Analog Means, Digital Means, or Both and The Drive: Which Method Is A More Important Platform To Use Toward Learning?

Benjamin Scott Coulson Howe

Introduction to Educational Neuroscience

Professor Todd Rose

Harvard Graduate School of Education

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Introduction

The goal of this paper is to provide an interdisciplinary research-based framework for designing for children in the preschool to elementary years. The research spans from various fields such as neuroscience, psychology, education, human computer interaction, and design/architecture. The end products of the design could be educational toys or spaces for young children to interact after formal instruction in the classroom. This framework is interested in the learning process from teaching to reinforcement in open-ended free-play. How can we motivate children to explore new toys and spaces on their own while seamlessly providing educational reinforcement of important concepts learned in class? How would one go about introducing a concept and then creating a play area that the children can build upon that learning? What structures are necessary to know in the brain and cognitive level that allows us to create effective teacher lessons that can be seamlessly mixed with open-ended activities that reinforce those lessons? Ultimately, this framework is working towards understanding what is more important for learning in young children: the means (the tools we use – analog or digital – are the key lever for learning) in conjunction with the drive (motivation and self-guided learning) or a combination of both analog and digital means with the drive? In the end, while the means, whether analog or digital, and drive can create motivation to learn, it is a combination of a mixed analog and digital means and drive within the child and the relationship between the two (means and drive) that leads to the greatest possible levels of learning.

The Background

How did the idea for this framework develop? One of the main underlying questions is an argument of whether analog, digital, or a combination of both is the best form of instruction for children. This is based on a theory in architecture that was taught by the author's professors' personal beliefs in the formal architecture program at Carnegie Mellon University. They believed that the best form of design and holistic understanding of a project was a mix of analog and digital means, such as physical models, hand drawings and sketches, computer 3D models, computer renderings, and mixed media of digital and analog means such as hand and computer drawings overlaid and edited together. The author is interested in taking this architectural theory and trying to adapt and apply it to the world of education and the design of toys and educational spaces for children. However, it should be noted that as design principles of architecture are used as a guideline for design, they are by no means formulaic. The end framework will be a set of guidelines that can be used for guidance, but as in architecture and design the authors have creative license to use various components that are relevant and leave out others that are irrelevant to provide the strongest case for their projects.

The Neuroscience

It is important to understand the filters that each argument will be looked through, that of motivation and the underlying neuroscience behind it. The main area of the brain that we will be looking at is the reward circuit and the link the chemical messenger or neurotransmitter dopamine plays between the ventral tegmental area (VTA), a group of neurons in the center of the brain that receives information and tells how well human needs are being satisfied, and the nucleus accumbens, which reinforces our behavior to satisfy our fundamental needs depending on the levels of dopamine received (Dubuc, 2012). The other important pathway is the mesolimbic pathway which consists of a bundle of dopaminergic fibers that are associated with the reward circuit. The mesolimbic pathway originates in the ventral tegmental area and innervates many structures of the limbic system (corpus callosum, olfactory tract, mammillary bodies, fornix, anterior thalamic nuclei, amygdale, hippocampus, parahippocampal gyrus, cingulated gyrus, and hypothalamic nuclei) which is part of olfaction, emotions, learning, and memory, and most importantly in our study that of the nucleus accumbens (Dubuc, 2012).

The nucleus accumbens, located in the ventral striatum, dopamine system plays a role in appetitive motivation, or behavior directed toward goals such as food and sex that produce positive hedonic or pleasurable states, and positive reinforcement (Salamone, 1994; Bozarth, 1994). When the nucleus accumbens receives dopamine from the ventral tegmental area and releases it, it directly mediates the process of positive reinforcement by creating a sense of a hedonic state. However, if the nucleus accumbens dopamine systems antagonists are produced, a state of anhedonia, or inability to experience pleasure normally found enjoyable, is produced by directly blunting the positive reinforcement properties of the hedonic stimuli. Thus the dopamine antagonists reverses motivation behavior by creating active avoidance (Salamone, 1994). The release of dopamine or the dopamine antagonist from the nucleus accumbens impacts the mesocoticolimbic systems, which has roles in mediating attention and sensorimotor (sensory and motor aspects of bodily activities) integration (Kelly & Berridge, 2002). During the process of rewarded habit learning the sensorimotor regions undergo tremendous dynamic changes (Jog et al., 1999) which when damaged can lead to learning impairment (Packard & White, 1990). This is important because it provides evidence that the sensorimotor regions play a large part in natural reward functions, which will be important when evaluating play with toys (White, 1989).

