Enhancing Children's Shape and Space Ability with Sensory Play

by

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Abstract

Some people can't imagine what a space will look like after a renovation is finished, can't read a map, or quickly get lost in an unfamiliar place. Some students in high school and middle school have terrible performances in mathematics learning. These problems are highly related to society's lack of a geometric focus on children at a young age.

Learning shape and space at an early age is essential for children's abilities in the long run, such as scene-mapping, creation, and mathematics. Current teaching methods are mainly focused on the current curriculum in a school setting, but not children's intrinsic interest. Thus, these methods often have ineffective outcomes. In contrast, play is children's work, and they can learn curricular objectives while playing. How to help children learn more through play is important for the whole society.

The study develops a guideline for designers to improve shape and space ability in children ages three to ten. It focuses on how children recognize the basic and complex combinations of shapes through the multisensory play process (toys, playground) and gradually develop their mathematic problem-solving ability, spatial ability, and even their imaginative-creative ability. Chapter 2 embodies play, children's development (both physical and cognitive), sensory play, and the development of shape and space ability, explaining the relationship among shape learning and

children's multisensory abilities. Chapter 3 analyzes the current teaching tools and activities to find the relation among teaching content and sense interaction. Chapter 4 is the thesis guideline, and Chapter 5 is the application of the approach.

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Chapter 1 Introduction

1.1 Problem Statement

1.1.1 Introduction

People perform differently in middle or high school mathematical learning, and even perform poorly in spatial thinking as an adult. There is increasing evidence that many students in the middle years of schooling have severe misconceptions concerning several important geometric ideas (Burger & Shaughnessy, 1986; Dickson, Brown, & Gibson, 1984). Some students cannot solve some problems due to flawed perspective thinking, poor geometry-reasoning, and lack of space-imaging ability. Many research findings suggest that early spatial skills provide a foundation for mathematics learning (Hawes, Tepylo & Moss, 2015).

Also, with the fast-growing economy, the children have more demand for various play tools. More companies manufacture playthings to meet the children's and parents' needs. According to O' Grady's research, a typical child owns 238 toys in total. Play is an essential part of children's development (Hinske, Langheinrich, & Lampe, 2008), especially children's learning. Children have more time for playing as the economy has grown. Therefore, how children can learn something and improve themselves when playing is an important concern to address.

1.1.2 Reasons

Considering the reasons for children's inadequate learning of shape and space, three aspects can explain the problem.

One is that children lack the attention to focus on the shape and space teaching both in school and out of the school at an early age. A lot of research shows that the shape definitions are typically the only prominent geometric ideas introduced in school, while manipulation of shapes and spatial exploration are generally neglected (Copley, 2000). Anecdotal evidence suggests many teachers do not consider the geometry and spatial relations to be important topics, which gives rise to feelings that geometry lacks firm direction and purpose (Pegg & Davey, 2007). Outside of school, caregivers don't necessarily have time to teach children shape and space ability. Parents prefer to buy many toys for their children because of the guilty feeling that parents have that they can't have enough time with their children (Bohn, 2011). Because of this lack of teaching in and out of the school, it is important to ensure that toys can supplement this gap.

Secondly, many teaching methods of shape and space ability lack a positive sense interaction, which leaves children unmotivated and uninterested. Most people view teaching children shape and space as part of the school curriculum. Most parts of teaching are through lecture and lack involvement of senses (sight, tactile, hearing, smell), which are highly related to shape and space learning. In this way, teachers cannot activate student's interests, causing the inadequate outcome of shape and space learning.

The third reason is about the quality of current play tools lacking reasonable educational meaning and much interaction with children (even some video games). Most advertisements for these tools are for benefits, exaggerating their products' characteristics. In actuality, manufacturers tend to lower the quality of their toys to reduce the costs and increase profits. As a result, more and more toys are inadequate educationally for children, serving a minimal or no educational purpose. Even some of the toys are not fit for children's body size. In this situation, playing tools do not attract the children's interest or provide interaction to invite the children to play. Without an active role in playing, children will not learn more knowledge.

1.1.3 Solutions

One solution is to give more positive sensory interactions when children learn shape and space during play to motivate their learning interest. Designers can add some sensory interactions by focusing on materials, color, sound, scents, etc. Although designers in some products add sensory interaction, poor interaction designs cause ineffective learning, leading to disorientation and cognitive overload (Calisir & Gurel, 2003; Lustria, 2007). Designers should appropriately use multiple senses of tactile, sight, auditory and olfactory (Chapter 2 will explain the relationship of these four senses and shape and space learning) in the process of children's play. In this way, children may actively play games by appropriating their senses to help their cognitive development.

The other is adding more educational meaning to tools (both teaching tools in school and playing tools out of school), improving a targeted age group and the knowledge expected of children of that age group through playing instruments with precise teaching content. With high demand for the playing tools, the designer can improve the tool's quality to make people attach importance to children's shape and space learning. For educating children about specific shape and space contents, we should consider the children's cognitive development and match the particular shape and space learning content to prerequisite cognitive skills, thus, letting children be active in playing tools.

1.2 Need for Study

With more and more attention focused on children's development, children's education is a big challenge for both parents and society. Maria Montessori said play is children's work; from an early age, play occupies most of their daily lives. How can we help the children learn more knowledge from playing, which is a long-lasting concern? How can we make them learn more things actively? How can we help children better understand shape and space at an early age?

The first direction focuses on play and children's development. According to research, playing an active role helps children's brain development and allows them to learn more things during play (Ginsburg, 2006). That means children are more engaged when playing. One of the good examples is the "junk" playground of C.T. Soreness (discussed in Chapter 2 and shown in Figure 2.2). Adventure playgrounds are the most flexible in terms of having open-minded materials. Children can choose materials and play. They can free play or decide to play under guidance. At the same time, designers should have a better understanding of children's physical and cognitive development to appropriately design children's play tools.

The second direction is about multisensory play. Once there are plenty of materials to see, touch, smell, hear, and taste, children must feel invited to take control and explore and use what playgrounds provide (Scarlett, Naudeau, Salonius-Pasternak, & Ponte, 2005). This understanding can be applied to other toys and games. Children are pleased to use their senses when interacting with playing things; through this experience, they can learn more knowledge. This is an unconscious way for children's education. Designers should research the content between the senses and the teaching. Which senses are related to shape and space learning? With this understanding, toys and games can benefit children's learning.

The third direction is researching the children's shape and space ability, giving the appropriate shape and space education for specific ages of children. According to Piaget's (1952) notion of the four stages of children's cognitive development, children culminate knowledge step by step, and each new step in development becomes integrated with the previous step. Learning shape and space is the same; what is known previously is crucial and foundational to the future. Farmer et al. (2013) found evidence to suggest that children's spatial skill at three years old was a strong predictor of how well the same children performed in mathematics two years later. For educating children about shape and space, we should consider the children's cognitive development and match the specific shape and space learning contents to prerequisite cognitive skills.

The active role from the children's interest and the multisensory experience helps their shape and space ability development. The literature review explores educational theories, children’s needs, and play to lay a foundation for the design guidelines proposed in this study.

1.3 Objective of Study

- Study the theories of child development and define children's needs.
- Study the concepts of play (analyze some playgrounds and toys cases), analyzing the playing type benefit for education to define play type for children to learn shape and space.
- Analyze children's shape and space ability (differences from ages 3-10) and influence later years.

- Analyze the four senses in play products (especially in playgrounds and toys) and the interaction between playing things and children's senses. Find the appropriate sense system for shape education.
- Analyze shape and space education toys, games, activities, and some good examples, and according to children's needs, define the educational purpose of the specific age groups of children.
- Apply the approach of sense interaction into the shape and space education playing tools.

1.4 Definition of Terms

Gestalt: Something that as a whole is organized but also seems greater than the sum of its parts.

Geometry Problem-solving: It includes an analysis of forms of knowledge required for successful performance (Greeno, 1978), a discussion of goal representation (Greeno, 1976), and a discussion of schematic knowledge involved in planning (Greeno, Magone, &Chaiklin, 1979)

Make-believe Play: It is also known as pretend play, a loosely structured form of play generally including role-play, object substitution, and nonliteral behavior.

Nonverbal Thinking: We observe some things without having any words for them, such as recognizing the faces of familiar persons without using words to describe their looks.

Perception: It is the beginning of knowledge, and so it is an essential part of cognition. More specifically, to perceive is to obtain information about the world through stimulation (Gibson & Spelke, 1983).

Place Learning: The learning of locations or physical positions of goals (e.g., finding food) (Tolman,1946).

Play: Engage in activity for enjoyment and recreation rather than a serious or practical purpose.

Proprioception: Awareness of the body's position.

Sensory: Sensory processing refers to the way that the nervous system receives messages from the senses and turns them into responses.

Sensory Stimulus: Stimuli are transformed by the brain into self-knowledge as signal and conceptual thought (Erikson 1985, p.85).

Social Cognition: This means cognition and knowledge about people and their doings. Machines, mathematics, and mental states are all objects of understanding.

Spinal Cord: The part of the central nervous system enclosed by and protected by the vertebrae makes up the backbone. The spinal cord is connected directly to the brain.

Toy: Something a child can play with.

Trachea: Also known as the windpipe, allowing the passage of air to the lungs.

Vestibular Sense: contributes to balance and the sense of spatial orientation.

World Knowledge: It allows for the prediction, identification, and interpretation of incoming information (Smith, 1971).

1.5 Assumptions of Study

- It is assumed that all the research, approaches, methods, and data I found are reliable.
- It is assumed that parents and society need to pay more attention to children's shape recognition ability.
- It is assumed that children have learned some basic movement before teaching shapes.
- It is assumed that play is an excellent way to improve children's shape and space ability.
- It is assumed that designers have adequate knowledge of other parts of a playing tool, such as structure, manufacture and so on.

1.6 Scope and Limits

The research is to study how to utilize senses in designing educational toys that enhance children's shape recognition. It focuses more on the four primary senses of sight, touch, hearing, smell, and two other senses, the vestibular sense and proprioception sense. This focus is because most research is in these areas. However, taste is a neglected study area, so its inclusion is more appropriate for future research and development of the proposed guideline.

Also, this research is more focused on children's play such as playing tools and playgrounds. There are other ways to cultivate children's shape ability, such as video games and drawing in some children's coloring books. These aspects will require more research in the future.

What's more, the study focuses on children at an early age, focusing on the early mathematical ability (geometry ability, problem-solving ability, creativity, space-thinking ability) and not on logical-thinking ability. During the entire preoperational period (ages 2-7), the child's thinking is unsystematic and illogical (Piaget, 1964a). According to Piaget's theory, children at this age range do not have the structure of logical thinking. Toys designed for older children will not be considered.

Last but not least, the study is focused on children who do not have any sensory impairment.

1.7 Procedures and Methods

Procedure 1:

- Study the concepts of toy, play types, and children's needs to define a specific educational catalog of playing (learn the current improvements about educational toys).
- Studying online research, articles, and library resources.
- Studying the current articles and thesis about playthings.

- Analyzing some specific educational toy examples.

Procedure 2:

- Study and summarize the theories of children's development.
- Studying online research, articles, and library resources.

Procedure 3:

- Study the ways for children to learn shape and space. Find the importance of the ways of learning form and space through playing.
- Studying online research, articles, and library resources.
- Doing observation and experiments.
- Analyzing good toys examples utilize interaction.

Procedure 4:

- Study the children's sensory process system when playing, the interaction between children, and playing tools. Draw conclusions how to utilize children's senses to learn when playing correctly.
- Studying online research, articles, and library resources.
- Doing observation and experiments.
- Analyzing good toy examples that utilize sense interaction.

Procedure 5:

- Utilize using children's sensory thinking in developing educational tools. Summarize the relationship of the environment and the children with four senses and the system of the interaction.
- Studying online research, articles, and library resources.
- Analyzing good examples of toys that help children improve.

Procedure 6:

- Use developed guidelines to design a specific tool.

1.8 Anticipated Outcome

The expected result is to set guidelines for designers to create educational playthings that employ the six senses (sight, smell, touch, hearing, proprioception, and vestibular) according to children's ages. This guideline will provide advice to develop educational play tools that help children learn more through play.

Chapter 2 Literature Review

Towards the goal to provide guidelines for designers to develop sensory play tools to enhance children's shape and space ability, this chapter lays a foundation by investigating and synthesizing current literature in the following areas:

- Role of Play
- Children's Intellectual and Cognitive Development
- Children's Biological Development, Senses
- Sensory Play
- Shape, Geometry and Space Education
- The Relationship of Multi-sensory Play and Learning Shape and Space

2.1 Role of Play

Children's play is a subject of considerable interest to historians of childhood and the family, to anthropologists, psychologists, folklorists, and to everyone concerned with human behavior (Mergen, 1982). To define play tools for children, first designers should study the different dimensions of play. Play and children are tightly connected with each other; the association of children and play is so strong that any discussion of one would seem to include the other (Mergen, 1982). Learning more about play increases understanding more about children's development and toys. So, what is "play"? How many play types are there? How is play developed? And what is the role of play for children's development?

2.1.1 Definition

Play is children's physical or sensory exploration of toys and the environment, or time spent in manipulation of objects or toys either alone or with others. Play influences children's development, just as it involves social competence, communication, cognition, symbolic use of objects, motor ability, and organizational and adaptive skills (Bundy, 1991, 2002). The influence of play on the children is relevant to intrinsic and extrinsic elements, such as children's sensory processes and the environment's interaction with children.

2.1.2 Play Types and Individual differences

This section lists some play types and explores the differences between boys' and girls' play. There are some gender specific preferences and individual differences among children, which should influence design choices when choosing the playing type for the intended product.

2.1.2.1 Play Types

There are two general types of play, *guided play* and *free play*. Guided play occurs when an adult aims a child towards specific knowledge in a playful, fun, and relaxed way (Lillard, 2013). For example, Van Hiele (1986) taught children shape and space by observing the child and asking questions through the process of playing the tangram. It is not the same as the didactic instruction (teacher centered); guided play is children centered, respecting the child's own interests and pacing.

Free play is fun, flexible, active, and voluntary, also often including elements of make-believe and often involves peers (Lillard,2013). That is, children engage in play activities without close adult oversight or control. As described by Fisher et al. (2011), free play includes object play, pretend play and sociodramatic play, and rough-and-tumble play. These several types of free play are discussed immediately below.

Physical Play: is defined as a gross and fine muscle activity or the use of body parts in play. Smith and Inder (1993) observed that boys tend to boisterously play and be active in the outdoors, while girls tend to be quieter and more passive indoors. These gender differences in physical activity emerge about the age of four to five years (Fagot & O'Brien, 1994). Overall, boys' play tends to be more active and rougher than girls' play, involving more physical contact, fighting and taunting (Maccoby, 1998).

Social Play: is any play in which children of the same age interact with each other. One study reported that girls are ahead of boys in social play during preschool years. However, earlier theories proposed the differences in social play are age-related but not gender related. Young children prefer same-sex playmates, explained by gender-typed toy preference theory (Hartup,

1983) and behavioral compatibility theory (Moller & Seribin, 1996). The different toys and behaviors cause different gender play groups, girls and boys, to have different communication and interaction styles. According to considerable research, boys' social worlds are more extensive, individualistic, and competitive, and girls' social worlds tend to be more intensive, affiliative, and subjective.

Object Play: is formally defined as the active, playful manipulation of objects (Bjorklund & Gardiner, 2009). There are significant differences of toy type between boys and girls. Boys prefer to play on the floor with pushing and pulling toys, blocks, or wheeled toys; girls like to play on the tabletop coloring, doing puzzles, or playing with dolls (Wardle, 1991), because boys have a tendency for functional play (use materials in ways that are somewhat stereotyped and repetitious, such as pushing a small vehicle) and girls tend to engage in constructive play (according to a plan, as in completing a puzzle or a coloring a page).

Pretend Play: is children enacting different people, places or times, and objects become symbols for what is imagined (Fein, 1981; Lillard, 2011). Research shows that in the early childhood years boys and girls do not have differences in pretend play. According to Sachs (1980), certain aspects of pretend play have gender differences, such as the theme of play; there are no gender differences in structural aspects of pretend play such as its organizational complexity, narrative richness, or transformational quality.

2.1.2.2 Gender Difference

Throughout life, age and gender account for more of variability in a person's general behavior than any other personal attributes. Gender is helpful for people to predict children's play behavior. There are some forms of play that emerge from gender differences.

Across cultures, parents, teachers, and other agents of socialization tend to treat boys and girls differently. Gender-differentiated behavior is first shaped within the family (Maccoby & Jacklin, 1974); parents tend to give children gender-matched education and objects to help them form gender concepts and develop in guided way. Teachers modify the organization of classroom to change children's sex-type play behavior, having a big influence on children's play behaviors and development. What's more, the peers also have influence on children's play behavior. Other researchers have found similar tendencies in preschool children. Boys who engage in male-typed behavior receive more positive responses from peers than do girls who engage in female-typed behavior（Fagot & Leinbach, 1989）.

2.1.2.3 Personality Difference

Play as an experience is highly individually different. The quality of play is experienced in relation to five ways of viewing play: as action, interaction, activity, disposition, and within a context (Henricks, 2015). There are several distinguishing characteristics when children generate experiences through play.

One major individual difference in play is object-versus-people orientation. That means some children have more interaction with people in the play process, and the others have less interaction and tend toward solitary activities.

Different children have different cognitive styles and skills when playing. More details will be provided later about the play for children's cognitive skill development. A lot of aspects illustrate the cognitive style difference, such as emotion and the active or passive role.

Playfulness is also different in individuals. Playfulness is a psychological construct involving individual differences in the disposition to play (Rogers et al., 1998). Researchers have studied playfulness as a personality dimension contributing to observed variations in play behavior and divergent thinking. What's more, fantasy-making predisposition, imaginative play styles and psychological adjustment also have individual differences.

The upper level of design exhibits more customization characteristics, which creates products that put more personal individually different desires into consideration with more customized results. The five categories of design (Joseph & Gilmore. 2011) in Figure 2.1 show that design can be divided into design commodities, good, services, experience, and transformation, which is a reminder for designers of children things. Designers come up against a big challenge because the plaything for children is not just a product, it is an individual experience; designers should take the individual differences into consideration.

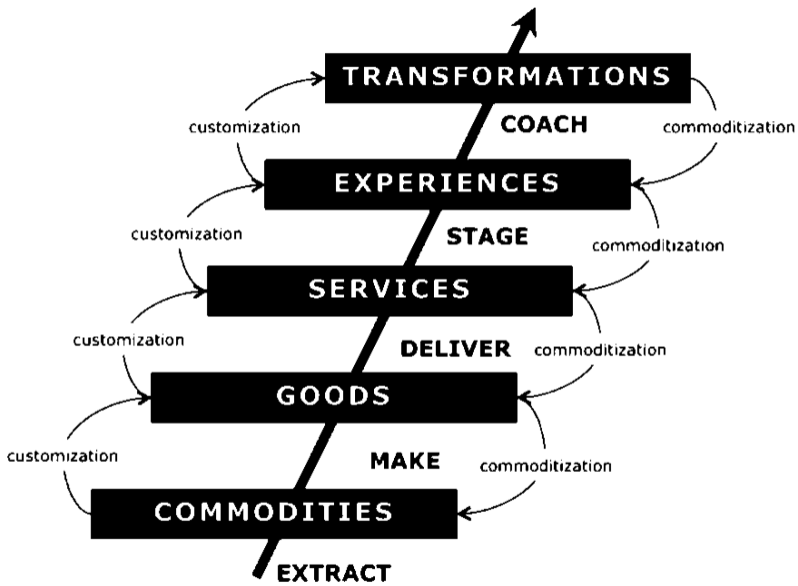


Figure 2.1 Five Levels of Design (Joseph & Gilmore. 2011)

2.1.2.4 Play Type Benefiting for Education

Among the play types, not all of them benefit from early-childhood education. In most types of play, there is a selective bias toward supporting constructive play that have a positive impact on children's early education or play in which a child is trying to construct something, such as a fort made with blocks or a picture of a house made with paper and markers (Forman & Hill, 1980; Forman, 1998).

To accomplish the goal of improving the children's thinking and learning through play, educators focus on three aspects taken from research on how the learning environment affects children's learning. The first way is to design the physical or built environment, which includes some bounded areas, accessible material, and disruptive play. The second one is programming, planning thoughtfully for children. The last one is good teachers.

Research has focused on constructive play recently (e.g., Forman & Hill, 1980; Forman, 1998), but there are some other play types that need more research to understand whether they will benefit early-childhood education.

2.1.3 Play's Role for Children's Development

Play can help the children's development in different ways. There are at least three ways: *Play simply reflects development*-- play behavior can serve as a window on the child's development. *The play reinforces development*-- play serves as a context and vehicle for the expression and consolidation of development. *Play results in development*-- play can serve as an instrument of developmental change (Bergen, 1988). The different paths of development are caused by different types of play. Play can help the children's development in different aspects.

2.1.3.1 Brain Development

Babies, children, and young preschoolers need to play and explore to construct the richest possible set of synapses, helping future brain development. Child development theories argue that as the brain begins in a state of high potentiality, so does play. Play's function in the early stages might be to assist the actualization of the brain potentiality to save in both brain and behavior more of the variability than would otherwise be saved if there was no play (Scutton, 1998).

Play experiences can mediate the development of brain; that is, high-quality experiences (high-quality brain development stimulants) help create more complex neuronal structures and mediate the brain development. According to the discussion of Bronfenbrenner and Ceci's (1994) bioecological model, high-quality play is related to *proximal processes*. So, the proximal processes are favorable to cognitive development and brain development. According to Bronfenbrenner and Ceci's illustration of the proximal processes, we can draw the conclusion that play provides active involvement, choice, and feedback from the environment (serving as a high-quality proximal process), which can stimulate optimal brain development, helping children to reach their full potential.

2.1.3.2 Culture Learning

Children's play can engage them with the knowledge of their culture and allow them to learn more about their specific culture. Regarding cultural learning, there is a long history leading to current theories. In the 1980s, the Piagetian theory dominated the developmental psychology. He thought that play with literacy has an influence on development of the mind across the cultures.

However, in the 1990s Vygotsky developed his theory in contrast to the earlier Piagetian theory. Vygotsky realized the limitation of the earlier research and pointed out that learning and development have a relationship mediated by the particular culture. Haight (1999) and Black (2001) provided some examples to support Vygotsky.

According to Haight (1999), children can learn more of their own cultural values and knowledge in pretend play. This means that children's play, especially pretend play, has a good influence on specific cultural learning.

2.1.3.3 Cognitive Dimension

Children's cognition develops greatly through playing and playing experiments significantly influences children's thinking and problem-solving ability in the long run.

2.1.3.3.1 Conceptual Development

Pretend play helps children learn more about abstract concepts, such as time, space, probability and causality. According to Smilansky's (1968) theory, sociodramatic play helps children integrate their experiences and unrelated concepts to connect separate things together. In another reference about conceptual development and play, the point is made that time is often altered in make-believe play episodes, sequence and structure, making it easier for children to understand these concepts during play (Athey, 1998).

2.1.3.3.2 Thinking and Problem Solving

Multiple experiments show that *make-believe* play helps children enhance their thinking and problem-solving ability, leading to them performing better in future tasks. Christie and Wardle (2005) illustrate two cognitive operations in make-believe play: decentration (the realization that one can act out a role and retain one's real-life identity) and reversibility (the awareness that one can change from one's make-believe role back to one's real identity at any time).

Much research shows the underlying cognitive structures under play promote children's formal operational thinking, which helps their future math skills. Play can enhance children's problem-solving ability by increasing their behavior options (Bruner, 1972). Children try many different behaviors through play episodes, options they will use in later problem solving.

Divergent Thinking: Divergent thinking is a process to generate creative ideas. Plenty of research shows the relationship between pretend play and creativity. Dansky and Silverman (1973, 1975) reported that children who were allowed to play with objects such as paper cups were later found to be more creative. Then Lloyd and Howe (2003) investigated the relationship between different forms of solitary play and divergent thinking ability. The conclusion is that solitary-active play did best to promote children's creativity and give more unintended uses of play materials (e.g., using puzzle piece as a car).

Therefore, the children sometimes need to be alone to practice their creative ideas, and their active role in play is important to their divergent thinking.

Theory of Mind: The theory of mind (ToM) (Leslie, 1987) is an implicit and rudimentary awareness about one's own and other people's world. As children develop, they are more sensitive to others' views and tend to have their own perspective. Pretend play holds an important role in the children's theory of mind. Smith has pointed out some reasons why pretend play facilitates the children's ToM: pretend play has a similar developmental time (between two to six years) to that of ToM, and pretend play gives practice to mental state attributions (important to the development of ToM).

2.1.4 Major Settings for Children's Play

The play environment influences children to a great extent because this environment connects the children with the toys and the environmental atmosphere influences the children's play condition (experience), which in turn influences the children's development. Having a deep knowledge of the children's play environment and the environmental impact on children helps people create a beneficial environment for children (Mohammad, 2017).

2.1.4.1 The Home Setting and Children's Play

The indoor setting has been the most important setting for the children because they play the most in the indoor environment. Children spend more time indoors playing with their toys, friends, siblings, and parents at home or in the neighborhood. Results from numerous research studies shows that creation of indoor conditions for play is more solitary than it used to be because today's toys have become more commercial, just as today's toys have little to do with introducing young people to adult life (Elkind, 2003).

Theories show that children should be given access to free play in major living areas (Johnson, 1987). One suggestion is to turn kitchens and living rooms into spaces for both children and adults (Cohen, McGinty, & Moore, 1979) and give children easy access to appropriate toys and play materials furnished in the major shared living spaces. In summary, researchers have suggested when considering children's play in the home setting that more attention should be paid to the interaction between parents, children and their toys.

2.1.4.2 Play in Outdoor Settings

The outdoor playground is another important setting for children to play in; this environment shows less influence on today's children's development because children today have far less access to outdoor play spaces (Allen, 1968, P.1). Children tend to be attracted by the indoor play devices and toys in modern, high technology industrialized societies, but outdoor play is also very important for children's development. Here are three types of playgrounds.

Traditional playgrounds: are made up of fixed metal structures such as swings, slides, jungle gyms, merry-go-rounds, seesaws, and concrete "flooring." Climbing structures are often located in the periphery of the yard.

Contemporary playgrounds: are built from a variety of natural materials (e.g., wood, stone), railroad ties, and recycled materials. They are the most aesthetically pleasing (George, Naudeau, Salonius, & Pointe, 2005) and always are integrated within a natural environment.

Adventure playgrounds: have loose materials for children to play with as they wish. Children can use these materials to create their own play space. It is not designed to be aesthetically pleasing to attract children; it is designed to help children's creativity development and free play. A good example is the "junk" playground designed by architect C. T Sorensen, shown in Figures 2.2 and 2.3.

Figure 2.2 Children's play at "junk" Playground (The Junk Playground of New York City, Timothy 2016)

Figure 2.3 “Junk” Playground of New York City (The Junk Playground of New York City, Timothy 2016)

A successful playground allows children to play regardless of where they play or what has been provided for them to play with. First, a successful playground gives children a range of natural and sensory experiences, such as rough and smooth objects; tough, heavy and light objects to lift; wet and dry materials; soft and hard surfaces to run and jump on; opportunities to use their voice, senses of smell and so on. Second, they provide control, making children feel like they are invited to play rather than being pushed, which provides children their own responsibility of choosing. Third, it can give children some challenges, such as some higher slides. Fourth, more choices are provided for children, such as solitary areas or group spaces, multiple entrances and exits. Fifth, it includes fantasy materials, such as a mound of dirt or a tree branch.

2.2 Children’s Intellectual and Cognitive Development

2.2.1 Piaget’s Four Stages of Cognitive Development

Children’s cognitive acts are seen as acts of organization of adaptation to the perceived environment. Piaget (1963) proposed that young children might think in a different way to the older children and adults, and considerable research supports this idea. Piaget pointed out four basic concepts to understand the processes of the children’ s intellectual organization and adaption. The following concepts of *schema*, *assimilation*, *accommodation*, and *equilibrium* all refer to definitions from Piaget (1963).

Schema: are the cognitive structures by which individuals intellectually adapt to and organize the environment. They can be simplistically thought of as concepts or categories (Wadsworth, 1992). According to Piaget, children have several schemata. One example is at birth, infants will suck whatever is put in their mouths- a nipple, a finger, there is no differentiation only a single global sucking schema exists. Shortly after infants learn to differentiate the milk-producing stimuli, and for non-milk-producing stimuli they have two sucking schemata.

Assimilation: is the cognitive process by which the person integrates new perceptual matter or stimulus even into existing schemata or patterns of behavior. Taking for example, a child is walking down the road with his father, his father points to a cow in the field and says, “what is that?" The child says, "That's a dog". To the child the cow has all the characteristics of a dog, so it fits in his dog schemata. The process by which that the stimulus (cow) was assimilated into the dog schemata can be viewed as *assimilation*.

