Bridging Constructivist Theories and Design Practice for Children to Grow as Active Technology Users

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Abstract

Background Technology has become pervasive in our lives and children's development is closely affected by using it. Technology designs for children should be based on a deep understanding of children and their development. A closer link between developmental theories and design practice is needed to meet children's needs and to support them to become active learners and users of technology.

Methods This research reviews constructivist theories, specifically the cognitive constructivism and social constructivism of Piaget, Papert, and Vygotsky. These theories suggest a perspective to see children as active agents who interact with their environment and learn through it. The theories explain how children develop through cognitive, physical, and social experiences, and give insights for design practices.

Results By reviewing the theories, this research suggests implications for designing technology for children: 1) technology should support children's developmental needs; 2) technology should be personalized to each child and support children in becoming creators; and 3) technology should support social interactions. Also, it presents how the theories can be applied to design practice using the examples of littleBits, KIBO, and DigiTile.

Conclusions To design technology that supports children in becoming active users and creators of technology, designers should design carefully based on an understanding of how children learn and develop. The constructivist theories can guide designers through their design process, help in making design decisions, and offer ways to verify designs in order to ensure that the design supports children's development.

Keywords Technology, Children, Development Theory, Constructivist Theory, Children Computer Interaction

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1. Introduction

Technology has become pervasive in our lives. For example, 37.7% of the world population owned smartphones in 2014, a figure is expected to grow to 52.5% by 2019 (eMarketer, 2015). The use of other smart devices such as tablets is also increasing. By 2019, 20.0% of the world population will own tablets (eMarketer, 2015). Children are no exception. In the US, three-quarters (75%) of all children aged 8 and under had access to some type of smart device such as a smartphone, an iPad, or similar devices, in their homes (Common Sense Media, 2013). Besides smart devices, the numbers of apps and computer programs have increased explosively. Apple announced that more than 2 million apps are available on the App Store. These apps have been downloaded 130 billion times since the App Store was launched in 2008 (Golson, 2016). Apple's Kids App Store, which launched in 2013, provides about 80,000 apps, and 60% of the apps are in the "education" category (Adjust, 2014). More than half of parents (58%) said they have downloaded apps for their children (Common Sense Media, 2013).

Obviously, children today spend a lot more time using technology than any other generation, from touchscreen smart devices to digital toys and wearable technology. Research has shown that children spend more time playing with touchscreen devices than with traditional toys such as dolls and action figures (Michael Cohen Group, 2014). Technology from devices to digital content is everywhere, and children are exposed to it from when they are born and are closely affected by it as they grow up.

Although technology targeting children is a large and fast-growing industry, how it is designed for and affects children's development has not been tested or verified thoroughly. Hirsh-Pasek et al. (2015) pointed out that only a handful of apps are designed with an eye toward how children actually learn. Given that technology can significantly influence the ways in which our children learn and think, we need a better way to ensure that technology is designed to support children's development. One way to achieve this is by designing based on a well-grounded theoretical foundation, not just based on designers' assumptions, own experiences, or intuition. There has been shared awareness that we need a closer link between design practice and theories from other fields, including psychology and pedagogy (Read & Markopoulos, 2012).

This study was conducted to link development theories and design practice better, so that designers, researchers, and educators can apply them in practice. In this article, I will 1) briefly give an overview of the field of child-computer interaction and then 2) describe how we can benefit from the theory-based design approach and review the key concepts of the constructivist theories of Piaget, Papert, and Vygotsky under two categories; cognitive constructivism and social constructivism. The theories will give us insights into how children think and learn, and what roles design should play to support this process. 3) Lastly, I will draw design implications for design practice and illustrate real-world examples to help in understanding and applying each theoretical approach.

2. Designing Technology for Children

As a discipline, designing technology for children is called as "child–computer interaction (CCI)" as a subfield of human–computer interaction (HCI) (Read & Markopoulos, 2012) or as "interaction design and children". As a separate discipline, CCI has been developed through its own conferences and journals as well as special sessions and programs within larger communities, such as HCI conferences. CCI, like HCI, is multidisciplinary. It is an interrelated field of psychology, education, learning science, computer science, art and design, etc. Each field has developed its own perspective and way to approach CCI.