How does this neuroscience information and evidence translate into motivation? At its simplest form, if a student was motivated to play with a toy or space, something about the sensorimotor process of playing with the toy stimulated a response in the ventral tegmental area that a need of play was being met, then sending a dopaminergic response to the nucleus accumbens, which then released dopamine into other parts of the brain and produce a hedonic and pleasurable state for the child. Through repeated play with the toy or space the child developed a habit forming need to interact with it, since the child has learned through repeated play and exposure with the toy or space that it leads to a hedonic and pleasurable enjoyment state. However, if the child went to play with a toy or space and something about the interaction or appearance of it produced a negative effect, the child's brain would now release the dopamine antagonist every time the child saw the toy or space and would engage in active avoidance behavior, ignoring and avoiding the toy or space at all costs whenever he or she saw it. The only problem is that theories in motivation do not follow this dichotomous relationship. Future research in neuroscience and motivation together would need to be conducted to see if there was a spectrum of dopamine and dopamine antagonists released that produced these varying levels of motivation.

The Motivation And The Drive

In order to understand motivation, it is important to first develop an understanding of the classical definitions and new directions in intrinsic and extrinsic motivation. At the basic dichotomous relationship students would be either intrinsically motivated, performing a task because it is inherently interesting or enjoyable, or extrinsically motivated, performing a task because it leads to a separable outcome (Deci & Ryan, 2000). However, new directions such as Deci's and Ryan's (1985) Self-Determination Theory posit that extrinsic motivation is divided into varied types. Within Deci's and Ryan's (1985) Self-Determination Theory is a subtheory called the Orgasmic Integration Theory that explains these varied types of extrinsic motivation (external regulation, introjections, identification, and integration) (See *Figure 1*). On the outskirts of extrinsic motivation to the far left is amotiovation, or lack of an intention to act, and to the far right intrinsic motivation. Within the extrinsic motivation spectrum tasks range from external regulation (behaviors to satisfy an external demand or obtain an external reward), introjections (perform an action with pressure to avoid guilt or anxiety or to obtain ego-enhancement or pride), identification (perform an act because of personal importance or behavior is accepted as a regulation of his or her own), and integration (perform an act because it is identified as fully assimilated to the self) (Ryan & Deci, 2000). Furthermore Paul Pintrich (2003) provides a series of motivational generalizations (adaptive self-efficacy and competence beliefs motivate students, adaptive attributions and control beliefs motivate students, higher levels of interest and intrinsic motivation motivate students, higher levels of value motivate students, and goals motivate and direct students) and design principles that can be adapted to explain students' motivation (See *Table 1*). Later we will see how these design principles are carried out in the following arguments of the means (analog or digital) and the drive.

In addition Zimmerman (1989) believes in an idea of a triadic interaction of the person, environment, and behavior as an explanation for driving self-regulated functioning and learning. By using a triadic understanding of the learning process, Zimmerman (1989) believes this sets him apart from other theories that focus on a single part or combination of parts as well as makes the learning process more transparent, so that it can be easily analyzed and intervened if necessary by teachers. In this model, it takes the individual student to initiate this chain process with the personal desire to be motivated, eliciting a behavior that would interact with the environment, which may or not satisfy their need.

In addition to the drive of a student determining their level of motivation to have a need for learning, others believe the classroom environment (non-physical objects) plays a huge role in initiating this drive. For example, Vandell and Powers (1983) found out that day care quality was associated with quality of children's free-play. High quality day cares had children more likely to interact positively with adults whereas lower quality day cares had children engaged in more solitary play and aimless wandering. Cordova and Lepper (1996) discovered that contextualization, personalization, and provision of choices increased student's intrinsic motivation, their depth of engagement in learning, amount they learned in a certain time period, and their perceived competence and levels of aspiration. Also Ames (1992) found that classroom structures (how "instructional demands, situation constraints, or psychological characteristics relate to various cognitive and affective outcomes in students" (p. 263)) and how they make different types of achievement goals ("integrated patterns of beliefs, attributions, and affect that produces the intentions of behavior and that is represented by different ways of approaching, engaging in, and responding to achievement type activities" (p. 261)) salient affect student's motivation. All three of these points show that while the initial drive of the student will cause him or her to seek out learning, it is imperative that the environment be supportive or else the child will choose not to learn in the environment or move to a more appropriate learning space.