Accommodation: is the creation of new schemata or the modification of existing schemata. Sometimes when a child sees something new, the characteristics of the stimulus do not approximate those existing schemata. Children will create new schemata or modify the old schemata to fit the stimulus into it.

Equilibrium: is the "balance" between assimilation and accommodation. A child experiences a new stimulus and tries to assimilate the stimulus into an existing schema. If he or she is successful, equilibrium is attained for the moment. If the child cannot assimilate the stimulus, then the child attempts to accommodate by modifying a schema or creating a new one. When this is done, assimilation of the stimulus proceeds and equilibrium is reached.

2.2.2.1 Four Periods of Child Development

Piaget proposed that young children might think in a different way to the older children and adults, and considerable research has confirmed this. However, there also are a lot of areas he didn't focus on, such as a child's understanding of mathematical and scientific concepts. He divided children's whole development into four stages that are shown in Figure 2.4 and defined more fully in the paragraphs that follow (Piaget, 1963).

Period I.	Sensorimotor Intelligence (birth to 2 years). Babies organize their physical action schemes, such as sucking, grasping, and hitting, for dealing with the immediate world.
Period II.	Preoperational Thought (2 to 7 years). Children learn to think—to use symbols and internal images—but their thinking is unsystematic and illogical. It is very different from that of adults.
Period III.	Concrete Operations (7 to 11 years). Children develop the capacity to think systematically, but only when they can refer to concrete objects and activities.
Period IV.	Formal Operations (11 to adulthood). Young people develop the capacity to think systematically on a purely abstract and hypothetical plane.

Figure 2.4 Four Stage of Children's Development (Piaget, 1963)

Sensorimotor Intelligence Period (birth-2 years):

There are six stages in the sensorimotor intelligence period (see Figure 2.5).

Stage 1 (birth to 1 month): the infant is born with performing simple reflex behaviors (sucking, crying, grasping, and movement of arms, trunk, and head). Soon the infant begins to search for something. Piaget found that his daughter at birth sucked on nipples placed in her mouth. Soon she began to "search" for the nipple if it could not be found. The searching behavior is viewed as a change in reflex behavior- an *accommodation*.

Stage 2 (1-4 months): several new behaviors appear during this stage. Infants begins to develop their hand-mouth coordination, eye coordination and eye-ear coordination. Through

Piaget's observations, he found that the infant begins to habitually suck her thumb (hand-mouth), follow her eyes with moving objects(eye) and move the head in the direction of sounds (eye-ear).

Stage 3 (4-8 months): the child continues to perform new behaviors which become increasingly oriented toward objects and events beyond his body, and also begins to have intentional behavior (prior to this time, infants' behavior focuses on themselves). At the same time, the child begins to develop the coordination between vision and tactile senses. Piaget found that the child grasps and manipulates all the objects he or she can reach and repeats interesting experiences.

Stage 4 (8-12 months): the infant begins to anticipate events, demonstrating prevision. At this age, he or she applies the previous simple development of *causality* to see that other objects in the environment can be sources of activity. At this time the child begins to search for objects that he or she sees disappear (Piaget, 1952).

Stage 5 (12-18 months): the child through "experimentation" (trial-and-error process) rather through habitual application develops new schemata. And he or she is able to follow displacement sequentially if it is visible (the child cannot find the object which they didn't see hidden). Also, the child can separate between self and objects (he or she is a part of the world). The child comes to realize the objects still exist even though they cannot be seen.

Stage 6 (18-24 months): in this stage the child is able to follow invisible displacement with his or her development of mental representation of objects skill (the child can search objects that they do not see hidden). Eventually children realize that the objects are permanent.

Stage	*General*	*Object Concept*	*Space*	*Causality*
1 Reflex O-l mo.	Reflex activity	No differentiation of self from other objects	Egocentric	Egocentric
2 First differentiations 1-4 mos.	Hand-mouth coordination; differentiation via sucking, grasping	No special behavior re vanished objects; no differentiation of movement of self and external objects	Changes in perspective seen as changes in objects	No differentiation of movement of self and external objects
3 Reproduction, 4-8 mos.	Eye-hand coordination; reproduction of interesting events	Anticipates positions of moving objects	Space externalized; no spacial relationships of objects	Self seen as cause of all events

Piaget's Theory of Cognitive Development

4 Coordination of schemata, 8-12 mos.	Coordination of schemata; application of known means to new problems; anticipation	Object permanence; searches for vanished objects; reverses bottle to get nipple	Perceptual constancy of size and shape of objects	Elementary externalization of causality
5 Experimentation, 12-18 mos.	Discovery of new means through experimentation	Considers sequential displacements while searching for vanished objects	Aware of relationships between objects in space, between objects and self	Self seen as object among objects and self as object of actions
6 Representation, 18-24 mos.	Representation; invention of new means via internal combinations	Images of absent objects, representation of displacements	Aware of movements not perceived; representation of spatial relationships	Representative causality; causes and effects inferred

The Sensori-Motor Period

Figure 2.5 Characters of Development of During the Sensori-Motor Period (Piaget, 1963)

Preoperational Thought Period (2-7 years): In this period of time, children's intellectual behavior moves from the sensorimotor level to the conceptual level. Children's thoughts are truly representational and behavior sequences can be played out in the head rather than only in real physical events (Wadsworth, 1992). In summary of the research, it is important for children learn shape and space, especially to develop children's mental rotational thinking (their intrinsic dynamic space skill).

Children develop language quickly with rapid conceptual development. Children begin to use words as symbols in place of objects around 2 years old. By the age of the 3 years old the typical child has mastered the use of language. The child can speak and use most grammatical rules and understand when spoken to (Wadsworth, 1992). Language skill as a symbol of an object allows children to for use the specific mathematic name in place of the shape (shape's name), such as triangle, rectangle, and so forth (Wadsworth, 1992).

During this period, children's thinking is egocentric, centric, unsystematic, and illogical. Piaget (1963) listed the features of these childhood periods to illustrate the reasons logical thinking is restricted. The main property of preoperational thinking is divided into *egocentrism*, *centration*, *reversibility* and *conservation*.

Egocentrism

Piaget characterized the preoperational child's behavior and thinking as egocentric. That is, the children cannot take the role of or see the viewpoint of another. They think that other people's thinking is the same as theirs. As Piaget stated, the language and social behavior of children age from 2 to 6 are largely egocentric. It's not until around the ages of 6 to 7 that they begin to accommodate to others' perspectives and become more social.

Transformation

Another characteristic of this period of child's thinking is that it is not transformational. There is an example in Piaget's research in that the preoperational children cannot draw or reproduce steps at the same time. They can only focus on the initial and final position.

Centration

As a characteristic of preoperational thought, children tend to center on limited aspects of the visual stimulus. This phenomenon will become decertation when they are more than 7 years old.

Reversibility

Reversibility is the most clearly defined characteristic of intelligence according to Piaget. They cannot follow the line of the reasoning back to where it started, but only through their sensorimotor thought.

Conservation

Conservation is the conceptualization (schematization) that the amount or quantity of a matter stays the same regardless of any changes in shape or position (Wadsworth, 1992). Piaget (1963) presented conservation of number, area, and volume problems to the children in a research project. The three examples below illustrate the results.

Conservation of Number: In Figure 2.6, when the second rows of circles in (b) are presented separately from (a), the children think that the second row has more circles than the first row in Figure 2.6 (b).

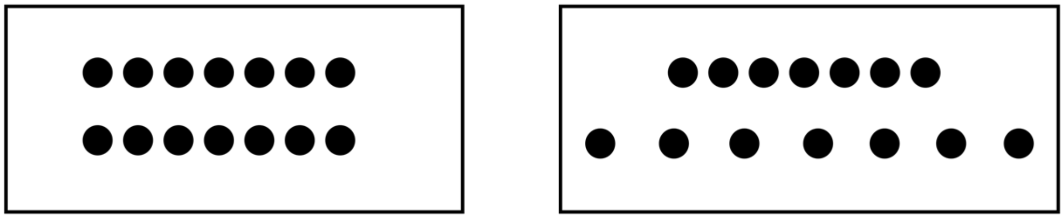
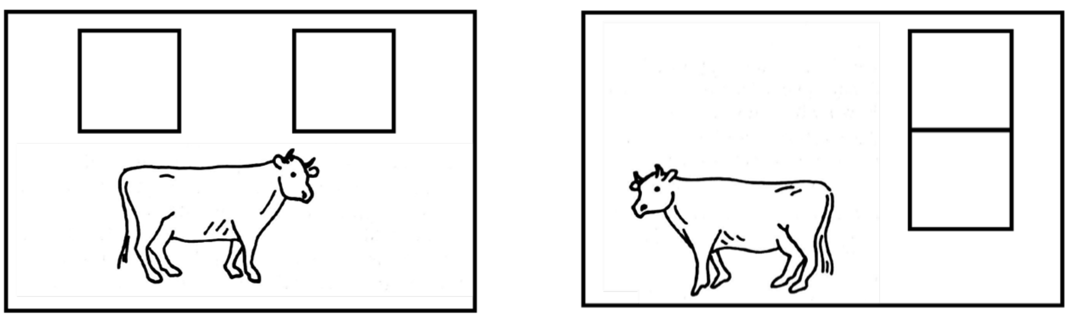


Figure 2.6 Transformed Length (Piaget, 1963)

Conservation of Area: In Figure 2.7, they think the cow in the second picture has more grass to eat even though area of the grass in the two pictures are same.



a b

Figure 2.7 Transformed Area (Piaget, 1963)

Conservation of Volume: Water was poured into a thinner but higher container from the previous one (Figure2.8). When asked, the children assumed that the higher container contains more water even though they are the same volume.

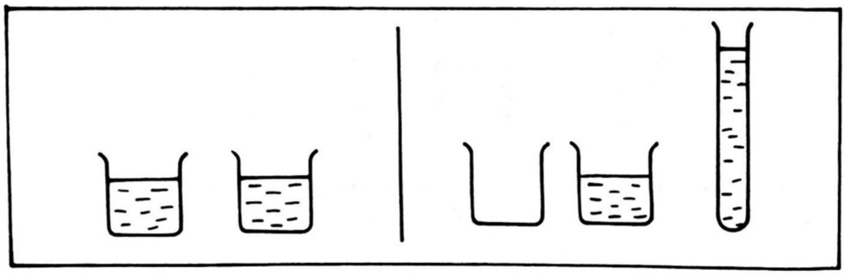


Figure 2.8 Transformed Volume (Piaget, 1963)

Piaget used the three mountains task experiment to explore children's sense of perspective and asked the child what he or she can see and what others from different perspective can see. The results showed that the child said that other people see the same as he or she does. The children's egocentric thinking restricts them from learning perspective view, which is a crucial part of extrinsic space skill. Extrinsic skills will be discussed in the following sections.

Concrete Operations Period (7-11 years): children develop the capacity to think logically and systematically to solve concrete problems (referring to concrete objects and activities, not solve hypothetical problems). They can assume the viewpoint of others and their language is social and communicative (they are not egocentric). They can decenter perceptions and attend to transformations and reversibility, so they can solve conservation problems (number, area, and volume) (Wadsworth, 1992). They no longer think the higher containers contain more water than the shorter containers in Figure 2.8. The two operations developed during this period are seriation and classification.

Seriation: they can mentally order events in a series, such as the length of stick A is less than the length of stick B and the length of stick B is less than the length of stick C, so they can visually determine the length of stick A as less than the length of stick C. Seriation learning occurs at different ages in an invariant sequence (Wadsworth, 1992). The child first learns to seriate length around 7, seriate weights of same size around 9, and seriate volume around 12 according to Piaget's observations (1963).

Classification: Most children can make simple classifications by age 4 (they prefer to compare one class). In the concrete operation period, children's classification develops to compare two classes at the same time. The following example from Piaget (1952) in Figure 2.9 illustrates the development of operations involved in the comparison of classes. In this period children can respond that there are more wooden beads than brown beads. They consider two or more kind of classes (material and color). In this period, children can focus on two or more features of the objects (such as putting the red triangle in the box).

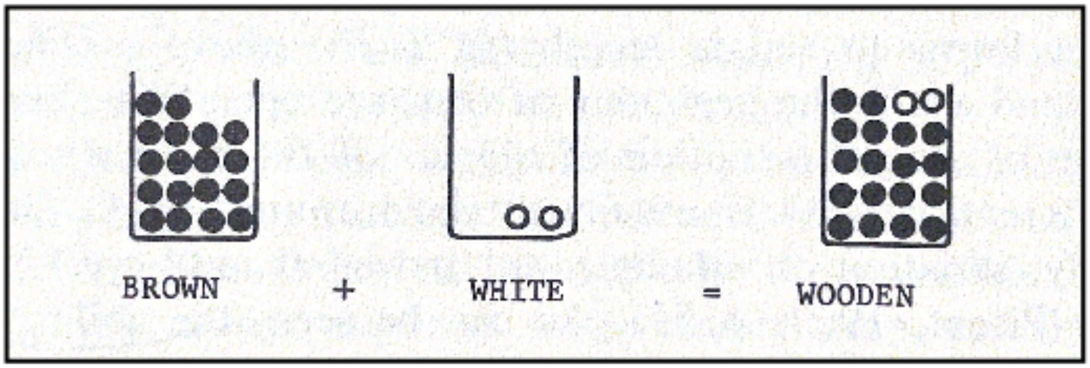


Figure 2.9 Comparison of Different Classes (Piaget, 1963)

Formal Operation Period (11-adulthood): They have the capacity to think systematically on a purely abstract and hypothetical plane. The period of formal operations is the culmination of the development of cognitive structures. Schemata typically reach maximum qualitative development by about age 15. The processes of assimilation and accommodation constantly modify cognitive structures through the period of formal operations. The adolescent can think logically in relation to all classes of problems, such as hypothetical problems and verbal problems (not only the previous period of concrete problems).

2.2.1.2 Factors Related to Cognitive Development

Piaget proposed that the children move progressively through four major stages. There are four broad factors that relate to the development of the child's cognition and intellectual development: *maturation*, *physical experience*, *social interaction,* and *a general progression of equilibrium*.

The contribution of maturation is in neurological growth and the development of the endocrine system. The second factor is physical experience; this part is important. A child must have experience with objects and stimuli in the environment in which he or she acts on objects in their daily life. According to Piaget's statement (1963), the growth of cognitive structures (schemata, assimilation, accommodation, and equilibrium) requires interaction with the environment. The interaction is between the children's organs (especially the sensory organs) and environment. This statement emphasizes the importance of sensory activities (sensory play) in children's cognitive development. Section 2.6 will continue to talk about the relationship between sensory play and learning shape and space (cognitive and intellectual development).

Another factor in cognitive development is social interaction. Piaget meant that interchange of ideas between people (peers, parents, and other adults) can construct and validate children's concepts. The equilibration (attaining equilibrium) is seen as an internal self-regulating system that operates to reconcile the roles of maturation, experience, and social interaction. All these factors are necessary and none of them by themselves is sufficient to ensure cognitive development (Piaget, 1952).

2.2.2 Biggs and Collis's SOLO Model of Intellectual Development

Biggs and Collis (1982) described the Structure of the Observed Learning Outcome (SOLO)

Model (commonly referred to as the SOLO Taxonomy) as a general model of intellectual development. SOLO had its origins in the stage development ideas of Piaget and the information processing concepts of the 1970s. It can be considered within the broad research framework referred to as neo-Piagetian. As such, SOLO has much in common with the writings of Case (1992), Halford (1993), and Fischer and Knight (1990), to name a few (cited in Pegg, 2014).

Five modes of children's thinking in SOLO model

According to Pegg's analysis the SOLO model divides the children's thinking into following five modes:

Sensorimotor (soon after birth): The individual reacts to the physical environment. For the very young child, it is the mode in which motor skills are acquired.

Iconic (from 2 years): the individual internalizes actions in the form of images. It is in this mode that the young child develops words and images that can stand for objects and events. The mode of functioning later assists in the appreciation of art and music and leads to a form of knowledge referred to as intuitive.

Concrete Symbolic (from 6 to 7 years): the individual is capable of using or learning to use a symbol system such as written language and number systems, which have an empirical referent. This is the most common mode addressed in learning in the upper primary and secondary level.

Formal (from 15 or 16 years): the individual can consider more abstract concepts and work in terms of “principles” and “theories”. The individual is no longer restricted to a concrete referent.

Postformal (possibly at around 22 years): the individual can question or challenge the fundamental structure of theories or disciplines.

Five levels of children’s response in SOLO model

Also, the SOLO model divided the children’s responses into the following five levels:

Prestructural (below the target mode): the learner is frequently distracted or misled by irrelevant aspects of the situation and does not engage the task in the mode involved.

Unistructural (U): the student focuses on the domain/ problem but uses only one piece of relevant data.

Multistructural (M): the students can use two or more pieces of data without perceiving any relationships between them. No integration occurs.

Relational (R): the students can now use all data available, with each piece woven into an overall mosaic of relationships. The whole has become a coherent structure with no inconsistency with the known system.

Extend abstract: the student goes beyond the data into a new mode of reasoning and can generalize from new and abstract features.

SOLO taxonomy model

To combine the propose of children's thinking mode and response levels Bigg and Collis (1982) use UMR mode to explain the development of intellectual development. That is, children learn knowledge through the UMR model, from using one relevant piece of information to more relevant data to using all the available data in Figure 2.10.

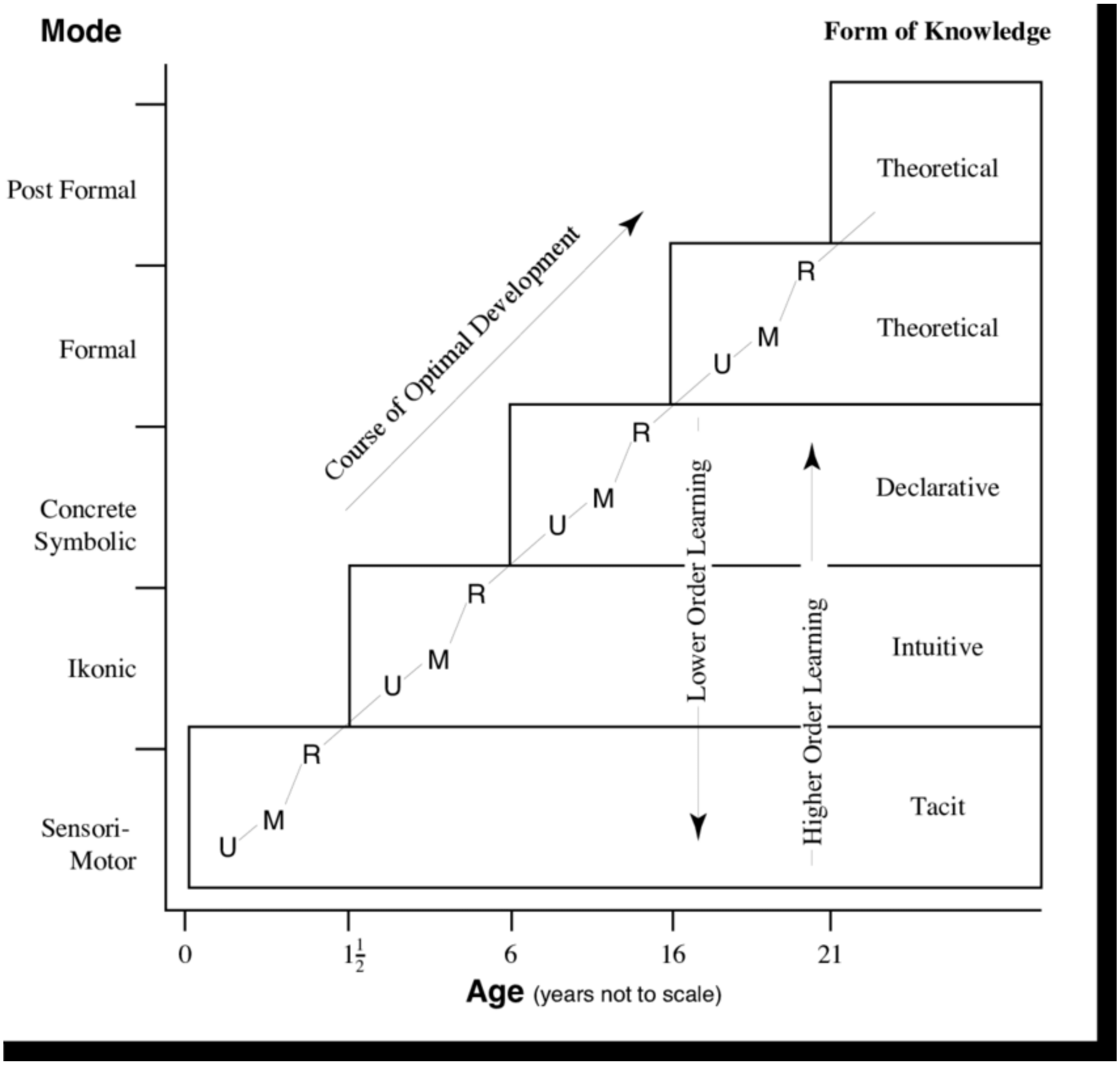


Figure 2.10 Modes, Learning Cycles and Form of Knowledge (Pegg, 2014)

2.2.3 The Different Between Piaget's and Biggs and Collis's Theory

Comparing with the Piaget's stages of development, the major modification of SOLO taxonomy model is that the SOLO model places Piaget's early formal stage (the last stage of cognitive development) into the earlier group of stages covered by creative operations. And the model gives the broad exploration of the higher thinking of Formal (consider abstract concept) and Postformal stages (critique structure of theories and disciplines).

What's more, Piaget implies that children's understanding and performance are related to their stage of cognitive development and related to their age. Instead, Biggs and Collis view the children's understanding and performance as more an individual characteristic and context specific. That variety is related to nature or abstractness (referred to as the mode of thinking) and the individual's ability to handle, with increased sophistication, relevant cues (referred to as the mode of thinking) (Pegg & Davey, 2007).

In sum, Biggs and Collis's theory can be viewed as hyphenated-Piagetism. The SOLO model is more mature compared to Piaget and suggests children's learning should take the individual differences and the environment into consideration. Just as talked about in the previous section, children can have the different performances and experiences for learning the same knowledge even in the same environment. Also, different genders at the early ages have different thinking modes which may have an impact on different abilities of learning.

2.3 Children's Biological Development of Senses

Babies begin to learn the environment through their sensory system. They take in information through their sensory organs, and then their senses and mind work together to make it a memory.

Sensory development forms the foundation of a child's learning and perception, especially in early childhood.

Babies start reacting to simple sensory stimulation from birth. Later they start to develop simple sensory coordination. Between one to four months, they suck their thumb (hand-mouth coordination) and move their head in the direction of sound (eye-ear coordination). From four to eight years old, they grab all objects they can reach (vision-tactile senses coordination). Much later their visual depth perception develops, which enables them to move safely without falling from stairs or walking into things. By the end of the first year, babies achieve sensory integration. They are then able to process information from multiple senses together-especially vision and hearing (De Witt, 2016).

This section mainly discusses the development of children's senses, while Chapter 4 will discuss more about the current activities to explore children's senses.

2.3.1 Senses System

Studies show that the sensory system contains five basic senses, visual senses, aural senses, skin senses (touch senses) and chemical senses (smell senses and taste senses), and two other important senses, proprioception and vestibular.

2.3.1.1 Sight (Visual)

Sense of sight: Of all senses, sight may be the most important because of all the information taken received, an estimated eighty percent comes in through our eyes (Pringle, 2000).

Through the sense of sight, humans can see many colors, objects near and far to identify various things, judge the size of faraway objects (judge the depth), and judge the distance and speed of moving objects (Pringle, 2000).

Seeing with the brain: When eyes look at something, the image enters the eyes and is sent through the *optic nerves*, seen at the rear of the brain in the *visual cortex* (the brain provides different information such as form, colors, motion and so on).

Development of sight: Sight is the least developed of the senses at birth. Babies cannot focus clearly or see further than 30cm ahead of them. By the age of one year and eighteen months, children have the same vision as an adult. Children also develop the ability to recognize different colors. At about 5-months old, children can see colors with their still developing vision. In early ages, children find bright colors such as the primary colors red, yellow, and blue, and the secondary colors green, orange and purple appealing. As their sight continues development, they can then recognize other colors, such as light shades of pink and beige or neutral shades of gray and brown.

2.3.1.2 Hearing (Auditory)

Sense of hearing: Through the sense of hearing, we are able to locate (determine the direction and distance) the sound, and the sense helps us communicate with one another through speech.

Hearing with the brain: The sound waves enter the ear, changes to physical vibrations by the *eardrums*, and then fluid vibrates in the *cochlea* and then transfers to electrical nerve impulses. The nerve impulses travel instantly to the back of brain (*medulla)*, sending messages to other parts of the brain, which makes split-second choices (which sounds can be ignored and which need attention) (Pringle, 2000)

When speaking: After hearing something, the brain chooses words to speak. It sends a stream of nerve impulses to muscles in the chest, throat, jaws, and mouth. Muscles in the upper chest push air from lungs up to the *trachea*. Muscles in the *larynx* move rapidly and change the steady flow of air into a series of puffs of air that pass over vocals cords. Air rushing over the vocal cords make them vibrate and produce sound waves.

Sense of balance and hearing: The special organs in the inner ears are related to balance ability. There are three semicircular canals at different angles help to detect different motions of the head: up and down, side to side, or forward and backward. Also, at the base of the semicircular canals are two other structures called the *utricle* and *saccule*. They contain hair cells, and crystals (*otoliths*). Otoliths cause the hair cells to move and send messages about the head's movement to the brain (Pringle, 2000).

Development of hearing: Humans begin to hear before they are born, when in the mother's womb (they hear the faint the sounds of the mother's heartbeat, voice, and music too) (Pringle, 2000). Newborns can identify their mother's voice early on and can hear high-pitched sounds well.

2.3.1.3 Smell (Olfactory)

Sense of smell: Compared with seeing and hearing, the sense of smell is simple and direct. Human can recognize thousands of odors. And of all the senses, the sense of smell is most closely tied to our memories (Pringle, 2000)).

Through the sense of smell, we can differentiate between smells. This can give people pleasure and sometimes warn them of danger.

Smelling with the brain: When people inhale, a sample of outside air goes deep inside the nose, scent molecules in the air are intercepted, an electrical message travels from the olfactory bulbs to the area of human's brain that is involved with memories, and the brain recognizes the odor (Pringle, 2000).

Name what smell: In 1752, Carolus Linnaeus divided all odors into seven groups: aromatic, fragrant, ambrosial (musky), alliaceous (garlicky), hygrine (cheesy), repulsive, and nauseous. In

1916, German Hans Henning divided smell into six groups, that is floral, fruity, resinous, spicy, putrid, and burned. People, especially scientists, try to clarify the categorization of smells, but no system clarifying all smells works very well (Pringle, 2000).

Development of smell: From birth, smell is well developed but must be further stimulated. And research show that females have a better sense of smell than males, even as children (Pringle, 2000).

2.3.1.4 Taste (Gustatory)

Sense of taste: The human sense of taste is much simpler than the senses of sight, hearing, and smell. There are just four kinds of taste receptors (buds) in the mouth, sweet, sour, salty and bitter. But humans don't have taste buds that detect hot things; instead that is related to pain (Pringle, 2000).

From the sense of taste, we can detect different tastes- sweet, sour, salty and bitter, and identify dangerous substances, all to decide if we can eat the food.

Taste with brain: When we bring food to the mouth, scent molecules rise to the nose. More scent molecules are released from the food when put it is into the mouth. They rise to the *pharynx*, the passageway that connects the back of the mouth to back of the *nasal cavities*. Scent detectors send messages to brain about the food's smell at the same time taste detectors are sending messages to the brain about its taste (Pringle, 2000). Even though there are only four taste buds, we can taste lots of flavors that are the result of both scent and taste.

Development of taste: Newborns are born with a full set of taste glands and are born with the sweet taste most developed. Babies have more taste buds than adults.

2.3.1.5 Touch (Tactile)

Sense of touch: Touch is unusual in many ways. It is located everywhere from head to toes in between. The skin is one giant sense organ.

Through the sense of touch, we can feel pain, heat, cold and pressure, and identify objects by feeling their shape and texture.

Proprioceptors (a special type of touch): This kind of touch sense enables people to keep track of the location of the legs, arms, head, and the rest of the body. This is demonstrated through Pringle's example of when closing eyes and making the two thumbs point inward, the thumbs touch each other. The ability of, without seeing, making the thumbs move and touch exactly, is related to the sense of proprioception. It always works when humans are on the move.