Educators and child psychologists began discussing CCI in the late 1960s. Early studies mainly focused on the impact of new technology on children as learners as well as educational theories, as a theoretical foundation from which to start. In the interaction design and HCI field, Seymour Papert at MIT conducted the early seminal work in the 1980s. Children started to receive more attention as a user group in the 1990s (Druin, 2002; Read & Markopoulos, 2012).

There has been a growing trend to link education, psychology theories, and design practice, and use the theories as tools and frameworks to understand children better (Yarosh et al., 2011). The next chapter will review the theories of three philosophers and practitioners. Each of these theories sees children as active agents and can help us understand children's perspectives better.

3. Theory–based Design and Constructivism

Why do we need a theory-based approach? Theories can provide designers with a wide range of perspectives and approaches through which to understand design areas. A theory-based approach does not offer designers explicit prescriptions but powerful heuristics to guide design processes and procedures (Hannafin et al., 1997). Hannafin et al. (1997) proposed the concept of "grounded design" and defined it as "a process that involves linking the practices of learning systems design with related theory and research." Grounded design approaches can ensure that the methods used are consistent with given theoretical foundations and assumptions.

In this chapter, the cognitive and social constructivist theories of Piaget, Papert, and Vygotsky will be reviewed. Constructivist theories were one of the main theoretical foundations of the CCI field. Constructivists saw children as active learners as opposed to the behaviorists like John B. Watson, Ivan Pavlov, and B. F. Skinner, who saw children as rather passive and reactive to external stimuli. The constructivists supported a learner-centered approach over teacher-centered approach and believed that objects and events have no absolute meaning; rather, the individual interprets each and constructs meaning based on individual experiences and evolved beliefs (Hanafin et al., 1997). Alimisis (2013) insisted

that the constructivist approach can contribute strongly to the development of the skills that the 21st century requires, including scientific reasoning, critical thinking, problem solving, creativity, teamwork, and communication skills.

3. 1. Cognitive Constructivism

3. 1. 1. Jean Piaget

How we perceive our children has changed over time. It was not long ago that we started to see them as independent human beings, rather than as small, imperfect adults. Jean Piaget, a Swiss psychologist and epistemologist who has heavily influenced education, was one of the pioneers who saw children in this new way. Piaget saw children as active agents who interact with their environment (Olson & Hergenhahn, 2008). From this perspective, Piaget suggested the stages of cognitive development (Table 1). He believed that every child passes through these stages and that cognitive development is based on physical development (Mooney, 2013). He insisted that the age at which children accomplish a certain stage can vary depending on individuals and cultures, but the order of the stages is the same for any child and no stages can be skipped. The stages are sensorimotor, preoperational, concrete operational, and formal operational (Piaget, 1976; Hourcade, 2007).

According to Piaget's developmental stage theory, during the sensorimotor stage from birth to 2 years old, a child learns about the world through his or her senses and physical activities, and his or her acts are reflexive rather than purposeful. Toward the end of this stage, a child gradually understands the concept of permanence and knows that an object still exists even if it is not in sight. As sensorimotor development is most important in this stage, children should be able to move safely and freely, and need to have various experiences through their senses. In the preoperational stage, from 2 to 7, the ways in which children think differ the most from the ways in which adults think. In this stage, children are egocentric; they understand the world from their perspective and have a hard time imagining the views of others. Also, children in this stage focus on one characteristic of an object or a person at a time. Children in this stage learn the most from what they experience on their own, rather than what they are taught and generalize and construct concepts from their own experiences. Hence, in this stage, children should have enough time and chances to have real-world experiences and learn by themselves. In the concrete operational stage, from ages 7 to 11 or 12, children start to learn more abstract concepts, including conservation, class, seriation, number, hierarchies, and reverse actions. Children in this stage can think based on reasoning but are still limited to objects or familiar events. In the next stage, the formal operational stage, children can think more conceptually, logically, and hypothetically.

