AC 2007-2926: PRECURSORS TO ENGINEERING THINKING (PET)

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Precursors to Engineering Thinking (PET) Project: Intentional Designs with Experimental Artifacts (IDEA)

Introduction

Children's play naturally employs skills of observation and experimentation that lead to the development of intuitive models for how things work. These spontaneously occurring activities are precursors to engineering thinking that we recognize as preparation for future learning. We are engaging in a research agenda to explore the learning progression [1] of *engineering thinking* in young children's development, to identify opportunities for expanding their thinking, and to foster interest in engineering. Literature on early childhood development documents how students' cognitive abilities develop over time. However, little research has been done to document how these activities relate to activities that require *engineering thinking*.

Engineering thinking relates to transforming our world; it uses what we know and observe to imagine and reconstruct the world, with the intent of improving our lives. We associate engineering thinking with creative problem solving, involving the balancing of multiple constraints to achieve an appropriate solution. Therefore, engineering thinking employs many learning goals for education, including development of cognitive skills associated with creative problem solving, sensitivity to others' perspectives, generating new knowledge and willingness to persevere toward a goal. We have observed young children continually display these qualities in their informal play.

We have several questions that motive our research into this area of informal play, learning and development. We want to better understand why children want to construct with blocks, what they construct and how do they use them when they are done. We also want to understand how students' natural powers of observation and kinetics help to build their intuitions of physical properties that govern our world. In addition, we are interested in understanding the process associated with how learners construct with blocks. We believe the process, not just the end product, can inform our understanding of how children development goals, problem solving strategies, and intuitions about how the physical world behaves.

A review of the literature suggests that developmental theory and empirical research firmly support the assumption that objects and their use by children constitute a universal part of development and learning. In addition, our own preliminary observations conducted in the context of collaborative exploration with preschool teachers supports our understanding of the use of manipulative objects and artifacts as vehicles of early learning. This work will lay the foundation for describing engineering thinking in young children and its implications for the design of learning environments and processes from a developmental perspective.

While this study seeks to enhance our understanding of the relationship between children's free play activity and *engineering thinking*, it will also be used to explore research questions that pertain to method. What are appropriate ways in which engineering thinking can be made visible to researchers and teachers? For this study we employ a mixed method cross-sectional research design with a phenomenological perspective in attempting to understand specifically "what is it that makes these spontaneous play-learning activities look like engineering". Data collection and analysis is being conducted in three phases.

We are in the process of collecting evidence of *engineering thinking* through a series of naturalistic field observations of preschool children engaged in free play with various open as well as semi structured and structured artifacts such as blocks, puzzles, Lego™ blocks, water tables, and snap circuits. Data from these observations will be used to help us understand children's intentions and processes from an engineering thinking perspective.

This paper presents some of the results from our initial study investigating the nature of children's spontaneous play relative to engineering thinking. We begin with a brief overview of some key concepts from developmental psychology related to study of free play. Next we describe the setting and analysis from observations of 4 children's construction with blocks. The paper provides a summary of our observations and analyzes their implications for more formal learning activities guided by teachers, aides and parents.

Background: Children learn through play

Young children display readily visible natural curiosity and creativity as they engage in free play. Play seems to be a mechanism that humans use to explore, construct and negotiate meaning. Play is a powerful imaginary vehicle that can transform any object into another in order to support the story to be told. The role of play in young children's social and emotional development has been thoroughly studied and its role is universally accepted as a developmentally appropriate part of the early childhood education curriculum [2]. Similarly, the role of play in children's understanding of mathematical and spatial relationships has also been well established within the field of child development and early childhood education [1]. Much of the literature discusses children's development of domain independent abilities such as language, social development, motor skills, and noticing of novelty. Several studies focus on learners' development of privileged domain knowledge that requires simultaneous processing and integration of multiple concepts and the abstraction of ideas (e.g. physics, engineering, mathematics).

While the term *play* is used to signify young children's spontaneous, intrinsically motivated and self-referenced activity, it also refers to curriculum structures that have historically been part of the early childhood education classroom [3]. These two antithetical definitions of play can be reconciled when we view them as part of a continuum that represents our assumptions about learning. Play as a naturally occurring developmental process is "used" to scaffold a learning space through which developmentally, culturally and personally appropriate curricula can be negotiated.
In addition, play constitutes a rich research context which has significantly enhanced our understanding of its developmental and educational value.