The Learning

Lastly, what do we mean by successful learning and academic achievement? Ideally, this framework believes any toy or space that leaves a child with a new understanding and remembrance for a material is successful learning. However, we will take this one step further by critically evaluating the learning using Susan Ambrose's et al. (2010) seven research-based principles for smart teaching. Ambrose et al. (2010) states that,

1. "Students' prior knowledge can help or hinder learning."
2. "How students organize knowledge influences how they learn and apply what they know."
3. "Students' motivation determines, directs, and sustains what they do to learn."

4. “To develop mastery, students must acquire component skills, practice integrating them, and know when to apply what they have learned.”
5. “Goal-directed practice coupled with targeted feedback enhances the quality of students’ learning.”
6. “Students’ current level of development interacts with the social, emotional, and intellectual climate of the course to impact learning.”
7. “To become self-directed learners, students must learn to monitor and adjust their approaches to learning.”

In order to determine how successful the method (analog means and drive, digital means and drive, or combination of both) for learning is, we will see how well each medium addresses each of Ambrose’s et al. (2010) seven learning principles.

The Analog Means And Drive

The first argument is that the analog means and drive alone provide the best platform to produce the greatest learning. Since our target age range is preschool to elementary children we will look at some popular analog toys used across schools such as blocks, art making supplies, and cars and their impact on learning for children. The first important step is that what toys adults pick for children elicits different behaviors. Kaiser et al. (1995) found that prosocial toys (baby dolls, baby bottles, stuffed animals, paramedic kit, and a foam basketball and hoop), which present prosocial cues such as helping, cooperation, sharing, and turn taking, elicit prosocial behavior and antisocial toys (G.I. Joe doll, revolver, rifle, sword, and toy soldiers), which are classified as violent, stimulate antisocial behavior such as swearing, insults, boasting, and threatening with preschoolers. The best toys were neutral toys (dinosaurs, cars, plastic animals, and plastic interlocking blocks) to where prosocial and antisocial behavior returned to baseline measurements conducted in the study. The reason that neutral toys were the best was because they created an atmosphere where boys and girls displayed similar levels of physical and verbal behavior versus prosocial toys where boy's physical behavior increased more than verbal behavior and girl's verbal behavior increased more than physical behavior (Kaiser et al., 1995). This is important because having similar levels of behavior would allow boys and girls to cooperate more easily between each other to learn from one another. Caldera et al. (1999) confirmed this neutrality idea where they found that participation in sex-neutral activities, such as making art by reproducing block structures, was positively related to spatial ability. By engaging with these analog toys children developed hand-eye coordination and the ability to observe the environment in more detail through practice with the art materials (Caldera et al., 1999).

Hendrickson et al. (1985) also discovered that different toys and material uses can promote various outcomes in play learning for preschoolers. A vast majority of the toys (puzzles, templates, parquetry, pegboard and pegs, toy animals, paper and pencil tasks, sink activities, car tract, pull toys, tinker toys, Legos, and paper cutouts) fell into an isolate play context and learning but others had the potential to elicit parallel play (climbing apparatus, musical instruments, play in a loft, toy trucks and cars, crayons, collection of bottles, toy phones, paint and easel, and sand and water table), sharing and cooperative play (books, balls, puppet stage, dress-up clothes, post office toy, wagon, giant pillow, clay and play dough, blocks, and toy housekeeping materials), and physical assistance (toy sewing machine, wagon, toy sink, and climbing apparatus). The type of analog toy used can be powerful for the learning outcomes such as a teacher would like the children to learn by playing individually or cooperatively.