Touch with brain: Regarding the skin senses, the sensation perceived through the skin are touch (vibration, tickle), temperature and pain. Receptors in the skin distinguish the different stimuli and send the information to the brain via the *spinal cord*. There are a number of receptors throughout the body; fingers are one of the most sensitive areas of the body.

Development of touch: The fetus can react to temperature and pain stimuli in the womb, and the sense is developed well at birth. Babies need to receive constant loving touch to develop cognitively.

2.3.2 Senses System and Perception

According to Ludel (1978), humans learn and adapt from their sensations. They use their receptors (eyes, ears, skin) to gather energy (light, sound, temperature, or other kind of stimulus) from environment, and change the energy in their nervous system. The nervous system analyzes, changes, and abstracts the sensory information. The process of analyzing, changing, and abstracting the physical sensations is called perceiving.

People perceive environments differently, related to their sensitivity and previous experience. The sensation stimulus and the experiences when playing is important for the children's cognition and learning.

Research finds some parts of the receptor system are the more sensitive areas of the body, such as toes, hands. The stimulation of these parts when playing would help children learning from senses perception.

According to Winne (1971), senses are the connection between the internal cognition and the external information from the environment. Children’s shape recognition ability is highly related to their senses. Theories pointed out that the sensory system records both tangible and abstract ideas, feeling and emotions. Feeling and emotions are closely linked with creativity (Yardley, 1970). The feelings when learning the shape are related to children's creativity. Therefore, the feelings when learning (recognizing shapes) should be emphasized. In summary, the children’s shape recognition is related to children’s senses and children's creativity.

Erikson (1985) advocates the need for ‘appropriate stimulation’ under the care of trained teachers to increase the acuity of the organs with which we have been endowed. Appropriate stimulation can come in many forms, such as 'hands on' activities, art, music, etc. Children immerse themselves in activities, using their ways of knowing (counting, touching), broadening, and organizing their knowledge, and exploring the knowledge they didn't know (such as shape recognition). Just as many suggest that experiences which challenge the senses lead to vivid self-discoveries (Yardley, 1970; Hall, 1970; Holdaway, 1978).

Taking children’s toys as an example, children play with geometrically shaped toys to learn shapes. They use their movement (grabbing) to put shapes in suitable holes. In the process of playing, they maybe cannot match the shapes and place the wrong shape in the wrong hole. They will retry. The wrong experience can help them recognize the shapes’ differences, which they didn't know before. The senses may enable children to perceive shape and space at greater depth. This thesis will talk more about the relationship of the multisensory system and shape and space learning in section 2.6.

2.3.3 Senses, Perception and Cognition Growing with Age

The perception picks up information from the environmental elements which receptors are collecting. Children's bodies discover and learn from the environment. Exploration becomes increasingly specific and systematic with age (Gibson & Spelke, 1983). Hence, it can be argued, that human perception improves, not declines, as a child grows in age. Their perception of such things as form, pattern, shape, size, spatial arrangement, as they are growing, develop gradually.

2.4 Sensory Play

For young children, play is the lifeblood of learning (Hendrick, 1990). Sensory play is also known as messy play, which includes any play that engages a child's senses (Maynard, 2009). Sensory and play are synesthetic. Young children grab, taste, and throw whatever they can get their hands on to understand their worlds, which involves the children's senses and helps children have a better play experience. On the other hand, the best way to develop and improve a child's sensory development is through play.

2.4.1 Introduction of Montessori Education

Montessori education is a prime example of sensory play learning. A well-known Italian educator, Montessori built a "children's house", an environment which is offered to the children (infant to twelve) to develop their abilities, such as language, math, science, geography, music, and so on. The technique of Montessori's education method can be divided into three parts: Motor education, sensory education, and language (Montessori, 1965).

According to the Montessori method, several characteristics can be compared to previous educational methods.

The use of object: Montessori provides children materials (eighty-three sets) that are designed for them. Children learn shapes through touch and even listening in addition to just seeing them. For example, the wooden cylinders involve placing a set of ten graduated cylinders into their appropriate slots in a long wooden base. Children will learn through the failure trials of the process of mismatch and rematch rather than under no guidance (Montessori, 1965).

Structure of materials: the materials used in Montessori is different to some wooden or plastic blocks for construction play in preschool; they are developed to teach spatial dimensions, for example in the three sets (the pink tower, the brown stair, and the red rods) shown in figure 2.11, each set varies from three dimensions to two dimensions to one dimension. These three levels perfectly match to children's ability. Children more than 7 years old focus from one difference parameter (centration thinking) to several parameters at one time (Wadsworth, 1975).

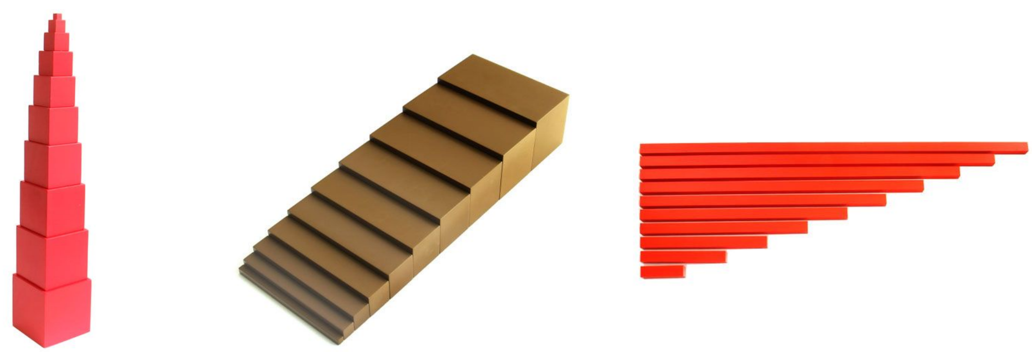


Figure 2.11 Montessori's Materials, The Pink Tower, the Brown Stairs and The Red Rods (montessori-nw.org)

Children are Interactive: Montessori lessons are also interactive. Most Montessori lessons involve individuals or group of two or more children. For most lessons, the teacher sits at a table, shows children how to use the materials, and the children take turns. Children in this way interact with materials which have a great influence on them. Just as Michelene Chi (2009) suggested, the best learning comes from contexts that are not just active or constructive, but also interactive.

Freely Chosen and Limited Choice: In some preschool settings children can choose their own abilities and spend time playing. This choice varies by level (Lillard, 2005) Free choice exists at the macrolevel of classroom environment: most of the time, students choose what they work on, such as, the children can choose to iron napkins or cut carrots offered in the classroom. At the more microlevel of exercises within the environment, Montessori offers less freedom (Lillard, 2013), such as children cannot choose to play with materials the teacher has not yet shown them how to use.

Giving children free choice with restrictions interfaces with children learning for specific purposes. Children of different ages have different abilities, which may be conducive for learning certain knowledge, which is similar to Piaget's (1963) point of view "giving no education is better than giving it at the wrong time". Under the teacher's restriction that limits choice, children can learn things better. It is the same in teaching children shape and space. Children's thinking levels and ability is important to their shape learning. Chapter 4 will introduce the children's ability matched to learning content in detail.

Solitary or with Peers: Montessori lessons can involve individuals or small groups. Apart from these lessons- each might typically take twenty minutes for each child- children choose whether to work alone or with peers. Younger ages prefer to work alone, and older age children prefer to work with peers, in line with Piaget's (1963) cognitive theory: younger children have egocentric thinking, but after 6-7 years old they transfer to social thinking and come to have more group interaction (cooperation and coemption) (Montessori, 1965).

Intrinsic rewards and fun: Compared to conventional didactic teaching methods in which the teacher will give children extrinsic rewards such as good grades to inspire them, in Montessori education does not give grades but instead relies on the intrinsic reward of learning as an end. Children concentrate and have fun playing with the materials they choose according to their interest. About the extrinsic rewards, a lot of research shows it can disrupt interest in previously attractive activities (Deci, Koestner, & Ryan, 2001; Warneken & Tomasello, 2008). Never receiving grades or rewards in Montessori school for doing schoolwork allows children to retain an intrinsic interest in such work (Lepper & Henderlong,2000).

2.4.2 Influence of Montessori Education

Montessori's method quickly spread to serve different populations of children after the first children's house opened. In just five years, her classrooms had opened around the world, including an outdoor "classroom" at the University of Virginia (Holsinger, Heblich, & Walters 1976).

2.4.3 Development of Montessori Education

Montessori's sensory method is more focused on the visual and tactile combination and doesn't take stimuli of other senses into consideration. The reason is based on the previous research in that period was more focused on the sight and touch. With continued multisensory research, studies demonstrate the other senses, such as chemical characters (olfactory), could also be used in the children's learning. Section 2.6.1 will talk about multisensory development and the following chapter will introduce how current activities explore all the senses and what sensory interactions designers can put into designing tools explained in Chapter 4.

2.5 Shape, Geometry and Space Education

Shape is an extensive concept. Geometry is concerned with shapes, space, and composition with shape's characteristics, size, and relation to each other (Vincenzo, 2015). Children's spatial sense is their awareness of themselves in relation to the people and objects around them (geometry and spatial sense in the early childhood curriculum) (Copley, 2000). Children's early education of geometry and space, two important math curricula, serve as the foundation of a mathematics ability in the future. This section will talk more about the development of these two concepts of education for young children, what to teach regarding geometry and space, why are they so important for children at a young age, and some basic teaching methods.

In Chapter 3, this thesis will continue to analyze the current shape and space teaching activities through case studies of current products. Chapter 4 incorporate shape and space learning content into design guideline.

2.5.1 The Development of Geometry in Young Children

2.5.1.1 The Piaget's Theory of Geometry Development

Regarding children's geometric conception, in 1967 Piaget and Inhelder claimed that the development of more sophisticated spatial concepts involves increasingly systematic and coordinated action. Their hypothesis statement was that geometric ideas develop from the topological relations levels (e.g., connectedness, enclosure, and continuity) to the projective (rectilinearity) and the Euclidean levels (angularity, parallelism, and distance). This statement was opposed by a lot of people because it focuses on cognitive psychology and is not grounded on education. Many people think the children's shape recognition ability exists before 7 years old.

2.5.1.2 The Pelevelan Van Hiele Model of Geometry Development

In 1986, Pelevelan Van Hiele stated that there are five levels of thinking and understanding in geometry: 1. visual, 2. descriptive, 3. analytic, 4. abstract and relational, 5. formal deductive, and mathematically rigorous (Figure 2.12).

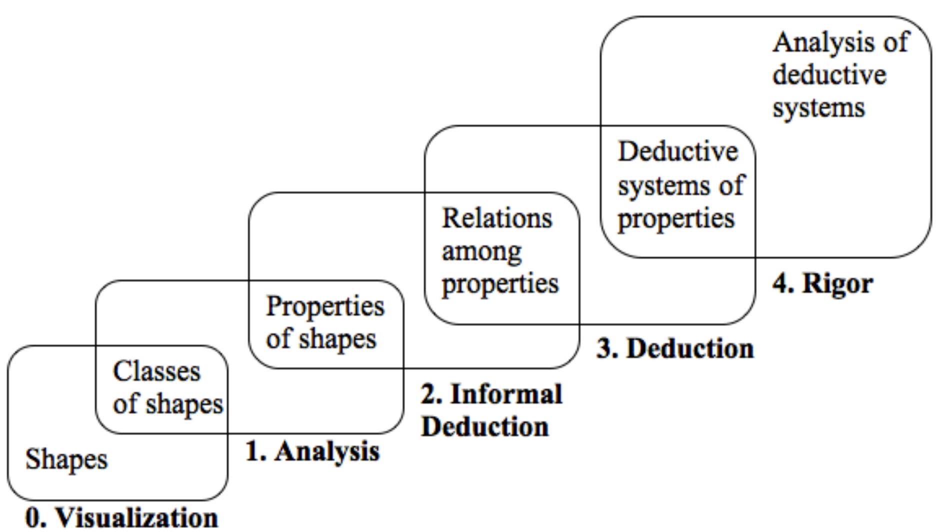


Figure 2.12 Van Hiele Theory of Geometric Thought (Pegg & Davey, 2007)

At the visual level, which begins with nonverbal thinking, children identify shapes according to appearance, recognizing them as visual gestalts using visual prototypes. For example, children might say "it's a rectangle because it looks like a box." At the descriptive level, figures are the bearers of their properties. Children judge the figure because it has certain properties, such as, an equilateral triangle has properties such as three sides; all sides equal; three equal angles; and symmetry, both about a line and rotational (Pegg & Davey, 2007).

At the informal deduction level, properties are logically ordered. Students use properties that they already know to formulate definitions, for example, for squares, rectangles, and equilateral triangles, and use them to justify relationships, such as explaining why all squares are rectangles or why the sum of the angle measures of any triangle must be 180 (Pegg &Davey, 2007).

At the deduction level, properties are in deductive systems. Students attain logical reasoning ability and prove theorems deductively. At the last level of rigor, analysis of deductive systems, people establish and analyze theorems in different postulation systems (Pegg &Davey, 2007).

Van Hiele's geometric thinking model has had a great influence in the field of the mathematic teaching. More recently Douglas H. Clements (1992) proposed a pre-recognitive level (3-6) that exists before Van Hiele Level 1 ("visual level") and that Level 1 should be reconceptualized as syncretic (i.e., a synthesis of verbal declarative and imagistic knowledge, each interacting with the other) instead of visual (Pegg &Davey, 2007).

2.5.1.3 Comparing of Piaget's Theory and Van Hiele's Model

Piaget Theory of Shape and Space

Even though Piaget and his coworkers published two significant works relating to this area, *The Children's Conception of Space* (Piaget & Inhelder, 1956) and *The Children's Conception of Geometry* (Piaget & Inhelder, 1960) (that have been followed by various studies in the field of spatial cognition), little impact on classroom practice has resulted. Part of the problem lies with Piaget's "topological primacy theory" and lack of supporting observation-oriented examples. There have been some fundamental doubts about this theory and according to these reasons it has proven difficult to build a school syllabus using this theory (Drake, 1982).

Van Hiele's Model of Shape and Space

Combining Piaget concept's problems, the team van Hiele and van Hiele-Geldof put forward their theoretical perspective for teaching and learning of geometry, which is in contrast to Piaget's psychological theory orientation. Also, their model is more descriptive than perspective (Pegg & Davey, 2007). Even though their model makes the significant progress of coming up with the structural invariants identified, new tools or a different framework still needed to be proved (Pegg & Davey, 2007).

2.5.2 The Development of Spatial Reasoning in Young Children

This section will introduce children's development of the spatial reasoning skills. What is spatial reasoning?

2.5.2.1 Dimension of Spatial Skill

This part will introduce Uttal et al.'s (2013) typological framework of spatial skill (Figure 2.13). It provides an overview of spatial reasoning, which can be divided in term of two dimensions: the static- dynamic dimension and intrinsic-extrinsic dimension. In brief, the static-dynamic dimension distinguishes two types of spatial information-one that is fixed (main analysis object or reference frame remain stationary) and the other that changes (objects move or are moved). The intrinsic-extrinsic dimension distinguishes the nature of spatial information (define or describe an object) to attend to (code objects' locations relative to each other or a frame of reference). Through this principle spatial skill can be divided into intrinsic-static, extrinsic- static, intrinsic-dynamic, and extrinsic- dynamic skills (Okamoto et al, 2015). The following content uses some specific examples and classical tests to introduce the four spatial skills separately.

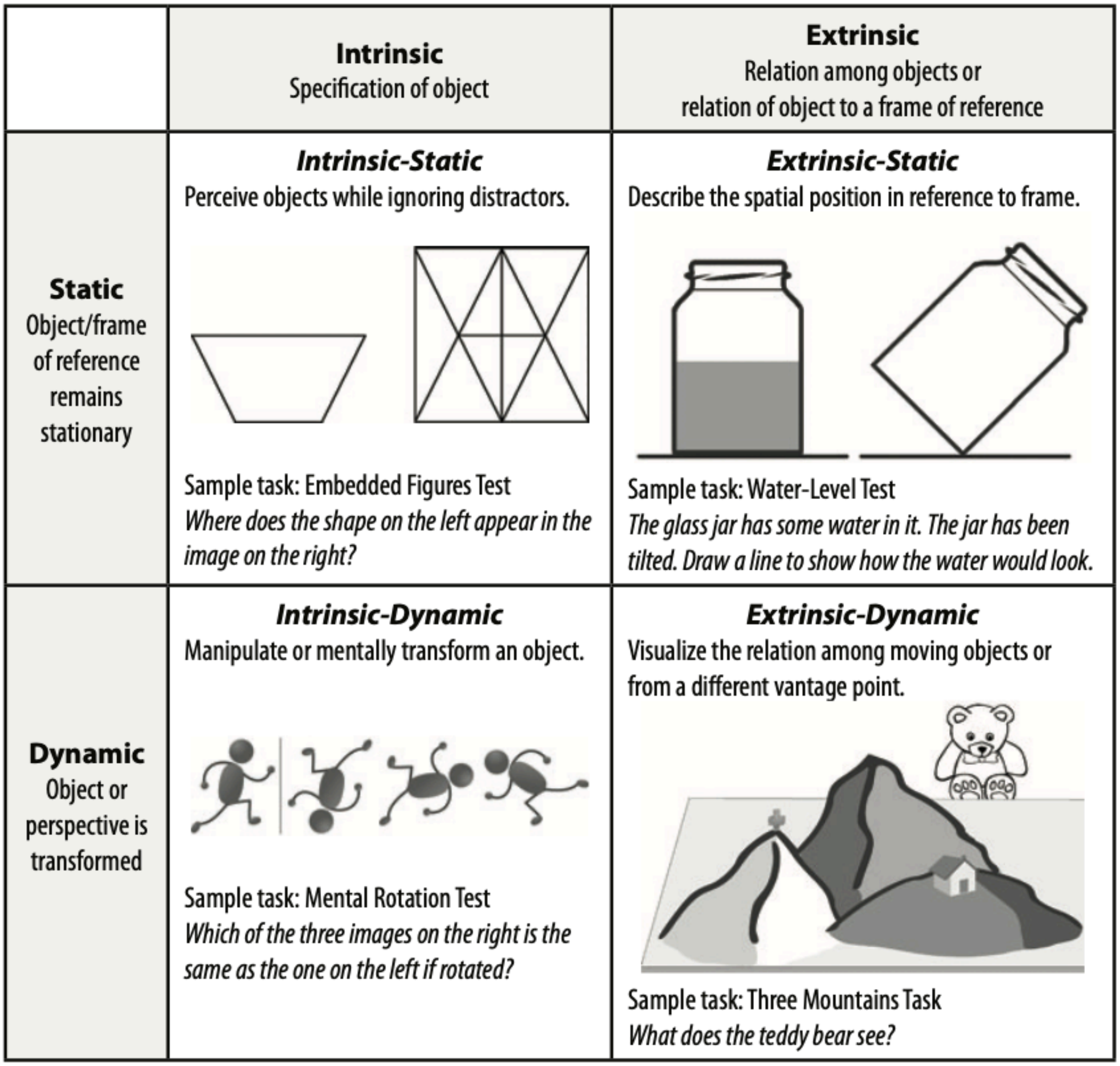


Figure 2.13 2*2 Typology of Spatial Reasoning Categories (Uttal et al. 2013)

Intrinsic- Static Skill

If you want to renovate your kitchen, can you imagine what your kitchen will look like when it is complete? If so, you are using spatial visualization skills, which is an intrinsic-static skill. Intrinsic-static skills are necessary for recognizing, describing, and classifying the spatial attributes of an object and the relation of parts within the object (Kastens & Ishikawa, 2006). This space skill has some overlap with the geometric skill of analyzing the property of the shapes.

Two common measures of the intrinsic-static skill are Embedded Figures Test (EFT; Witkin, 1971) and Hidden Figures Test (Ekstrom et al., 1976). Witkin's EFTT (see Figure 2.14), for example, asks participants to identify simple shapes that are embedded in a complex shape. The original test has been modified for use with children 5 to 12 years old (children's Embedded Figures Test; Karp & Konstadt, 1971) as well as with preschoolers 3 to 5 years old (Preschool Embedded Figure Test; Coates, 1972).

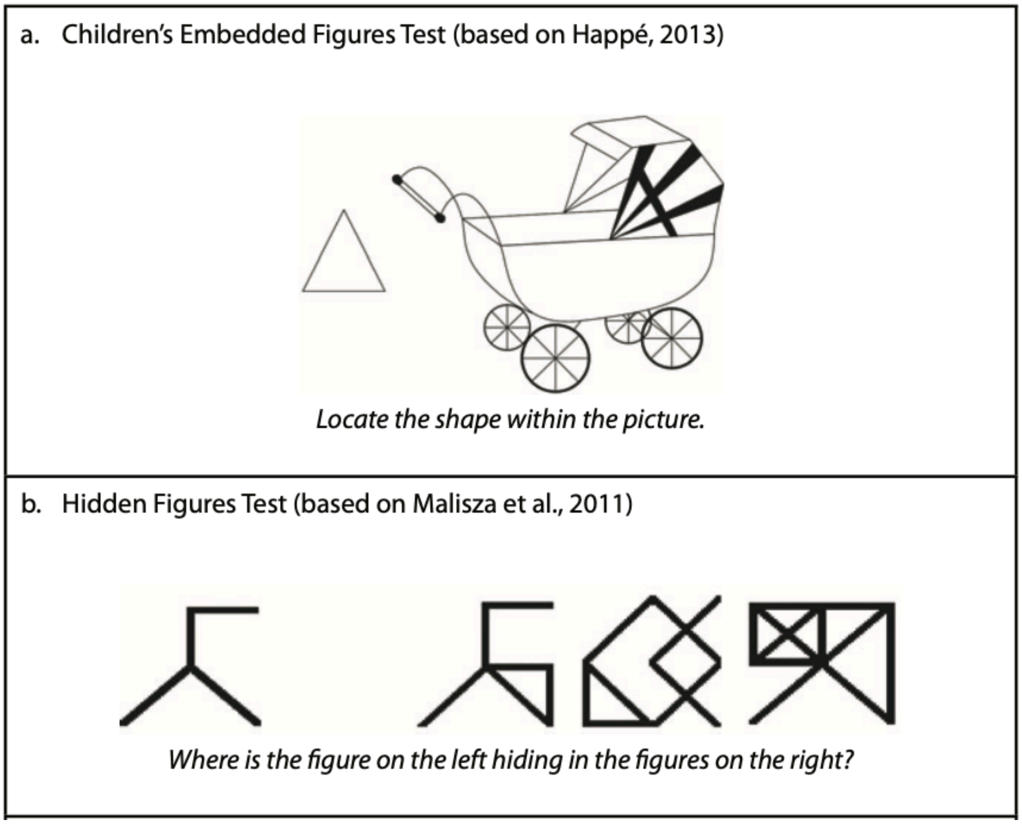


Figure 2.15 Tests of Intrinsic-static Skills (Uttal et al. 2013)

The results of the test show that preschool children's (from age 3 to 5) intrinsic-static spatial understanding (attributes of an object and relation of parts with object) are scarce. Preschool children have not yet developed the correct measures to identify the shapes, or their perceptions of intrinsic-static information (attributes of an object and relation of parts with object). Clements et al. (1999) examined preschool children and found that these students recognize the basic geometric shapes. He finds children can have visual cues and property cues, but they preferred to identify the simple shapes through visual cues, not property cues. For instance, the children preferred to explain that it looks like a circle but not that it has no corners to identify a circle. This age group of children matches to Level 0 of Van Hiele's levels model of thinking and understanding in geometry. They recognize the shape from its appearance (Okamoto et al, 2015).

Extrinsic- Static Skill

Imagine you come to an unfamiliar city, and you try to get from A to B. Now you stand in front of the subway map. Could you make a route plan to take you to your destination? Extrinsic-static skills, such as planning a route, predominantly relate to mapping (symbolism map and standard map) or other perceptual tasks (code objects' location in relation to reference system against a distracting field change) (Davis, 2015). According to Uttal et al.'s (2013) meta-analysis, extrinsic-static skills have the greatest potential to be learned through education and training compared to the three other spatial skills. Figure 2.15 shows some classical tests of the extrinsic-static skill.

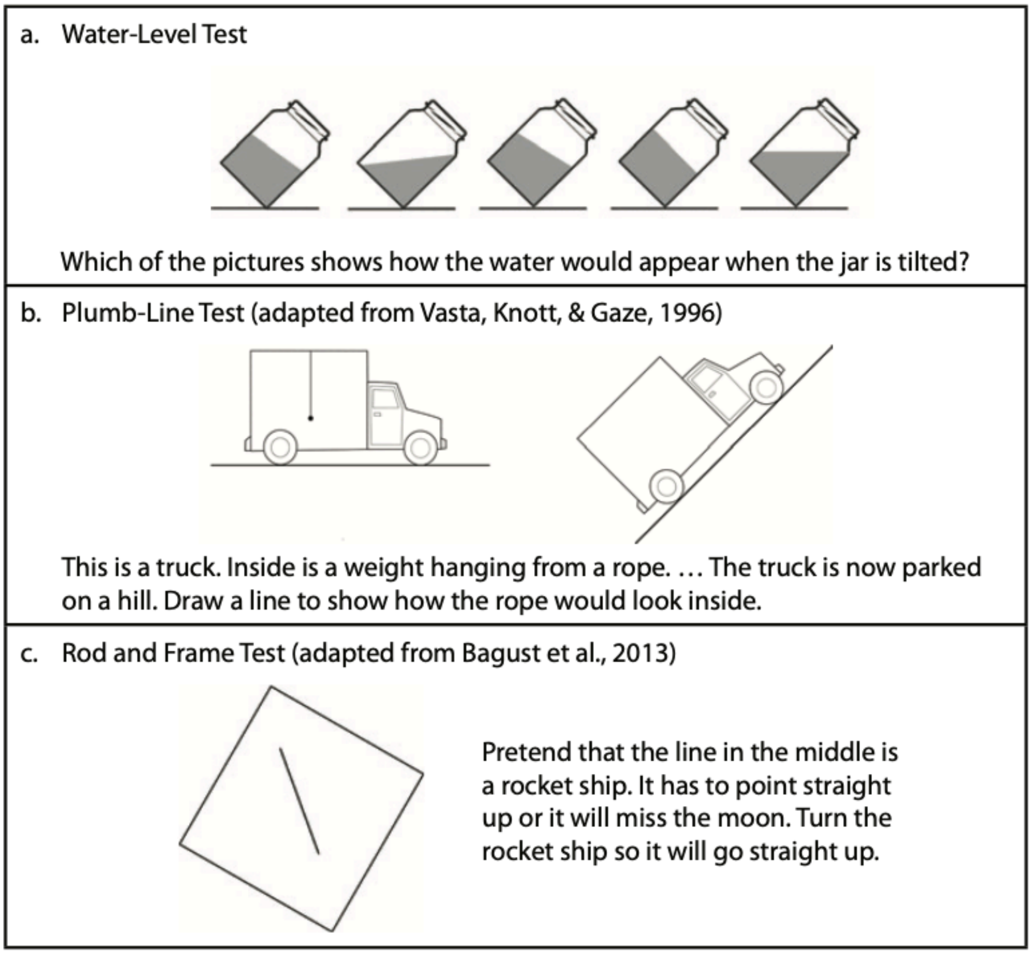


Figure 2.16 Test of Extrinsic-static Skills (Uttal et al. 2013)

The extrinsic-static information develops in young children when studying simple maps and models. Children's understanding of a simple map is initially from the children's egocentric perspective, which is a distinct feature for the preoperational thought period for children ages 2 to 7 in Piaget's cognitive development model. According to the survey, children of three years old children show early signs of the ability to identify the location of an object in a 2D representation and its corresponding location in an enclosed room or small space using a relatively simple map (locating the position of the bed in a room, using 2D rectangular shape to represent the bed location and the paper to represent the room) (DeLoache,1987; Huttenlocher, Newcombe, & Vasilyeva, 1999). With another couple of years, children begin to identify object location through inference such as using combinations of objects to form geometric cues or partially constructed geometric objects (Vasilyeva & Bowers, 2006).

For this skill, more evidence suggests that children may perform better when using real or 3D models than 2D representations of them (Baldy, Devichi &Chatillon, 2004). This serves as a reminder for educators to better teach children in an 3D environment, not through 2D drawings or electronic devices.

Intrinsic-Dynamic Skill

When a child spends hours playing Tetris, the game requires their mental rotation. That is spatial transformation in their mind, an element of the field of intrinsic-dynamic skills. The intrinsic-dynamic skills concern some spatial transformation of a given object such as rotation, folding, cross-sectioning and deformations (Newcombe & Shipley, in press) and is associated with a number of measures, including block designs, paper folding and the Wheatley Spatial Test (Wheatley, 1996; Uttal et al., 2013). Figure 2.16 demonstrates some tests related to the intrinsic-dynamic skills.