Earlier work on children's free play focused on four classifications of successive stages of activity. The stages described by Ruben et al [4] include "1) functional play – repetitive actions with or without objects; 2) constructive play – manipulation of objects to construct or to "create" something; 3) dramatic play – the substitution of an imaginary situation to satisfy the child's personal wishes and needs; and 4) games with rules – the acceptance of prearranged rules and the adjustment to these rules." Our conjecture is that each of these stages can align with various specific activities related to engineering thinking and that complex engineering tasks employ combinations of each of these tasks. Therefore, we begin by exploring the larger vision for engineering thinking, and then evaluate activities that relate to the classifications of expertise to help us align the theories of learning with engineering thinking. The result will be a definition of the precursors to engineering thinking.

Our preliminary analysis is focused on the processes that young children use to construct with blocks. Much of the literature has traditionally attempted to classify block structures in terms of complexity and elaboration arriving at typologies that are object-based. Children's block building is considered an end state capable of revealing something about the inner world of the child at a steady state. In our own analysis of a series of video taped vignettes we concluded that children are as much interested in the process as they are in the product at least while they are actively engaged in construction.

Learning Engineering Thinking with Manipulatives (Concrete and Digital)

Children's play with blocks develops from placing them side by side to placing them on top of each other. By age three children place patterns of blocks to form surfaces and walls. These lead to more complex configurations with walls and a ceiling to construct enclosures representing 3D space compared with the initial starts in 2D space. These activities help learners attach meaning to spatial relationships such as on, by, above, and under. The language of these relationships is developed with the support of others. We see learners going through a natural learning progression as their ideas expand and grow. A number of studies have investigated the learning progression of spatial abilities [4, 5]. Students' learning with blocks emerges from their exploration, both individually and with others. They continually test the limits of their experimental designs by adding "one more block" and observing what works and what does not. In other situations, observing other learners' constructions can provide them with ideas about how to build their next project. What are the opportunities for supporting the development of specific engineering principles associated with complex systems?

The literature has not described learners' acquisition of physical properties associated with support structures and how these can be systematically developed within the context of free play. As part of this study we will develop an instrument that evaluates learners' constructions based on their structural complexity.

Methods

Our ongoing research is conducted in a child care facility for children ages 2-5 on a full-day basis throughout the year. The program was founded in 1983 to provide child development practicum and student-teaching experiences for students. Each classroom has a maximum of 20 children, a Head Teacher, an Assistant teacher, a morning Teacher's Aide, and an afternoon Teacher's Aide. We've conducted two observational studies in this facility. Our initial study was done in the Spring of 2006 when we observed 3-5 year old children engage in a number of formal and formal learning experiences. Observations were made by the authors using field notes. In the winter of 2007 we began an on-going study to observe and video record children engage in free play. These observations were done on a daily basis within a two hour block of time in the morning and in the afternoon.

Many of the children played with the blocks in the dramatic play area and engaged in this activity with very little adult guidance or coaching. However, they sometimes asked for an adult's opinion of something they had created, such as "What do you think of this?" or "Isn't my 'design' pretty?" On occasion an adult participated in their play when asked to hold blocks, move blocks, or even assist with make-believe design instructions. At times, multiple building projects were in progress simultaneously; on average there were 2 simultaneous projects.

When the children decided to construct something with the blocks, they may or may not elicit the assistance of 1 or more classmates. Sometimes, a child decided to start a project solo and was then approached by an interested classmate. The classmate first asked for permission to assist and then joined in if permission was granted – if permission was denied they either started their own project or moved along to another play area. Permission was rarely denied and rarely, if at all, did the other children just watch. If the child had already decided what s/he wanted to build then they would give verbal instructions and guidance to their "assistant(s)" as to what was acceptable and what was not in their design. In general, the helpers either added new pieces that replicated a current pattern in the design or started on a "new addition" off to the side of the main structure. These "new additions" included but are not limited to swimming pools, garages, and driveways. The skill level and spatial abilities [6] of each child did vary but in general they were willing to work together, learning from and sharing with one another.

Results

Observation - Group 1

It is widely accepted that preschool-age children become very adept at using blocks to construct houses, roads, farms, space stations and other things with which they are familiar [6]. For example, we've observed a 5 year boy, Nick, who can construct elaborate block towers that rely on counterbalancing weight and matching block forms to create intriguing architectural structures. When asked if we could safely move certain blocks from the structure, he could appropriately predict and explain whether the tower would remain standing or fall. At some level Nick has become an "expert" block builder capable of building complex structures of his own design. In fact he stated his goal for building the tower as wanting to "make something interesting". Nick's approach to constructing the tower resembled that of an artist continually walking around and analyzing the form. See Figure 1 for Nick's construction.