Where these analog toys stand strong as a platform for learning is that most of these studies were observational: there was no forced play. Children could choose to not participate by not playing with the analog toys at any point in time. The toys were appealing and attractive enough to motivate the children to engage in play and that would in turn produce dopamine response and produce a hedonic and pleasurable state, since the toys provided children with fun, pleasure, and learning. In following Pintrich's (2003) design principles for motivation, the analog toys clearly had tasks that offered opportunities to be successful but also challenging; the variety of toys to use provided opportunities to exercise some choice and control; the toys provided stimulating and interesting tasks, activities, and materials with some novelty and variety in them; and the toys provided content material and tasks that were personally interesting and meaningful to the students.

However, when we specifically apply the analog toys to Ambrose's et al. (2010) learning principles, it becomes less clear how successful the analog toys alone are due to the nature of the studies. In order to provide a successful example of how an analog toy alone can hold up to these principles we turn to Howe's (2012) study on how open-ended play with magnetic unit blocks for preschoolers can lead to educational and collaborative outcomes. During this study children were given a teacher lesson on magnetism and then allowed to play with the magnetic unit blocks freely in groups of four. In terms of Ambrose's et al. (2010) learning principles the students' prior knowledge did help their learning and how students organize the knowledge influenced how they learn and apply what they know, as Howe (2012) observed children noticing the different colors on the blocks, which reinforced magnetic polarity they were taught and used the discovery to explain and talk about their discovery and understanding with other children. Students also seemed motivated and it determined, directed, and sustained what they did to learn, as the children had fifteen minutes to play and they chose to interact with the toy versus leaving the room and explored magnetism, cooperated to build structures and understand architecture, and carried out cooperative play of stories about pirates, Mario games, and adventures on airplanes, thus developing collaborative skills (Ambrose et al., 2010; Howe, 2012). The children's level of development was appropriate to interact with the toy on a social, emotional, and intellectual level to impact learning on block play and concepts of magnetism. The children had the freedom to be self-directed learners and monitor and adjust what they wanted to learn (Ambrose et al., 2010; Howe, 2012). Where analog toys may fall short is in Ambrose's et al. (2010) principles of "goal-directed practice coupled with targeted feedback enhances the quality of learning" and "to develop mastery students must acquire component skills, practice integrating them, and know when to apply what they have learned." Without a manual that children can read or some sort of teacher training on a subject, children have no way to check their understanding in correct uses of the analog toy. Analog toys in general also do not provide clear feedback that children may understand. While Howe's (2012) blocks will let the children know if two blocks do not go together by the magnetic repulsion or structures fall due to gravity, the children have no way to get immediate feedback of these concepts unless they have previous knowledge of the content material or teacher present nearby to explain what happened.

The Digital Means And The Drive

The next argument is that the digital means and drive alone provide the best platform to produce the greatest learning. In order to understand this we will look at a few case studies of successful digital toys and how they played a role in the children's learning. The first is Hinske et al. (2008) who created an environment in which interactive technology and traditional toys are combined to enhance the educational value of play. Hinske et al. (2008) created a toy called the

Augmented Knight's Castle, which uses *Playmobil* characters and a castle set embedded with RFID tags that when activated provided background music, sound effects, verbal commentary between characters, and feedback to the children's play. The goal was for the children to learn about the Middle Ages through free-play and creation of stories. Hinske et al. (2008) also provided four important design guidelines for educational toys: "provide clear challenges and feedback; stimulate sensory and cognitive curiosity; allow the children to control the (learning) environment; support fantasy by relevant metaphors and analogies; and iteration of important sequences with opportunities for reflections (i.e., feedback)."

The next case study toy is from Luckin et al. (2003) who evaluated if interactive digital toys, such as the plush cartoon toy Arthur and DW, with embedded sensors that responded when squeezed provided support for collaboration between peers. While the software that is linked to the toy on a computer works without the toy, Luckin et al. (2003) results suggested that a tangible interface increased interaction around, with, and through the technology. However, they found that the plush toy was not as impressive as a collaborative partner alone, since most of the software the children used on a desktop computer had its own avatar and could be operated if the plush toy was lost. In the end, Luckin et al. (2003) also found that the toy studied help repertoire was inadequate and inappropriate, but the children had the potential to master multiple interfaces (toy and computer screen) and when the help was appropriate the children pursued it and used it.