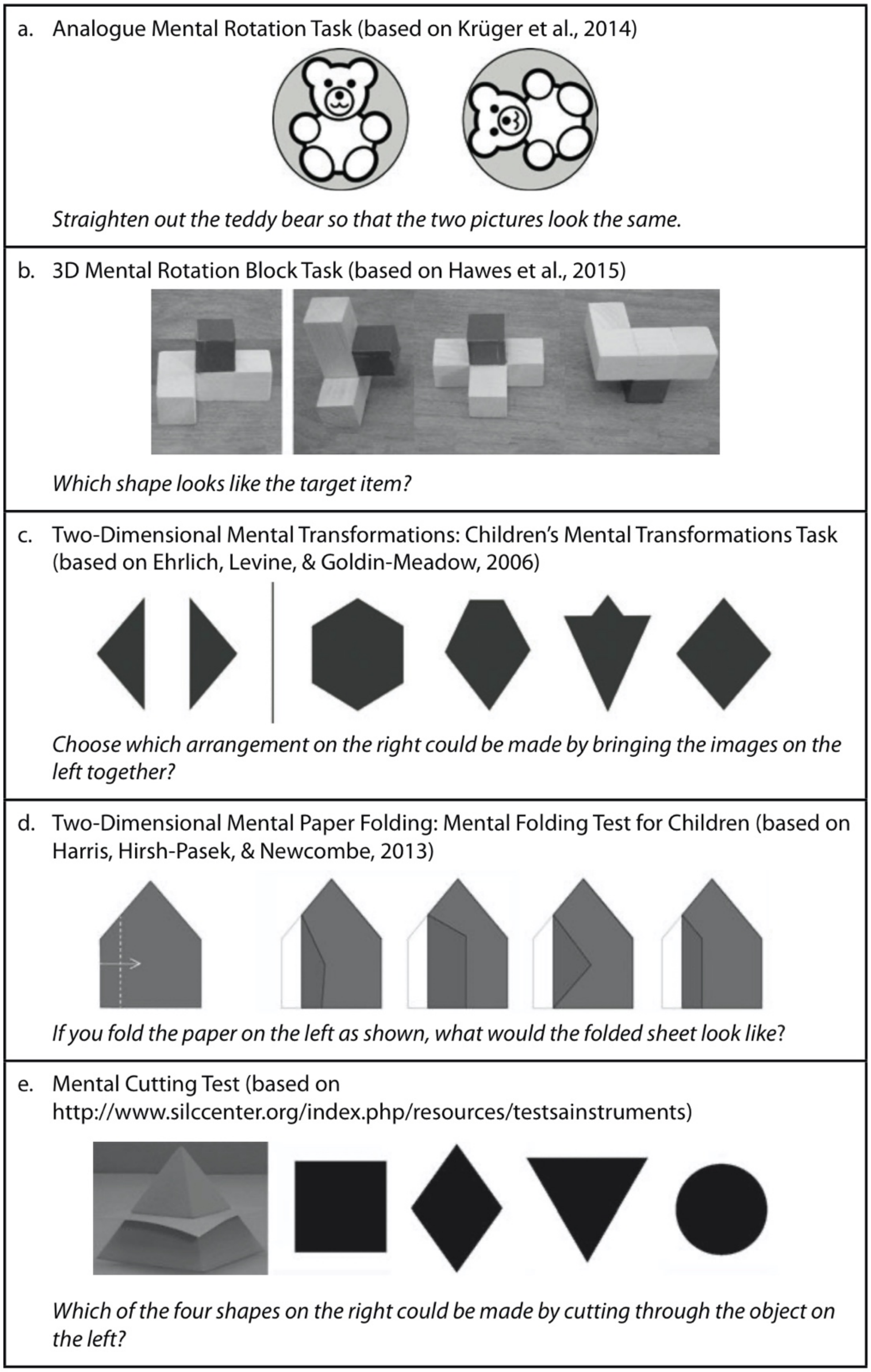


Figure 2.17 Test of Intrinsic Skills (Uttal et al. 2013)

Intrinsic-dynamic mental transformations have documented a special phenomenon, that it emerges in infancy (as early as 3 months old), disappears temporarily at around age 3 or 4, and re-emerges after 5 years of age (Frick & Wang, 2014).

Also, mental rotation (one area of intrinsic-dynamic space reasoning) appears to have a gender difference (male advantage). Research shows a male advantage for some tasks related to rotation such as copying a teacher's design of a Lego car with a motor and simple drive system. The reason is related to the difference of thinking processes. Females prefer a stepwise process to analyzing shape orientation, while males tend to an automatic process. It is important for educators to focus on group differences in regard to average group performance and promote no spatial anxiety for the girl's performance (Okamoto et al, 2015). Awareness of these gender differences help educators not unconsciously promote gender stereotypes regarding math skills.

Extrinsic-Dynamic Skill

Imagine a solar system model in which planets rotate around the sun, moons rotate around the planets. Could you predict when a solar, lunar, or planetary eclipse will occur and from where it might be visible? The extrinsic-dynamic skills involve recognizing the dynamic or changing spatial relations among two or more objects or between one's own moving body and objects or landmarks in the environment. It has two categories; those are self to object and object to object navigation. Self to object navigation is highly related to *response learning* (a spatial coding, object locomotion that uses self-referenced coding requires distance and direction information from viewer's movement through the world). It is both physical and imagined movement (visualizing the spatial environment from different perspectives, or perspective view) such as how to get to place D from different places (A, B or C). Object to object is highly related to *place learning* (a spatial coding that uses external landmarks requires coding distance and direction information from distant landmarks) such as children using cues of direction and distance of landmarks (above the table near the window) to find hidden objects (Newcombe, 1998). Figure 2.17 has several example tests for extrinsic-dynamic skills (Okamoto et al, 2015).

Taking a brief example of finding the teddy bear in the room helps to better understand two types of navigation. The self-object category is that I look around the room to find the red teddy bear (using the geometric cues and other featural information such as its shape and red color). The object-object category is that the teddy bear is always put on the bed, so I look around to find the bed to find the teddy bear (using the distance and direction between the landmark bed and the target object bear).

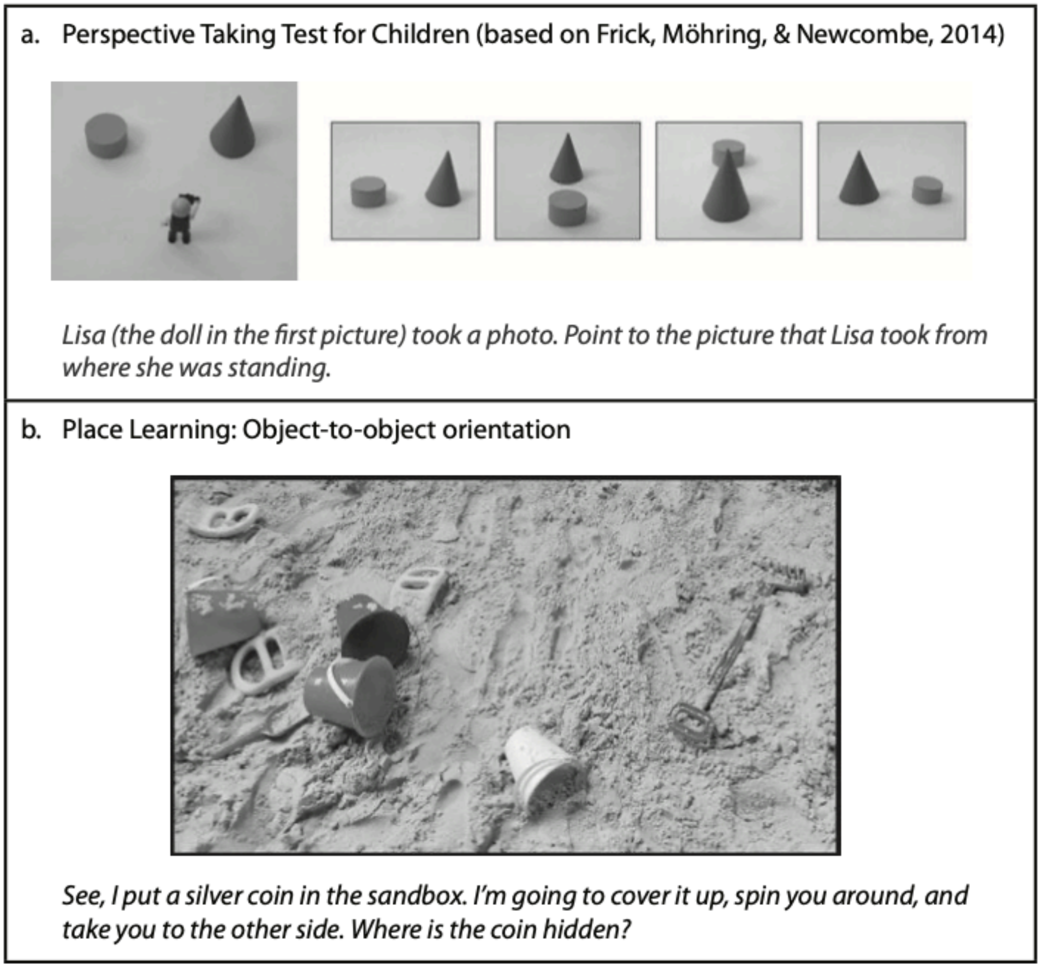


Figure 2.18 Test of Extrinsic Dynamic Skills (Uttal et al. 2013)

Infants by three to four months of age, from the perceptual categories of "above" and "below" (Quinn, 1994), show the ability to recognize the location of objects early in the self-object spatial category. It is not until 8 years old that perspective taking skill emerges to so that children can view from other people's perspectives (Okamoto et al, 2015). That corresponds to Piaget's notion of *concrete operations period* (children from 7 to 11 years old).

For navigation in dynamic contexts, spatial language is important, such as through, around, across over toward. Recent research suggests that children's spatial language is a predictor of future spatial skill (Pruden, Levine, & Huttenlocher, 2011)

2.5.2.2 Gender Difference of Spatial Skill

Males typically perform better than females on several spatial tasks (e.g., Haplen & Collaer, 2005). There are multiple reasons that account for the gender differences. Haplen and Collaer point out two reasons: one suggests hormonal differences between genders from the aspect of biological exploration. and another offers the prehistorical role difference between male and female. Other research on the causes of gender difference focus on an experiential explanation, that is the males experience more spatial activities during life, such as Lego building, that may cause higher spatial abilities (Baenninger & Newcombe, 1989).

However even gender differences in spatial ability have been found in adults, and they are not always found in children. Johnson and Meade (1987) conducted a study and found gender differences to be present from the age of ten.

From exploration of gender differences in spatial ability, research shows that the females have more room to improve their spatial ability (Baenninger & Newcombe, 1989). But recent studies failed to find the differences in training effects between males and females (Ben-Chaim et al., 1988; Casey et al., 2008; Clements et al., 1997; Sanz, de Acedo, Lizarraga & Ganuza, 2003; Shavalier, 2004). The research suggests that if there are some differences in spatial ability between males and females, it also difficult for girls to improve enough to catch up with the boys. This suggests it is important for children to develop more understanding of spatial abilities before 10 years old. Girls should have a better spatial ability at an early age to narrow the gender difference before it develops.

2.5.3 Current Geometry and Space Teaching Standards (in class)

The common core teaching standards define geometry and space standards and list the current teaching goals in the classes for young children of different ages. The following part lists what children need to learn of geometry and space from birth to eight.

Based on the National Center for Education statistics, children of 4-6 years old in kindergarten should be able to identify, describe, analyze, compare, create and compose shapes. They should be able to use the names to identify the certain shapes in the environment and describe the relative positions of objects using specific mathematic language such as above, below, besides, in front of, behind, and next to. They should be able to answer if the shape is a two-dimensional or three-dimensional (flat or solid)?

This age group should be able to analyze two- and three-dimensional shapes in different sizes and orientations. From instruction, they should use informal mathematical language to describe similarities, differences and other features of shapes, such as numbers of sides and corners, symmetry, and equal isosceles. They should be able to build shapes from components and draw shapes or compose simple shapes to form larger shapes, such as sticks and clay balls.

Children of 7 to 8 years old in grades one and two should be able to identify triangles, quadrilaterals, pentagons, hexagons, and cubes. They also need to distinguish between defining attributes (e.g., triangles are closed and three-sided) versus non-defining attributes (e.g., color, orientation, overall size); build and draw shapes to possess defining attributes. What's more, children of this age need to learn more about the shape composition and decomposition. They should be able to compose two-dimensional shapes (rectangles, squares, trapezoids, triangles, half-circles, and quarter-circles) or three-dimensional shapes (cubes, right rectangular prisms, right circular cones, and right circular cylinders) to create composite shapes. On the converse, they should be able to decompose the shape to create smaller parts. In this process, they need to have better acquaintance of specific mathematical language such as halves, thirds, fourths, and quarters (half of, three of, fourth of, and quarter of).

Compared to the previous discussion about Piaget and Van Hiele's theory, these standards are more detailed. But they are restricted by a heavier focus on teaching in class, with not much context about the extrinsic environment. The Case Studies in Chapter 4 showcase more complete and more concrete conclusions about what children can learn both in and out of school.

Kindergarten (4-6)	match to environment	Describe objects in the environment using names of shapes
	shapes name	Correctly name shapes regardless of their orientation or overall
	identify shapes type	Identify shapes as two and three dimentional (flat and solid)
	analyze shapes	Analyze shapes property, orientaion
	compare shapes	Compare shapes property, orientation similarities and differences
	compose shapes	Compose simple shapes to larger shapes or other objects
	describe position	Describe the position of these objects using spatial vocabulary
Grade 1 (7)	defining, nondefining attributes	Distinguish beween define attribures and undifining attributes
	compose shapes	Compose difficult two and three dimension shapes to create new shapes
	Decompose shapes	Partition circles and rectangular into two or four equal shares
Grade 2 (8)	recognize specific attributes	Recognize the specific attributes: angles
	decompose shapes	Partition rectangle into rows and colums
	identify shapes type	Identify triangles, quadrilaterals, pentagons, hecagons, and cube

Table 1 Geometry Teaching Content for Children Between 4 to 8 Years Old

2.5.4 The Importance of Learning Geometry and Space Concepts

2.5.4.1 Influence of Mathematics

Geometry connects richly with mathematics. It is ideal for helping to expand a student's conception of mathematics in the long run. It might help children build good bridges, for example, attracting a more diverse group to mathematics in general.

More specifically, geometry is related to mathematical reasoning ability. Research finds that most people find it very hard to draw 'impossible figures' like the one in Figure 2.18a without first dissecting it in their minds, as in Figures. 2.18b and 2.18c. This is because they did not learn geometry well enough, which involves finding patterns in the relationships among and between elements of some figures.

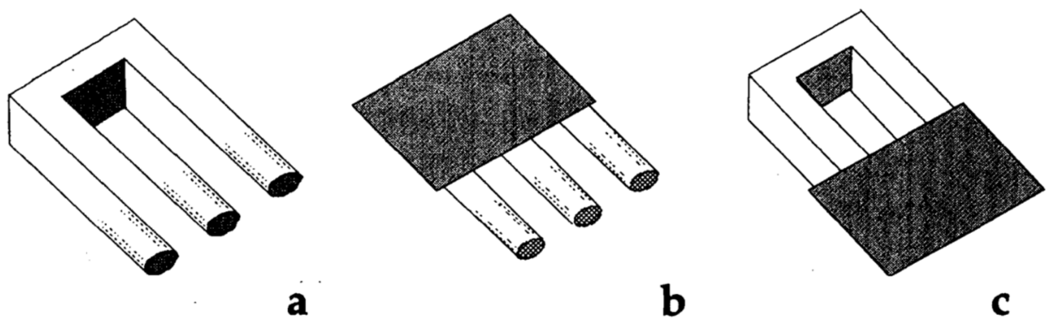


Figure 2.19 Learning to See Clearly: Drawing the "Impossible Figure" (adapt from Richard & Daniel, 2009).

2.5.4.2 Shape, Geometry, Space and Other Abilities

Geometry has a dual character of being "both abstract and concrete." Weeks (1985) used this dual character to advantage in *The Shape of Space*. He began with a fantasy based on Abbott's Flatland (1980). However, his extension of the geometry focused on two dimensions. *Until A Square* proposed that the world is a sphere, and that the shapes began to develop in three dimensions.

Shape has extensive elements. Thus, it is related to a lot of other abilities in the long run, such as observation ability, number-counting ability, imagining ability and creativity. Geometry learning can help children find the figures' relationship. The geometer, like the artist, learns to see clearly the relationship among figures: eyes are not at the top of the head, but in the middle (Richard & Daniel, 2009) (see Figure 2.19).

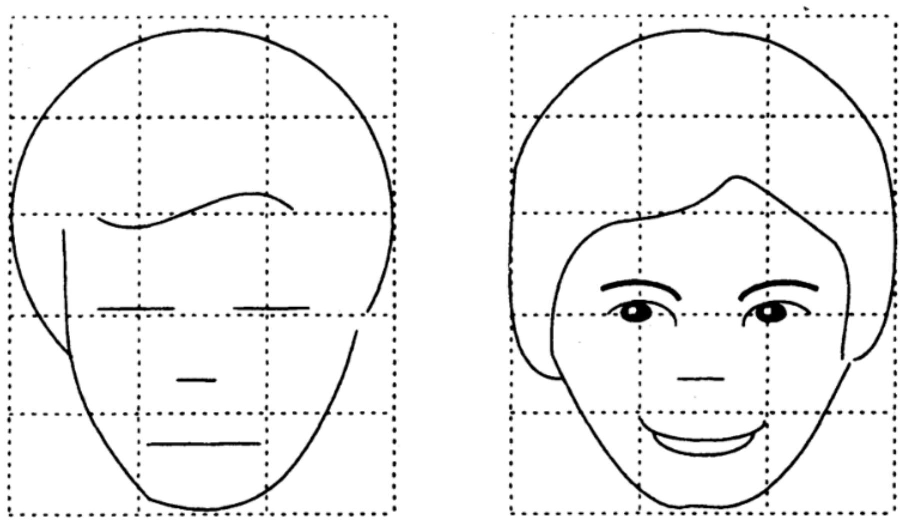


Figure 2.20 Learning to See Clearly: The Eyes Are in the Middle of the Head (adapt from Richard & Daniel, 2009).

2.5.5 Geometric and Space Education ways and Situation

Current geometric and space education methods mainly work through instruction teaching (dissertation by teaching or videos) and through play (we talked before about guided play and free play in section 2.1.2.1). This part will compare in detail the advantage and disadvantage of these two ways of learning. There are many methods used to help children learn shape and space, such as through objects (toys), activities (outdoor games), electronic games and so on. The Case Studies in Chapter 3 introduces details about these ways.

Geometry and space are some of the first areas of mathematics teaching content for young children. Teaching methods have changed from history to recent years. Historically, it is more focused on the solids, such as the tangram in the 1850s, which were the "gifts", or sets of geometric blocks designed by Friedrich Froebel, "the Father of Kindergarten".

In the later years this geometric and space focus was lost both in and out of school. In traditional school, shape definitions are typically the only prominent geometric ideas introduced, while manipulation of shapes and spatial exploration are generally neglected (Copeland, 2021). This restricts children's development of geometry and space learning because for the most part young children do not develop their concepts of shape from looking at pictures or merely hearing verbal definitions ("a triangle has three sides and three angles"). These methods have less interaction (senses) with children, which causes children to have less interest and less effective results.

Even in the Montessori school, promoting learning through play put most attention on the tactile and sight combination and didn’t take hearing and others senses into consideration.

Out of school, electronic devices, games and videos are common into the lives of children. This often takes the place of manipulating solids, the latter of which benefits the children's shape and geometric knowledge learning that develops spatial sense (Gerhardt, 1973; Prigge, 1978).

Research in children’s spatial learning shows that using real, or 3D models is better than 2D representations for children ‘s extrinsic-static skills (Baldy, Devichi, & Chatillon, 2004). Solid cutouts of shapes are more conducive to shape learning than are printed forms (Stevenson & McBee, 1958). Also, electronic devices restrict certain sensory stimulus (such as tactile) because children cannot touch them, reducing stimuli from different materials. This has a negative influence on children's cognitive development. Section 2.6.1 explains in detail of the cruciality of multi-sensory and intersensory play for the development of children's intelligence (learning shape and space).

2.6 The Relationship of Sensory Play and Learning Shape and Space

2.6.1 Multisensory and Learning Shape Space

There are many research studies that discuss the relationship between multisensory systems and shape and space learning. They mainly focus on the contents of shape and space. Shape (recognize, understand, and interact with objects) is an amodal property process by both vision and touch (Marko & Dorothy, 2012). Spatial behaviors (balance, locomotion, orientation, navigation) are the process of intersensory and multisensory systems interacting (e.g., vision, audition, touch, proprioception, vestibular system).

Multisensory and Shape: We recognize, understand, and interact with objects through both vision and touch (Arlette, 2004), through encoding the objects' properties such as shape and texture. Also, in learning shapes, there is a preference for particular sense transfers. In many studies concerning shape (a macro geometric property), transfer from haptics to vision has been found to be easier than transfer from vision to haptics in both children and adults (Connolly & Jones, 1970; Newham & Mackenzie, 1993; cf. Hatwell, 1994; Juurmaa & Lehtinen-Railo, 1994).

Multisensory and Space: Spatial behavior must be directed towards (or away from) significant objects and location in the environment. Considering the spatial behavior of orientation and navigation, balance and locomotion provide the basis of those actions (Marko & Dorothy, 2012).

Balance (signaling relative motion between an observer and their environment) is related to visual input, vestibular input, and muscle input "proprioception". That is, when we catch the ball, through visual senses we see the fast-moving ball towards us, then we make decision to lean backward to catch it through the vestibular system, and at last the muscle moves, through the proprioception system (Marko & Dorothy, 2012).

Locomotion is a lot like balance. It is not only related to sensory inputs of keeping our balance, but also haptic inputs. Regarding balance and locomotion, visual information seems particularly heavily weighted in infancy and early childhood. Around 5-6 years a period of change begins, where visual information is gradually downweighted in favor of somatosensory (proprioception) and vestibular inputs (Marko & Dorothy, 2012).

In the space section it is necessary to consider the development of the ability to orient and navigate to the significant objects and locations. Information about objects and locations commonly comes from multiple senses (e.g., vision, auditory, touch), which must be combined appropriately. Information about one's own movement in space also comes from multiple senses (e.g., vision, auditory, proprioception, and the vestibular system). Many spatial tasks (such as finding the way home) also require memory (Marko & Dorothy, 2012). That means it may be related to the olfactory input, because the olfactory system is highly related to memory, which was discussed in previous parts.

Self-motion and landmarks play important roles in spatial orientation and navigation in human adults (Burgess, 2006; Wang & Spelke, 2002). Children may not be integrated in an adult-like fashion until after 8 years old (Marko & Dorothy, 2012). According to the research, infants in the first year found added visual landmarks significantly more useful than self-motion information alone. That means visual and audio cues play a more significant role during this period.

2.6.2 Play and Learning Shape and Space

Playful learning was called for by many educators as an appropriate alternative to didactic instruction (Fisher et al., 2011), so that learning occupies the span between free play and guided play.

Play can help children learn shape and space better. Through play, children improve their mathematic skills, such as early geometry, classification skills, and mapping or "real world" application skills (Ojose, 2008), not only because children's play can involve more senses in the activity, but because this is also helpful for their cognitive development. For the most part young children do not develop their concepts of shape from looking at pictures or merely hearing verbal definitions ("a triangle has three sides and three angles"). Rather, they need to handle, manipulate, draw, and represent shapes in a variety of ways (Lillard, 2013).

At the same time, children have a happy experience when playing. They are concentric and active, which will give them intrinsic motivation and help them to improve memory.

2.6.3 Sensory Play and Learning Shape and Space

Sensory play has a significant role in children's cognition development and learning (shape and space). Children learn shapes through handling objects of different forms, perhaps tracing the forms with their fingers in addition to seeing them. In this way, playful learning embodies cognition. A wealth of evidence suggests that learning is enhanced when it is embodied across modalities (Barsalou et al. 2003; Lilard, 2005); and there are specific benefits when hands are involved (Beilock & Goldin-Meadow, 2010; Lagnado & Sloman, 2002; Sobel & Kushnir, 2006; Cook, Kuangyi Yip, & Goldin-Meadow, 2010).

These results correlate with the Montessori method for sensory play, as was discussed in section 2.6.1 Montessori educational methods for children help preschool children learn shape and space better than other didactic methods. Chapter 3 will talk more about these shape and space toys and how they work for children's learning.

Chapter 3 Case Study

3.1 Examples of Shape Cognition Education Toys

How is a child's shape recognition ability taught? People tend to use games such as spotting shapes around the house or sorting objects by their shape, and they are great for teaching shapes. Incorporating shapes into craft time is another way to include shapes in fun time. Parents also teach their kids using electronic devices and videos. This section includes some examples of shape cognition educational toys.

3.1.1 Shape Puzzles (2D Shape)

Shape Puzzles are among the most popular ways to improve a child's shape ability. In addition to the typical jigsaw puzzle, there are many other forms of graphic puzzles, ranging from physical toys to video games, and some products that combine physical products and electronics.

Physical toys include Mighty Mind logic puzzles, video games such as Tangram King，Zen，Tangram Puzzle and so on. The physical and electronic combination is evident in toys such as Osmo (see Figure 3.1).

Figure 3.2 2D Shape Blocks and Osmo Electronic Solid Combination Games

In addition to focusing on the interaction between products and children, these examples mainly combine children's touch and vision, even listening. They all also have two main features. First, the game is divided into different levels, and second, they provide positive rewards when playing.

The following will take the tangram and mosaic puzzles as examples, specifically introducing how these work under guidance when teaching children shapes.

3.1.1.1 Tangrams (2D)

Tangrams include seven pieces of flat shapes that can be combined differently to form different shapes. Tangram puzzles help children comprehend specific mathematic geometry shapes and develop their problem-solving ability. It inspires a child's observation, imagination, shape analysis, creativity and logical thinking (Lee, et al., 2008; Olkun, Altun & Smith, 2005; Russell &

Bologna, 1982; Sedig, Klawe & Westrom, 2001; Yang & Chen, 2010) (see Figure 3.2).

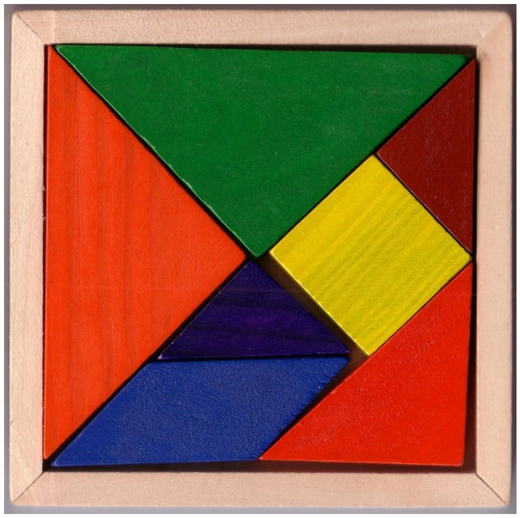


Figure 3.3 Traditional Tangrams

About the traditional tangrams, there is a paradox about the dissection fallacy through its history. At first, Henry Dudeney made two figures composed with the same piece, but one has a foot while the other one does not, as seen in Figure 3.3. Then according to Sam Loyd's *The Eighth Book of Tan* (1903), the magic dice cup shape has the same paradox (see Figure 3.3).

