4. Introduction

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Cognitive Origins of Graphic Productions
battle between the Ojibwa and the Sioux in which the Ojibwa lost one man.

How can these depictions be characterized? Of course, generalizations are problematic. Many of the more sophisticated communicative depictions consist of discrete elements in a linear array. The elements appear to represent persons or objects or events, and the linear array seems to correspond to a sequence. The sequence is typically temporal, either the sequence of events, as in the second example (where time goes from right to left), or a sequence of thoughts/words, or both, as in the first example. Simpler depictions, like many petroglyphs, often consist only of icon-like elements, with no relations between them.

A: [Image of a deer and other symbols]

B: [Image of a battle scene]

FIGURE 4.1. Pictographic messages on birch bark (Ref. 1). A) "I am going across the lake to hunt deer" (p. 331); B) Battle between Ojibwa and Sioux (p. 559).

Many of the surviving depictions seem to have been used in communication and record-keeping. Other depictions seem to have had aesthetic and sacred functions. Depictions have served all the functions of written language, and then some. Depictions are compelling. Compared to purely symbolic script, they are easy to produce and easy to understand. Indeed, in his first encounter with pictures at an early age, a child was able to correctly label simple line drawings of objects he was familiar with from real life [2]. Pictures are increas-

ingly used on highways, in airports, in books, in the mass media, and in computers. Depictions are not just used, their current popularity and ease of production has insured that they are also abused (for examples, see Tufte [3], Wainer [4]). Of course, interpreting depictions is not always immediate, and often depends on shared conventions. Even if we recognize an icon as an airplane, it is not immediately obvious that it stands for an airport, though it is undoubtedly more readily interpreted than a comparable word in an unknown alphabet.

The graphic inventions for both concrete and abstract concepts produced by different cultures show remarkable similarities, and show similarities to the graphic inventions produced by children. The changes in graphic inventions over time within cultures often parallel the changes over time within children. One theme of this paper, then, is that ontogeny recapitulates phylogeny in the production of graphic inventions. Some of the uses of space to convey meaning in depictions have parallels in language and gesture as well. These similarities and parallels suggest that the depictions of many concepts and relations are natural or cognitively appealing, that there are cognitive principles underlying the similarities. That is the second theme of this paper. All along, I will discuss a number of graphic inventions produced by children, and compare them to historical examples for similar concepts. I will attempt to draw some cognitive principles for graphics from these examples.

4.1.1 ELEMEHNT AL AND RELATIONAL CONCEPTS

It is common in discussions of language to distinguish objects or elements from attributes or relations or predicates, the subjects of discourse from the qualities or activities attributed to them. This distinction has parallels in the grammatical distinction between subject and predicate. It also has parallels in the distinction made in cognition between schemas or data and operations performed on them. This is a functional distinction, and while it holds for many cases, it breaks down for others. Two assertions about elements and relations seem self-evident. First, it is easier to depict concrete elements than to depict abstract elements or to depict relations, concrete or abstract. Depicting items of food is easier than depicting a restaurant, which, in turn, is easier than depicting a law firm. Depicting a customer is easier than depicting making a purchase and depicting a car is easier than depicting renting a car or selling one. The sec-
4.1. Icons and Pictographs

4.1.1. Representation

4.1.2. Pictographs and Symbols

Process is defined as the sequence of actions or events that transform input into output. In a cognitive psychological perspective, this sequence is not just a series of steps but a complex interplay of mental processes. The representation of a concept is not just a static image but a dynamic process that involves the activation of various cognitive mechanisms.

4.2. How Deplotions Are Used to Convey Meaning

Deplotions (from Greek déplēō, to fill) are used to represent concepts, ideas, and processes. They are often used in diagrams, charts, and other visual representations to convey meaning in a clear and concise manner.

Example: A diagram showing the steps in a process, with each step represented by a symbol or icon. This helps to illustrate the sequence of events and makes it easier to understand the process as a whole.
is used to represent the object. In Figure 4.2, the Hittite sign for a man was the head of a man, and the Sumerian sign for an ox was the head of an ox. The Crow Indians used horse foot prints to signify and quantify horses [1]. These are examples of synecdoche, using a part to represent a whole. Synecdoche is common not only in pictorial signs, but also in figures of speech, using the same principle. Ranchers count “head” of cattle, and teenagers drive their “wheels” to school. Related to synecdoche is metonymy, where an associated object is used to represent an object. To convey famine, the Dakotas portrayed empty racks for drying buffalo meat [1]. In Figure 4.2, all of the signs for water use the movement of water to portray water. Crowns are used to represent kings, both in pictures and in speech. “The church” and “the White House” may refer to buildings, but they may also refer to the institutions the buildings symbolize.

