Blocks, Bricks, and Planks
Relationships between Affordance and Visuo-Spatial Constructive Play Objects

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The authors consider the strengths and weaknesses of three different visuo-spatial constructive play object (VCPO) types—blocks, bricks, and planks—and their impact on the development of creativity in spatial thinking and higher learning during free play. Each VCPO has its own set of attributes, they note, leading to different purposes, functions, aesthetic outcomes, and narratives. They argue that one key to understanding the impact of these toys is to determine, based on the diversity of their attributes, each VCPO's level of affordance. The authors suggest that the specific qualities of some play materials may help establish the scientific, mathematical, and technological foundations required in such professional disciplines as architecture and engineering. In contrast, they argue that the use of VCPOs hobbled by formulaic, scripted play properties may have the opposite effect, that the use of products manufactured with specialized, commercialized themes runs the risk of impeding self-regulation and even creative ideation. They hope their findings serve as a starting point for future studies that examine the benefits and shortcomings of specific play objects on cognitive development and creativity.
Key words: affordance; block play; brick play; child development; constructive play; plank play; spatial thinking; visuo-spatial constructive play objects

Cognitive psychologists and early-childhood and elementary education specialists and practitioners have historically found children's use of blocks or bricks during free play to be an important measure of intellectual development (Hirsch 1996). Given this time-honored relationship of blocks and bricks to human development, the literature is replete with seemingly intrinsic connections between block play and the work of architects, engineers, scientists, and other professionals who specialize in science, technology, engineering, and mathematics (STEM) and related disciplines (Brosterman 1997; Farenga and Ness 2007; National Research Council 2006; Ness and Farenga 2007; Zevi 1993). Only recently, however, have researchers expressed an increased interest in the

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extent to which block play either correlates or causally relates to mathematical and scientific thinking in general and to spatial thinking in particular (Wolfgang, Stannard, and Jones 2001; Ness and Farenga 2007; Verdine et al. 2014).

More empirical research demonstrating such correlations between block play and spatial cognition might answer important questions about whether the type of object that children or adolescents use influences the development of their spatial thinking. In considering an analytical framework of play objects used during constructive play, we have concluded that the terms "blocks" (signifying the toy) and "block play" (signifying the task) are too generic and lack clarity and specificity. These terms prove even thornier when we investigate children's constructive free play and their everyday, spontaneous concepts or their spatial language development (Farrara et al. 2011). Therefore, instead of blocks, we use the term "visuo-spatial constructive play objects" (VCPOs). VCPOs include blocks (for example, standard wood blocks, plastic blocks, and foam blocks), bricks (such as LEGO bricks and Mega Bloks), and planks (1 × 3 × 15 cm wooden rectangular cuboids). The multifarious uses of VCPOs may provide cognitive researchers with insight about the rates at which children develop their spatial abilities. Because constructive play, unlike other types of play, involves the use of smaller objects as a means for building larger and often more elaborate structures, we define VCPOs as those materials individuals use when they model what they imagine and construct something in their world. These play objects either snap together or touch each other and remain positioned by the force of gravity.

Popular media seems already to have intuitively predetermined that block or brick play stimulates knowledge or brain development—and, to a smaller extent, so has cognitive and educational research. But both empirical studies and theoretical research focusing on the relationships between block play and cognitive advances often overlook important variables that have the potential to promote or limit children's intellectual development. Block studies, for example, have not considered the role of affordance, an important dynamic in the attempt to identify cognitive advances or progressive success in school.

We consider the following questions in our theoretical examination: Do different VCPOs offer different levels of affordance to an individual? What relationships exist between a child's and an adolescent's use of nonscripted VCPOs and cognition in spatial skills, creative fluency, and self-regulation? To address these questions, we first define affordance and its association with VCPOs, and then we consider the theoretical underpinnings of affordance. We follow this with an examination of the literature on VCPO play that attempts to demonstrate relationships between block, brick, or plank use during constructive free play and intellectual development. Next, we examine VCPOs in terms of their levels of affordance. Finally, we consider the potential applications and constraints of specific VCPOs that either encourage or limit creativity.

Affordance

Affordance alludes to the qualities of an object that define its possible use or make clear how it can or should be used. The term "affordance," as defined by Gibson (1979), emanates from the field of gestalt psychology and serves to explain why we can perceive the functions and properties of an object instantaneously and without hesitation. Affordance adheres to the idea that perception and action are inseparable. That is, we immediately perceive the operational properties of particular objects and easily see how other people might interact with them (such as a handle for holding a cup or a knob for opening a door).

For our purposes, then, affordance refers to the meaning of an object in terms of what it provides users that allows them to maximize their potential in constructions and related spatial behaviors. Thus, an individual examining affordance would want to know what a specific VCPO offers a user. For example, does the object provide a user components that have a specific purpose, or does it afford the user little specificity of function? In addition, an examiner would want to learn whether a user sees a particular VCPO either as a means to an end or as an end in and of itself. Affordance also can relate, at least in part, to an individual and an environment and the material objects within it—in particular, how the individual uses specific objects collectively as a means of forming character and function. Krampen (1989) uses the example of a large rock—one fit for a child to sit on or for an adult to use as a table. In general, affordance has to do with any aspect of an object that engenders some type of function for a given individual and in a given situation. Affordance is essential in characterizing and analyzing VCPOs because it allows the investigator to tap an individual's uses and intentions for use of a particular object in question.