A second example is David. David, a three year old boy, worked next to Nick to construct a roadway system for his block cars to drive under and around Nick's tower. David's structure was flat on the ground with blocks laying end to end to form his roadway. He used triangular blocks as ramps to allow the cars to move up from the floor level to the height of the blocks. This is in contrast to younger students who would make similar block roads but were willing to have their cars jump over the height difference in an imaginary way. David's structures included the constraints of the physical world where cars need smooth transitions to go from one elevation to another. When asked if we could replace one of the rectangular blocks in the roadway with the triangular block used as a ramp, David gave me a quizzical look and said “the car would fall down”. Again from younger students the cars can be magical and simply fly over gaps in the road. See Figure 2.

Figure 1 – Nick’s Domino House

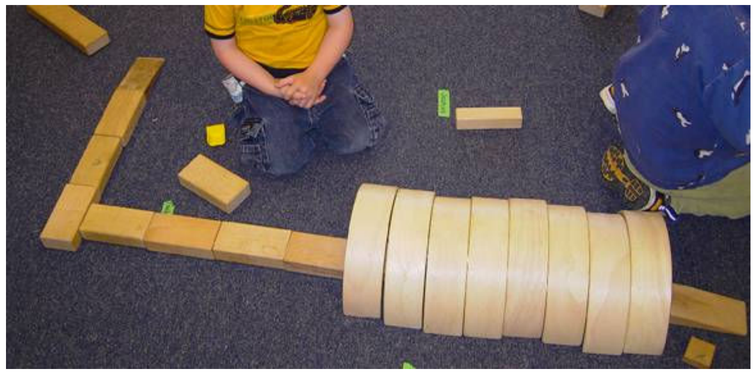

Figure 2 – David’s roads near the Domino House

Observation - Group 2

In the analysis that follows we present ideas that emerged as two preschool age girls (age 4) and their friends engaged in block building activity over a period of one month.
The first builder, Annie, likes to work in various centers that are available to her in her classroom and occasionally she chooses to build. She is an imaginary builder; she seems to execute a predefined plan.

In one instance she devoted an entire 40 minutes to **construct, revise, deal with challenges, rebuild as necessary and finally use** a compound structure of a hotel and surrounding swimming pools. Throughout this 40 minute period (long beyond the expected attention span of a child her age) the young builder was focused on executing a plan that seemed to be very vivid to her. We argue that close observation of how she conducted herself as a master builder reveals a mental model for the structure that was being followed while remaining sufficiently open to other input. Accepting help from others and allowing their participation in the building activity was welcomed but it had to conform to her model. When other children violated this expectation the master builder was quick to “correct” the action and would move pieces around or remove them from the structure completely.

As the structure evolved and grew vertically some of the elements that were added were decorative and seemed to follow an expectation for symmetry and order. Structurally, her buildings are stable and tall and very elaborate in terms of symmetry and ornamentation. Here construction process followed a pattern of going from side, to middle, then other side, as opposed to going from the bottom up. That is, Annie constructed the north wall first, by piling long blocks on top of each other creating a precariously tall, thin structure, and then she moved to constructing the middle structure consisting of arch with a long board creating the roof. Then, the other wall was built and new interesting additions were made to enhance its look. See Figure 3 for the progression of the construction activity.

1 – Starts with north wall

2 – Builds center support structure

3 – Adds south wall

4. Annie's Hotel complete with pools provided by other child contractors.

Figure 3 - Construction Process of Annie's Hotel

Annie began by telling the researcher that she needed a book of instructions and went to get one. She would then pretend that the book contained her blueprints for construction and would consult the "book of instructions" as she continued to build. The book she selected was not related to a construction task by any means, it was in fact a princess story book that contained sketches of the princes and text. No castles or houses were in the book that served as models for her construction.

Our young builder was greatly concerned with the idea of making things fit, of making the blocks work out according to an emergent plan. She made numerous attempts to work within the limitations of the medium in order to achieve an overarching goal. In many instances acceptance of a solution meant acceptance of the limitations of the medium; for example, achieving stability by adjusting the position of two half arches in order to make one large one.

Our analysis of a second example of block building behavior reveals the engineering dispositions of another preschool age girl and her friend. The pair built approximately 10 houses over a period of a month-long observational time, sometimes constructing four structures in a single day.

This builder Sara and her friend Bea built every day around the same theme of shelter and protection for their toys. The sophisticated assumptions about shelter and safety gave this builder and her friend an impetus for engaging in block building that always resulted in providing what was needed by someone that they considered important**.** In this instance we assume that the primary motivation came from the desire of the builder and her friend to build a house for their fish. Living and working comfortably in the realm of the imaginary did not inhibit these two girls from engaging in elaborate construction activities that required a variety of solutions to smaller problems of balance, pattern preservation and above all protection for their beloved fish.