4.2.1.2 Rebus Principle

Indeed, most authorities agree that most writing systems began as pictures, presumably representing meaning directly [6]. Representing meaning directly quickly becomes problematic. For example, it is difficult to represent abstract concepts and proper names. All true writing systems solved those problems by inventing ways to represent sound. One widespread means of representing sound is based on the rebus principle where a pictograph of an object with a similar name is used to represent something that cannot be easily depicted [5, 7, 8]. An example would be writing “before” using a picture of a bee and the numeral 4. The contemporary use of hearts to mean “love” in bumper stickers is an application of the rebus principle. There is recent and still controversial evidence that Sumerian cuneiform, the world’s earliest writing system, grew out of the shapes of clay tokens used in accounting, rather than from depictions [9]. Nevertheless, the evolution of cuneiform from representing meaning directly to representing sound presumably followed the same rebus principle.

4.2.1.3 Schematization

Even when an icon is used in a straightforward manner to represent the thing the icon depicts, icons are schematic and undergo further schematization over time. That is, icons are simplified representations of classes rather than representations of classes. The reasons for this are many. With constant repetition, ease of execution be-
4.22. Special Arrangement of Graphic Productions

4. Cognitively Organized Graphic Productions

4.22.1 Special Arrangement

4.22.2 Symbols

4.22.3 Symbols

4.22.4 Special Arrangement of Graphic Productions
4.2.2.3 In Sum

The attempts of preliterate children to write reveal many of the characteristics of writing systems developed all over the world. They display a linear organization, they separate words, and they produce marks for concrete objects prior to marks for activities. In producing marks for words, children used the same correspondences that written languages have used, correspondences of appearances of the objects and the written signs, that is, representing meaning directly, and correspondences of the sounds of the names of the objects and the written signs, that is, representing meaning by representing the sound system of language.

4.2.3 Children’s Early Arithmetic

Unlike fully developed writing, arithmetic symbols do not reflect the sounds of the names of the numerals or operators. Mathematical writing is a visual system, not a phonetic system. In truth, many modern day writing systems have visual, non-phonetic elements as well. The visual elements of writing include spacing between words, punctuation, numerals, and certain signs important enough to be included on keyboards, %, $, and &. Although mathematical writing does not reflect sound, current mathematical writing does not reflect appearance either, though, like writing, historically, some aspects of it did.

4.2.3.1 Representing Numbers

Hughes [18] asked preschool and early school-aged children to represent various arithmetic concepts on paper. In one task, he put one to six bricks on a table, and gave a child a piece of paper, asking the child, “Can you put something on paper to show how many bricks are on the table?” (p. 55). There were four types of responses. Idiosyncratic responses were squiggles, bearing no relationship to the number of bricks. Iconic responses were pictures of things other than bricks, where the number of things corresponded to the number of bricks. Often the iconic responses were lines, like tallies, but sometimes they were unrelated objects, like houses. These two categories of responses were dominant in the preschool years, but dropped to very low levels in the first grade. Pictographic responses were pictures of bricks, where the number in the picture corresponded to the number on the table. This type of response increased in frequency from preschool to first to second grade, and dropped in third grade. Finally, symbolic responses used the conventional numerals. This type of response was infrequent in preschoolers, but increased steadily thereafter, so that by third grade, it was the dominant response.

4.2.3.2 Representing Zero

Hughes’ next step was to brush aside the bricks, and to ask the child to “show that there are no bricks on the table” (p. 63). The children who were using the numeric symbols put down zero with little difficulty. Children who did not know the numeric symbols, however, were often confused, and did not know what to put. Some left a blank, and some drew a line. In short, amongst children who did not know zero, there was considerable confusion and little agreement.

4.2.3.3 Representing Addition and Subtraction

Hughes and his collaborator Jones [18] used techniques similar to those that extracted number representations from children to extract representations of addition and subtraction. In one task, they put two bricks on the table, and then added two more, and asked, “Can you show that we first had two bricks and then added two more?” (p. 72). In another task, they removed one brick from a pile, and asked, “Can you show that I took one brick away?” (p. 73). These questions stumped the children. Many simply recorded the total number of bricks, or the numbers of the two sets of bricks to be added. None of the children, not even those who used arithmetic daily in the classroom, used the standard plus and minus signs.