From a developmental perspective, the philosophical underpinnings of affordance emanates in part from Jean Piaget's notion of the interaction between empirical abstraction and reflective abstraction (Piaget 2013). Empirical abstraction fosters the development of mental constructs that represent physical knowledge and occurs through an interaction with objects—in our case VCPOs, in a given environment. The different types of VCPOs possess a variety of physical characteristics that provide a child with an opportunity to gain a wealth of experience by experimenting with physical properties. Empirical abstractions name the properties of the VCPOs—they may be rectangular cuboids, they may be wooden or plastic, they have mass, they can be balanced, and so forth. For example, blocks might have distinct colors and have smooth surfaces for allowing the sliding movement of one block on another, while LEGO bricks or Mega Bloks have pips for affixing or interlocking one piece to another.

Properties of distinct VCPOs afford different physical constraints that need to be overcome when considering construction. Depending on the VCPO in use at any given time, the smooth surfaces of blocks or the pip-filled surfaces of bricks require an individual to acknowledge the unique and seemingly innumerable possibilities of positioning and placement. Blocks or planks do not lock into place; rather, they are kept in place by their relative position with respect to other blocks. If a single block of a block structure is remotely repositioned by moving or sliding, structural imbalance may occur, thereby affecting stability of inertia and balance. Bricks, on the other hand, due to pips and other interlocking parts, provide a context that promotes a different content knowledge from that of blocks, one related to inertia, balance, and mass. So, an individual who encounters different VCPOs for the first time will already have different notions about what can be done with them.

When an empirical abstraction is realized, a reflective abstraction may follow. Reflective abstraction is a subsequent cognitive process that develops from the contemplation of actions, and the coordination of those actions, and forms the basis for the development of logico-mathematical knowledge (Piaget 2013). Logico-mathematical knowledge is an internal process that consists of the mental relationships formed from our understanding of the properties of the object. For a child building a structure, logico-mathematical knowledge is the result of observable, behavioral processes that may include classification, seriation, number, and spatial and temporal relationships.

Each of these observable behavioral processes is affected by the level of affordance inherent in the properties of the VCPOs. In considering the placement of blocks to obtain balance, for example, an individual who reflects on balancing one block on another realizes that the block placed on top can only extend so far before it becomes unbalanced and consequently falls (see figure 1). The interaction between empirical abstraction and reflective abstraction is

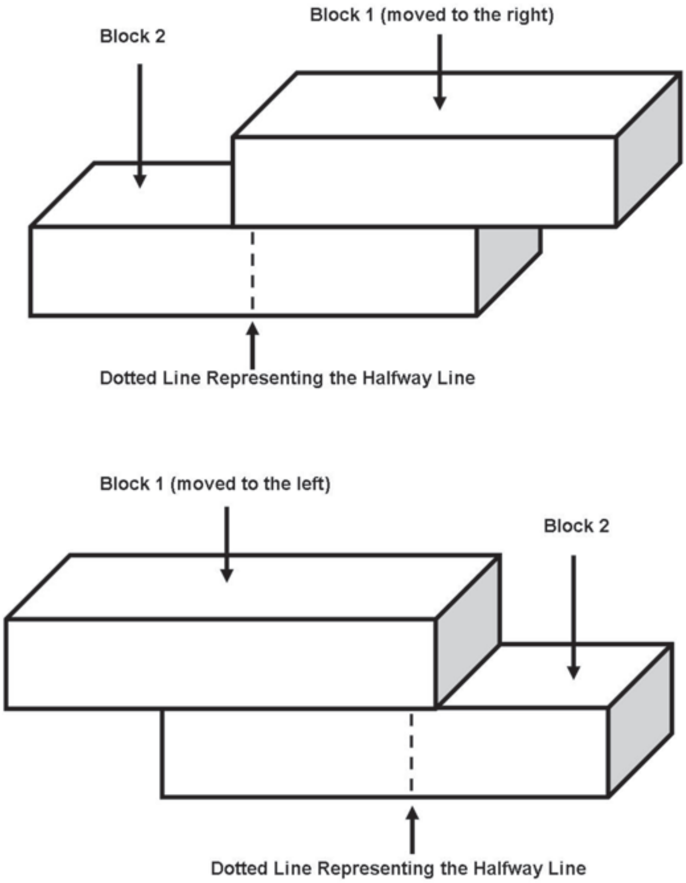

Figure 1. Blocks 1 (the movable block) and 2 (the stationary block), in and of themselves, represent examples of empirical abstraction. The knowledge obtained from working with blocks and understanding outcomes of actions is reflective abstraction. The transition between the empirical and reflective abstractions is pseudoempirical abstraction. The generalization formed from the pseudoempirical abstraction is that block 1 will balance if it does not hang over block 2 beyond the halfway line.

explained by pseudoempirical abstractions, which are transient and based on the individual's actions. With regard to our research, pseudoempirical abstractions are defined by the momentary contemplation of the properties and relations of

VCPOs that result from the coordination of a child's actions of when, say, the child discovers physical principles governing balance only after the blocks have actually been balanced. Piaget suggested that reflective abstractions are extensions of pseudoempirical abstractions because they are contemplations of the properties of objects that have been manipulated by a child. A child, therefore, may make the cognitive leap and realize that the block will balance, either midway to the left or midway to the right, and that the order of placing the block to the left or to the right will not change the result. Pseudoempirical abstractions seem to be the contemplation that takes place when a child considers what is necessary to balance one block on another. It is the knowledge that a child may possess when he or she realizes that the block will balance if placed midway or less on a block of the same size. Reasoning results from the coordination of any actions in testing where the block can be placed and maintain its balance. For our purposes, we call attention to how the diversity of affordance for VCPOs affects conceptual knowledge offered by empirical and reflective abstractions. Our understanding of VCPOs—their levels of affordance and their impact on constructive play environments—proves fundamental to understanding abstractions.

