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Implicit cognitive development in cultural tools and children: lessons from Maya Mexico

Ashley E. Maynard^{a,*}, Patricia M. Greenfield^b

^a *Department of Psychology, University of Hawai'i, 2430 Campus Road, Honolulu, HI 96822, USA*

^b *FPR-UCLA Center for Culture, Brain and Development, 1282A Franz Hall, 405 Higgard Avenue, Los Angeles, CA 90095-1563, USA*

Abstract

Zinacantec Maya weaving tools and apprenticeship practices contain an implicit theory of cognitive development that corresponds to Piaget and Inhelder's explicit theory of cognitive development [The Child's Conception of Space, London, Routledge and Kegan Paul, 1956]. A set of preoperational and concrete operational spatial problems from the weaving domain provided empirical support for the ethnotheory of cognitive development implicit in Zinacantec weaving tools and their developmental sequencing. A structurally similar set of preoperational and concrete operational spatial problems were adapted from Piaget and Inhelder's Swiss research. Both sets of problems were presented to children aged 4–13 in Nabenchauk, a Zinacantec hamlet in Chiapas, Mexico, and in Los Angeles, CA, USA. While the sequence of operational development was the same across both domains and both cultures, Zinacantec children were more precocious with the weaving problems, whereas U.S. children were more precocious with the spatial problems adapted from Piaget and Inhelder. After a brief instructional procedure, children in both Nabenchauk and Los Angeles improved on the weaving problems only, within the maturational constraints typical of concrete operational development. Nonetheless, the brief learning experience could not reverse the advantage of long-term cultural familiarity with backstrap-loom weaving. Our conclusions are threefold: (1) An implicit ethnotheory of cognitive development, built into the sequencing of cultural tools, can be as developmentally valid as an explicit formal theory. (2) Culture-general Piagetian stages are harnessed in culture-specific situations. (3) Maturational readiness interacts with both long-term cultural experience and short-term learning experience to actualize concrete operations in

* Corresponding author.

E-mail address: amaynard@hawaii.edu (A.E. Maynard).

a specific context. Cross-context generalization of Piagetian stages is far from automatic; it requires cultural learning.

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It is not unusual to think about cultural tools being designed for people of specific ages or with specific skills in mind. On a trip to most any toy store in a typical city in the United States, one can find toys with age-graded suggestions: “Suitable for ages 3–5” or “Not suitable for children under the age of 2.” Indeed, many toys are cultural tools that are designed for specific ages of children to develop specific skills, either cognitive or social. Educational toys, in particular, are cultural tools that are designed to train cognitive skills such as memory, reasoning, spelling, or analysis to children at specific ages or skill levels. Are these age designations arbitrary, or do they fit with parents’ implicit views of children, with children’s own motivations to play with the toys, or with explicit research on children’s abilities? This is the issue we set out to address in the present study, but in a different cultural context, that of Zinacantec Maya weaving.

We knew from prior ethnographic fieldwork that different cultural tools used in Zinacantec weaving seemed adapted to different levels of cognitive development, as described by [Piaget and Inhelder \(1956\)](#). In a sense, these weaving tools had implicit stages of cognitive development embedded in them. We also knew that parents helped children to use these different tools at ages that corresponded to the appropriate Piagetian stages; and, indeed, children sought out the different tools at the corresponding ages ([Greenfield, 2000a, 2000b](#)). Clearly, a model of Piagetian stage development was operating at the implicit level in children and parents, as well as in the tools. The major goal of the present empirical study was to examine whether this implicit theory of cognitive development corresponded to actual cognitive development of the children using the tools at the various ages. Would, for example, children make the predicted preoperational errors if they were too young to use a weaving tool that required concrete operational thought?

In the tradition of [Dasen, Mishra, and Niraula \(submitted for publication\)](#), we investigated the role of cultural learning, itself an implicit process, in the development of Piagetian stages of spatial representation. We investigated this by comparing the same children on two sets of concrete operational tasks. One set represented an important target of cultural learning in Zinacantán, weaving, the other less familiar, loops of string with spools of thread on them which were turned into figure-eights or “knots” (adapted from [Piaget’s 1956](#) knots task). We utilized a crossover design, comparing Zinacantec children with children in Los Angeles in which Maya backstrap-loom weaving is totally unfamiliar. The children’s cultural familiarity of the knots materials was, in a sense, equally familiar and unfamiliar; however, the task was a totally decontextualized one, without a real-world counterpart. The cultural familiarity of solving problems for their own sake, rather than

for the sake of solving a real-world problem, would be much more familiar in Los Angeles. By comparing performance across domains, we could empirically test the extent to which Piagetian stages are domain specific and the extent to which they are domain general.