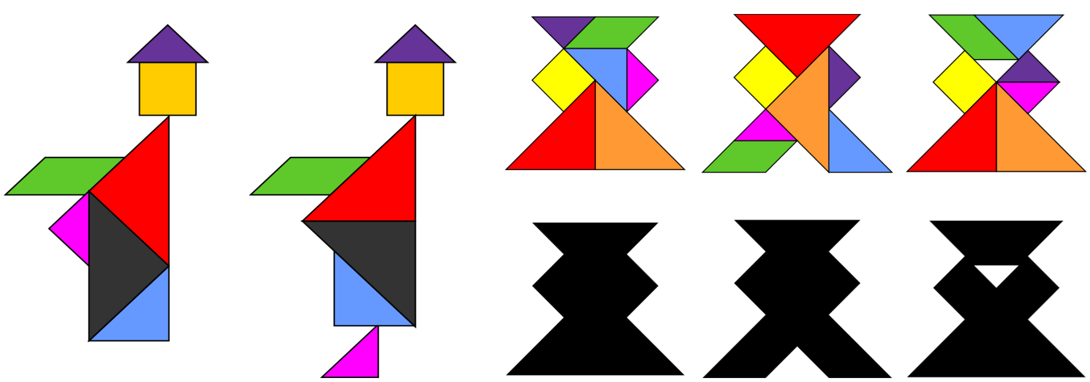


Figure 3.4 Similar Figure Shapes and Magic Dice Cup Shape

After numbers of experiments, and with the number of pieces of tangrams increasing, in

1942 Fu Traing Wang and Chin Hsiung confirmed that only 13 convex shapes match the tangram set (see Figure 3.4).

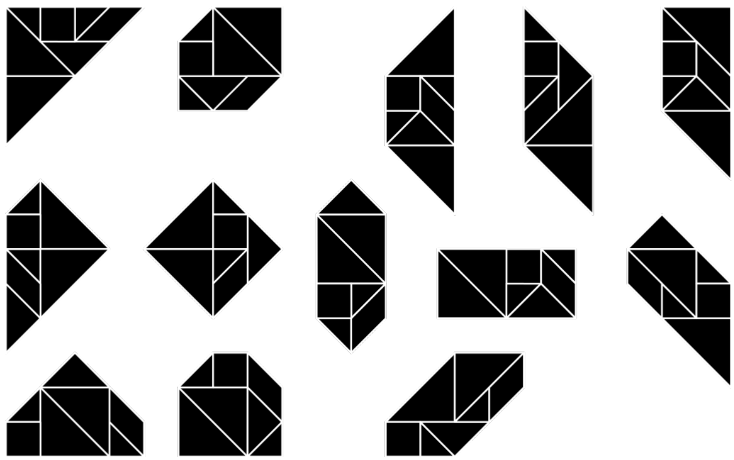


Figure 3.5 13 Shapes Matching Tangram

3.1.1.2 Beginning Geometry and the Mosaic Puzzle (Under Guide)

Seven-piece mosaics in playful explorations deal with certain shapes and their properties, symmetry, parallelism, and area. The large rectangle in the picture below has been broken into seven pieces: an isosceles triangle (piece 1); an equilateral triangle (piece 2); two right triangles (piece 5 and 6); and three quadrilaterals consisting of a rectangle (piece 3), a trapezoid (piece7), and an isosceles trapezoid (piece 4) (see Figure 3.5). In the activity for geometry education proposed by Van Hiele, the tangram had been divided into several parts to explore the educational meaning of the Mosaic Puzzle. The process is described below.

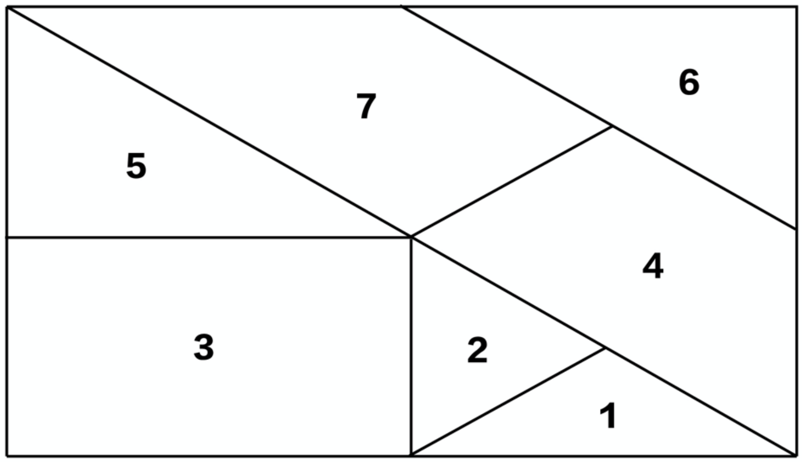


Figure 3.6 Mosaic Puzzle

Part 1: Begin with asking what can we do with these pieces? Children are given ample opportunity for play and sharing their creations. Such play gives teachers a chance to observe how children use the pieces and to assess how they think and talk about shapes.

Part 1-1: Find all the pieces that can be composed of 2 or 3 other pieces, such as using piece 5 and 6 to make piece 3. Figure 3.6 shows all possibilities; only pieces 1 and 2 cannot be made from other pieces. In this activity, children can place pieces on the top of pieces they want to form for easy visual comparison.

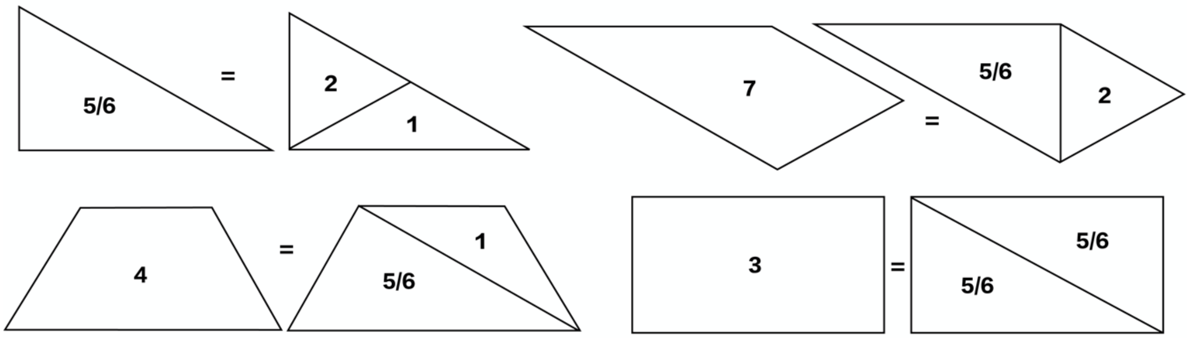


Figure 3.7 All Pieces Made from 2 or 3 Other Pieces of Mosaic Puzzle

Part 1-2: How many different shapes can be made with a pair of pieces? Try 5 and 6, then try the same activities with 1 and 2. For example, with 5 and 6, six shapes are possible. Figure 3.7 shows all possibilities.

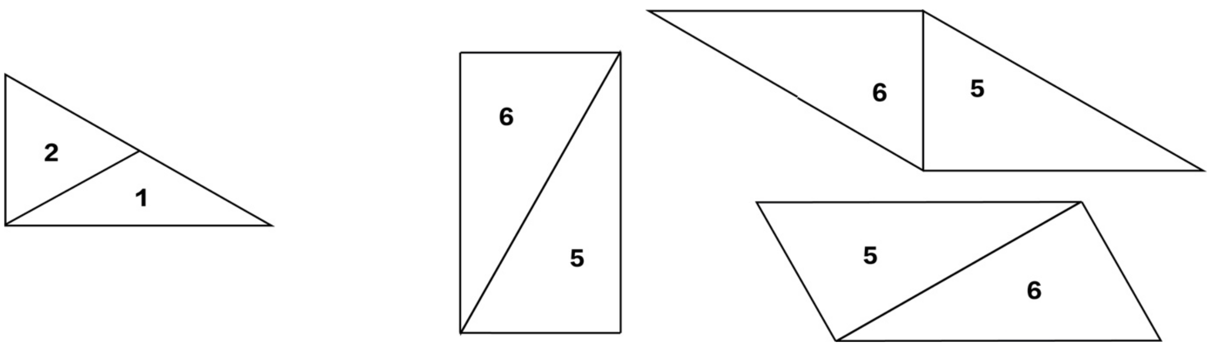


Figure 3.8 All Pieces Made from a Pair of Pieces of Mosaic Puzzle

Part 2: How many ways can a new shape be made into a particular figure? For example, a parallelogram can be made of 1 and 7. Figure 3.8 shows all possibilities.

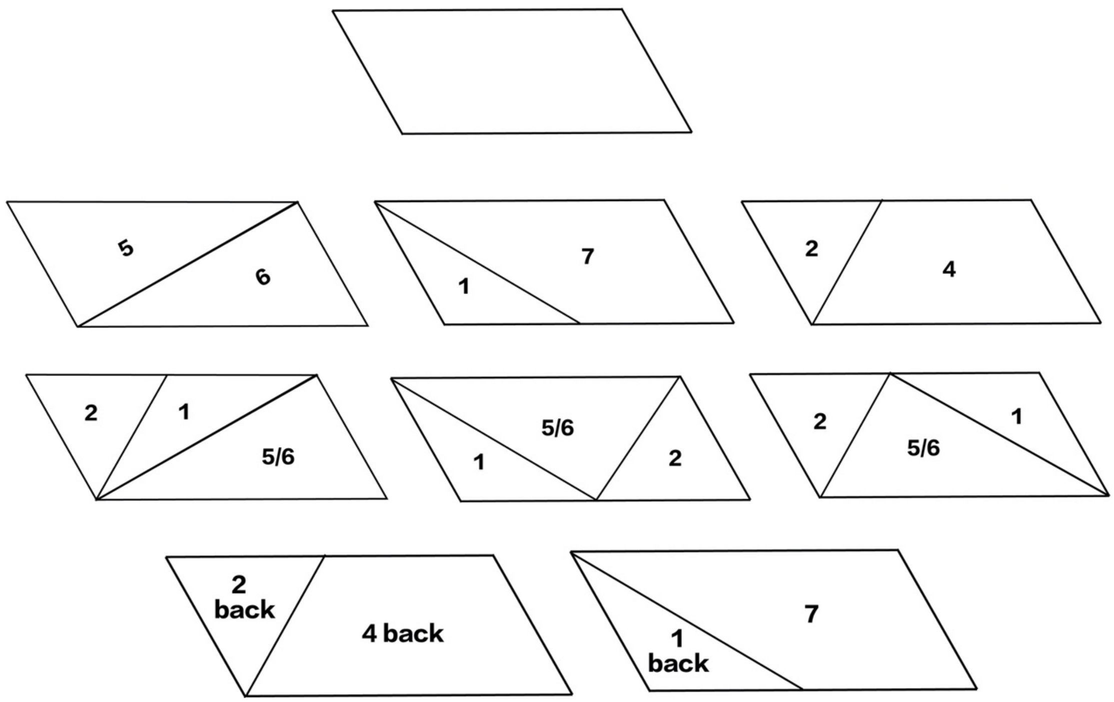


Figure 3.9 Different Ways can Made a Specific New Shape

Part 3: Can we also make a figure with 1 of the 2 pieces flipped over? Find some pieces that fit with either side up. For instance, pieces 2 and 3 fit either side up; piece 7 does not. Figure 3.9 shows all possibilities.

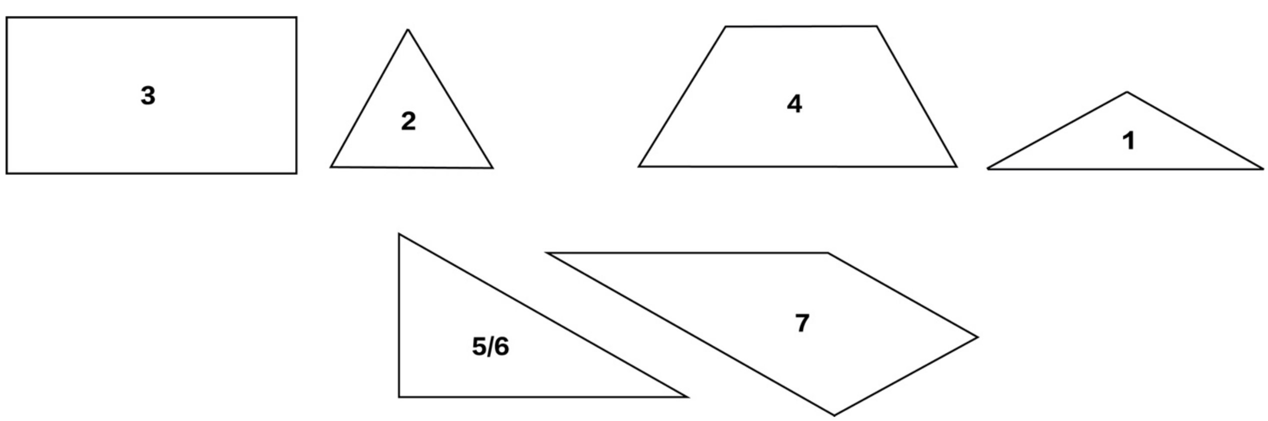


Figure 3.10 All Pieces can Make it Flip Over

In solving puzzles like these, children work visually and have a better understanding of shapes' construction and deconstruction (part 1 and 2) and the properties of the shape (part 3), such as the symmetry property.

3.1.2 Tupperware Shape Toys (3D Shape)

The Tupperware shape toy is an extremely well-designed toy that provides a great range of educational activities from recognizing shapes to problem solving and fine motor skill development. Children use their hands to grasp, hold, and shake, a series of behaviors that allow children to develop a better understanding shape. Through the process of using trial and error to match the shape blocks into the hole in the ball, children can improve their problem-solving ability.

Toddlers will also develop fine motor skills as they pick up the shapes and fit them through the holes in the ball, as each shape needs to be positioned correctly to fit through the corresponding hole.

The yellow blocks are made of different shapes, such as a trapezium, oval, pentagon, and hexagon. Children can have a better learning experience in the process of playing (see Figure 3.10).

Figure 3.11 Tupperware Shape Toy

3.1.3 Frobel Gifts 2000

As the father of early childhood education, Froebel at first came up with the notion of "kindergarten" and had a worldwide influence on children's education, including Montessori, Waldorf, Vygotsky, Reggio Emilia, and other experiential, self-active, child-centered preschool programs (Scott, 2000). True learning comes from the impressions children form during play. These series of toys are simple but help children develop their spatial reasoning, analytical thinking and creative design skill under the adult's instruction or through free play. Below are listed several games related to children's shape and space learning.

Gifts 1: Soft yarn balls. No points, corners, no flat planes, and lines. Children can use it to make different forms; it is more imaginative.

Figure 3.12 Frobel’s Gifts Set 1: Soft Yarn Balls

Gifts 2: Two Cubes. One cylinder, one sphere and a hanging apparatus, shown in Figure 3.12 This toy is for children 3 years old and older. The following directions show how to use this set to teach children shape.

Shake the box and ask children “what is inside”, open this lid to have the children touch, feel, smell, hold and examine the sphere (cylinder, and the cube), tap them, and listen to the sound.

Spin the sticks or suspend them with string from the hanging apparatus.

From this set children can use these pieces to represent things from the child’s life. Also, children can build through imaginative play. They learn the properties of the geometric shapes as they sort them, such as counting numbers of the surface edges and corners. This allows the teacher or parent to introduce space language such as on/under, front/back. Children can also learn what the shape will be when it is rotated; this is the foundation of the children’s mental rotational thinking.

Figure 3.13 Frobel's Gifts Set 2: "Rotating" Cube Blocks

Gifts 3,4,5,6: Gifts 3-6 are all cubes but divided into different ways: 3 divides a cube into eight cubes. 4 divides the cube into eight rectangles. 5 divides a cube into cubes, half cubes and quarter cubes. 6 divides cube into oblong blocks, columns, and flat square blocks. As the number goes on, the game becomes more and more difficult to play; the different numbers of cubes are targeted for different ages of children. 3 and 4 are used with children aged 3 and older, while 5 and 6 are suited for ages 5 and up. These shape learning toys may also allow thinking about the hierarchy of the different sets even though they are similar to each other.

Children can create their own forms of beauty with shape learning toys. The possibilities designed in Figure 3.13 embody the symmetry principle. Children can learn the shape's construction and deconstruction and also understand some properties of shape such as symmetry, size and so on through the play process.

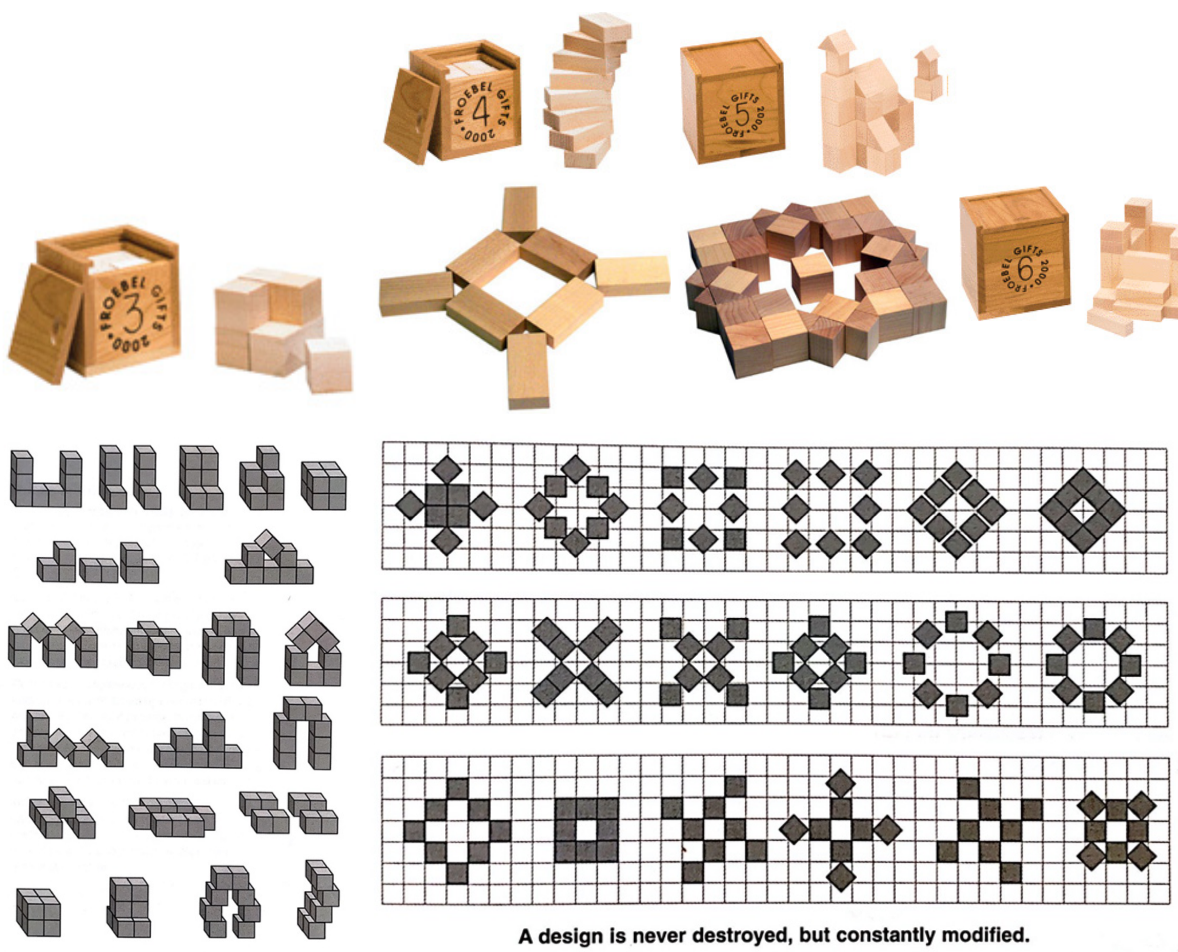


Figure 3.14 Frobel's Gifts Set3-6: Cube Blocks

3.1.4 Montessori's Sensory Education Material

Cylinder Sets: There are four sets of cylinders in Figure 3.14. They are varied into two dimensions of diameter and height and divided into four sets. The first cylinders are decreasing in height only, the second are decreasing in diameter only, the third decreasing in diameter and height, and the fourth decreasing in diameter and increasing in height. According to Piaget's theory of children's cognitive development, children develop from the centration period to the decentration period, that is from focusing on one dimension to focusing on more than two dimensions at a time (Piaget,1963). The different levels of sets are suited for different ages of children and help children profoundly understand the size and surface over time as they play with the sets.

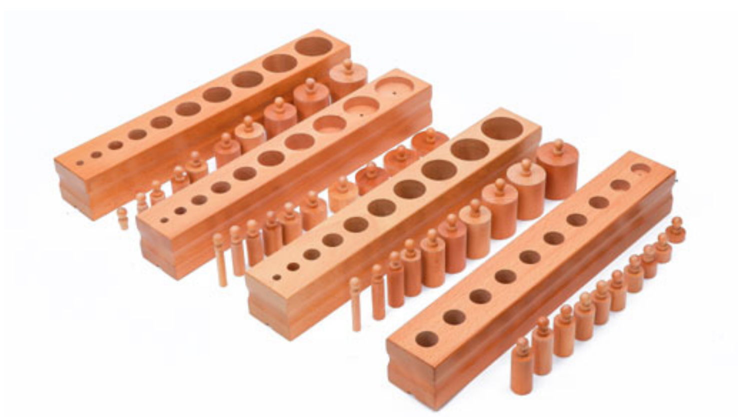


Figure 3.15 Montessori's Education Materials -Cylinders Sets of Different Dimension

Six Geometrical Sets: There are six sets of geometrical shapes in Figure 3.15: sets of six circles, rectangles, triangles, polygons, quadrilaterals, and irregular figures. At first the adult shows children that figures differ widely from one to another, next presents figures that are similar, and so on. The adult or teacher may at first show children six different shapes: square, rectangular, triangle, circle, ellipse, and hexagon and then show them six triangles but in different sizes.

Children can classify the different shapes and identify the properties of shape in the process of sensory play.

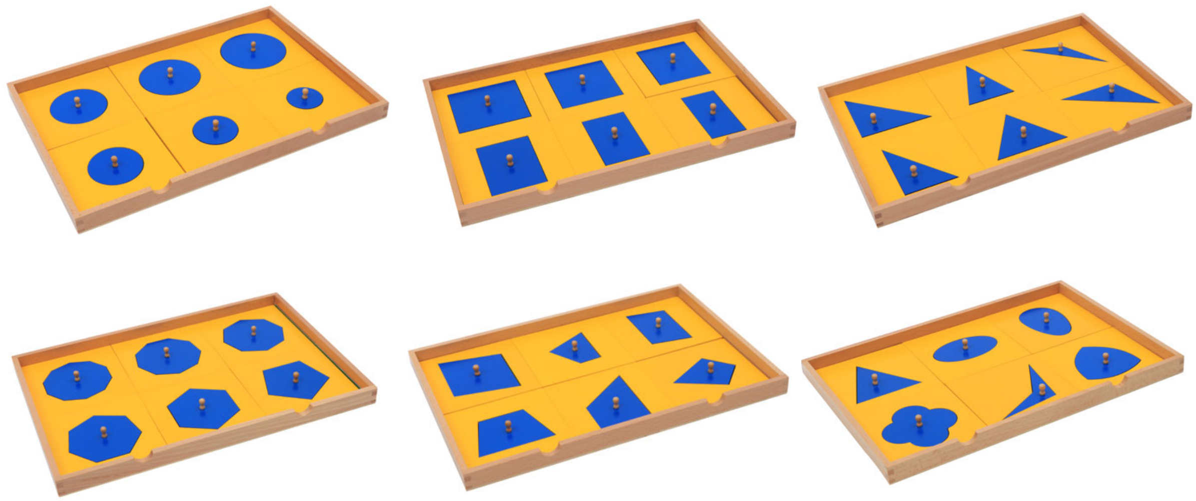


Figure 3.16 Montessori's Education Materials – Six Geometric Sets of Different Shapes

Mini Pink Tower: This toy is made of blocks different across two dimensions. It can be played with other sets that are different in three dimensions (pink tower) and different in one dimension (red rod). Through playing with these sets, children can gradually find the differences and have a better understanding of their sizes (see Figure 3.176).

Figure 3.18 Montessori's Education Materials -Mini Pink Tower

3.1.5 Maze Puzzle (2D and 3D)

Mazes are the typical tools to improve children's space ability, especially for children's extrinsic space ability (extrinsic static and extrinsic dynamic ability). There are several types of mazes from maze books to toys. Regarding 2D maze puzzle books related to a map, children need to code the object's location in relation to a reference system, and then choose the best route plan among a number of possible routes to complete the task. This is a good way to enhance children's extrinsic-static skills.

Playing with a 3D maze puzzle can enhance children's extrinsic dynamic skill (one or more objects in the system is in motion). Examples are varied, such as the money maze puzzle and ThinkFun Gravity Maze. Taking the money maze puzzle as an example, children need information regarding the balls' direction, distance to barriers and mental rotational ability to navigate the best route to the terminal (see Figure 3.197).

Figure 3.20 Maze Books, ThinkFun Gravity Maze and Money 3D Maze Toys

3.1.6 Cube

"Cube" is a typical toy for training children's mental rotational ability. Its learning content is about the shape's rotation, which is one of the transformations of both shape and space. There are many different types of cube toys, like the Rubik's cube. What's more, Spingram, an app game, is related to the cube game. But the difference between Spingram and traditional cube toys is that it has different levels (see Figure 3.218).

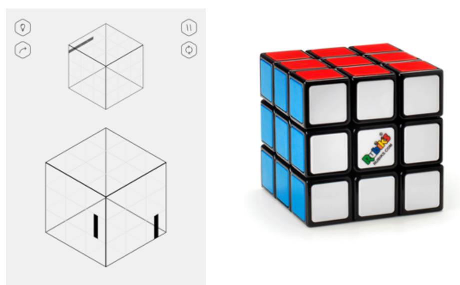


Figure 3.22 Spingram Appliance Games and Traditional Rubik's Cube

3.1.7 Reading Maps

Map reading is a typical and important way for children to learn extrinsic-static spatial information, such as the location of certain things (themselves or a terminal place along a route; objects) as well as the direction and navigation of the route. There are two kind of maps children of different ages can learn. One is the simple symbolism map for younger children, using 2D representation instead of the true objects, and the other one is traditional map for much older children (see Figure 3.239).

Figure 3.24 Children Play with 2D Representation Maps

Regarding the differences in map reading ability for different ages of children, not only are there variances in the map's complexity levels, but also children of different ages show different thinking preferences in recognizing maps. Younger children, around three years old, understand maps from an egocentric perspective. They are able to use geometric cues that are explicit (e.g., defined lines) for locating objects on maps. Within the following couple of years, children begin to identify object location through inference (e.g., combinations of objects) to form geometric cues for locating objects on maps (Vasilyeva & Bower, 2006).

Research has pointed out that children's interpretation of maps is related to an ability to use features and landmarks and the ability to use geometric properties such as length or distance and angle (Cheng, Huttenlocher, & Spelke, 2012; Lee, Sovrano, & Spelke, 2012).

3.1.8 Construction Blocks

There are a number of construction-building block sets made by different companies for children; they are made of different combinations and materials such as plastic (blocks made of Maga, Lego, Hubelino, Kre-O, Unico Plus company), foam (hand 2 mind 3D blocks), and wood (blocks made by Melissa & Doug Company and Kids Company) (see Figures 3.20 and 3.21). Most of these blocks rely on using children's tactile-visual senses combination to let them learn more about shape construction and deconstruction.

Figure 3.25 Maga, Kre-O, Hubelino, Unico Plus 3D Building Blocks

Lego and Duplo blocks (Denmark) are a time-tested favorite with children. Duplo are the same as Legos but are larger and safer for children under three years old. Maga blocks (Canada) are larger than Duplo blocks and also much more of a Duplo alternative. Kre-O (United States) are more about the engineering building kits and themes compared with other basic blocks. Hubelino blocks (German) give a more interesting experience by adding running track elements and marbles in the kits. Children can build a ball track to let running elements go through. The marbles will produce different sounds when going over different materials of marbles and plastic (see Figure 3.20).

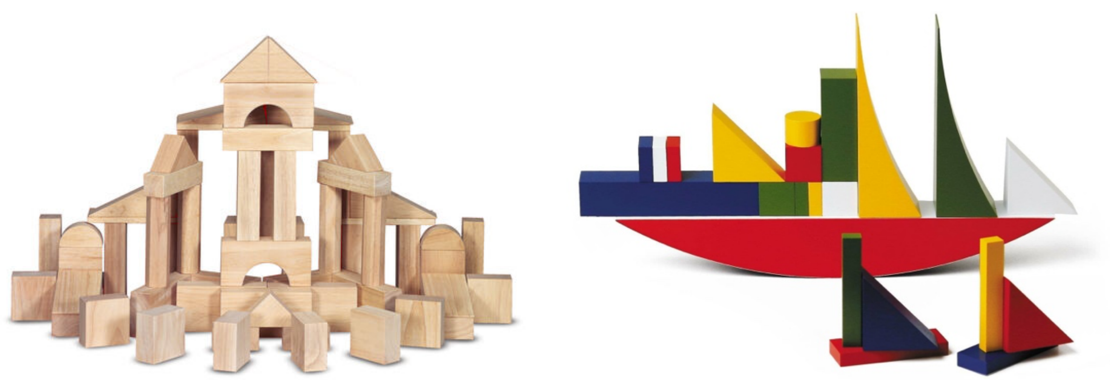


Figure 3.26 Melissa & Doug, Bauhaus 3D Wooden Building Blocks

3.2 Conclusion

Shape and space ability build the foundation for mathematics, problem-solving and other abilities in the long run. The senses of children give them more opportunities to learn more things about the environments through playing. At certain ages children can develop their shape, geometry, and space ability appropriately through play.

