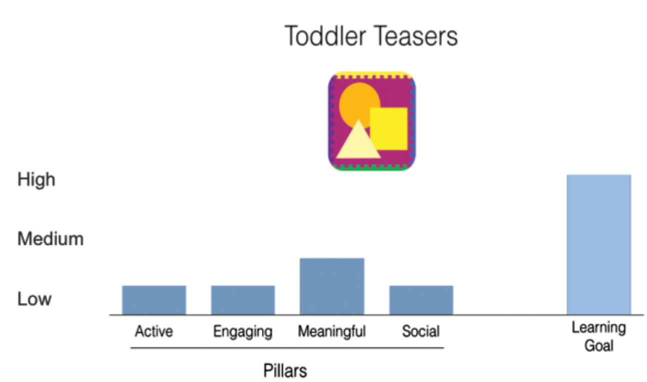

Fig. 3. A profile of Toddler Teasers showing how the app rates on each of the four pillars from the Science of Learning and how it rates on furthering learning goals.

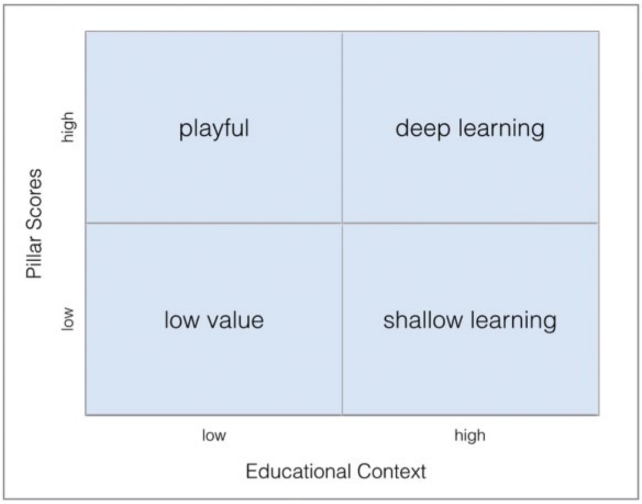

Fig. 4. A grid for determining the pedigree of an app.

become a more stringent evaluation. Even at this preliminary level, however, these caricatures begin to offer some insights about just how educational an app might be.

Looking at the grid, we find that in the upper right-hand corner—with high learning goals and high summation of the pillars (highly active, engaging, meaningful, and socially interactive)—we meet the true, evidence-based educational app. An app falling into this quadrant is likely to result in deep learning, as it is designed in a way that is concordant with our Science of Learning–inspired pillars.

In the upper left quadrant, we find an app that is low on learning goals but high in the summation of the pillar scores—what we might call a pure entertainment app. This kind of app, like the Toca Hair Salon Me app that we have described, may be fun to play and might lead to some ancillary learning, but it is largely noneducational in flavor (as the CEO of Toca Boca suggested).

Moving to the lower right-hand corner, we find those apps that are high in learning goals but low in the summation of the pillar scores. These are "educational" apps that do not align well with the Science of Learning and that are not likely to lead to deep learning in the children who use them. These apps were created when designers translated existing materials onto tablets without additional thought as to how to prompt true learning. Many of these apps have pitfalls we describe below.

Finally, there are apps that fall into the quadrant that is low both in learning goals and in the summation of the pillar scores. These apps might be those that are neither educational nor entertaining. They are not likely to keep a child's interest for any length of time and will not likely result in learning.

The grid presented here allows us to evaluate any app currently on the market for children. Designers too would profit from understanding the psychological foundation that can support the development of educational apps. Furthermore, if an app focuses on particular content areas such as reading, math, or spatial development, it is critical for developers to consult the literature on how to best frame the content so that it is consistent with scientific evidence.

The first wave of apps, revisited

The first wave of apps have offered an exciting inroad to a new technology that can be used both for entertainment value and for education. As developers design new products, and as parents and teachers evaluate these products, there are also pitfalls that they will want to avoid. Some of these pitfalls are discussed below.

The fire-alarm syndrome. Imagine you are reading a traditional book to a child and the fire alarm goes off. How much of the story do you think the child will recall? While this is an extreme example, its effects are not far from those of the bells and whistles included in many first-wave apps. App developers and parents should be mindful of the activities within an app: Do the enhancements actually add value and increase engagement, or do they cause distraction?