Vygotsky (1933/1969) lent further support to the importance of affordance as it relates to VCPOs when he argued that things (e.g., objects, materials, VCPOs) themselves dictate to a child what can be done for the thing in question to function properly and effectively. Theorizing on the mediation between action and meaning in play, Vygotsky emphasized the meaning of situational or environmental constraints and how children are bound to them during play. To buttress this important claim, Vygotsky referred to Lewin's (1935) study about motivational factors of the environment on the child and argued that things impose rules concerning what the child must do to perform a particular task. Just as a pen requires a user to manipulate it for it to release ink for writing or designing, so, too, do blocks, bricks, or planks place demands on the user. To extend Vygotsky's argument, a LEGO minifigure possesses a clear-cut set of constraints in that it can be used for relatively few situations (e.g., an intergalactic vehicle, on horseback). It, therefore, has a great deal of affordance because the user clearly understands how the minifigure should be used. A plank, on the other hand, is simply a thin rectangular cuboid. The constraints of a plank are ambiguous, thus exhibiting a low level of affordance and more possibilities and cognitive demands for the user.

We suggest that the greater the affordance of a VCPO, the easier it is to use in construction, and therefore, the more it impedes creative processes, problem solving, spatial thinking, and cognitive development in general. VCPOs with higher levels of affordance generally lead to more constraints on creativity and the relevant aspects of performance. These constraints, which tend to place more restrictions on creative actions, may lower the level of interest, enjoyment, and satisfaction in completing a particular activity (Deci and Ryan 1980; Amabile and Hennessey 1986; Amabile and Pillmer 2012). Some also have argued that the more intentionality in the manufacture and design of the material, the less potential the object has for creative expression (Elkind 2007). Thus, we propose the existence of an inverse relationship between the level of affordance of a particular VCPO and spatial-related cognitive skills, which can also contribute to intrinsic motivation and creative fluency of the individual engaged in constructive play. This position can be summarized mathematically by

$$a = \frac{1}{x}$$

where a refers to affordance and x (i.e., chi) to spatial thinking, skill acquisition, and development. That is, the affordance of a specific VCPO is inversely proportional to the acquisition of spatial skill and cognition as well as to the development of creative processes. Greater affordance, then, brings about ease of use of the VCPO with which the individual is playing. This ease of use leads to less interaction with materials, limits the problem-solving strategies required to complete a particular construction, and takes less overall time to complete a construction, all of which means fewer minutes engaged in the activity.

Scripted VCPOs—namely, those with specified narratives or plots that are often accompanied by detailed directions—account for high levels of affordance, while nonscripted VCPOs tend to possess low levels of affordance. We contend that the more thematic, formulaic, or scripted the constructive play object, the greater the affordance. In other words, the user of highly thematic play objects will know the end product prior to the completion of the final structure. Therefore, we argue that the greater the affordance, the less creativity and development of spatial skills. In the analyses of blocks, bricks, and planks that follow, we discuss both scripted and unscripted VCPOs. For many readers, it might seem counterintuitive that some types of play objects actually place limits on cognitive development. But research suggests that overstructuring a child's environment may limit creative and intellectual development rather than promote it (Elias and Berk 2002; Krafft and Berk 1998).

We propose that affordance poses a central problem for instruction in the upper levels of elementary schools and in secondary schools. In general, many schools devise exercises and activities in these grades that eliminate different points of view and therefore focus on predetermined results. They structure answers to fit course assessments and, in an attempt to accommodate generally rigid curricula, often jettison what we call the cognitive intrigue the students feel about school subjects. We define cognitive intrigue as the curiosity that intrinsically motivates an individual to willingly engage in an activity. We believe that the loss of cognitive intrigue results from the use of play objects tied to predetermined conclusions, especially those reinforced by rote instruction, exemplified by toys, games, and lessons that are an end in themselves and require an individual only to master the planned objectives. The following vignette from The *Importance of Average* by Farenga and his colleagues exemplifies the dilemma of themed VCPOs.

> The act of taking a tree branch and turning it into a magic wand may actually have more influence on promoting cognitive intrigue than a plastic, manufactured version of Darth Vader's light saber. The five-year-old son of one of the authors . . . was invited to his friend's birthday party, where approximately 20 children played in the backyard, imagining they were Star Wars characters. His friend is an avid fan of superheroes and Star Wars figures. So Star Wars paraphernalia, mostly light sabers, were strewn throughout the backyard. The "problem" was that although there were about 20 children, there were only 12 or 13 manufactured light sabers. What is a young child to do without a light saber, especially one of the seven or eight who weren't lucky enough to get one? A couple of children at the party picked up small hockey sticks and used these instead of the plastic light sabers. Others went with this idea and picked up generic, surrogate objects—such as a piece of wood or stick—that they pretended were light sabers. The remaining two or three children were not interested at all in the surrogate objects and thus tried to negotiate with one of the children who had plastic light sabers. Over time, the children using the surrogate objects in lieu of the plastic sabers became more spirited, committed, and imaginative in their play than were the children who had the manufactured plastic light sabers. This was evidenced by a longer play period with fewer interruptions and a play activity that went beyond Darth Vader, Stormtroopers, and the magical wonder of the Force. The novelty

> of the manufactured plastic light saber eventually wore off, but the use of the surrogate objects did not (2010, 125).

This story suggests that children's play using products manufactured with a specific design or theme runs the risk of stifling self-regulatory behaviors and even creative ideation. Such play possesses a prescribed outcome evident in a set of specific instructions that must be followed to obtain a desired result. Additionally, such play necessitates repetitive actions with no latitude for variation in the activity and no freedom for a child to express his or her imagination. Research suggests free play offers an opportunity to observe an intrinsically motivated action—which is important because the levels of intrinsically related activities significantly correlate with creativity (Deci and Ryan 1980; Amabile and Hennessey 1986; Amabile and Pillmer 2012).