Common Features of Space and Shape Learning Toys:

Most activities are graded by different levels that increase the interest of the games and take personal differences into consideration for children of different ages and different cognitive development levels.

The activities have rewards systems that are divided into the extrinsic rewards of encouraging words such as “excellent”, music; gifts such as the money maze; and the intrinsic rewards of children’s interest and passion such as Montessori materials.

Colors:

Most playing tools or games (except some kinds of storytelling activities) mainly use red, yellow, blue, and green and other bright colors. These are related to the children’s development of visual recognition ability at an early age as was discussed in the literature review in section 2.3.1.1.

Children’s Senses:

Most activities focus on the children’s sight and touch senses. The olfactory senses have an underlying influence on the shape and space learning.

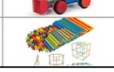
The Educational Content:

Activities that have more shape and space education content are relatively simple but need children to play under guidance. On the contrary, activities that have less content also are less targeted and suitable for playing alone.

Most activities focus on the children's shape construction and deconstruction (also the intrinsic-dynamic skill). Fewer activities focus on children's intrinsic-static skill, especially such as the map reading ability.

3.3 Conclusion Chart

Table 2 shows an analysis of different products according to the learning approach and content related to geometry and space.

ACTIVITY		APPROACH					LEARN CONTENT								
							Geometry						Space		
		sight	hearing	touch	proprio-ception	vestibular	name	match environment	property	classify	construction & deconstruciton	transform	intrinsic static	extrinsic static	extrinsic dynamic
geimetric cabinet		■		■	■	■				●					
pink tower		■		■	■	■				●	●				
geometric cabinet		■		■	■	■	●	●		●					
"gifts"1-yarn balls		■		■			●		●						
"gifts"2-cylinder		■	■	■			●		●		●	●			
"gifts"2-cylinder		■		■			●		●		●				
"gifts"3,4,5,6		■		■				●			●				
shape sticker		■		■			●								
tangram		■		■			●	●	●	●	●	●			
Tupper-ware		■		■			●			●					
geoboard shapes		■		■			●		●	●					
pattern blocks		■		■			●			●	●		●		
magic tiles		■		■							●				
Osmo		■	■	■							●		●		
3D Money maze		■	■	■								●			●
thinkfun maze		■	■	■							●				●
Labyrinth maze		■	■	■											●
maze book		■												●	
Spingram app		■	■	■								●			
Rubix's cube		■		■								●			
Origami		■		■								●			
Lego blocks		■		■							●		●		
Mega blocks		■		■							●		●		
Kre-O blocks		■		■							●		●		
Unico Plus blocks		■		■							●		●		
Hubbelino blocks		■	■	■							●		●		●
3D shape blocks		■		■			●			●	●		●		
3D building blocks		■		■							●		●		
Bauhaus blocks		■		■							●		●		
Bristal blocks		■		■							●		●		
straw construction		■		■	■	■	●		●		●				

Spitial-rich books		■												●	
mable run		■		■							●				●
mable madness		■	■	■											●
teris		■	■	■							●	●			
take photoes		■		■											●
playing music			■								●				
Tridio board		■		■					●		●				
shape climbers		■	■	■	■	■	●	●		●			●		●
muti-sided climbers		■	■	■	■	■	●	●		●			●		●
playground slides		■	■	■	■	■	●	●					●		●
Monopoly		■		■										●	
Pokemon Go		■	■	■	■	■	●	●						●	●

Table 2 The Teaching Content and Related Senses Interaction of Current Activities

Chapter 4 Design Guideline

This chapter gives designers a guideline for designing children's toys that teach children shape and space through sensory play. The guideline will direct designers to achieve their design and educational goals step-by-step. First, designers need a better understanding of children, including their biological, physical, and psychological abilities; the literature review can be helpful in providing a basis for that understanding. Moreover, designers need to decide what to teach through their design product.

The guideline is divided into eight steps: 1. Select Product Category (identify the type of free play or guided play, thinking scenario), 2. Identify Design Goals (identify age range and educational goals), 3. Select Sensory Strategy (using case study reference table in Chapter 3 to define senses combination type and using the senses activities reference chart to determine sense interaction methods), 4. Explore Concept (using sensory strategy to generate specific shape and space education concepts, brainstorm- sketches- model), 5. Evaluate Concepts (assessing teaching content of each concept to define best solutions), 6. Further Development (considering the children's psychology and ability development to define appearances such as color and shape; considering manufacturing system design to define structure such as materials and components list), 7. Final Delivery and 8. Evaluate Design.

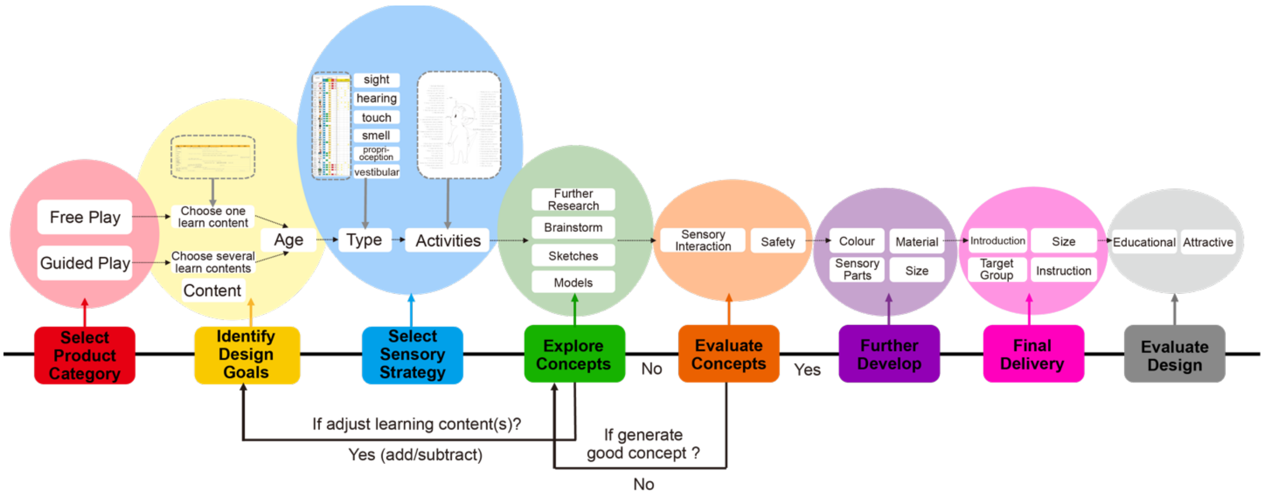


Figure 4.1 Flow Chart of Design Guideline

4.1 Select Product Category – Free Play or Play Under Guidance

Through the case studies in Chapter 3, and there are two types of specific play tools affecting the characteristics of play activity types. First is a tool for children's free play, typically with explicit and simple teaching goals (for shape teaching), mostly with one educational content, but different levels for specific teaching knowledge. A typical example is Montessori's educational materials, such as the red rods (10 pink cubes with different lengths), which are for helping children understand the size of shapes.

Second is a tool for children's play under guidance, and these toys tend to have multiple levels of teaching goals. One example is Tangram, for which children can learn the names and properties of shapes, shapes' construction, and other knowledge through different types of play as instructed by teachers or other adults. These types of tools are often used in the school.

This chapter gives designers two separate guidelines for the different design processes for these two different play types. Designers first need to define the design scenario (for children's free play or guide play) to determine the type of tool.

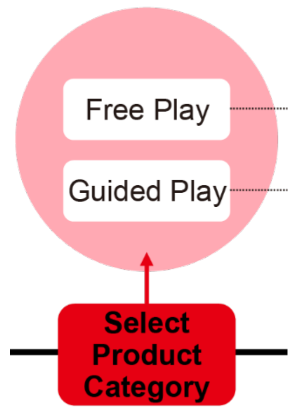


Figure 4.2 Select Product Category Phase

4.2 Identify Age Range and Learning Content

Designers should first review the three tables about form and space teaching content provided in the 4.2.1 Learning Content Reference section to identify the desired shape and space teaching content before defining the age range.

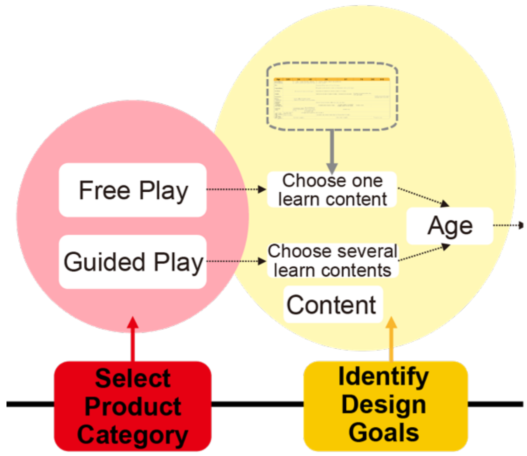


Figure 4.3 Identify Design Goals Phase

4.2.1 Learning Content Reference

These references give designers multiple-choice and references to design specific, meaningful educational tools. This learning content conclusion map shows three levels and associated sub-levels of learning content.

4.2.2 Learning Content Conclusion Map

This map (Figure 4.4) presents the content from Chapters 2 and 3 of children's needs to learn shape and space. This information is drawn from historically essential theories of both principles (Piaget, Van Hiele, Clement) and practice (Montessori, Common Core State Standard). It includes learning shapes intrinsically and extrinsically. Intrinsic form learning includes shape's name, property, and transformation, and extrinsic shape learning includes matching shape to the environment, comparing shapes, shapes' construction, and deconstruction. Space can be divided into four categories: intrinsic to extrinsic and static to dynamic, intrinsic static space, intrinsic dynamic space, extrinsic static, and extrinsic dynamic space. Symmetry, shape construction/ deconstruction, and shape transformation are coincident in shape and space learning.

Spatial vocabulary is a foundation of learning all space learning contents shown in Figure 4.5.

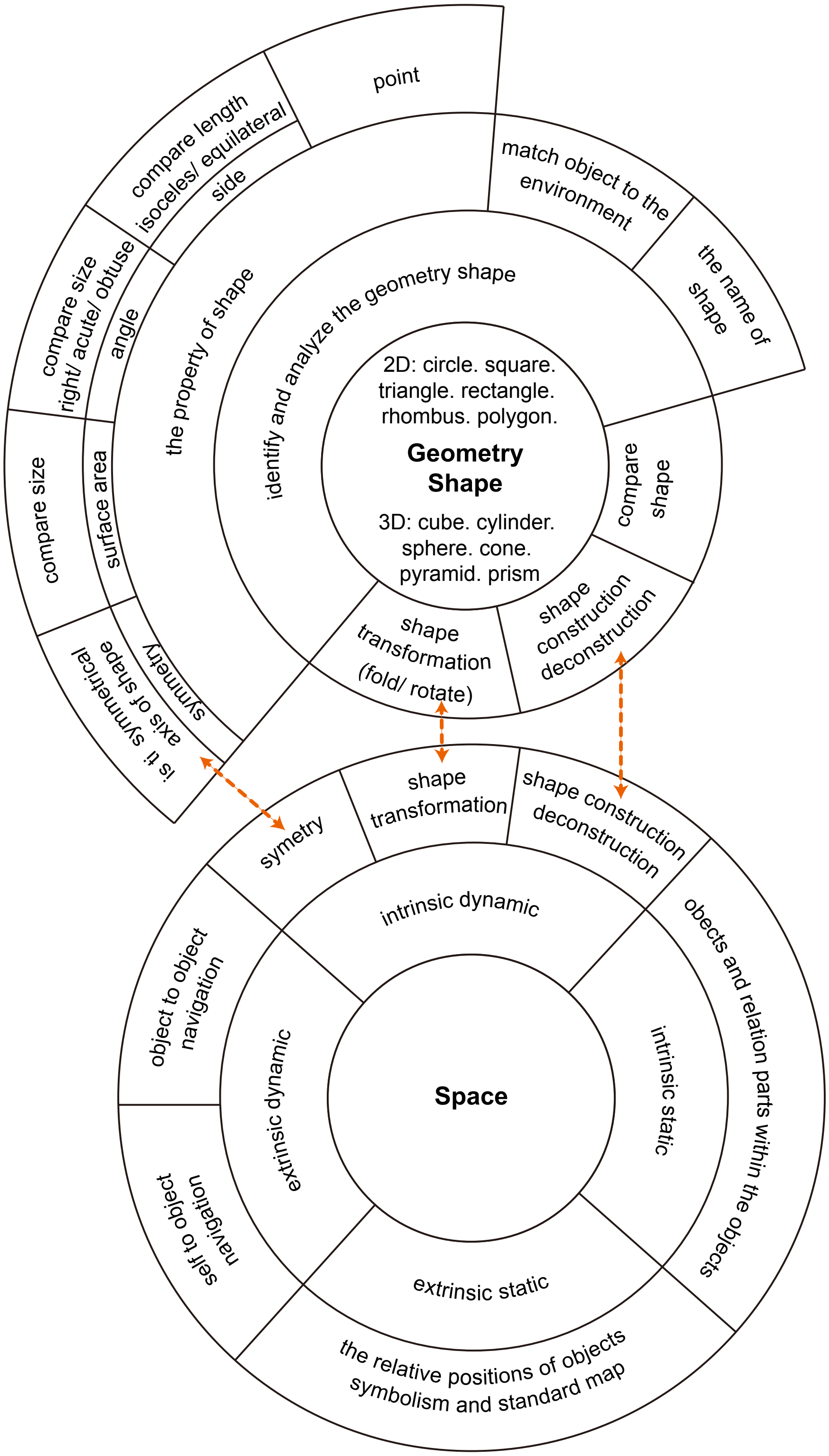


Figure 4.4 Shape and Space Learning Content Map

Spatial Vocabulary	
Location/ Position	on, off, on top of, over, under, in, out, into, out of, top, bottom, above, below, in front of, in back of, behind, beside, by, next to, between, same/different side, upside down
Movement	up, down, forward, backward, around, through, to, from, toward, away from, sideways, across, back and forth, straight/ curved path
Distance	near, far, close to, far from, shortset/ longest path
Transformation	turn, flip, slide

Figure 4.5 Spatial Vocabulary

Three Levels of Learning Content

According to Piaget's and Van Hiele's theories, children learn shape and space from recognizing it through simple features (such as mathematical language), to analyzing its more interior features and properties, then applying them to solve problems in a system. This guideline divides all the learning content into three categories: Recognize, Analyze, and Application (see Figure 4.6).

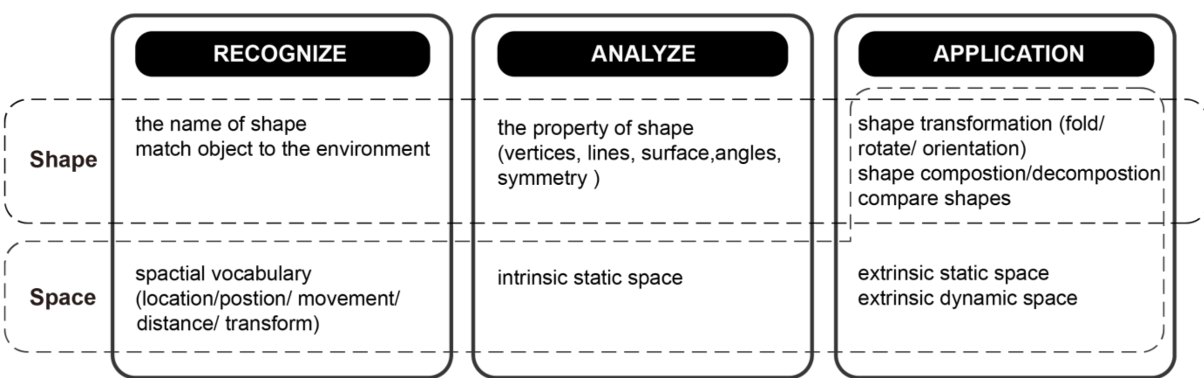


Figure 4.6 Three Levels of Learning Contents

Sub-levels of Learning Contents for Ages

Children learning the right thing in certain stages, step by step, is of great importance. Piaget's point of view was that "giving no education is better than giving it the wrong time". Learning shape and space is the same. What is known before is crucial and foundational to the future. Similarly, Farmer et al. (2013) found evidence to suggest that children's spatial skills at three years old were strong predictors of how well the same children performed in mathematics two years later. So, learning shape and space by development and age-appropriate steps is vital for children. For educating children on form and space, designers should consider children's cognitive development and match the specific shape and space learning content to prerequisite cognitive skills. In this part, it will explain what to learn at what age or stage of development. Figure 4.7 shows all the learning contents by age.

Age		2.5-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10
Name/Match Environment			2D: circles, squares, 3D: sphere, pyramid,	triangles, rectangles cone,cuboid and cube	2D: rhombus, polygon, trapzoid, hap quarter cicle 3D: prism, cylinder				
Size					Recognize different sizes of 2D and 3D shapes				
Points/Sides					Recognize and describe the numbers of vertices/sides of 2D and 3D shapes				
Surfaces			3D shapes are made from 2D shapes		Recognize and Describe the numbers of faces of 3D shapes				
Angles					Describe the numbers of angles of shapes	Recognize the right angles	Recognize the angles greater/ less than right angles		
Symmetry									Identify line-symmetric figures, recognize lines of symmetry
Shape Transform			Explore different foldable shapes Rotate 2D/3D shapes to form new shapes						
Compare Shapes					Describe shapes'similarities, differences,parts, and others				
Compose/ Decompose					Compose simple shapes to larger	Compose shapes to composite shapes, partition of half /fourth	Partition of third		
Extrinsic Static			Use geometric explicit cues to locate objects on map	Use combinations of objects as geometric cues to locate objects on symbolic map	Standard map				
Extrinsic Dynamic	Loco-motion	Use target object's shape and color feature to locate it	Use target object's geomtric cues to locate it						
					Use spatial cues between target object and the landmark to locate it				
	Navi-gation		Self-object navigation		Object-object navigation				Perspective view

Figure 4.7 Guideline of Learning Contents

Each of the specific areas of content are defined below and Figures 4.8 through 4.19 illustrate each of them.

The Name of Shape and Matching Objects to the Environment: Clements (1999) examined preschool (3-5) children's recognition (including name) of basic 2D geometric shapes. They could identify circles more accurately, and the accuracy declined for squares, triangles, and rectangles, in this order. Children can recognize and name the common 3D shapes, such as spheres, pyramids, cones, cuboids, and cubes. Based on the Common Core state standard, in the following school years, children need to be able to recognize more difficult 2D and 3D shapes, rhombus, polygon, trapezoid, half-circles, quarter-circles, prism (3D), and cylinders (3D).

Age	3-5	5+
Shape Name/ Match to Environment	2D:circle,square, triangle, rectangle 3D:sphere, pyramid, cone, cuboid and cube	2D: rhombu, polygon, trapezoid, half quarter circle 3D: prism,cylinder

Figure 4.8 Shape Name and Match to Environment Learning Contents

Size: Children should learn to recognize the different sizes of shapes in kindergarten (ages 5-6). What they learning concerning size is differentiated from one dimension to two dimensions, and even three dimensions (of 3D shapes).

Age	5+
Size	Recognize the different size of 2D and 3D shapes (3Dshapes: different from 2D to 3D)

Figure 4.9 Size Learning Content

Points (Vertices): Children should be able to recognize and describe the numbers of vertices for both 2D and 3D shapes in kindergarten (ages 5-6).

Age	5+
Points (Vertices)	Recognize and describe the numbers of vertices of 2D and 3D shapes

Figure 4.10 Vertices Learning Content

Lines (Sides/ Edges): Children of kindergarten (ages 5-6) should learn shapes' edges and recognize and describe the numbers of lines for 2D and 3D shapes.

Age	5+
Lines (Sides/ Edges)	Recognize and describe the numbers of lines of 2D and 3D shapes

Figure 4.11 Lines Learning Content

Surfaces (Faces): Preschool teaches the flat shapes that make up the sides of the 3D shapes. The children should be able to describe the numbers of faces of 3D shapes in kindergarten (ages 5-6).

Age	3-5	5+
Surfaces (Faces)	3D shapes are made up from 2D sides	Recognize and describe the numbers of faces of 3D shapes

Figure 4.12 Faces Learning Content

Angles: Children need to learn to describe the numbers of angles of 2D shapes in kindergarten (ages 5-6). They should also be able to recognize the right angles at ages 6-7, and then recognize the angles greater or less than right angles at ages 7-8.

Age	5-6	6-7	7-8
Angles	The numbers of angles of 2D shapes	Recognize the right angles	Recognize greater/ less than right angles

Figure 4.13 Angles Lerning Content

Symmetry: The Common Core State Standard mandates that children in grade 4 (ages 9-10) identify line-symmetric figures and recognize lines of symmetry.

Age	9-10
Symmetry	Identify line- symmetric figures and recognize lines of symmetry

Figure 4.14 Symmetry Learning Content

Shape Transform:

Fold (flip): According to Van Hiele, preschool children explore different shapes through folding paper. Common Core Standards require that children recognize the line of symmetry for 2D figures as a line across a figure, the line along which the figure can be folded into matching parts in grade 4 (ages 9-10).

Rotate: According to Frobel's teaching methods, children from 3-5 learn that 2D shapes rotate to form 3D shapes, and 3D shapes rotate to create new shapes.

	Age	3-5
Shape Transform	Fold (Flip)	Explore different foldable shapes
	Rotate	Rotate 2D/ 3D shapes to form new shapes

Figure 4.15 Shape Transform Learning Contents

Compose/ Decompose: Common Core State Standard requires that children in kindergarten (ages 5-6) can combine simple shapes into larger ones. In grade one (ages 6-7), children learn to compose more 2D shapes (rectangles, square, trapezoids, triangles, half-circle) or 3D shapes (cubes, right rectangular prisms, right circular cones, and right circular cylinders) to create a composite shape and compose new shapes from the composite shape. For decomposition, children understand the partitions of halves and fourths in grade one and understand of the sectioning of thirds in grade two (7-8).

Age	5-6	6-7	7-8
Compose Decompose	Compose simple shapes to larger	Compose 2/3D shapes to composite shapes, partition of half/ fourth	Partition of third

Figure 4.16 Compose and Decompose Learning Contents

Compare Shapes: Children in kindergarten should learn to compare 2D and 3D shapes of different sizes and orientations, using informal language to describe their similarities, differences, parts, and other attributes.

Age	5-6
Compare Shapes	Use informal language to describe shapes' similarities, differences, parts, and other attributes

Figure 4.17 Compare Shapes Learning Contents

Spatial Vocabulary: Common Core State Standards state that children should be able to describe the relative positions of these objects using terms of spatial language (see Figure 4-5) such as below, besides, in front of, behind, and next to.

Extrinsic-Static Space:

Symbolic Map/Standard Map: Standard maps are more complex than extended maps because they are proportionally smaller than reality; children need to measure the distance. Even elementary school students may have difficulty interpreting a map when considering the distance between objects (Liben & Downs, 1989; Liben & Yekel, 1996). That is why it is important for children after five years old to learn standard maps.

Children at three years old use geometric cues that are explicit (e.g., defined lines rather than inferred shapes) to locate objects on maps (Vasilyeva & Bowers, 2006). They should be able to identify the location of an object in a 2D representation and corresponding location in a small space using relatively simple maps (DeLoache, 1987; Huttenlocher, Newcombe, & Vasilyeva, 1999). Within another couple of years, children begin to identify object locations through inference, such as using combinations of objects to form geometric cues or partially constructed geometric objects on maps (Vasilyeva & Bowers, 2006).

Age	3-4	4-5	5+
Extrinsic-Static Space (Map)	Simple Symbolic map Use explicit object self geometric cues to locate objects on maps	Symbolic map Using combinations of objcts as geomtric cues to locate objects on map	Standard map

Figure 4.18 Extrinsic-Static Space Learning Contents

Extrinsic-Dynamic Space:

Locomotion Skill: Children as young as 2.5-3 years of age can use a simple target object's featural information (shape, color) to locate objects (DeLoche, 1995). Children between 3-6 use the target object's geometric cues (angular relations, relative lengths of line segments) to locate objects. Children more than five years old can use spatial cues between the target object and the landmark (e.g., distances and angles to the landmarks) to find corresponding locations and can transfer distances on a map to actual physical space when maps employ simple two- dimensional layouts (Liben & Downs, 1989; Liben & Yekel, 1996).

Navigation Skill: Children develop their self-object navigation skills early, using physical motor movement to locate target objects. As they grow, they build their object-object navigation skills, references combinations of landmarks to find the target (Vasilyeva & Bowers, 2006). This change corresponds with Piaget's egocentric phase; egocentric children consider all objects as a whole as a reference to a target object. Children over eight years old can take spatial perspectives of others (perspectives view skills).

	Age	2.5-3	3-5	5-6	6-8	8+
Extrinsic-Dynamic Space	Locomotion	Use target object's shape and color feature locate it				
			Use target objects's geometric cues (anglar relations, length of line) locate it			
				Use spatial cues between target object and the landmarkt locate it		
	Navigation	Self- object navigation		Object- object navigation		Perspectives view

Figure 4.19 Extrinsic-Dynamic Space Learning Contents

4.2.3 Choosing the Learning Content and Defining Age Range

Choose Learning Content(s):

Free Play Tools: Under the limitation of the play type (giving children explicit learning content), choose one (learning content) among all the learning content options as the design goals. Figure 4.7 Guideline of Learning Content contains the different levels of knowledge matched to ages.

Guided Play Tools: Choose several learning contents as the design goals.

Define Learning Content(s): Using the Guideline of Learning Content from Figure 4.7, the designer should choose their target group's learning content and put it into the following chart.

Age	a
Content A	m
...	...

Figure 4.20 Define Learning Content Chart

Free Play Learning Content: If designers choose the early age group "a," as shown in Figure 4.21, then the age range is "a," and the teaching content is "1". But if the designer chooses an older group, that means children have already learned the previous knowledge. The designer can just choose to teach new knowledge "2" or learn new knowledge and go over the old knowledge that is "1+2". The teaching content could be "2" / "1+2" (shown in Figure 4.22).

Age	a	b
Content A	1	2

Age	a	b
Content A	1	2

Age	a
Content A	1

Figure 4.21 Define Learning Content for Early Age Phase (Free play)

Age	a	b
Content A	1	2

Age	b
Content A	2 / 1+2

Figure 4.22 Define Learning Content for Older Age Phase (Free play)

Guide Play Learning Content:

Age	a	b
Content A	1	2
Content B	3	4

Age	b
Content A	2 / 1+2
Content B	4 / 3+4

a, b – the certain numbers match to learning contents (refer to learning content and age charts)

Figure 4.23 Define Learning Content for Older Age Phase (Guide Play)

Refine Age Range: Designers put all the chosen learning content into the following chart. There are two situations here: content A and B have the exact age spans of the selected age group. Second, as in Figure 4.18, designers should delimit the teaching content to refine the appropriate age range. The advanced age range is a-c. Refer also to Figures 5.1 and 5.2 in the design implementation to see how this chart can be utilized.

<table>
<tr><th>Age</th><th>a</th><th>b</th><th>c</th></tr>
<tr><td>Content A</td><td>...</td><td colspan="2">1</td></tr>
<tr><td>Content B</td><td colspan="2">2</td><td>...</td></tr>
</table>

Figure 4.24 Refine Age Range

4.3 Select Sensory Strategy

There are two things that designers need to do before coming up with design ideations. After defining the design goals, designers should define the sensory strategy used in the tools' design. According to their design goals and chosen sensory strategy, designers should select the multi-sense type and interaction methods for their intended product.

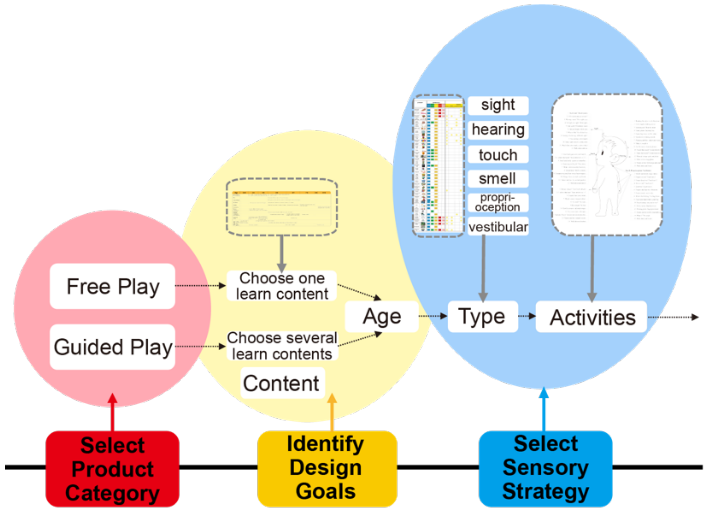


Figure 4.25 Select Sensory Strategy Phase

4.3.1 Identify Multisensory Type and Value

The core concept behind multisensory learning is that individuals learn better if they are taught using more than one sense (Rosenberg, 2015). The more senses involved; the better experience people have (Jinsop Lee's Five Senses Design, 2013). Children's shape and space learning content contains considerable specific teaching goals, so there may be a need to have various senses involved from the different vantages of learning content. This chapter gives designers a way to choose the most appropriate senses for specific learning content.