The builders organized their activity and executed a series of tasks that began with an overall plan, building a house for the fish, and proceeded through the solution of smaller problems that included balancing as well as other structural challenges. For example, the girls wanted to construct a roof over their fish's bed to protect him from the sharks. However, they could not determine a way to structurally support it with the existing structure. After a few attempts of working with the blocks and recognizing that laying the block on the fish will "squish" him they abandoned that idea. However, later a wall was built that served as protection from sharks. Sara and Bea worked synergistically and used imaginary language to share their ideas of the building tasks as they related to the larger goal. See figure 4 as an illustration of their structure.


Figure 4 – Fish House

We can argue that these two builders have strong internal models of the concept of home and its usefulness in providing shelter to humans. This sophisticated understanding is very interesting and warrants further investigation.

Another observation of these two girls relates to their proficiency for using the blocks as a medium. Both have good motor skills necessary for lifting and placing the blocks in position. Sara spends a lot of time experimenting with the blocks to discover what configurations is self supporting and which pattern of blocks are beautiful. For example, on multiple occasions Sara constructed the archways, and each time she had to rediscover how to position the arches so they would support each other. Once a block was in place, Sara seldom moved a block again unless it had fallen. Bea demonstrated on several occasions the ability to refine the construction with nuances to either provide more support, or to make the construction more "beautiful". As we continue our investigation we will be exploring how this proficiency builds in learners as they gain more experience with the materials.

Discussion

In the first observation we see children's progression of block building skills similar to earlier studies done with building blocks. However, we also see learner's employment of details of physical properties in their world to invent increasingly complex and interesting designs and designs that satisfy the governing properties of the world. That is, through years of play with blocks, Nick has developed an appreciation for how to move beyond a basic structure that meets obvious constraints (a tower with a wide base) to more interesting shapes that display a creative use of materials beyond just function. Also, David could have bounded his world of a block roadway to the edge of his first rectangular block, but he chose to include the floor as part of this world. Instead of his car magically jumping up from the floor to the roadway, David used a ramp to smooth the transition. In both examples we see these boys employing their observations of how the world behaves into the design of their objects of play. How do these observations emerge? How do students move from relying on only the power of their imagination to developing a world that also complies with the constraints of physics? How do these intentions develop and what are the bounds of these observations?

The ability to construct beyond a simple visual representation of an imaginary world to an actual structure is an important step toward developing engineering thinking. Through their experiences children develop an understanding of material properties and the laws of physics that govern them. Building blocks have very obvious limitations as a construction material because nothing fastens them together. The builders must work with the shapes, weights, texture (friction) and position of the blocks to develop the structural integrity of their creations. This ability to notice these governing principles has been observed even in infants. [8] Piaget demonstrated that 4 ½ month infants can distinguish the possible from the impossible when they see the top block of a tower slide off the top but not fall when it clears the stack of blocks. Therefore, even very young children are developing the precursors to notice events that they can later employ in the creation of their imaginary worlds and later into the concrete world.

Next Steps

We see play involving personal goals as an incredible bridge toward support for young children's intuitions about how the world works and how they can apply the properties of nature to design artifacts for themselves and for others [9]. Through play and interaction with things (objects) in the world children learn how to express their thoughts and share them with others. Studies have been conducted for years using manipulatives as a means of studying developmental trajectories of learners' skills in linguistic, social, cognitive (spatial), mathematics (number sense and operations) and scientific inquiry [8,9,10]. We see these as important precursors to engineering thinking. We intend to expand our investigation on how a learner masters media such as blocks, Legos™, paper and pencil and other open-ended materials. Additionally, we would like to study the transfer of this learning toward engineering activities like designing things that serve others. Therefore, we will be designing several studies that describe children's play with open-ended materials (e.g. blocks) from an engineering perspective and pilot test new instructional materials that help children develop intuitions about general physical principles (weight, distance, balance, pressure, flow, energy transfer) that allow them to anticipate the success of a design and explain how to appropriately improve a design based on these intuitions. Also, we want to describe how a child incorporates multiple constraints, including other's needs, into the design of an artifact.

Conclusion

This paper shares our initial exploration of engineering thinking in young children's activities of block building. We are building on prior research on early childhood development, but focus our attention on questions that relate to specific precursors to engineering in addition to the language literacy and spatial development of earlier studies. The knowledge from this study will be fundamental to informing our development of curriculum materials that integrate engineering thinking with activities teachers are already familiar with and value as learning activities. In addition, these studies provide us with assessment methods to help teachers identify and stimulate engineering thinking in their students.

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