This question is another way of putting the issue of generalization of everyday cognition, a question that has a venerable history in cross-cultural cognition (e.g., Greenfield & Lave, 1982; Guberman & Greenfield, 1991; Nunes, Schliemann, & Carraher, 1993; Schliemann, Carraher, & Ceci, 1997; Scribner & Cole, 1981; Saxe, 1991; Segall, Dasen, Berry, & Poortinga, 1999). With respect to weaving, Tanon (1994) found an effect of weaving experience in Ivory Coast, West Africa, on planning tasks, both in and out of the weaving domain. With respect to Piagetian stages, transfer from a culturally familiar domain to an unfamiliar one has occurred with extensive experience in the culturally mandated domain in both concrete operations (Price-Williams, Gordon, & Ramirez, 1967; Saxe & Moylan, 1982) and formal operations (Schliemann, 1988). On the other hand, there has been a suggestion that implicit procedural knowledge does not transfer as well as explicit declarative knowledge (Guberman & Greenfield, 1991).

Another question is how culturally mandated long-term experience, which has an implicit nature, interacts with short-term learning experiences of an explicit sort. We can see these two kinds of learning experience as partly resulting from two kinds of pedagogy, implicit pedagogy and explicit pedagogy. It is known that long-term cultural experience has an impact on the development of concrete operations, using the classical situations developed by Piaget (Dasen, 1977). It is also known that familiar materials, a component of everyday cultural experience, can improve the performance of unschooled participants on tests of concrete operations (Saxe & Moylan, 1982). Finally, short-term learning experiences can activate concrete operational thinking in unfamiliar situations (Dasen, Lavallee, & Retschitski, 1979). What is not known is how explicit short-term training interacts with implicit long-term cultural experience. Our design was able to address this question.

Another issue also comes into play. In much cross-cultural research on Piagetian concepts in nonindustrial societies, children lag behind the rate of development of children from the United States or Western Europe (Segall et al., 1999). This gap cannot always be closed by introducing culturally familiar materials (e.g., Greenfield & Childs, 1977; Saxe & Moylan, 1982). But what has rarely been tried is to introduce culturally familiar tasks, as well as materials (an important exception being Nunes et al., 1993). Can familiar tasks close that gap? Our study derives a task, as well as materials, from a nonindustrial culture to test concrete operations. In consequence, we will be able to answer that question.

There is another side to the same coin: Are U.S. and European children superior on all manifestations of Piagetian tasks, or can they too have difficulties with unfamiliar materials and tasks? Our cross-over design aimed to answer this question.

1. Overview of the community and the studies

Our research on implicit cognitive development is part of a larger research program that has focused on one community, Nabenchauk, a Zinacantec Mayan hamlet in the highlands of Chiapas, Mexico. The Zinacantecs have participated in various investigations since the 1960s (Vogt, 1969). Our studies in the community cover the period of time from 1969 to 2003. As in the year 2000, when our data were collected, Nabenchauk was a village of about 4500 inhabitants, where most of the families participated in some form of commerce, such as trucking flowers from one city to another for a profit. Many families also grow flowers to sell. Opportunities for formal education in the village were limited to elementary school. In this paper, we focus on the implications of an implicit theory of cognitive development in the year 2000. However, the tools and processes under study have been used for generations in Nabenchauk and for thousands of years in Mesoamerica (Childs & Greenfield, 1980; Greenfield, Brazelton, & Childs, 1989; Greenfield, *in press-b*; Maynard, Greenfield, & Childs, 1999).

The focus of much of our work in Nabenchauk, both naturalistic and experimental, has been on backstrap-loom weaving, a complex technical skill acquired by virtually all girls in the community through processes of informal education (Childs & Greenfield, 1980; Greenfield, 1984; Greenfield, Maynard, & Childs, 2000, 2003). Weaving is seen as an alternative to schooling; it is the central skill-learning context for girls in the indigenous culture. Girls begin learning to weave on toy looms, as early as 3 years of age. They typically move to adult looms between 8 and 10 years of age.