In terms of our lenses both case studies would have been activating a dopamine response for a hedonic effect that motivated the children to enjoy playing with these toys, which provided them with fun, pleasure, and learning. The children also had the free will to play or not play with these toys, so the way they were designed was appealing enough to motivate the children to interact and learn from them without any form of adult instruction or supervision. In fact, Plowman and Stephen (2005) found that when preschool children who are novices at computers use them during free-play there were few examples of peer support, adults rarely intervened or offered guidance, and the common form of intervention was reactive supervision. The digital means seemed to provide all the necessary support for learning for the children as can be seen in the two case studies described. Pintrich (2003 would say the toys are designed to be motivating because they follow the design principles:

> provide clear and accurate feedback regarding competence and self-efficacy, focusing on the development of competence, expertise, and skill; design tasks that offer opportunities to be successful but also challenge students; provides opportunities to exercise some choice and control; provide stimulating and interesting tasks, activities, and materials, including some novelty and variety in tasks and activities; and use tasks, reward, and evaluation structures that promote mastery, learning, effort, progress, and self-improvement standards and less reliance on social comparison or norm-referenced standards. (Pintrich, p. 672, 2003)

Lastly in terms of Ambrose's et al. (2010) learning principles both toys clearly addressed how prior knowledge could help or hinder learning. The *Augmented Knight's Castle* was designed to be built upon a current student studying the Middle Ages and provide a new way to learn the material through creative storytelling and play. The Arthur and DW toy provided a help menu that children could use effectively if they struggled with the material as well as allowed them to be self-directed learners, seeking out help if they struggled with the learning. Both toys also provided continuous feedback, such as characters recounting events in the Middle Ages or the computer interface reporting how the child was progressing through the game with Arthur or DW, an example of goal-directed practice coupled with targeted feedback that enhanced the quality of the children's learning. In both toys students were motivated and that determined, directed, and sustained what they learned as well as the toys seemed to provide the necessary materials to develop mastery of the material and skills without a need to consult an adult or outside help. Both toys were also designed to be relevant to the students' current level of development where it did not negatively interact with the social, emotional, and intellectual climate of the toy or play space to impact learning.

The Means (Analog & Digital) and The Drive

However, neither the analog means and drive nor the digital means and drive provide the best methods for achieving successful learning, but a synthesis and combination of the two. In order to come to this understanding we will begin with a progression and recap of how the analog toys and drive work together well, digital means and drive work together well, and then ultimately a mixed analog and digital means and drive together as the best.

To begin we will look at two examples of successful analog toys and drive working together well. The first is a study by Ferrara et al. (2011) who concluded that block play created the highest elevated levels of spatial language when used in a guided play scenario with parents and preschoolers of the three scenarios tested (free-play, guided [given five steps to create garages, helipads, etc.], and preassembled [glued together models of garages, helipads, etc.]). This means that students had the greatest spatial language learning when motivated to carry out a few steps to the understanding versus just having the parts to play with or a completed model to talk about. The other study by Ferrara et al. (2011) concluded that normal interactions with parents and preschoolers do not involve spatial talk to as great of an extent as with using blocks and construction materials. In other words, just being driven to talk about spatial ideas through general questioning of the world around them was not as great a means of improved spatial language learning as being driven to talk about spatial ideas and having the materials and toys necessary to talk out and discover these ideas. Furthermore, Kontos (1999) found that preschool teachers spend most of their time during free-play in constructive and manipulative activity settings. Kontos (1999) found that the most successful forms of play had talk and questions supporting play with objects, including practical/personal assistance. Thus while children may by driven to play with toys or the toys may drive them to play, a combination of the children's motivation to play, the toys being used as a platform for learning, and having the teacher give further feedback and answer questions produce richer play and understanding for the children.

Next we will see how successful digital means and drive can work together with three quick case studies. Ruckenstein (2010) concluded and argued that interactions between preschoolers and virtual pets (*Tamagotchi*), showed how technology can facilitate mobility crucial for interacting with the world and create social interactions among peers. Ruckenstein (2010) believed that it was important for preschoolers to practice these skills as they became adults in the world and believed that only through digital technologies will children be able to develop the skills to interact with the global world. It was the combination of the drive of a student to seek out ways to practice being adults and the tools providing the appropriate means that led to successful learning for the children. Additionally, Cherubini et al. (2008) was able to use the digital means *DigitalSeed* to provide four- to five-year-olds with play-driven experiments on plant and seed relationships such as reproduction, growth, and development. This study showed how a topic that is normally uninteresting but important to learn can become motivating to children to want to interact with the device and learn more about the material of plants.