Some of the children drew hands to show the action of adding or subtracting, or feet to show bricks walking away. Other children used arrows. On the whole, the depictions were not satisfactory representations of these abstract concepts.

4.2.4 Historical Examples of Arithmetic

4.2.4.1 Counting Systems

The children's inventions were then compared to the history of written number systems in other cultures in support of the idea that ontogeny recapitulates phylogeny. Except where noted, the historical discussion comes from Hughes [18]. Prior to recording numbers,
No one of these symbols was widely used, and none survived. The plus symbol (+) was used by children in Pugh’s studies for similar purposes. Both were used by children in Pugh’s studies for similar purposes. Both these symbols were used by children in Pugh’s studies for similar purposes. The plus symbol (+) was used by children in Pugh’s studies for similar purposes.

In this example, no symbols were used for the operation of addition. Each symbol was used by children in Pugh’s studies for similar purposes. If the number of objects and the number of objects were represented by the symbols, then the operation of addition would be represented by the symbols. If the number of objects and the number of objects were represented by the symbols, then the operation of addition would be represented by the symbols.

4.1.4.2 Representation of Numbers: Pictographs

Pictographs are images that represent numbers. They are often used in everyday contexts to convey information. For example, a picture of a apple might represent the number 1. Pictographs are often used in everyday contexts to convey information. For example, a picture of a apple might represent the number 1.

4.1.4.3 Representation of Numbers: Textual and Symbols

Textual representations are more abstract and less concrete than pictorial representations. They are often used in written and spoken language to convey information. For example, the word “three” might be used to represent the number 3.

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and minus signs in use today appeared in Germany in the fifteenth century, and the equal sign about a century later.

4.2.5 Historical and Developmental Parallels in Arithmetic Representations

The parallels between children’s inventions and historical inventions of numbers are striking. Prior to recording, body parts, especially fingers, were and remain used for counting and keeping track of sums. Early permanent records, Sumerian tokens, counted different kinds of things with different tokens, a practice that endured after writing began. For ancient Sumerians and Hughes’ young children, the number of sheep or bricks was indicated by a one-to-one correspondence between items in the world and pictures or tokens of the items. Later, tallies replaced pictographs or tokens. In tallies, the same marks are used to represent quantities irrespective of the type of quantity. Still later, number symbols replaced tallies. Number symbols are more efficient, both in conserving space and in arithmetic manipulations. The children most likely did not invent number symbols, rather, they seemed to be applying what they were learning in school. Historically, number symbols were slow to be developed, and symbols for arithmetic operations appeared even later. Complex as elemental concepts can be, relational concepts can be even more complex, and consequently more difficult to depict.

4.3 Pictorial Space and Pictorial Devices

4.3.1 Children’s Graphic Productions

The arithmetic operations have generally been represented by symbols. Another way to represent relational concepts is to use spatial relations in pictorial space. Maps are a simple and straightforward example, where distances and spatial relations among cities are represented in miniature by distances and spatial relations on paper. Another prevalent modern example are graphs. In contrast to maps, graphs are a relatively recent invention. Graphs began to appear in significant numbers in Europe only in the late eighteenth century [3]. I turn now to discuss cross-cultural research on children’s graphic productions for a variety of concepts.

4.3.1.1 Task

Kugelmaess, Winter, and I [20] were interested in how children use space to represent increases in abstract concepts, temporal, quantitative, and preference. The task we developed was simple. We sat next to a child and gave the child a square piece of paper and some stickers. We told the child that we were going to put down a sticker for, say, breakfast time, and the child should put down one sticker for lunch time and another sticker for dinner. That was one of the temporal concepts, and there were one or two others depending on the experiment. Examples of a quantitative dimension were the number of books in a child’s backpack, the number of books at home, and the number of books in the library. For preference, we asked the child for their favorite food, a food they dislike very much and a food they sort of like. For all these attributes, the task was the same. The experimenter put down the first sticker in the middle of the square page, and the child put down the next two stickers.