Table 1 Piaget's stages of cognitive development (Mooney, 2013)

Stage	Age	Behaviors
Sensorimotor	Birth to age 2	Learn through the senses; learn through reflexes; manipulate materials.
Preoperational	2–7 years	Form ideas based on their perceptions; can only focus on one variable at a time; overgeneralize based on limited experience.
Concrete Operational	7–11 or 12 years	Form ideas based on reasoning; limit thinking to objects and familiar events.
Formal Operational	11 or 12 years and older	Think conceptually; think hypothetically.

Piaget spent his life trying to understand what knowledge is and how people learn. He believed that learning does not just happen by providing instruction. Learning only happens when children have experiences by themselves and internalize the knowledge they get from the experiences. Piaget thought that children actively construct knowledge by experience, and that this construction is based on the knowledge they already have. This idea is called constructivism. According to him, every experience from which children learn requires two ongoing processes of assimilation and accommodation. Assimilation is the process of responding to the environment in accordance with one's available cognitive structure. Accommodation is the process of modifying the existing cognitive structure to deal with a new environment (Olson & Hergenhahn, 2008). Piaget emphasized that each child's curiosity is the key that drives learning, and children can learn most by doing rather than being instructed (Mooney, 2013).

From a design perspective, Piaget's constructivism emphasizes fundamentals and claims that technology should not try to convey knowledge to children. Rather, technology should observe and understand what a child is interested in first, offer chances for the child to explore real-world experiences, and help him or her to find an answer on his or her own.

3. 1. 2. Seymour Papert

Seymour Papert was one of the pioneers of technology for children. Based on his experience working with Piaget, he expanded and developed constructivism, calling it constructionism. Like Piaget, Papert criticized the conventional contemporary idea that knowledge is just conveyed from one end to the other, which he called instructionism (Papert & Harel, 1991). He agreed with Piaget that individuals construct their own knowledge by experiences. However, he emphasized the importance of context and media in the learning process. He believed that learning could happen most effectively through making. According to him, by making an artifact, children can externalize their emotions and thoughts, and make them tangible and shareable, which then makes it possible to elaborate and refine them. In this process of making, Papert emphasized the importance of tools and media. He was especially interested in digital media and computer-based technologies. Papert insisted that technology should support children in becoming authors and creators, rather than passive recipients (Ackermann, 2001; Papert, 1993).

Papert developed toolkits, programming languages, and other materials for children from the 1960s onward. The Logo programming language is one of his major works. It is a tool to help children think about and solve problems. Logo was the first expressive, student-centered educational technology to be applied to the K–12 education system in the US (Blikstein, 2015). He also participated in developing Lego Mindstorm. Papert believed that the computer could be the most powerful tool ever in offering personalized experiences, by serving thousands of forms and functions depending on each person's interests. He thought computers could teach children the concepts of science and mathematics (Papert, 1993).

Papert's theory and works give designers a clear message on how to design technology for children's learning. He asserted that technology for children should be carefully designed, as even a small element of technology could limit or enhance children's learning.

Also, he separated an understanding of the inner workings of technology from the content that children could learn through its use. Through Logo, Papert wanted children to learn about computer science and mathematics, and not about how computers work (Blikstein, 2015).

3. 2. Social Constructivism

3. 2. 1. Lev Vygotsky

Lev Vygotsky's work on the social aspects in children's education was widely influential. Like Piaget and Papert, Vygotsky emphasized learning through doing. While Piaget focused on personal and internal experience, Vygotsky focused more on social experiences through social surroundings and interactions with teachers and peers (Table 2). Vygotsky insisted that personal and social experiences cannot be separated, and that children develop socially and cognitively through both experiences. According to him, children grow up by adapting to their social surroundings, such as their family, communities, socioeconomic status, education, and culture (Mooney, 2013; Vygotsky, 1978).