On a broader level, Plowman and Stephen (2007) provide us with a framework for guided interaction that educators can use with information and communication technologies (ICT) and preschoolers. This framework provides a tool to help practitioners articulate, reflect upon, and change pedagogy, allowing them to find new approaches to working with ICT. Where this differs from the digital means and drive being a motivator argument is the role the teacher now plays in manipulating the digital means and drive of the student. Plowman and Stephen (2007) list two types of interactions, distal (guided interaction from a distance) and proximal (face-to-face interaction between children and adults). They believe that sometimes letting a child engage in self-direct exploration is a form of guided interaction from afar (distal) and sometimes it is necessary to interact one-on-one (proximal) with the children to enhance learning.

Yet, the author believes it is a digital and analog mixed with student drive that leads to the greatest outcomes in learning. To show this we will look at two case studies. The first is Petimo, an interactive robotic toy that makes social networking safe for children and teaches them about it. Children must physically pet and touch the robot to become friends similar to the natural way of becoming friends and there are parental authentication securities as well to protect the children. Petimo also has a 3D space where children can interact with their avatars to understand their friendships more and send gifts (Cheok et al., 2010). With Petimo, children are driven and motivated to practice becoming friends, practice what friendship making is like in the physical world through interacting with the analog and physical Petimo, and can practice their friendships even more with feedback and guidance in the online 3D space with the child's avatar.

The other case study is Ryokai et al. (2009) who developed a project for children to create stories that are programmed to control a robotic dinosaur character. Ryokai et al. (2009) developed a system in which children drew pictures, planned their stories, programmed a character's behavior, ran their programs, and edited their programs. Children were driven to learn and used the mix of analog and digital means to support their verbal, visual, and kinetic expression, and storytelling. Like Petimo, the students using the robotic dinosaur were driven to work on storytelling and they got to use the analog form to practice it by physically making, writing, and drawing out the story. The children then used the digital means of programming it into the dinosaur to see their story acted out, thus providing feedback to the children on how their story sounded. The digital means could also be used to tell the child's story to other children and then they could receive feedback from them on how well they executed their ideas.

In neuroscience terms, the child receives a message in the ventral tegmental area saying there is a need to play or do something to learn about a particular subject. The child would then seek out toys and through successful interactions with various toys produce a habit forming hedonic response to certain toys that satisfy their need for learning. However, where this differs in previous arguments, is when the means interact together, they play off of one another creating a satisfying complementation. In other words, the toys must be able to provide feedback to adapt and satisfy to the different levels of the child's needs and this is where a mix of analog and digital means is necessary. It is sometimes important to be able to physically manipulate objects or use analog toys because it satisfies the nucleus accumbens release of dopamine impacting sensorimotor aspects of the body, but is also necessary to have digital means, since they can provide real time instant feedback on a child's understanding of a particular topic, such as Petimo who can tell whether the child made an appropriate gesture toward another avatar that would lead to strengthening of a friendship.

In terms of Pintrich (2003), the mixed digital and analog toy with a driven student covers many more of his design principles than previous arguments. In fact according to Pintrich (2003) this argument would cover the design principles of:

> provide clear and accurate feedback regarding competence and self-efficacy, focusing on the development of competence, expertise, and skill; design tasks that offer opportunities to be successful but also challenges students; provide feedback that stresses process nature of learning, including importance of effort, strategies, and potential self-control of learning; provide opportunities to exercise some choice and control; provide stimulating and interesting tasks, activities, and materials, including some novelty and variety in tasks and activities; provide content material and tasks that are personally meaningful and interesting to students; display and model interest and involvement in the content and activities; use organizational and management structures that encourage personal and social responsibility and provide a safe, comfortable, and predictable environment; and use tasks, reward, and evaluation structures that promote mastery, learning, effort, progress, and self-improvement standards and less reliance on social comparison or norm-referenced standards (Pintrich, p. 672, 2003).