Definitions and Research on VCPOs

Although the literature on play objects and their use in play environments is relatively abundant, research in play, developmental psychology, and education that examines VCPOs for their causal or correlative influences on cognitive development in general, and spatial development in particular, is harder to find. Unfortunately, the research considering causal relationships between VCPOs (primarily blocks) and cognitive ability in language, science, mathematics, and technologically related fields is extremely rare. The greater part of the research literature on constructive play objects focuses on the role of blocks (and, in fewer instances, bricks) on children's cognitive, social, and sensorimotor development. Accordingly, with the exception of Ginsburg and his colleagues (Ginsburg, Inoue, and Seo 1999; Ginsburg, Pappas, and Seo 2001; Ginsburg et al. 2001; Ginsburg et al. 2003), Ness (2001), and Ness and Farenga (2007), the role of brick play in cognitive play seldom receives a mention, and, to our knowledge, the research literature says nothing whatsoever about the role of plank play.

Blocks

Blocks, commonly referred to as "wood blocks" or "standard-unit blocks," are so ubiquitous in schools and homes that nearly everyone who encounters children or remembers their own childhood are most likely familiar with them. Essentially, blocks come in a variety of geometric figures. The most common of these figures are unit blocks, which come in the form of a rectangular prism. Blocks twice the size of unit blocks are called double-unit blocks and those four times the length are called quadruple-unit blocks. In addition, standard block sets usually contain blocks of arches, cylinders, and other shapes of various triangular prisms. Blocks are ecologically familiar to most children because they have been cornerstone materials in early-childhood education for more than a century (Lascarides and Hinitz 2013).

The study of blocks used in play and their role in social, emotional, and cognitive development is evident in the literature, and when compared with bricks and planks, blocks are, by far, the most discussed of the VCPOs. Based, in part, on Edward L. Thorndike's attempt to link education and behaviorism (Thorndike 1912), early research about blocks focused on behavioral approaches and the environmental influences of blocks on children. Examples include Hulson and Reich's (1931) study of children's play options during free play and Bailey's (1933) development of scales for determining children's motor manipulations and complexity of structure. A shift in the focus of the research seems to have occurred in studies after the mid-1940s with an increasing interest in gender and block play. A large number of these studies have been based on Erikson's (1950) investigations, which essentially concluded that differences in approach and intent defined the block play of girls and boys—namely, that girls generally construct open spaces and enclosures while boys build tower-like structures. While some studies extend or corroborate Erikson's findings (Schuster 1973; Blackman 1977; and Wilcox 1979), others have countered his claims (Goodfader 1982; Mayer 1991). Other gender studies examined social interaction and the amount of time engaged in block activities (Cartwright 1988; Kinsman and Berk 1979) and selection of block play compared to other types of play (Massey 1969; Rubin 1977).

Provenzo and Brett (1983) and Hirsch (1996) have devoted entire volumes to the history, development, and use of blocks. Provenzo and Brett offer a thorough treatment of the history of block building, the theory behind it, the research supporting the theory, and the use of blocks in home and school environments. The volume Hirsch edited includes discussions on the functions of blocks within different subjects and across social domains. Brosterman's (1997) treatment of the history of Kindergarten parallels that of Provenzo and Brett, establishing a historical connection between today's popular blocks and gifts developed by Friedrich Froebel and between Froebel's gifts and Frank Lloyd Wright's architecture. Hewitt's (2001) history of blocks corroborates Brosterman's contention that block play builds mathematical knowledge.

Many works advocate the importance of play in general—and block play more specifically—to intellectual development. For example, Pollman (2010) has suggested that blocks serve as an important play type in the development of spatial abilities in mathematics, language, and science. Although these publications emphasize the apparently intrinsic link between play and intellectual development as well as the need to introduce blocks and bricks into the early-childhood curriculum, they fail to shed light on how constructive play pieces promote the spatial development necessary for motivating students at middle school and high school grade levels in STEM fields. Moreover, although block play does seem, at least intuitively, linked to the development of mathematical and scientific thinking, we believe it is even more important to consider how particular types of block play can impede academic performance. We argue that the type of play object matters and that some themed play products actually stifle rather than enhance cognitive growth, specifically creativity (Farenga et al. 2011).

Another segment of the literature about blocks concerns block construction stages. Guanella (1934) identified four stages—preorganized, linear, bidimensional, and tridimensional—that are based entirely on childhood maturity. Forman (1982) offers stages that consider block activity from infancy and the grasping of a single block with both hands and ends to the building of symmetric constructions. Reifel (1984) has presented a useful framework for educational practitioners and researchers in understanding children's own ideas about spatial relationships with blocks. Based on Piaget's theory regarding children's development of the conception of space, Reifel organizes children's development of block constructions into several stages. Before discussing more advanced types of block constructions, Reifel treats particular spatial representations with blocks as discrete components within a so-called developmental progression. Following Piaget and Inhelder's argument that children acquire knowledge of the proximity of objects before they develop an understanding of enclosure (1963), Reifel argues that children's initial block constructions, mostly those built by children younger than four years, result either from the process of piling blocks on top of one another and thus creating vertical structures or from the placing of individual blocks horizontally next to other blocks. During and after their fourth year, children progress to another level in which their block construction includes the necessity for inner space. Constructions of this kind involve various types of enclosed or arch-like structures. His framework, then, names four elemental block structure types: the stack, in which individual blocks are placed on one another (vertical); the row, in which individual blocks are placed beside one another (horizontal); the flat enclosure, in which blocks are placed by one another in such a way that produces inner space—that is, space surrounded by blocks touching one another; and the arch-like enclosure, in which one or more blocks are suspended by at least two other blocks. Reifel's framework, then, sheds light on how researchers and practitioners might identify the progression of children's block play in terms of the increasingly complex sequencing of block placements (Reifel 1984; Reifel and Greenfield 1982).