2. Implicit cognition in weaving tools

In the present study, we investigated the link between modes of apprenticeship and the development of spatial skills by examining the spatial skills involved in creating, setting up, and weaving the warp of a loom. We had observed in prior fieldwork that Zinacantec weaving tools appeared to be adapted to the developmental status of learners (Greenfield, 2000a, 2000b). There is a winding tool, called the toy loom (Fig. 1a), adapted to younger girls who are first learning to wind a warp, and a winding tool, called a warping frame (in the foreground of Fig. 1b), adapted to older girls who have some experience in weaving. The winding tool that is adapted to older girls reflects a more advanced stage of cognitive development, one that requires mental transformation. For example, one needs to understand that the threads on the left side of the dowel of the warping frame in Fig. 1b will end up at one end of a loom, for example the top of the loom shown in Fig. 1c, while the threads on the right side of the dowel of the warping frame in Fig. 1b will end up at the other end of the loom, for example, the bottom of the loom shown in Fig. 1c. Once this transformation is carried out, either mentally or in practice, one implication is that the resulting piece of cloth, after weaving, will be almost twice



Fig. 1. (a) A toy loom. The weaver, Rosy, age 5 years, daughter of Maruch Chentik and Telex Pavlu, has wound her warp directly on the loom between the two end sticks. The warp consists of the threads between the ribbons on the outside of the loom. These lengthwise warp threads will later be woven by crosswise (weft) threads. Note the way the ribbon goes around the back of the weaver, hence the term backstrap loom. Photograph by Patricia Greenfield. (b) Maruch Chentik, Rosy's mother, is winding her white warp on a komen or warping frame. Note a stick at the left of the winding frame holding the looped threads in place. Threads at the left side of the dowel will go to one end of the loom, say the top, while the threads on the right side of the dowel will go to the other end, the bottom. © Lauren Greenfield/VII. (c) This loom, set up with a white warp in the process of being woven, illustrates what is meant by the top and bottom of a loom. © Lauren Greenfield/VII.



(c)

Fig. 1. (Continued).

as long as its length on the warping frame, where it is in essence folded in half, with one half on the right side of the frame, the other half on the left side of the frame.

The winding tool that is adapted to younger girls reflects a less-advanced stage of cognitive development. This tool does not require mental transformations; the weaver simply winds the warp from top (longest stick in Fig. 1a) to bottom of the loom (stick closest to weaver in Fig. 1a). What you see is what you get: The length of the warp on the loom reflects the length of the resulting piece of woven cloth. We noted that parents and other weaving teachers typically assigned the less-complex tool to younger learners, starting about age 3, and the more complex tool to older learners, starting about age 7 or 8. Note that the latter age is right squarely in the typical range for Piaget's stage of concrete operations. Sometimes girls themselves take the initiative to weave, either on the toy loom or the real loom. Generally, they would not take such initiative at a younger age than 3 for the toy loom or 7 for the real loom.

3. Questions

We had several specific questions regarding the use of these winding tools and cognitive development. Our questions were based on the premise, from Piagetian theory and research, that mental transformation is the hallmark of concrete operations in every domain, including the spatial. A corollary of this premise is that preoperational children are unable to carry out mental transformations; they are limited to understanding materials as a perceptual display.

3.1. Question 1a: Does the use of the winding tools correspond to actual cognitive development?

We hypothesized that before age 6 children would be able to understand the connection between warp threads and woven cloth on the toy loom (theorized to require no mental transformation) but not on the warping frame (theorized to require mental transformation).

3.2. Question 1b: Do girls begin to use weaving tools at the appropriate level of cognitive development?

Our hypothesis was that girls would begin to use the various tools when they are at or near the requisite level of cognitive development for each one. We saw this developmental sequencing of weaving tools as part of an implicit ethnotheory of cognitive development shared by girls and their mothers (Harkness & Super, 1992). The tools themselves can be thought of as working in the zone of proximal development, simultaneously reflecting and inducing particular cognitive operations characteristic of different stages of cognitive development (Scribner, 1985; Vygotsky, 1962, 1978).

3.3. Question 2a: Do children structure the real-world weaving tasks in line with our hypothesized stages of cognition?

We hypothesized that very young children would make the errors that would be predicted if they failed to mentally transform the configuration of threads on the warping frame. We tested this hypothesis by looking at the error strategies used by children of different ages in the warping frame problems.

3.4. Question 2b: Are these modes of cognitive structuring the same as those revealed by more traditional piagetian spatial tasks??

We also hypothesized that very young children would make the errors that would be predicted if they failed to mentally transform the configuration of spools in a set of necklaces, a task derived from Piaget's own experiments on the development of spatial cognition. We tested this hypothesis by looking at the error strategies used by children of different ages on a set of problems derived from Piaget and Inhelder (1956).