Once the designer has defined the specific learning content, they can find products that teach children this delimited content and the sense application types by referring to Chapter 3 Table 2-The Teaching Content and Related Senses Interaction of Current Activities. Designers use this case study table in Chapter 3 to find what senses are applicable to specific teaching content. Figure 4.26 showcases that the designer currently "transforms" educational products ("gift" 2, Tangram, money maze, and so on) using children's sight, hearing, and touch.

At the same time, when choosing the multisensory type, designers should also think of the value of different sensory types used in the teaching tools. For other content teaching goals and designers' preferences, the percentage of each sensory types are adjustable. The case studies in Chapter 3 give designers some references.

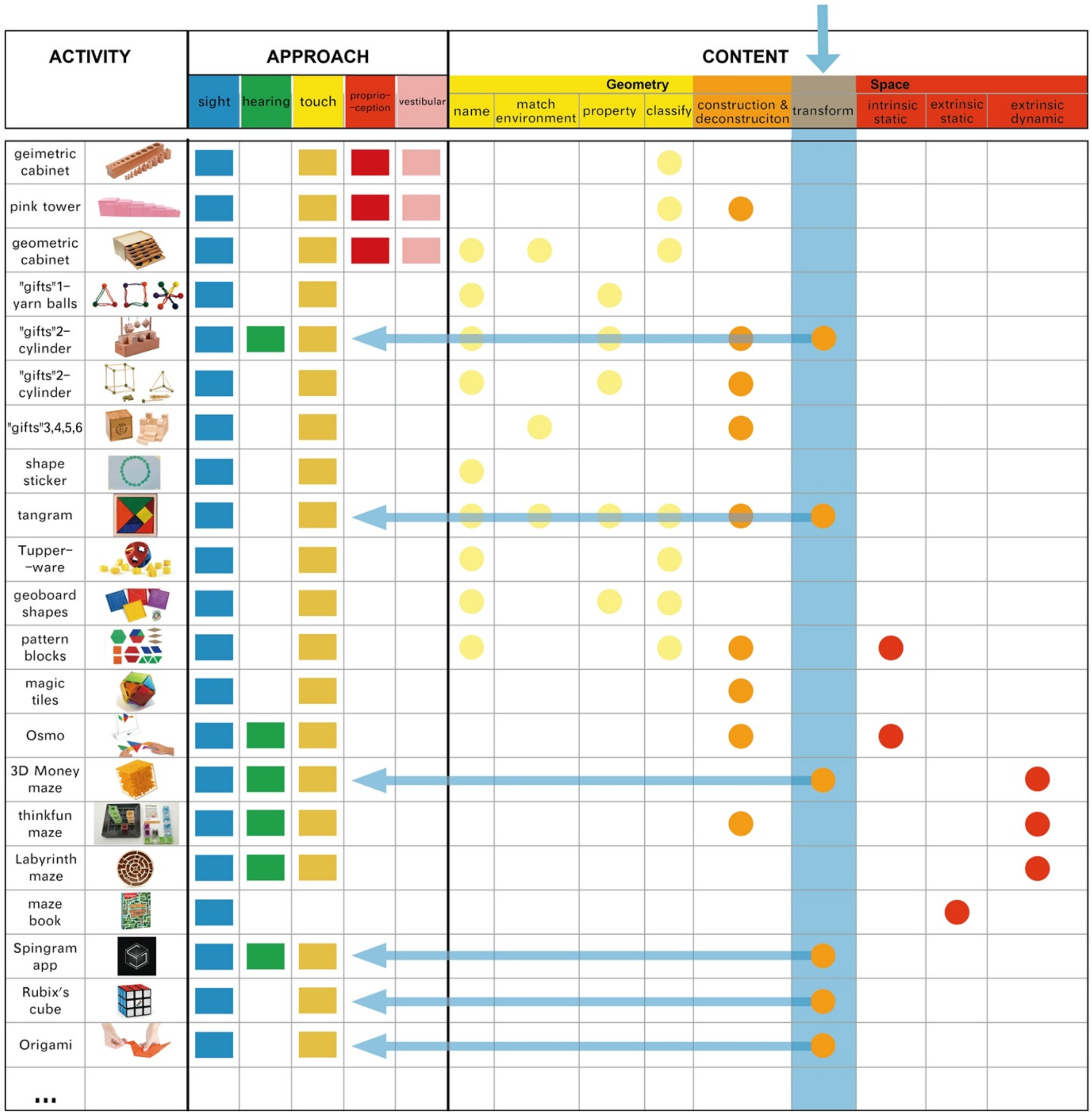


Figure 4.26 Define Involved Senses Type

4.3.2 Identify Sensory Interaction Ways

After defining the senses that will be used by the children playing with the designed tools, the designer should decide the specific interaction activities and methods of the chosen senses.

This part gives the reference of all the sense-related activities for designers.

Chapter 2 explains what designers can do through children's senses. In this part, the discussion is more focused on the possible sense-abilities (see Figures 4.27 and 4.28). Each sense-related activity is specifically explained for designers to find what children can do through each type of sense. This figure can provide inspiration to explore multisensory ways.

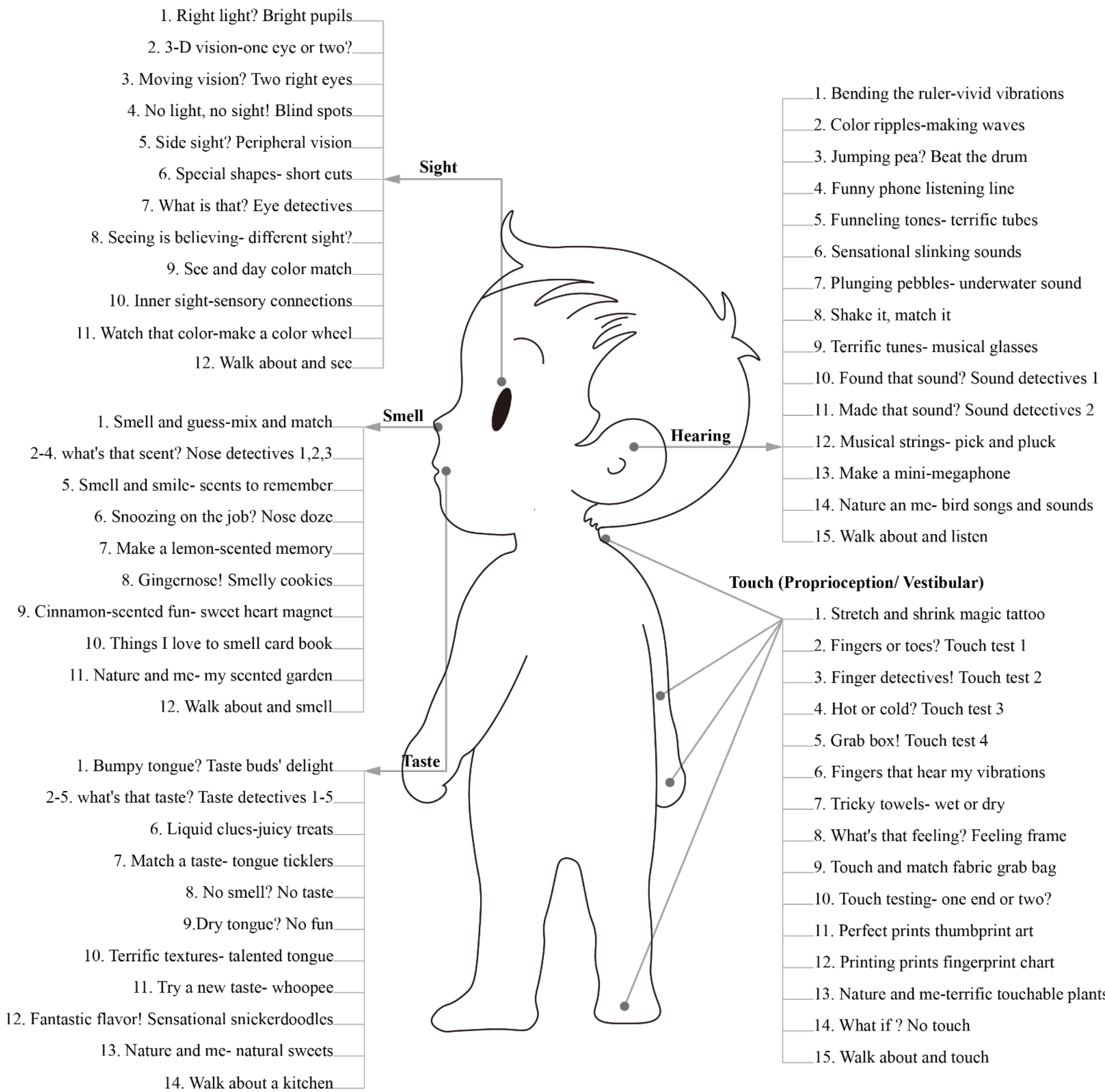


Figure 4.27 Senses Abilities

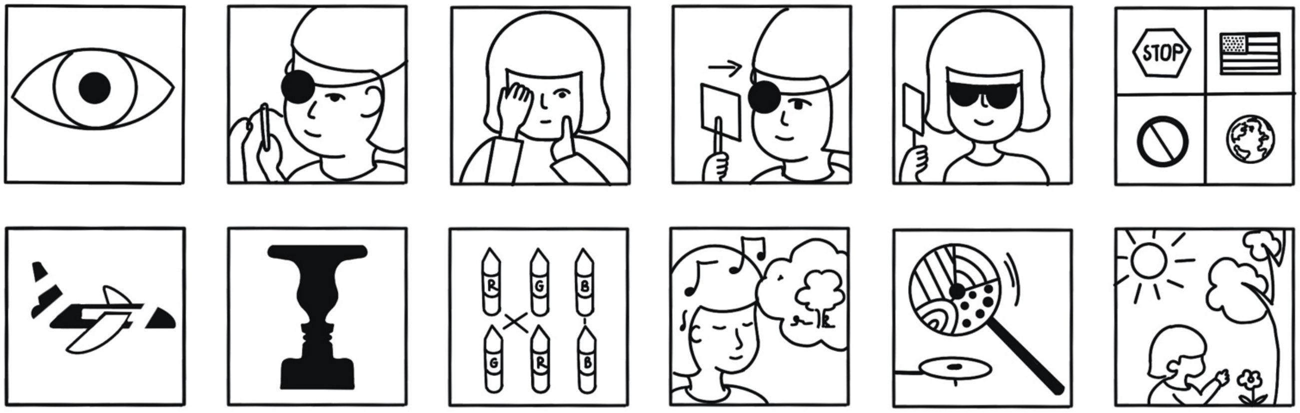


Figure 4.28 Senses Abilities 2

Michelle O'Brien-Palmer's sense- abilities book gives the parents and teachers guides for exploring children's five sense's abilities. The following parts showcase the activities that designers can explore, as well as list materials that designers can use for further design.

Children's sight-related activities showcase:

- Directly detect some colors, motion of objects, shape from indoor to outside environment.
- Detect different things through parts of things, such as the Gestalt.
- Materials can be used: eye cover, glasses, boxes

Hearing activities showcase:

- Directly hear and detect some sounds (music) from indoor to outside environment.
- Directly hear the sound near or far.
- Explore the vibrations and waves (the essence of sound).

- Materials that can be used in the design: string, cup, metal, toilet paper roll, paper, box, cans, pans.

Smell activities showcase:

- Directly smell and detect some scents
- Explore the favorite scent of the individual (smell related to memory, so smell helps to have a better play experience.).
- Materials that can be used: non-toxic materials

Taste activities showcase:

- Combine smell and detect the different four tastes- sweet, sour, salty, and bitter
- Materials that can be used: non-toxic materials

Touch activities showcase:

- Directly touch and detect different things, wet or dry, temperature, shape, different feelings (of materials), soft or rigid.
- Explore different parts of the skin (touch sense organs) to feel the different levels of sensitivity, such as the toe is more ticklish than fingers
- Materials can be used: crayon markers, paper, ink pad.

4.4 Exploring Concepts

After defining design goals (particular educational teaching meaning(s)), target age of group, interaction ways (involves senses and sensory activities), the designer begins to generate multiples of different ideations through the process of further research, brainstorming, sketching, and modeling. In the concepts exploration phase, designers should consider whether they adjust the learning contents. If designers add or subtract learning content, they should redefine the design goals (age and learning content); because of the correlation of age to learning content, a revision to one requires a change to the other.

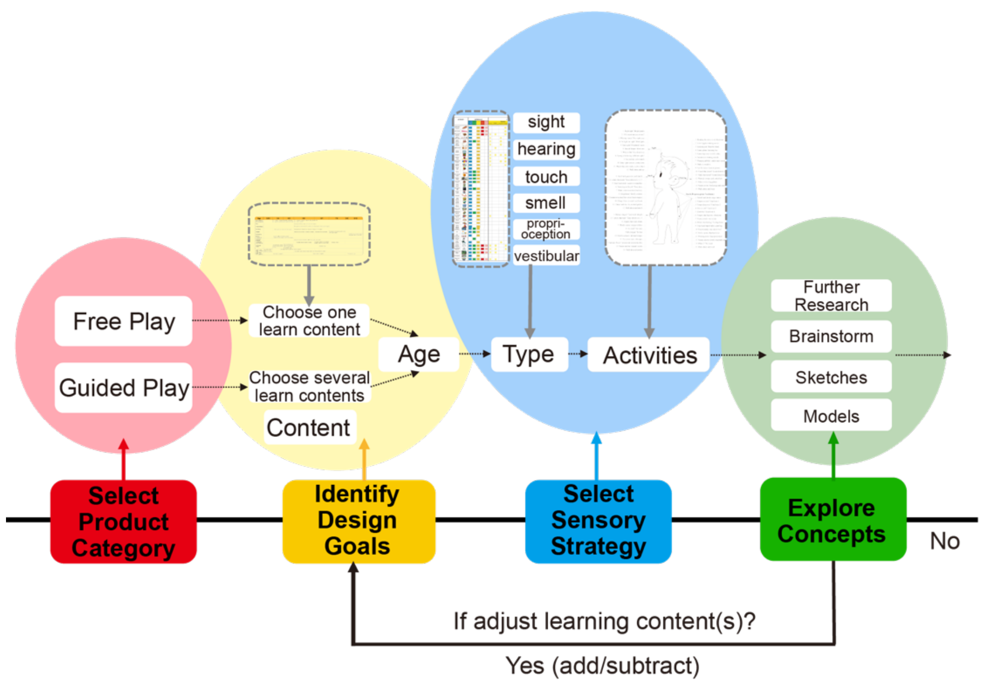


Figure 4.29 Explore Concepts Phase

4.5 Evaluating Concepts

After generating several concepts, the designer should also have the ability to evaluate design quality and define the best solution for teaching children the chosen content (or use the evaluation phase to improve the previous concept). Directly assessing the learning value of the design by questioning children specifically about the product's learning content is complicated and unclear, as children are not qualified to discuss the value of what they are in the process of learning. Instead, designers are suggested to use the parameters that influence shape and space to assess the learning outcome of their design. These parameters, according to Chapter 1, include multisensory play, which improves children's interest and interaction to help children understand learning content better. The children's senses interaction and the children's interest directly impact the children's learning of the outcome. So, designers are suggested to use the level of involved senses and safety (as all products designed for children should follow appropriate safety standards) as primary criteria to evaluate the design concepts.

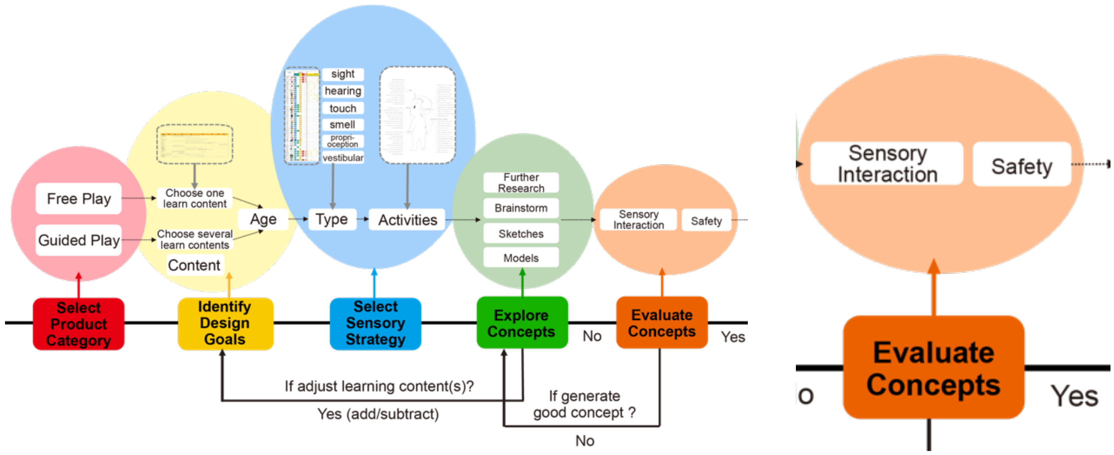


Figure 4.30 Evaluate Concepts Phase

Level of Involved Senses: The designer evaluates the involved multisensory level according to the degree of use of each sense.

The following chart in Figure 4.31 shows an example in which "senses interaction" and "safety" account for 50% each. According to the previous chapters senses interaction influence the outcome of children's learning. Also, it is important for designers to consider children's safety when playing with the designed objects. How safe is this tool? Is there potential for harm at the specified age range?

Designers should first weight the different sensory type (sight, hearing, touch, etc.). The total of the sense's weights should equal 50%. Then they should evaluate the score of each sense interaction and the safety. The scores should be one (low) to five (high). The final score is senses interaction rating (wt.%* evaluation) plus safety rating.

Evaluation Concepts		Senses Interaction Designer should weight the % age desired for each sense, and these should total 50%							Safety	Concept Score = Sum of Rating for Senses Interaction +Safety
		Sight	Hearing	Touch	Proprio-ception	Vestibular	Smell	Sum of Senses Total		
Concept 1	**Weighted % age**	__ %	__ %	__ %	__ %	__ %	__ %	50%	50%	100%
	Evaluation 1 low | 2 | 3 | 4 | 5 high									
	Rating = Wt % * Evaluation									
Concept 2	**Weighted % age**	__ %	__ %	__ %	__ %	__ %	__ %	50%	50%	100%
	Evaluation 1 low | 2 | 3 | 4 | 5 high									
	Rating = Wt % * Evaluation									

Figure 4.31 Evaluation of Concepts Chart

4.6 Further Development

Following their concept evaluation, designers should develop more details of their concepts as they further advance them. Figure 4.32 illustrates this phase. These include color, material, sensory applications, and size. Material parameters can be used in sensory play tools to help designers generate different ideas.

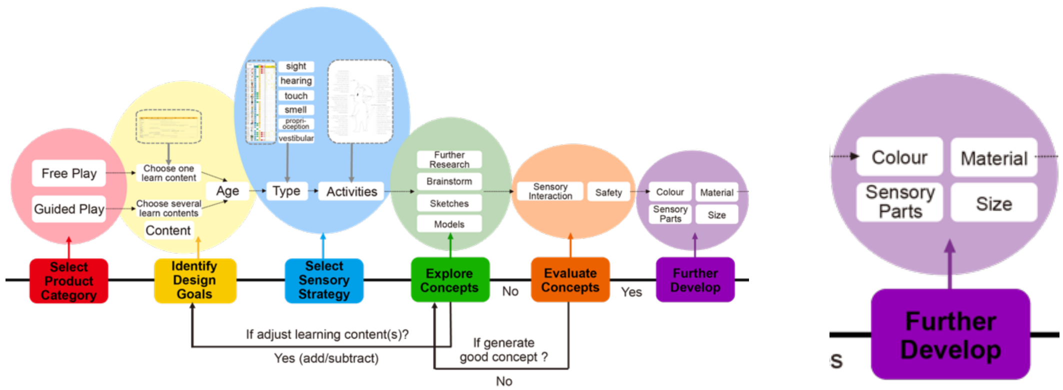


Figure 4.32 Further Develop Phase

Material parameters can be used in sensory play tools to help designers generate different ideas.

Materials: According to Trudi Schwarz and Julia Luckenbill's article (2020) exploring sensory activities related to materials, the materials are divided into five categories: available commercially, found at thrift stores, non-toxic natural materials, found in-home or classroom, and created from scratch. These materials include popsicle sticks, colored sand, paper, contact paper, tape, stamp pads, and stamps, birdseed, feathers, soap, sponges, straw, non-toxic leaves and seeds, flowers and sticks, wool, shells, rocks, gourds, pinecones, sand, and mud, among other possibilities. Using these materials is beneficial to young children as they engage all of the child's senses.

4.7 Final Delivery

Reflecting on the children's psychology and ability development to define appearances such as color and shape, designers should consider manufacturing system design to define structure and materials. Then, they should finish developing all the needed elements for the concept they chose in section 4.4. The final design outcome should clearly illustrate the following: product introduction (what is included in the product recommendations for how and where it is intended to be used), product size, target group, and use instruction. Figure 4.33 shows the guideline and highlights this phase.

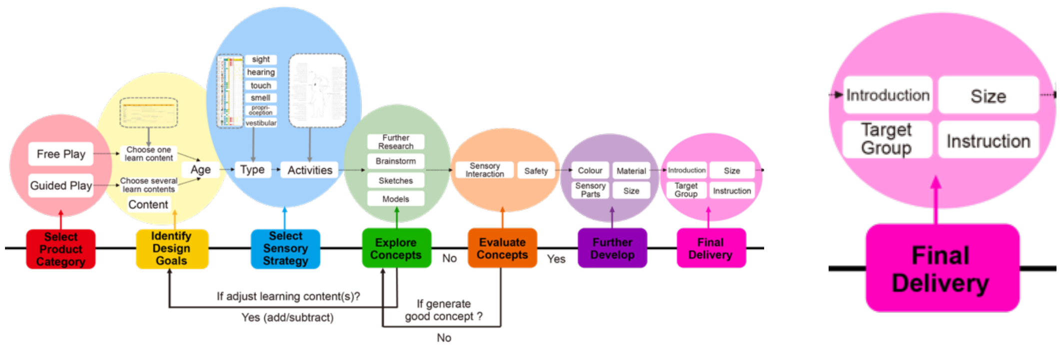


Figure 4.33 Final Delivery Phase

4.8 Evaluating Design

After finishing the whole design concept, designers still need it evaluated by children for feedback on the teaching goals. Designers should explore whether the product interests the children and teaches the planned learning content through observation of their play with the prototype. As mentioned above, directly asking children if they are learning the content selected as the design goal is impractical, so designers should pay attention to children’s engagement, interest, and possibly their spontaneous utterances regarding the toy (see Figure 4.34).

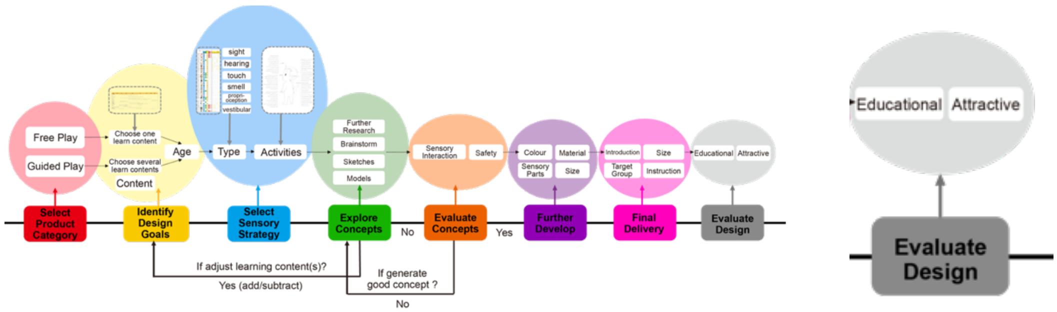


Figure 4.34 Evaluate Design Phase

To evaluate the children's interest in the product, consider the following questions:

- Are the children engaged when playing?
- Do the children play with the prototype longer than average? (See below for a brief discussion of attention spans.)

According to Christina M. Ward (2020), children's average attention spans are as following: 2 years old: 4 to 6 minutes; 4 years old: 8 to 12 minutes; 6 years old: 12 to 18 minutes; 8 years old: 16 to 24 minutes; 10 years old: 20 to 30 minutes; 12 years old: 24 to 36 minutes; 14 years old: 28 to 42 minutes; 16 years old: 32 to 48 minutes. Children can expand their attention time if they are attracted, according to research into brain balance achievement centers. If children's playtime is less than average, the children aren't tempted by the tool, so the concept has less influence on children. In contrast, children who spend more time on tools they are more interested in can get more intrinsic rewards.

- Are children active when playing (sensory interaction)?

- Do children still want to play when the play period ends?

According to the previous teaching goals, designers should study outcome to evaluate if children learn certain content through play.

Chapter 5 Design Application

5.1 Select Product Category

To better illustrate to the designer how to use the guideline, the implementation described in this thesis focuses on guided play, including multiple teaching contents. Designers should consider product needs and primary use scenario of their intended product when selecting guided play or free play. Also, considering that some current teaching tools are not that attractive to students and therefore have ineffective learning outcomes, the design goal is to design a teaching tool for kindergarten that will assist teachers in educating children in the class.

5.2 Identify Learning Contents and Age Range

Pre-identify: Looking through the learning content conclusion in Chapter 4, the application teaching tools include both shape and space, two categories of learning content. The design implementation has a goal to teach children to "match the environment" and "extrinsic dynamic space" (self-object navigation). The following chart in Figure 5.1 lists all the knowledge and ages associated with that content.

Age		2.5-3	3-4	4-5	5-6	6-7	7-8	8+
Name/Match Environment			2D: circles, squares, 3D: sphere, pyramid,	triangles, rectangles cone,cuboid and cube	2D: rhombus, polygon, trapzoid, hap quarter cicle 3D: prism, cylinder			
Extrinsic Dynamic	Loco-motion	Use target object's shape and color feature to locate it	Use target object's geomtric cues to locate it					
					Use spatial cues between target object and the landmark to locate it			
	Navi-gation	Self-object navigation			Object-object navigation			Perspective view

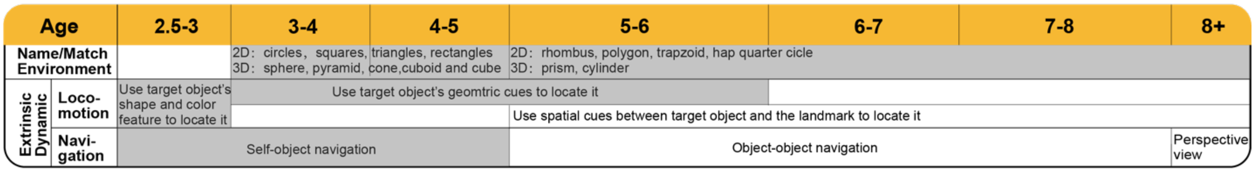


Figure 5.1 Choose Learning Contents

After defining the teaching content, the age group can be identified. In this project, the age range chosen is children in preschool and kindergarten. Teaching goals exhibit a remarkable difference between primary school and kindergarten (preschool). Children learn to understand shape and space through movement and sensory interaction for all these age groups. Combining the target age group and the previously chosen content, this implementation project focuses in the area as shown in Figure 5.2.

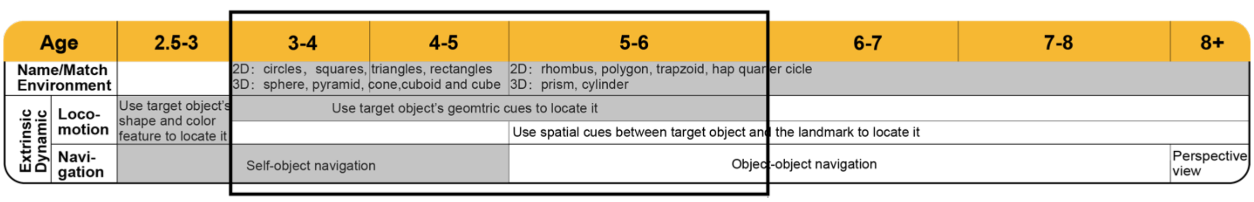


Figure 5.2 Define Age Range

Re-identify: In the ideation phase, this implementation project adds more learning content and redefines the age range again. The ideation phase will illustrate more about this step.