The combination method of analog and digital means and a driven student cover far more design principles that will lead to motivation to learn, showing it is a far superior method for learning.

In looking at Ambrose's et al. (2010) seven learning principles, the combination argument clearly articulates each principle very well. Students' prior knowledge can help or hinder learning and the instant feedback of a digital toy can adapt to compensate for this. Also how students organize and influence what they know will determine how they learn and apply it to the many learning outcomes a mixed analog and digital toy can provide them. Students' drive to learn will determine, direct, and sustain what they do to learn from the mixed means. To develop mastery the students must acquire the skills necessary, practice integrating them, and know when to apply them. By having both analog and digital means it should cover every possibility for the knowledge they need and it can provide instant feedback to determine how to adapt and use the new material learned. Students will be driven and goal-directed to learn and the interactive nature of an analog/digital toy provides a more comprehensive feedback targeting what the child needs to learn, such as Petimo that lets the children physically understand and feel friendship formation and role play it in the 3D world. If designed correctly as in the case scenarios presented above, the student's current level of development will appropriately interact with the social, emotional, and intellectual climate of the toy to impact their learning. Lastly, since in this argument children are driven and motivated to learn by an innate biological need, they will become self-directed learners and monitor and adjust their approaches to their learning.

The Framework

The last question remains: what knowledge from these arguments will be helpful in creating a series of principles to follow when designing future toys and spaces for children to have the maximum potential for learning? In terms of our neuroscience understanding we know that children should have an innate biological signal entering the ventral tegmental area for a need to play for enjoyment or move through the world to learn and develop into adults. However, we must provide toys and spaces that will produce hedonic and pleasurable states for the children initiated by dopamine release from the nucleus accumbens. This can only be achieved if the toy or space through repeated habit interaction provides some benefit to the children, such as learning a new concept or enjoying interacting with the apparatus, that causes them to come back to it repeatedly for a deeper understanding of the material (Salamone, 1994; Bozarth, 1994; Dubuc, 2012; Kelly & Berridge, 2002; Jog et al., 1999; Packard & White, 1990; White, 1989).

However, children will vary in levels of motivation so the toy or space needs to be adaptable to meet the needs of the child (Deci & Ryan, 1985; Deci & Ryan, 2000; Pintrich, 2003). We also know that the toy or space must stand up to and surpass Ambrose's et al. (2010) seven learning principles in order to critically evaluate if the toy or space could lead to an improvement in the child's understanding of a material. It is also necessary that the means used as a platform for learning be a mix of digital and analog as demonstrated by the previous case studies (Cheok et al., 2010; Ryokai et al., 2009). As we saw in the argument for either the analog (Kaiser et al., 1995; Hendrickson et al., 1981; Caldera et al., 1999; Howe, 2012; Ferrara et al., 2011; Kontos, 1999) or digital (Plowman & Stephen, 2005 & 2007; Luckin et al., 2003; Hinske et al., 2008; Ruckenstein, 2010; Cherubini et al., 2008) means alone as a platform for learning, they had their strengths on their own, but when combined together they provided greater feedback and possibility for learning for the children (Cheol et al., 2010; Ryokai et al., 2009).

Future research should also be done to see if this theory could hold with a single subject to learn and whether a driven student had the greatest improvement of the subject with an analog toy, digital toy, or mixed analog and digital toy. Theoretically, the mixed toy should be the best since it can provide real time feedback through digital components and allow a physical understanding of a subject through a manipulative, as was the case with Petimo (Cheol et al., 2010). The question for future researchers is if the subject or task is dependent on certain means. Some subjects may lead to a greater understanding in one material, but based on the architectural theories, multiple representations and understanding should lead to a more rich and complex understanding of the material. Lastly, as with design and architecture, these recommendations are not formulaic. They are meant to serve as a guiding methodology. While the combination method may be the most fruitful understanding, some subjects to learn may bode well for a heavier reliance on the drive of the student and use of either an analog or digital means.

Figure 1. Taxonomy of human motivation from (Deci & Ryan, 2000).