Stiles and Stern (2001) conducted two studies to identify developmental changes in spatial processing in block construction. Their results indicate that a child's spatial array depends on numerous factors, such as the complexity of the array and the child's spontaneous or invented strategies. Accordingly, spatial complexity is based not on quantitative or qualitative differences in the child's construction but on the information that the patterns in the spatial array offer a child as well as the approach he or she takes in interpreting this information. In a related study, Kamii, Miyakawa, and Kato (2004) examined the development of logico-mathematical thinking through young children's use of blocks and found that increasing spatial complexity, which influenced changes in classification and enumeration, correlated with increasing age. Kamii and her colleagues have suggested that teachers need to address children's abilities to think and make mental relationships rather than focus on lessons that emphasize elementary school curriculum.

Albeit limited, the literature about block play has also considered the ways in which blocks have contributed to achievements in mathematics and gains in visual-spatial ability. Miller (2004) suggests that children engaged in block play may tap numerous cognitive, kinesthetic, and social skills as well as emotions. From a cognitive perspective, because block sets often include different three-dimensional figures, children, through their experiences, are introduced to geometric shapes as well as concepts of balance, force, and motion. Hansel (2015) goes further and proposes that engagement with blocks during play promotes and fosters skills that facilitate the specialized development of professionals such as engineers and architects.

Wolfgang, Stannard, and Jones (2001) conducted a longitudinal study to determine the likelihood that block play influenced future achievement in mathematics. They examined the constructive play behaviors of thirty-seven four-year-old children. They used the Lunzer (1955) Five-Point Play Scale to measure block play and the McCarthy (1972) Scales of Children's Abilities to control for social class, I.Q., and gender. Although their findings showed no influence from block play on children's mathematical class work in the third, fifth, and seventh grades, they have found a significant relationship between frequent block play and high standardized test results. Further, they found a statistically significant relationship between block play and high overall academic achievement at the high school levels. It is difficult to know, however, whether the Lunzer scores resulted from time spent engaged in block play activities. Because the Lunzer scale uses subjective terms that are hard to operationalize, it is tough, for example, to determine the meaning of "highly insightful" when describing a child at the highest play level. Casey, Pezaris, and Bassi (2011) conducted two studies to determine the relationship between males and females with respect to block-building characteristics and whether these characteristics have an effect on mathematical achievement. In support of Erikson's (1950, 1951) contention regarding differences in block constructions by gender, Casey and colleagues found that male participants primarily built towering structures with more elaborate bases while females produced more varied structures. Further, the main predictor of mathematical achievement was the measure of structural balance.

We argue that an essential missing parameter in nearly all block studies, however, is how different VCPO types might alter each of the findings. More specifically, might the results of gender differences change the outcome had planks or certain types of bricks been used? While a small cross section of these studies allude to the role of the kinds of information that blocks provide about logico-mathematical reasoning, no study, to our knowledge, has examined the roles of blocks specifically, and of different VCPOs generally in affording individuals' cognitive development and creativity.

Bricks

The term "brick" is generic for plastic pieces, usually in the shape of rectangular solids that snap together. Other generic terms for brick include "snap cubes" and "snap pieces." Generally, the public does not often hear the terms "brick" and "snap piece" because popular company trademarks—such as LEGO, Mega Bloks, KRE-O, or Cobi—eclipse the use of generic terms. While the term "brick" implies rectangular solid or box shape, bricks come in a plethora of sizes and styles. In fact, they can appear in the form of flat or curved puzzle-like pieces. LaQ is one such type. Developed and produced in Japan, LaQ is a fascinating brick-style, constructive-play toy that fosters the building of various figures, even spherical structures. In fact, the "Q" in the title stands for "kyuu," which, in Japanese, is equivalent to "sphere." One's capacity to make spherical structures lies in the physical characteristics of the LaQ pieces, which include five different joint types and two surface types. While the two surface types, a square and a triangle, are flat pieces, the five varied joint types allow for a curved structure.

The most popular brick is the LEGO brand. LEGO bricks come in numerous cuboidal shapes and thicknesses and include generic pieces and pieces from themed sets with instructions for assembly. The first LEGO sets, created in 1930s by the Danish carpenter and joiner Ole Kirk Kristiansen were not at all generic plastic snap pieces. In fact, the first LEGO toy was a wooden duck on wheels known as Kirk's Sandgame. LEGO, which, in Danish, derives from the term "leg godt," or "play well," developed into plastic bricks for construction play during the late 1940s. These bricks came in four- to eight-stud pieces that could be bound together with a larger brick. The so-called LEGO interlocking principle—that is, a method of snapping pieces together—was invented and patented in 1958. By the 1960s, the company developed bricks of numerous lengths and thicknesses. The so-called mini-figure first appeared in 1978. Although not as time honored as blocks in preschool and elementary school play areas, bricks have been an essential constructive-play object in those grades since the 1960s. We can even argue that ecologically their familiarity to children in the play center environment has surpassed that of wood blocks because they are now not only a staple play object in schools but are also prevalent in homes throughout the world.