5.3 Select Sensory Strategy

Identify multisensory type: Referring to the chart of case studies in Chapter 3 shown in Figure 5.3, it can be seen that the current teaching of the "match to the environment" and "self-object navigation" ways have the following features:

All ways use sight and touch sense types. Most methods using hearing senses, but just a few outdoor playground playing facilities use vestibular and proprioception senses. And the smell sense is almost never utilized.

Sight, hearing, and touch have the primary influence on children learning "match to the environment" and "self-object navigation."

ACTIVITY	APPROACH					LEARN CONTENT								
						Geometry						Space		
	sight	hearing	touch	proprio-ception	vestibular	name	match environment	property	classify	construction & deconstruciton	transform	intrinsic static	extrinsic static	extrinsic dynamic
geimetric cabinet	●		●	●	●				●					
pink tower	●		●	●	●				●	●				
geometric cabinet	●		●	●	●	●	●		●					
"gifts"1-yarn balls	●		●			●		●						
"gifts"2-cylinder	●	●	●			●		●		●	●			
"gifts"2-cylinder	●		●			●		●		●				
"gifts"3,4,5,6	●		●				●			●				
shape sticker	●		●			●								
tangram	●		●			●	●	●	●	●	●			
Tupper-ware	●		●			●			●					
geoboard shapes	●		●			●		●	●					
pattern blocks	●		●			●			●	●		●		
magic tiles	●		●							●				
Osmo	●	●	●							●		●		
3D Money maze	●	●	●								●			●
thinkfun maze	●	●	●							●				●
Labyrinth maze	●	●	●											●
maze book	●												●	
Spingram app	●	●	●								●			
Rubix's cube	●		●								●			
Origami	●		●								●			
Lego blocks	●		●							●		●		
Mega blocks	●		●							●		●		
Kre-O blocks	●		●							●		●		
Unico Plus blocks	●		●							●		●		
Hubbelino blocks	●	●	●							●		●		●
3D shape blocks	●		●			●			●	●		●		
3D building blocks	●		●							●		●		
Bauhaus blocks	●		●							●		●		
Bristal blocks	●		●							●		●		
straw construction	●		●	●	●	●		●		●				

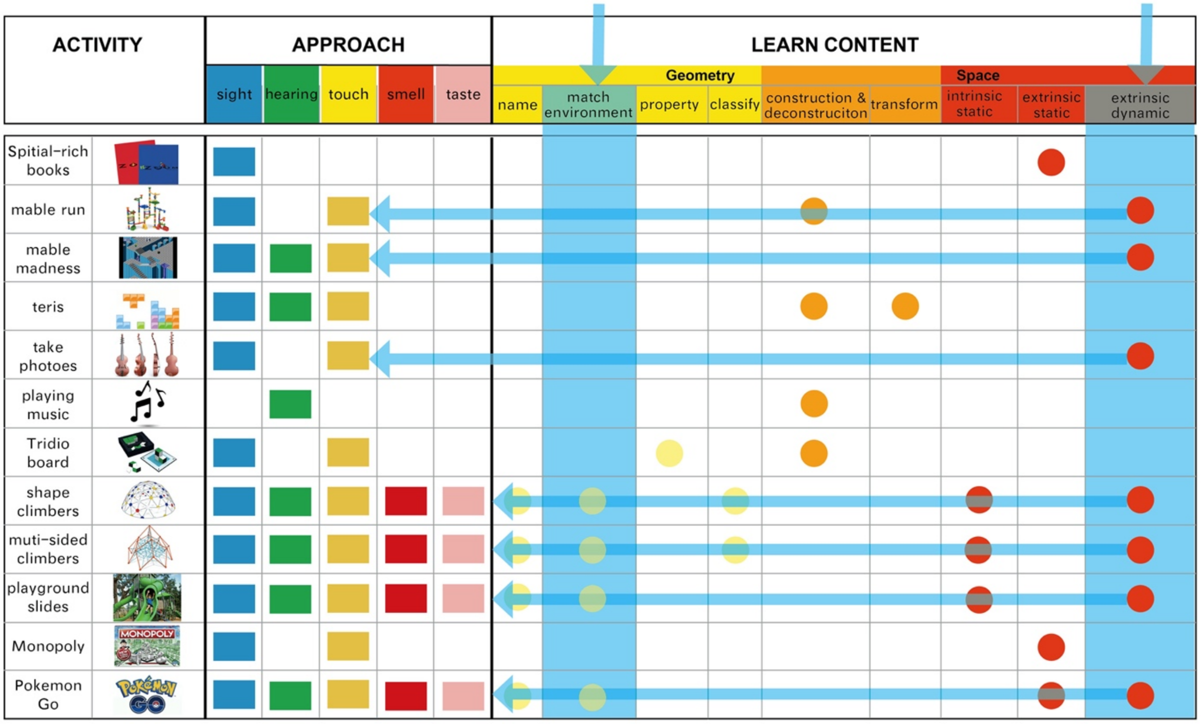


Figure 5.3 Using Case Study Chart as Reference to Choose Multisensory Type

According to the previous research, all five senses in the chart as well as the sense of smell/taste help children learn these two learning content selections. Especially for self-object navigation, children moving in the space helps them understand the space better. The proprioception and vestibular senses are essential for these two learning content choices.

This application selects sight, hearing, touch, proprioception, vestibular, and smell/taste, all sensory types, and defines the percentage of different sensory types used in the teaching tools (see Figure 5.4).

Sight	Hearing	Touch	Proprio-ception	Vestibular	Smell	Sum of Senses Total
15 %	7.5 %	10 %	7.5 %	7.5 %	2.5 %	50%

Figure 5.4 Planning for percentage of sensory types incorporated into the design

The sense of sight is most important, so more sight signs are chosen to put into the design tools. The second in importance are touch and also proprioception and vestibular senses. Next is hearing acuity, and the last is smell, which has an indirect influence on teaching children shape and space.

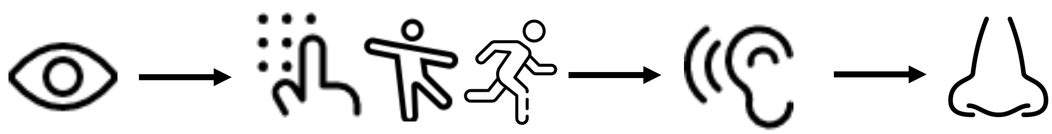


Figure 5.5 Sequence of Different SensesTypes

Identify Sensory Interaction Ways: After reading all the possible ways in Chapter 4.3.2., the following sensory stimulation ways are selected to use in the design:

- Sight: light, appearance form, color
- Touch: material
- Hearing: different sounds
- Proprioception and Vestibular senses: hand and body movement
- Smell: children's preference for scents

5.4 Explore Concepts

Research: Next is researching how to teach children to match a specific shape to the environment.

Chapter 3 gives multiple examples as show in Figures 5.6, 5.7 and 5.8.

Figure 5.6 Case Studies-Match to Environment Teaching Ways

Figure 5.7 Case Studies-Extrinsic Dynamic Teaching Ways

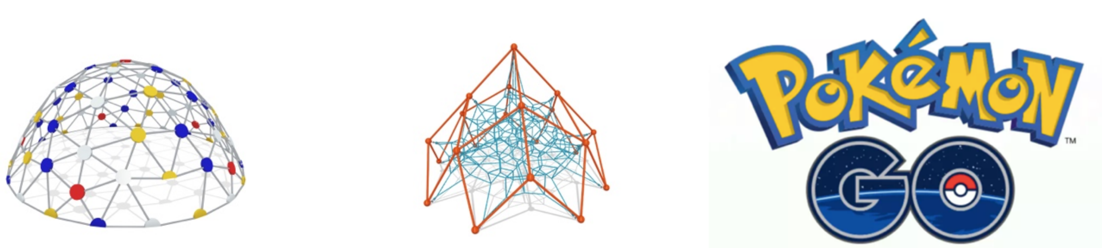


Figure 5.8 Case Studies-Both Match to Environment and Extrinsic Dynamic Teaching Ways

Ideation: After all the above research, the idea is to combine these two processes of knowledge: children can walk into the environment to find the object matched to the shape they have been shown. Children have a small form in their hands, and they walk around in the kindergarten to find the same larger form that was previously put in place by the teacher somewhere in the room. There are two products: one is the magnetic shape blocks children hold in their hands, and the other is the larger matching shape put somewhere in the kindergarten room (for example, hung on the wall or placed on the table). Children can match through the appearance; second, children can also match the objects through the sound emanating from the oversized shape. Children find the larger shape and attach the small magnetic shape block to it, and then the shape will make another sound and flash a light. Different children have different preferences for scents, so the teacher can help children make their favorite scents sample, and then the teacher can spray some liquid to employ smell (see Figure 5.9).

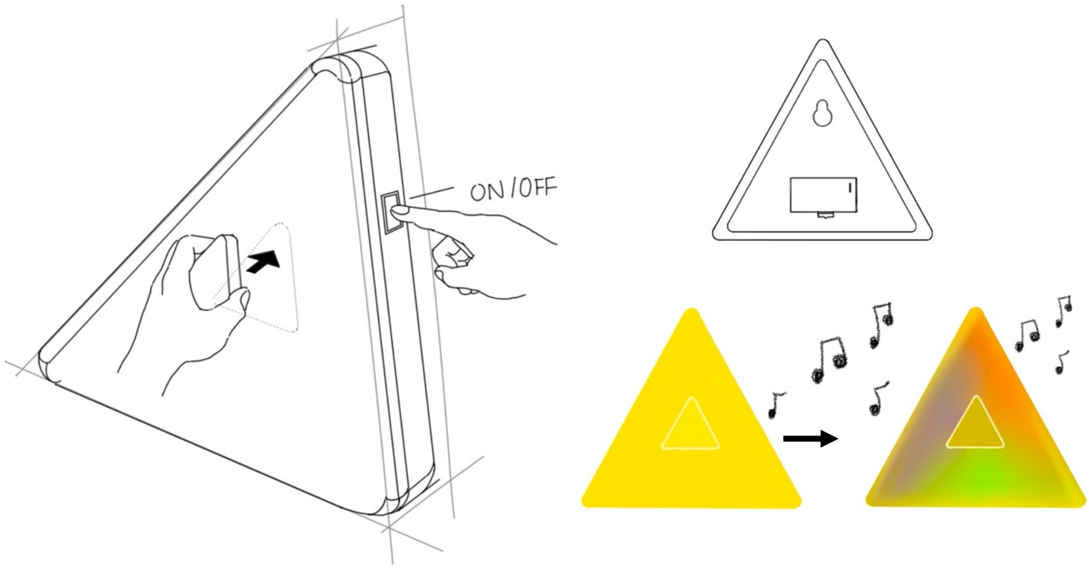


Figure 5.9 Sketch of the Previous Idea

As for shape and space teaching tools, this tool can also have more teaching content under the teacher's guidance. So, the designer goes over the previous shape and space learning content conclusion chart and lists the possible learning contents that can be added into this tool and figures out how to teach children to use it. The list is as follows:

Shape Name: The small magnetic block and big shape plane can be made into different shapes shown in Figure 5.10. Children play with small blocks, and the teacher holds the larger shapes and provides their names.

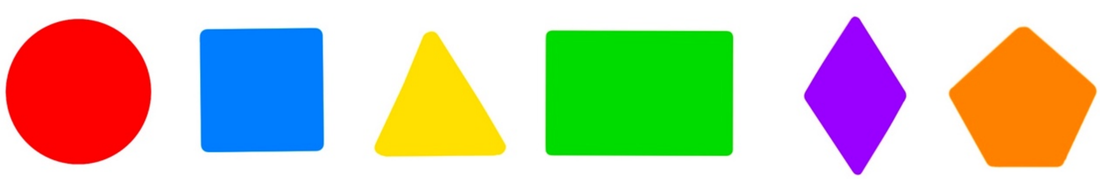


Figure 5.10 Multiple Big Shape Planes

Point/Side/Surface/Angle: Teachers hold the big shapes to teach children points. The colorful light on the end will flash, and when teaching children to recognize the side angles, the bright light will go through the sides of the shape (see Figure 5.11).

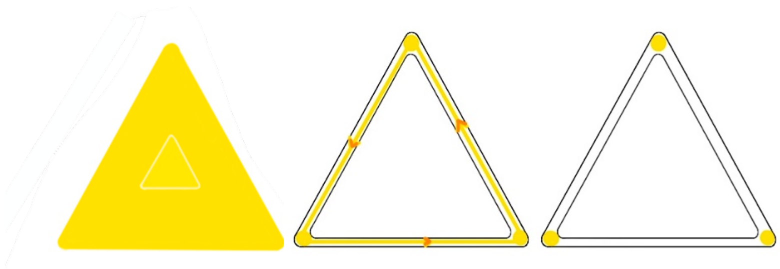


Figure 5.11 Light Face, Sides, and Points

Compose/ Decompose Shape: Children, through touch and sight, play with small magnetic blocks.

Compare Size of Shapes: Through touch and sight, children compare the different sizes of small magnetic blocks.

Intrinsic Static Space (Map): This skill can be combined with the process of children learning to match to environment learning content. After children find specific big shapes in the environment, teachers let children draw the route they walked to find the matching larger big shapes using the kindergarten indoor iconography.

After adding more learning contents into the teaching tool, age and learning contents are refined, as well as multisensory types and ways redefined. The percentage of each sense used changed, just as shown in the following figure 5.13. The specific practices are not changed.

After adding more learning contents into the teaching tools, the designer refined the learning contents as the following figure 5.12. Most space and shape knowledge start at three years old. Most of the learning targeted contents separate at five years old and six years old, but considering the children's cognitive development, including the later ages is better to ensure that all children using this teaching tool, regardless of gender, develop the targeted abilities. So, the age range is redefined as 3 to 6 years old, which is coincident with the children's age in kindergarten and preschool.

Age		2.5-3	3-4	4-5	5-6	6-7	7-8
Name/Match Environment			2D: circles, squares, 3D: sphere, pyramid,	triangles, rectangles cone,cuboid and cube	2D: rhombus, polygon, trapzoid, hap quarter cicle 3D: prism, cylinder		
Points/Sides					Recognize and describe the numbers of vertices/sides of 2D and 3D shapes		
Surfaces			3D shapes are made from 2D shapes		Recognize and Describe the numbers of faces of 3D shapes		
Angles					Describe the numbers of angles of shapes	Recognize the right angles	Recognize the angles greater/ less than right angles
Compare Shapes					Describe shapes'similarities, differences, parts, and others		
Compose/ Decompose					Compose simple shapes to larger	Compose shapes to composite shapes, partition of half /fourth	Partition of half /fourth
Extrinsic Static			Use geometric explicit cues to locate objects on map	Use combinations of objects as geometric cues to locate objects on symbolic map		Standard map	
Extrinsic Dynamic	Loco-motion	Use target object's shape and color feature to locate it	Use target object's geomtric cues to locate it				
					Use spatial cues between target object and the landmark to locate it		
	Navi-gation		Self-object navigation		Object-object navigation		

Figure 5.12 Case Studies

The next step is redefining the multisensory types and ways. After adding more knowledge, children use the hand blocks more, so touch has more value than proprioception and vestibular (which are the same percentage), as is shown in Figure 5.13. Sight accounts for 30%, touch accounts for 20%, proprioception, vestibular, and hearing account for 15%, and smell accounts for

5%.

Figure 5.13 Refine Sequence of Different Sense Types

Then the designer re-researched more different ways and further thinks through the details. The specific practices are not changed.

5.5 Evaluate Concepts

In this application example, only one concept was evaluated. However, designers are not limited to developing, evaluating, and testing one concept at a time. Designers may have multiple concepts; this evaluation phase is useful in comparing concept scores to choose the better one. In this concept, sight accounts for 30%, touch is 20%, hearing, proprioception, and vestibular are all 15% each. Smell is 5%. The sight, touch, hearing, proprioception, and vestibular score are 4, 3, 3.5, 3, 3, and 4 (each maximum score is 5). The final score for this concept's sense interaction test is 74.5% (see Figure 5.14).

Evaluation Concepts		Senses Interaction Designer should weight the % age desired for each sense, and these should total 50%							Safety	Concept Score = Sum of Rating for Senses Interaction +Safety
		Sight	Hearing	Touch	Proprio-ception	Vestibular	Smell	Sum of Senses Total		
Concept 1	Weighted % age	15 %	7.5 %	10 %	7.5 %	7.5 %	2.5 %	50%	50%	100%
	Evaluation 1 low | 2 | 3 | 4 | 5 high	4	3	3.5	3	3	4		4	
	Rating = Wt % * (Evaluation/5)	12 %	4.5 %	7 %	4.5 %	4.5 %	2 %	34.5%	40%	74.5%

Figure 5.14 Evaluating Concepts

5.6 Further Development

The Color of Product: The big shapes are made of transparent colors to enable transmission of different colors of light. The small blocks are made of red, blue, green, yellow, orange, and purple, colors chosen based on research discussed in Chapter 2.

The Color of Light: In line with the understanding of colors preferred by children discussed in the literature review, the color of the flashing lights can be red, blue, green, yellow, orange, and purple.

Materials: The big shapes are made from plastic, and the blocks are made of wood.

Sound: There are two kinds of sound: one is the music that helps children locate the big shape (listen to the sound to find the source), while the other is gives feedback when the small blocks are correctly attached to the plane of the big shape.

Size: The larger shapes are about 35$cm^{2,}$ which is big enough for children to see, no matter where they are in the classroom in relation to the teacher. Because children accidentally swallowing objects that pose a choke hazard, the block lengths are at 70mm for safety.

5.7 Final Delivery

Product Introduction: The larger 2D shapes include circle, square, triangle, and rectangle as shown in Figure 5-15. Small magnetic shapes blocks include sphere, pyramid, cone, cuboid, and cube. Figures 5.15 through 5.16 illustrate this product concept.

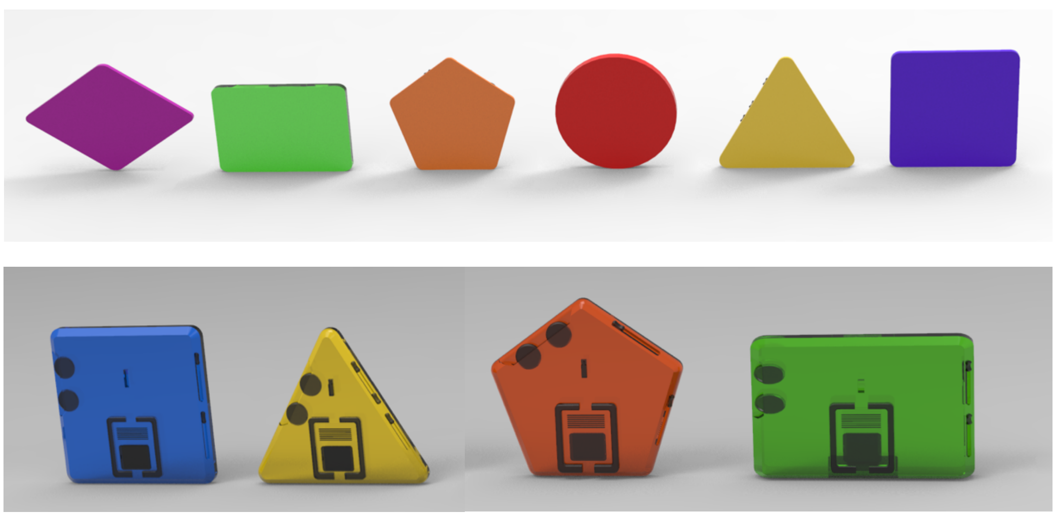


Figure 5.15 Six Different Types of Shapes of Big Plane

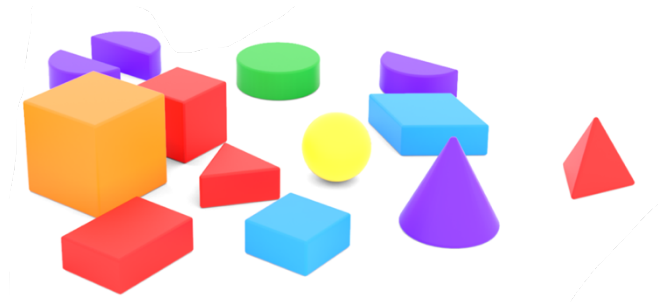


Figure 5.16 Small Magnetic Shape Blocks

Figures 5.17 and 5.18 show in rendering pictures that planes have two control knobs and two slide buttons. One knob can adjust the sound volume, and the other one can adjust the intensity of light. One slide is the modes transfer button, and the other one is the yellow-colored transfer slide button, which has six colors (see Figure 5.19).

Figure 5.17 Front Color Light Plane

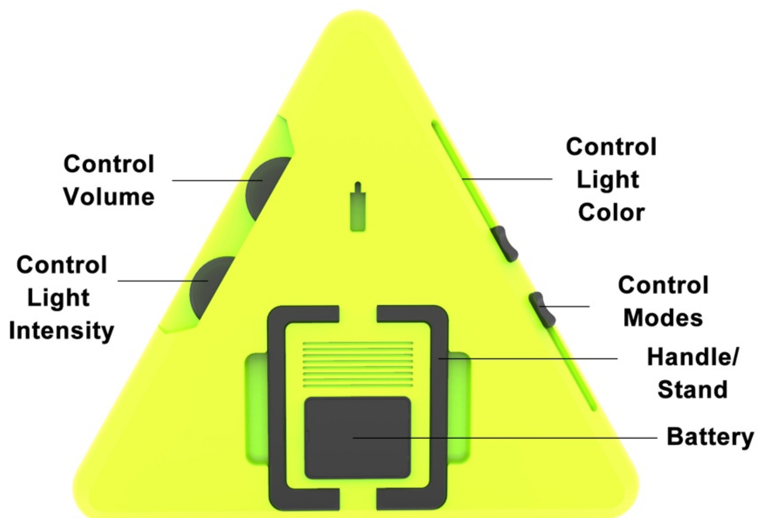


Figure 5.18 Back of the Big Shape Plane

Figure 5.19 Light Color Choice of the Big Shape Plane

The planes can be hung on the wall, stand on its side surface, or be held in the hands (Figure 5.20).

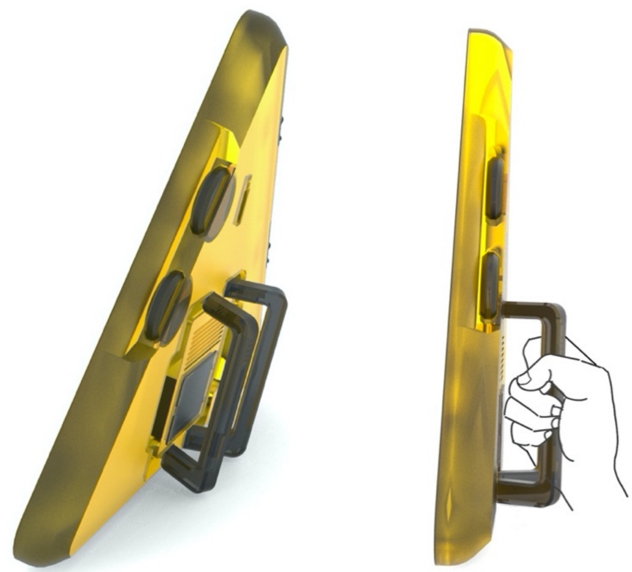


Figure 5.20 Standing on Surface and Holding in Hand

Product Size: The sides of the triangular plane are 300mm in height (see Figure 5.21). The blocks have two sizes. One is 50mm in length, and the other is 70mm in length.

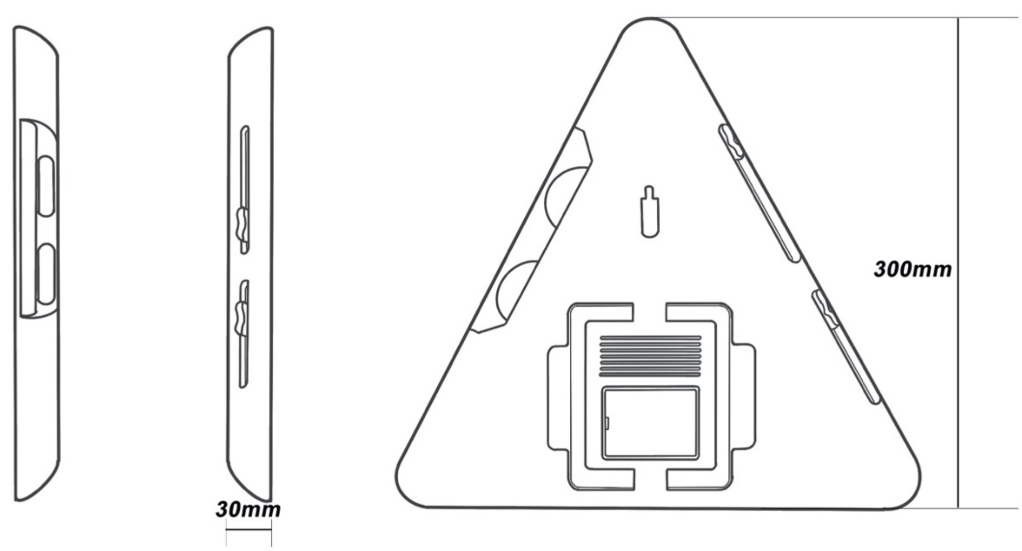


Figure 5.21 Dimensions of Big Light Plane

Target Group: The design is for children between three to six years old.

Usability Instruction: Instructions for teachers are shown in Table 3. There are four modes teachers can use to teach students shape and space content. Mode 1 (the usual mode) is intended to be used most of the time. Mode 2 (search mode) allows children to learn extrinsic dynamic space and match the environment (see Figure 5.22). Mode 3 (point mode) is made for children learning points and angles, and Mode 4 (side mode) is made for teaching shapes' sides.

Figure 5.22 Mode 2: Children Learn Match to Environment and Extrinsic Dynamic Space

TEACHING CONTENT	PRODUCT MODE	TEACHING INSTRUCTION
	MODE 1 + BLOCKS	Children play with small blocks and teacher holds the larger shapes and provides their names.
	MODE 2 + BLOCKS	Children walk to find the big shapes match to shape blocks in their hands
	MODE 3 + BLOCKS	Teachers hold the big shapes to teach children points (angles). The colorful light of the point will flash
	MODE 4 + BLOCKS	Teachers hold the big shapes to teach children lines. Colorful light go through the sides of the shape.
	BLOCKS	Children through touch and sight compare the different size of small magnetic blocks.
	BLOCKS	Children through touch and sight play with small magnetic blocks.
	MODE 2 + BLOCKS	After children find certain big shapes in the environment, teachers let children draw the route they walked to find the big shapes by using the kindergarten indoor iconography
	MODE 2 + BLOCKS	Children walk to find the big shapes match to shape blocks in their hands

Table 3 The Product Instruction for Teachers

Figure 5.23 Children with Small Shape Blocks and Big Shape Planes

5.8 Evaluate & Test Design

According to the teaching content, the designer should conduct a test survey of the design and make sure the children learn knowledge through sensory play with the designed tool. Because of the limitation of IRB, the application example given here did not evaluate the design. However, designers can reference Chapter 4 for a discussion of how to evaluate a prototype in use as the final step of the design process.

Chapter 6 Conclusion

6.1 Conclusion

What will a space look like after a renovation is finished? How do you read a map, or find your way in an unfamiliar place? These problems are highly related to society's lack of a geometric focus on children at a young age.

Learning shape and space at an early age is essential for children's abilities in the long run, such as scene-mapping, creation, and mathematics. How children recognize the basic and complex combinations of shapes through the multisensory play process gradually develops their mathematic problem-solving ability, spatial ability, and even their imaginative-creative ability.

This thesis has studied the relationship between sensory play and children's shape and space learning and developed an approach to help designers create play tools for children aged 3-10 years old to learn shape and space through sensory play. However, further research and development beyond this thesis is needed.

6.2 Further Development

Three aspects need to be developed further. First, this thesis focuses on sight, hearing, smell, touch, proprioception, and vestibular senses. Other senses such as taste and some inner senses, still need further study. There simply are not many studies and theories that focus on these senses, making their application in multisensory play tools not feasible at this time. Because they are not well understood or scientifically correlated with children's cognitive development to the extent that other senses are, their inclusion in play toys and association with age-specific learning content is not as well grounded. Second, understanding space learning requires further research, especially for map reading details and the sense of orientation. Current limits on the understanding of how children learn space also probably limit their application in toys; further research would illuminate more possible teaching methods. Third, more study to help children above ten years old (beginning to use what they learn before to solve problems) learn shape and space is needed. Such work in all these areas would help to expand these guidelines in terms of applicable ages, learning content, and teaching methods, addressing society's need for this kind of learning in a fuller way.

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