One of the central concepts in Vygotsky's theory is the zone of proximal development (ZPD), which is the distance between the most difficult task that children can do on their own and the most difficult task that children can do with help from others. Vygotsky explained that children can learn new concepts or skills with the help of more capable people such as peers or teachers. The help that children need to complete a task is called scaffolding, which is a concept often used in interaction design for children (Hourcade, 2007). Vygotsky believed that teachers and parents should observe children closely to determine their ZPD and offer appropriate social support for it. He emphasized that cognitive development is affected by not only physical development but also social interaction. According to him, language plays a key role in social interaction. Children learn new knowledge through communicating with others (Mooney, 2013).

Vygotsky's theory broadens the design perspective. First of all, technology for children should observe them to determine what they are interested in and want to know about. After observation, technology should verify each child's ZPD and offer chances to stretch the child's current knowledge or skills further by interacting with other people.

Table 2 Concept comparisons for Cognitive and social constructivist theories

	Cognitive Constructivism	Social Constructivism
Theorist	Piaget, Papert	Vygotsky
Role of learner	Active	Active
Primary place of learning	In the individual's mind (the social environment is important as well)	In social practices (individual responsibility is important as well)
How learning is initiated	Working on problem solving activities	Pre-teaching, then providing support to mature learners psychological tools in the ZPD
Role of the activity	Drive learning	Increase competency in tool use
Tools	Cognitive: express thinking or decrease cognitive load	Psychological: mediate learning, and change and form the thinking processes
Role of teacher	Ensure the activity is effective and provide another viewpoint	Mediate learning through relationships and analyzing tool maturity to identify the ZPD

*note. From Hall, 2007

4. Design Implications and Applications

In this chapter, I will suggest the implications for designing technology for children's development based on the theories reviewed and show how these cognitive and social constructivist approaches have been applied to real-world design projects.

4. 1. Implications from Cognitive Constructivism

Technology to support children's developmental needs

Technology for children should support developmental their needs at each stage. For 2-year-olds and younger, technology should offer chances for them to explore using various senses and their bodies. The American Academy of Pediatrics recommends avoiding any screen time for this age (AAP, 2013). Hence, designers should avoid screen-based interfaces, if possible, and consider tangible, auditory, or other types of interfaces. From ages 2 to 7, technology should provide real-world experiences that children can try out and learn from through their own experience. We could take advantage of virtual reality or augmented reality technology, but the effectiveness of indirect experience versus direct experience needs to be investigated. For ages 7 to 11 or 12 and for teenagers, technology should expand and develop abstract and conceptual thinking, as children in this age range are able to deal with more complex ideas.

Technology to be personalized to each child and to support children in becoming creators

As Piaget and Papert stressed, each child's curiosity and interests are the key to learning. They make children focus on and engage with new knowledge or skills. Every child has different interests and ways of achieving things. Technology should be tailored to individual interests. Also, as Papert believed, technology should support children in becoming creators, rather than just passive recipients. Many products offer preset questions and let children find the answers. Not only is it hard to hold children's attention over time, but doing so can also limit children's potential to grow. Open-ended play is more highly recommended, so that children can freely and actively play on their own.

4. 2. Application of Cognitive Constructivism: Computationally Enhanced Toolkits for Children

Ever since Papert worked on the Logo programming language and Lego Mindstorm, computationally enhanced toolkits have been developed in robotics, environmental sensing, scientific experimentation, and interactive art, and have provided children with hands-on experiences based on constructivism. Blikstein (2013) insisted that such toolkits and technologies "showed it was possible to engage children in complex uses of technology . . . [as] children could actively construct with technology rather than just consume technological products."

littleBits and KIBO are great examples of computationally enhanced toolkits for children. littleBits is a platform of electronic building blocks that are easy to use for everyone, including children aged 8 and up (Figure 1). The blocks are color-coded and do not require soldering or wiring as they contain magnetic connectors. Children can combine them with traditional materials, such as paper, and create anything they want.

Also, littleBits provides an open-source library that currently offers more than 60 modules, so that children can easily build a running system without programming knowledge.