In contrast to the research about blocks and their influence on creativity and spatial development, bricks have been far less examined. Discussions of bricks are often embedded in the context of block studies. As a result, block or brick literature has not taken the distinctive qualities and characteristics of these toy forms into consideration. And the specifics of the relationship of bricks to cognitive development and spatial thinking are even hazier in the less extensive research about brick play. Indeed, the common thread of these studies is the notion that LEGO bricks, like blocks, promote cognitive advances. In tapping young children's everyday mathematical activities, Ginsburg and his colleagues developed six categories that reflect broad areas of emergent mathematical constructs evident during free play (Ginsburg, Pappas, and Seo 2001). Children's active free play with bricks or blocks seems to manifest two of these categories—pattern and shape and spatial relations. Moreover, this surfacing expression of pattern, shape, and spatial constructs is evident cross-culturally with no significant differences in terms of gender and social class (Ginsburg et al. 2003).

In a longitudinal study to determine whether brick play in the preschool years correlates with higher levels of mathematical ability in middle and high school, Wolfgang, Stannard, and Jones (2003) found no relationship between three- and four-year-old children's LEGO play and their later level of mathematical achievement based on the awarding of letter grades in the third, fifth, and seventh grades. Similar to their study on children's block play, their results for children's LEGO play was significant in terms of increased standardized test scores during seventh grade. However, Ko (2010) has suggested that the sample size of Wolfgang's study was statistically insignificant. In a related study, Hussain, Lindh, and Shukur (2006) attempted to determine whether an entire year of regularized LEGO play influenced children's mathematical performance in school. While preliminary findings showed improvement in mathematics in the fifth grade, overall results were inconclusive. Verdine and colleagues (2014) measured the spatial performance of three-year-old children using Mega Bloks to determine possible relationships between spatial constructions and early mathematical skills and language. Mega Bloks were used for the easy manipulation of the three-year-old age group. However, the study did not take into account the unique properties of Mega Bloks themselves, which might constitute an important variable in construction. Similarly, it is important to note that brick studies often use brick play for measuring cognitive performances without considering the role of affordance as a potentially major factor in cognitive development.

Planks

Not as common as blocks and bricks, planks make excellent constructive play materials for several reasons. First, the very fact that all planks are the same shape and structure means they suit creativity in construction. Children who regularly play with generic, no-frills objects that are not theme related may enhance their self-regulation during constructive play and may be more likely to engage in creative tasks that involve synthesis and higher-order thinking (Amabile and Hennessey 1986; Amabile and Pillemer 2012). Unlike blocks, which usually include at least eight types, and bricks, which come in a cornucopia of themes and even a greater number of shapes and styles, planks are unique—all planks look and feel the same. Each one is in a ratio of 1:3:15 centimeters. They can be stacked, used as posts and lintels, or serve as foundations for larger structures.

Second, architects frequently use planks to build test models that help them develop blueprints. And Pottmann (2010) contends that planks serve as exemplary models of geodesic structures and other architectural constructions.

Third, planks are not sold in themed packages. Aside from the description included in the plank box, users will not find elaborate instructions for constructing objects with planks. Sets of planks do not come with a preconceived script. Neither superheroes nor intergalactic space stations play any role in the manufacturing of planks.

Again, unlike blocks and bricks, planks are relatively new to the constructive play market. They are seldom found in schools or homes. At present, most children and adults may encounter planks in a small number of museums and science centers because some curators see planks as important tools for learning about concepts in the physical sciences. Given their consistent, uniform structure, planks are more amenable to proportion than are blocks and bricks. For example, a model representation of the Coliseum in Rome using planks will be more proportionate than one of blocks and bricks because planks have a consistent form.

VCPOs, Affordance, and Conceptual Knowledge

Although wood blocks promote creativity, the large variety of figures offsets the consistency common to originality of structure. In other words, a block in the shape of an arch clearly has a function—it can be used to create an underpass or an ornament on top of a structure. But, in comparison to the standard-unit block, the arch block and cylindrical block have fewer ambiguities and—we propose—fewer ways in which they can be used to cultivate conceptual constructs and knowledge. On the other hand, unit blocks, in the form of the rectangular prism, as well as related blocks that are both longer and shorter, can encourage development because the level of affordance is lower than that of arch blocks, cylindrical blocks, and other more ornate block pieces. Unit blocks are more generic in terms of their appearance and, thus, can be used in more complex, intricate, or elaborate ways.

Children engaged in brick play often demonstrate extremely advanced spatially related behaviors (Ginsburg et al. 2003; Ness and Farenga 2007). Important when considering affordance, bricks are most often sold in themed packaging and require the user to follow directions for construction. These sets are sold with pieces that serve specific purposes and fail to provide children and older students with the opportunities for creative play. The downside of bricks is indeed their constant branding, which focuses on specific themes, many of them involving famous superheroes, episodic suspense stories, intergalactic dramas, city-related themes, and the like. The themes require children to follow scripts of instructions for building. Unfortunately, scripting adversely affects a child's ability to create structures (and a researcher's and practitioner's ability to analyze children's spatial propensities). We observed that the themed brick constructions lack flexibility in design, solving problems, and originality; they often call for building replicas of real (e.g., Empire State Building) or fictional (e.g., *Star Wars* Millennium Falcon) structures, activities similar to painting by numbers. The ideal bricks most conducive for creativity are generic, bricks available as loose, strictly cuboidal pieces sold in bulk.