The too-many-choices trap. Much like the importance of content being age-appropriate, it is also crucial for apps to offer children the appropriate level of decision making. Adults can be overwhelmed by trying to decide among 30 varieties of peanut butter in the supermarket aisle. Similarly, one common pitfall of apps is to overwhelm children with too many choices. While having a few choices may help children to stay minds-on by involving them in the narrative of the app, having too many choices presents the opportunity for distraction and lack of engagement increases.

The masquerading "educational" app. Looking at the bottom right quadrant in comparison to the top right quadrant, we can now plainly see a difference in what might be a *true* educational app and one that simply bears that name. One of the easiest ways for app developers to make the claim that an app is educational is to make sure that it includes "educational" content such as numbers and letters. Rote memorization of numbers and letters, however, is not sufficient for deep learning. Young children need to understand the underlying number principles of cardinality, the order-irrelevance principle, and so on, and the app should touch base with what is known in the Science of Learning to include ideas from research on how number knowledge develops (Cross, Woods, & Schweingruber, 2009).

Empty calories. Some apps are very well designed, with careful attention paid to maintaining user engagement, but little or no emphasis placed on educational content. Apps designed primarily to entertain may fall into this category, in the upper left-hand quadrant. For example, the game Candy Crush has been noted as being very addictive for players, with short levels, attractive production design, and positive reinforcement used to maintain player engagement (Pentchoukov, 2014). Success in the game is often (but not always) determined by random luck rather than mastery of subject knowledge. Even apps with empty calories can be useful to educational-app developers in the future if they consider adapting and integrating features of popular, noneducational apps to improve the quality of their own apps. Perhaps intermittent reinforcement will raise the level of engagement and more strongly support learning.

The attention-deficit design. Some apps attempt to keep children engaged by constantly changing what is presented. For example, switching from screens designed to teach shapes to screens designed to teach mathematics to screens designed to teach early literacy promotes distraction and does not allow the depth of processing required for solid learning. Science of Learning research has revealed that children need repetition to learn best. Encountering the same content repeatedly, and in multiple contexts, reinforces learning, especially for younger children.

Heralding the Second Wave: Conclusions

A recent YouTube video put out by the New America Foundation (2014) begins, "Many parents and teachers think screen time is something to be avoided. . . . That's often the right response. But new research shows that not all screen interactions are created equal." The video continues with examples of when screen time can benefit children—when they talk to a grandparent over a chat program, are exposed to math concepts, work with teachers and parents to learn new things in many domains, and even learn new words. This is exactly the position we have taken in this article: Not all screen time is bad. Data indicate that screens are becoming increasingly ubiquitous (Heggestuen, 2013) around the world. We have argued that creating screen-based experiences for children that capitalize on the Science of Learning can only make apps better and children's exposure to them more profitable.

We live in the first wave of app development, when apps are often just migrations of games and learning scenarios that already exist in nondigital form. In this "Wild West" of discovery and change (Guernsey, Levine, Chiong, & Severns, 2012), app production is largely unregulated (with the exception of efforts like the Children's Online Privacy Protection Act, which is meant to protect children's personal information). Research from the Science of Learning can help guide developers and inform consumers about best practices for the second wave of app development.

How can we foster digital experiences that are cognitively active, deeply engaging, meaningful, and socially interactive within the context of a learning goal? With the Science of Learning as a foundation, we are in a position to take a proactive approach to the development and evaluation of educational apps. This new framework invites dialog from the research community, app developers and evaluators, and teachers and parents. It is a first step in considering the advantages and drawbacks of this medium.

Apps offer a digital doorway between the physical world in which children and families live and the rapidly growing digital cloud. The second wave of educational apps should be designed and used with this broad potential in mind, rather than simply mimicking and extending older media like books, worksheets, television, or even video games. The design of educational apps should creatively combine principles from the Science of Learning with the affordances of this versatile medium.

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The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

Note

1. Note that author Michael B. Robb is Director of Education and Research at the Fred Rogers Center for Early Learning and Children's Media and is an executive producer for this app. The app exemplar analysis presented here does not reflect an endorsement but is used solely to illustrate the way the pillars presented here may be applied to any app. James H. Gray received financial compensation for writing an article on imaginative play that was published on the Toca Boca website in December 2014, after this article was sent to press, and had no influence on the authors' choice to mention Toca Boca apps.

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