Figure 1 littleBits (http://littlebits.cc/)

KIBO is designed for younger audience aged 4 to 7. It is a robotic kit with which children can build a robot they want with wooden blocks (Figure 2). Children can easily create a sequence of instructions by simply scanning wooden KIBO blocks and then decorate the robot. As it targets young children, screen time using PCs, tablets, or smartphones is not required. According to the KIBO team, even young children can learn programming and engineering if they are provided with developmentally appropriate tools, and KIBO can let young children learn how technology works by playing with physical objects (KinderLab Robotics, n.d.).

Figure 2 KIBO (http://kinderlabrobotics.com/)

4. 3. Implications from Social Constructivism

Technology to support social interactions

Vygotsky insisted that children could learn and develop new knowledge or skills by interacting with a more capable person. Technology should provide ways for children to connect with other people, such as peers and family members. There are many design opportunities to connect children with people located remotely. Children could learn new languages by pairing up with a peer in another country or could have fun with grandparents in other cities. Technology should be designed to encourage children to communicate in a natural way.

4. 4. Application of Social Constructivism: Interactive Tabletops

Social constructivism has influenced instructional design for children widely, from distance learning to computer-supported collaborative learning. Interactive tabletops have also been developed under the influence of social constructivism. They are computer interfaces that resemble a table and are usually large enough to allow several users to interact simultaneously.

These tabletops are spreading quickly throughout schools and informal learning environments (Dillenbourg & Evans, 2011).

DigiTile is a collaborative multi-touch application for a tabletop for learning about math and art by designing colorful mosaic tiles (Figure 3). The original version of DigiTile, DigiQuilt, was designed based on the constructionist theory that people learn particularly well when designing personally meaningful public artifacts (Rick & Rogers, 2008). DigiTile is designed for two children sitting next to each other and encourages users to challenge and help each other to create a tile together. DigiTile researchers conducted a user study with pairs of children aged 9–11, and the results showed that interacting with the DigiTile system could facilitate collaborative learning and that the benefits of working together differ based on the group dynamics (Rick, Marshall, & Yuill, 2011).

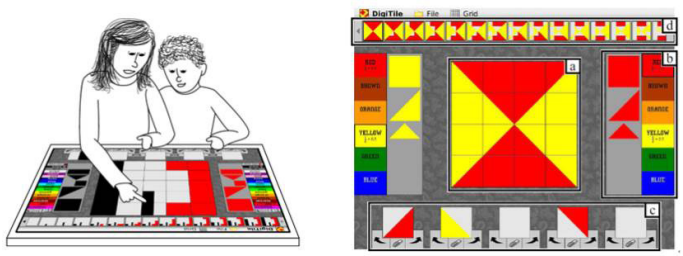

Figure 3 DigiTile (Rick, Marshall, & Yuill, 2011; Rick, & Rogers, 2008)

5. Conclusion

Technology has become part of our lives, and children are growing up under its influence. To create technology that supports children's development, designers should have a deep understanding of children and their development. To grow up into people with scientific reasoning, critical thinking, problem solving, creativity, teamwork, and communication skills, which the 21st century requires, children should become active users and creators of technology, and not just passive recipients of it. To understand children and their development better, I reviewed the constructivist theories of three psychologists and practitioners who saw children as active human beings: Piaget, Papert, and Vygotsky. By reviewing their theories, I drew insights for design and suggested implications for designing technology 1) to support children's developmental needs, 2) to be personalized to each child and to support children in becoming creators, and 3) to support social interactions.

This article presented the key ideas of cognitive and social constructivist theories, and showed how they can be applied to design products. Designers, students, researchers, and educators can benefit from understanding development theories when they design technology products for children, as the theories can guide them through the design process, help them to make design decisions, and offer a way to verify designs. This research is in a primary stage for linking developmental theories and design practice.

Future works will include how to evaluate whether and ensure that technology products support children's development from various aspects as well as specific design methods that can be applied for each theoretical approach.

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