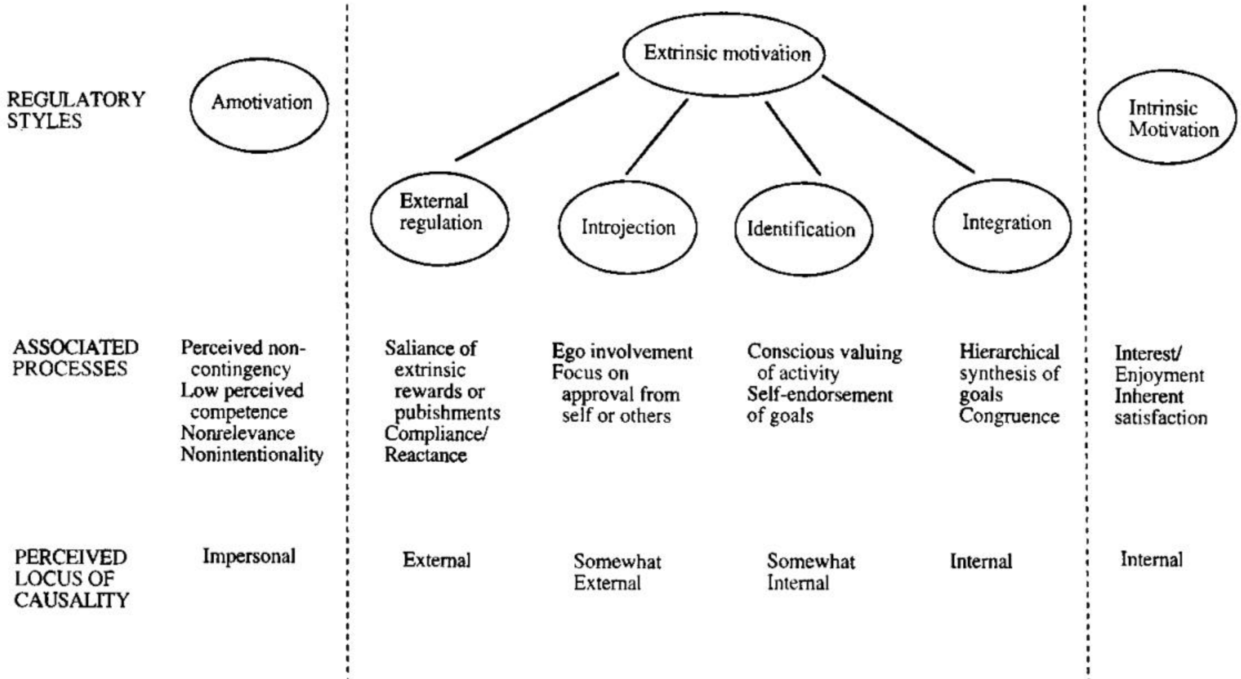

Table 1
Motivational Generalizations and Design Principles.

Motivational Generalization	Design Principle
Adaptive self-efficacy and competence beliefs motivate students.	Provide clear and accurate feedback regarding competence and self-efficacy, focusing on the development of competence, expertise, and skill.
	Design tasks that offer opportunities to be successful but also challenge students.
Adaptive attributions and control beliefs motivate students.	Provide feedback that stresses process nature of learning, including importance of effort, strategies, and potential self-control of learning.
	Provide opportunities to exercise some choice and control.
	Build supportive and caring personal relationships in the community of learners in the classroom.
Higher levels of interest and intrinsic motivation motivate students.	Provide stimulating and interesting tasks, activities, and materials, including some novelty and variety in tasks and activities.
	Provide content material and tasks that are personally meaningful and interesting to students.
	Display and model interest and involvement in the content and activities.
Higher levels of value motivate students.	Provide tasks, material, and activities that are relevant and useful to students, allowing for some personal identification with school.
	Classroom discourse should focus on importance and utility of content and activities.
Goals motivate and direct students.	Use organizational and management structures that encourage personal and social responsibility and provide a safe, comfortable, and predicable environment.
	Use cooperative and collaborative groups to allow for opportunities to attain both social and academic goals.
	Classroom discourse should focus on mastery, learning, and understanding course and lesson content.
	Use task, reward, and evaluation structures that promote mastery, learning, effort, progress, and self-improvement standards and less reliance on social comparison or norm-referenced standards.

*****From (Pintrich, 2003).

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