In considering affordance, we find that individuals are apparently less likely to know the immediate use of planks because each plank is strictly the same

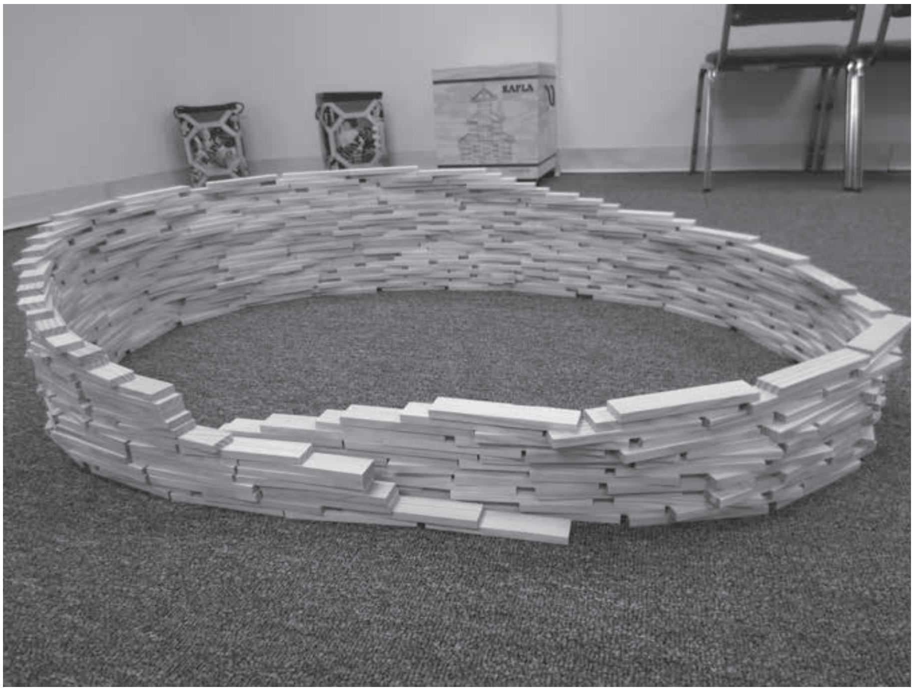

Figure 2. A curvilinear model representation of the Coliseum in Rome using planks.

ratio in terms of length, width, and thickness. This uniformity may be why planks seem to be so versatile and more adaptable than blocks and bricks, thus potentially better enabling the divergent thinking of children and adolescents. The very ambiguity of the plank may lead to a period of cognitive dissonance. A user will need to imagine each rectangular plank in terms of how it can be manipulated or positioned to build a structure that may possess either curvilinear properties or a curvilinear appearance (see figure 2).

As we have discussed, an empirical abstraction necessitates the physical manipulation of an object to recognize its potential uses based on physical properties. A reflective abstraction is based on prior experience learned from the empirical abstraction and is the conceptual understanding based on the object's properties. The reflective abstraction involves knowing the outcome of manipulating an object without having to do so physically. An essential question to consider, then, is how the affordances of VCPOs may affect the gradual transition from empirical abstractions to reflective ones. To answer this question, it is important to examine the basic concept of balance by comparing a construction using planks to one using bricks. The design of a structure that requires

Figure 3. A comparison of cantilever constructions when considering bricks (left) and planks (right).

the building of cantilevers—structural components in the form of balconies, terraces, or jutting edges that extend from a structure's center of gravity—can provide additional insight. We suggest that each of the two building materials afford the child varying degrees of experience leading to two different levels of tacit knowledge. The relative positioning of the planks is critical to the success of the cantilever construction. In contrast to a brick piece, each plank is more sensitive to the placement of each successive plank to maximize friction and defy gravity. Because of their pips and interlocking design, bricks offer slightly more resistance to gravity. If the brick structure is built on the flat, rectangular, and pipped base supplied in many brick sets, the cantilever design becomes much easier to achieve (see figure 3).

Based on the cantilever example, it becomes evident that each type of VCPO provides a different level of experience necessary to recognize and understand the nuances required to fully integrate the concept involved.

Creativity and Affordance

Creativity has received scant attention in recent years because education polcy makers have advocated following the Common Core Standards in literacy and mathematics. The increasing emphasis on nationalizing high-stakes testing has led to the woeful limitations of curricular offerings. Such limitations have excluded the development of important constructs, such as creativity and spatial thinking, which may support cognitive development. We define creativity in spatial thinking as the individual's ability to demonstrate divergent thinking through the use of a variety of geometric, architectural, and scientific principles in his or her constructions. In our analysis, creativity is important in the growth of general learning strategies such as problem finding, problem solving, and working with ill-defined problems. We find this definition of creativity useful based on our observations of young children engaged in VCPO play (Ness and Farenga 2007).

In examining the creative processes of young children, it is important to consider the task at hand and the context in which the task occurs, and it is often difficult to assess the creativity of young children because it requires a different set of parameters than those used for adolescents. Goetz (1989) contends that "creativity for the preschool child is based typically on that child's own past behavioral history for a given task" (414). In Goetz's definition of creativity for a preschool child, researchers and educators must assess the child's initial construction as novel, ingenious, or original or as a newly discovered individual response. The same construction completed by an older child or adolescent would be judged as an imitative act, unoriginal and uncreative. So, we do not judge creativity for a young child by the same criteria we use to judge an adolescent. Indeed, the adolescent's creativity is determined by a wider set of cultural precedents. We concur with Goetz that the measure of creativity for a young child should be evaluated in relation to the child's prior experiences. Further, when an examiner applies geometric and architectural principles to a structure created by a child, it is possible to recognize a higher level of creative ability. Therefore, from these observed behaviors, we infer that some cognitive processes, such as creativity, are associated with and fostered by VCPOs.

Our view of the creative process blends the structuralist perspective with the spontaneous, everyday actions of the individual. This is analogous to both a top-down and a bottom-up approach to the study of creativity and levels of complexity in the development of spatial functionality using VCPOs. By top-down we mean examining the literature about creativity and identifying specific characteristics of cognitive conceptualizations. Observation and analysis of video recordings serve as a bottom-up approach because an individual's speech and actions contribute to the development of our understanding of creativity. When we impose the structuralist view on our work, we are looking beyond the individual to establish a set of regulatory norms for recognizing and categorizing creative behaviors. This is consistent with Piaget's attempts to establish what he calls the epistemic subject (Bringuier 1980). We seek to identify the regulatory norms of creativity in the spatial, geometric, and architectural thinking of young children. We combine this view uniquely with the opposing strategy of examining how each child uses VCPOs and their relationship to the creative process. This path of inquiry fosters a wider search for understanding creative production in spatial reasoning.