4.3.1.2 Information Preserved

We were primarily interested in three aspects of the data. The first was information preserved in the children’s mappings on paper. Would they see the relation as nominal, as three unrelated items, and put the stickers down in a disorganized fashion, or would they see the relation as ordinal, and put the stickers on a line? In the second and third studies, we asked children about inequally spaced items, giving them the opportunity to preserve interval information in their mappings. In nominal representations, things belonging to the same category are placed together, and there are no relations between categories. In ordinal representations, the order of the items is meaningful and interpretable, and in interval representations, the intervals between items are meaningful and interpretable, the greater the spatial distance between items, the greater the conceptual distance. As expected, there were age effects in the information preserved in mappings. Some of the kindergartners and first graders preserved only nominal relations, though most of them preserved ordinal information. Only a few of the fifth graders preserved interval information, though with considerable coaching, some of the third graders came to represent interval. There were some effects of content as well. Interval information was represented at an earlier age for the most concrete concept, time, next for the quantity, and latest for the most
4.3.4.4 Abstract of the concepts' preference

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For quantitative and preference concepts, there was no single dominant direction for increases. Instead, upwards and the two horizontal directions were used about equally often. The downwards direction was never used for expressing increases. The upward direction corresponds to pervasive expressions in language associating up with good or more. This suggests that there is a natural cognitive correspondence between the upward direction in space and positivity that is revealed in both language and graphic productions (cf.[25, 26, 27]).

4.3.2 Spatial Pictorial Devices

Now, I'd like to apply these findings along with examples from the "visual language" we have all around us to point out some general principles for the way spatial relations and related spatial devices are used to convey meaning, primarily to represent relations. Many of the relations are based on Gestalt principles, especially those of grouping, in particular, proximity, common fate, and similarity. The device of primary interest is the use of spatial relations to convey other relations. Other pictorial devices are also commonly used, such as size, color, and highlighting of elements. The devices separate neatly into those conveying nominal or categorical relations, those conveying ordinal relations, and those conveying interval relations.

4.3.2.1 Categorical Relations

The simplest devices are those used to group elements into classes, sharing a single feature or set of features. One device has already been mentioned, separating the letters of one word from the letters of another word by leaving a space between words. Indentation of paragraphs is another example, where major ideas are separated by a spatial device. Empty space is not the only device for delineating groups. Another common practice is delineation, using a line to enclose a group, as in a frame, or parentheses, or a box, or a circle. Color, shading, and cross-hatching are other ways to signify that some elements are related by being in the same category.

Some spatial devices group and juxtapose at the same time. A good example is organization into rows and columns, where, again, space separates items along the rows and the columns. Usually, the column items are related to each other in one way and the row items are related to each other in another way. Rows and columns class-
REPRESENTATIONS

4.4.2 Two Aspects of Meaning and Two Aspects of Cognitive Conventions of Scientific Charts

Conclusions

A cognitive convention of graphic productions is a set of conventions about a generalization of the graphic productions that it is intended to illustrate.

Whenever one attempts to interpret the relation between the graphic productions, one must assume the existence of some basic conventions that are involved in the graphic productions. The conventions of the graphic productions are those conventions that are assumed when interpreting the graphic productions. The conventions of the graphic productions are those conventions that are assumed when interpreting the graphic productions.

4.3.2.3 Internal Relations

Without any change of meaning, the graphic productions are abstracts of the conventions of the graphic productions. They can be interpreted without changing the meaning of the graphic productions. The conventions that are involved in the graphic productions are the conventions that are assumed when interpreting the graphic productions.

When we think about extension, we think about the evolutionary development of the graphic productions.

4.3.4 Original Relations: Directly Involving Cognitive Charts

The graphic productions are a set of conventions about the generalization of the graphic productions. They are not conventions about a generalization of the graphic productions. They are conventions about the generalization of the graphic productions.

Whenever one attempts to interpret the relation between the graphic productions, one must assume the existence of some basic conventions that are involved in the graphic productions. The conventions of the graphic productions are those conventions that are assumed when interpreting the graphic productions. The conventions of the graphic productions are those conventions that are assumed when interpreting the graphic productions.

When we think about extension, we think about the evolutionary development of the graphic productions.
4.4.3 COGNITIVE NATURALNESS

4.4.3.1 Grapheme Perception

Graphemes are represented by symbol sets. Graphemes are the minimal units of written language that are distinguished from one another. In general, graphemes are the smallest units of written language that can be perceived and processed as a single unit. Graphemes are typically represented by symbols, such as letters or characters, that are used to represent specific sounds or phonemes. Graphemes are the building blocks of written language and are used to represent the sounds and meanings of words.