How is Creativity Measured with Respect to VCPO Play?

Researchers who specialize in the field of creativity seem to agree that there exists no unified definition of the concept. However, the literature continually considers some basic characteristics of the creative process. Through observational analysis, we have identified some creative behaviors evident in the procedure and product of the constructive process with VCPOs. The behaviors demonstrated during constructive free play can generally be categorized by the concepts that researchers in the field of creativity use liberally in the literature. The Torrance Test of Creative Thinking (Torrance 1968) for children is probably one of the best known. Based on the attribute theory of creativity, Torrance's test looks at creativity as a composite of specific aptitudes. We have observed and identified the following abilities in visuo-spatial constructive play activities: (1) flexibility in the number of ways VCPOs are used, (2) fluency in the number of objects constructed, (3) originality in design of the construction, (4) elaboration in the greater number of intricate details that enhance the construction, (5) abstract nature of building yet still functional for its intended purpose, (6) bending boundaries in relation to physical principles that govern design, (7) creating a script that provides the construction within a given context, and (8) an ability to create an image of the construction either by hand or computer drawing.

To support our modified eight-point scale based on Torrance's test, we also find it helpful to integrate Taylor's (1959) levels of complexity on the creative processes observed in children's constructions. Taylor suggested that the nature of the creative process can be construed in levels of complexity. These hierarchical levels are expressive creativity, technical creativity, inventive creativity, innovative creativity, and emergentive creativity. In expressive creativity, VCPOs are used to model a unique idea or project with no concern for design quality. In technical creativity, the construction lacks creative expression but it is skillfully crafted. For example, a child might follow a script or build a structure using environmental cues, such as building a perfect cube. Inventive creativity involves the use of VCPOs in a nonconventional manner. VCPO constructions that are inventive generally demonstrate expressive spontaneity with minimal environmental cuing. Innovative creativity involves an individual's use of VCPO in ways that attempt to challenge the natural laws of physics. With innovative creativity there is minimal to no environmental cuing. Emergentive creativity is extremely rare. For Taylor, an accomplishment categorized as emergentive would rise to a level that incorporates abstract ideational principles, which transform thinking and ways of knowing in a field of science. Examples include Darwin's notion of evolution, Augusta Ada King's development of the mechanical engine, Einstein's theory of relativity, and Guido D'Arezzo's invention and implementation of musical notation. In the context of VCPO use, although a specific VCPO might serve as a model for revolutionizing the way we think about the world, VCPO use with respect to emergentive creativity does not apply.

Conclusion

Our research on the development of spatial thinking from the perspective of observing children's constructive play has evolved considerably. In our earlier studies, one of our original central premises regarding Piagetian theory of children's concept of space was that young children had a well-developed sense of Euclidean space—a conclusion that ran counter to that of Piaget and his colleagues. Based on their topological primacy thesis, Piaget and Inhelder (1963) argued that young children's spatial conceptions are homeomorphic in that two objects are similar in their physical relationships and therefore one can be reformed into the other. In other words, preoperational concepts of space and the objects within it are construed in a more plastic, dynamic way—one in which formal notions of parallelism and perpendicularity are absent. For example, individuals with this conception would see more of a relationship between a cube and a sphere than they would a cube and a square.

Over time, we have come to terms with this argument. When Piaget and his colleagues employed the clinical method with individual children—some as young as two and one-half years, others adolescents—they were mostly interested in what a child of a given age could know and was able to do on a specific occasion. Although Piagetian constructivism considers prior knowledge as an essential dynamic in the acquisition of new knowledge, Piaget himself did not seem to emphasize the importance of the child's past experiences, at least during the clinical interview process. And to our knowledge, he did not seem concerned with play as a decisive factor of intellectual development. Further, there is no evidence to suggest that Piaget was interested in the naturalistic observation of children's constructive play, and he was unconcerned with play materials altogether. Given his primary concern with children's intellectual development through the clinical method—an approach that provides a snapshot of a child's knowledge and not necessarily a narrative—there would be no reason for him to consider play objects or materials. Like Piaget and Inhelder, we did not consider the importance of play objects in shaping children's conceptual contexts until it became increasingly evident that the very embodiment of play materials gives rise to shape and form. Just as young children's and adolescents' active participation in block, brick, or plank play eventuates in the embodiment of shape and form, so, too, do the materials of professional engineers and architects. In fact, children's blocks and related play materials and the construction materials of engineers and architects have something important in common—they both engender Euclidean concepts.

Arriving at the realization of this common feature transformed our thinking because it placed children's individual play experiences with Euclidean play objects at the forefront of what is important to both STEM education, professional expertise in the sciences, and applied science fields like architecture and engineering. With this intrinsic connection, we reach a better standing to compare three forms of VCPOs and their possible strengths and weaknesses with regard to creativity and spatial skills in mathematics and science.

Finally, the study of VCPOs is a fruitful area of inquiry with the potential to help us better understand the strengths and weaknesses of various object types for promoting creativity and inventiveness. Such inquiries may also help increase career interests in science, engineering, and mathematics during middle school and high school. This investigation is only the beginning of a long venture in determining the benefits and shortcomings of specific VCPOs on the cognitive development and academic and creative potential of children and adolescents. Greater attention must be given to expanding our assessment of young children beyond that of quantitative and verbal abilities to include constructs such as creativity in spatial and architectural thinking.

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