3.5. Question 3: What is the role of cultural learning in the development of piagetian stages of spatial representation?

We investigated this question by comparing the same children on two sets of concrete operational tasks, one an important target of cultural learning in Zinacantán, weaving, and the other less-familiar genre, Piaget's "knots" task. We used a

cross-over design, comparing Zinacantec Maya children with children in Los Angeles, where weaving is not an important target of cultural learning. The “knots” task, in which one predicts the configuration of “necklaces” of spools, is in a sense equally familiar or unfamiliar in Los Angeles and Zinacantán. That is, necklaces exist in both cultures; necklaces of spools exist in neither; and the task of twisting a necklace into a figure-eight and predicting what it will look like untwisted exists in neither. In a sense, it is a meaningless problem, *vis-a-vis* the real world. However, in U.S. culture, children learn to solve decontextualized problems for their own sake; in Zinacantán this is not the case (cf., Greenfield, *in press-a*). By comparing children’s performance across domains, we could empirically test the extent to which Piagetian stages are domain specific and the extent to which they are domain general. Our research design included three levels of cultural experience relevant to weaving: (1) observation of weaving, plus direct weaving experience or preparation for future weaving in the case of Zinacantec girls; (2) observation of weaving, without direct weaving experience or preparation for future weaving in the case of Zinacantec boys; and (3) no experience with backstrap-loom weaving in the case of girls and boys in Los Angeles. Within the group of Zinacantec girls, we also developed a more refined scale of winding and weaving experience to assess its connection to skill in carrying out mental transformations on the warping frame problems.

3.6. Question 4: How does experience, both implicit cultural experience and explicit instruction, interact with maturation to develop cognitive skills in spatial transformation?

We added a short-term instructional procedure where we tried to teach children who had initially failed items on the two types of tasks. After brief instruction, we tested the children with one final novel transfer task. Any age differences in learning from this instructional procedure would allow us to assess maturational constraints on learning how to carry out spatial transformation. This instructional procedure also enabled us to test the ease and extent of cross-domain generalization and the interaction of implicit long-term experience with explicit short-term teaching.

4. Method

4.1. Participants

We tested 160 children in Nabenchauk and Los Angeles who ranged in age from 4 to 13 years. The sample represents 80 children in each location and 80 children of each gender, balanced by location. Every age level from 4 to 13 years was equally represented in each gender and cultural group. The Zinacantec children in Nabenchauk had an average of 1.91 years of schooling, with a range from 0 to 6 years. The median schooling was 1 year. The majority of the sample ($N = 47$) had either

no schooling or only 1 year of schooling. All of the children in the Nabenchauk sample were of unmixed Zinacantec Maya ethnicity. The children in Los Angeles had an average of 4.26 years of schooling, with a range from 0 to 9 years in a fairly even distribution. The median was 4 years. The ethnicity of the Los Angeles sample was predominantly Euro-American, with a few children being of mixed ethnicity, for example with one parent of Mexican, Asian, or African ancestry. All of the children in the Los Angeles sample were from middle-class or upper-middle class families; they were much wealthier than the Zinacantec families.

4.2. Procedure

All children were tested individually. Zinacantec children came to the home of Maynard's field research assistant to participate in the study. Children in Los Angeles were tested in one of three locations: in a room located in a private school, at a private home, or at a university recreation center.

We presented the children with multiple-choice match-to-sample tasks in which they were asked to examine a pattern and then choose its match from among an array of woven choices. In the case of the toy loom (Fig. 2) and the warping frame (Fig. 3) problems, we asked them to figure out how the warp would look when it was woven into cloth. In the case of the "spools" problem, the participant was asked to copy a design of spools on a stick that had already been assembled (Fig. 4). In the case of the "knots" problem, the participant was asked which of the four choices would the "sample" necklace look like if it were straightened out.

For the warping frame and "knots" problems, which were concrete operational, we designed the answers to represent different levels of cognitive development. Some answers reflected an ability to do complete or partial mental transformation, while others reflected an ability simply to match stimulus choice and sample by perceptual means. In the case of the toy-loom problems, a complete perceptual match was always the correct answer, whereas a perceptual match resulted in a wrong answer for the warping frame problems. For all of the toy-loom problems and occasionally for the warping frame and "knots" problems, there were some "random" alternatives that represented neither a perceptual match nor a possible transformation.

Toy-loom problems preceded warping-frame problems for half the participants, selected at random; warping frame problems preceded toy-loom problems for the other half of the participants. "Spools" and "knots" were grouped together, in that order. The problems from the weaving domain were counterbalanced with the spools and knots problems. Thus, there were four different orders of the problems: toy-loom problems, warping-frame problems, spools and knots; warping-frame problems, toy-loom problems, spools and knots; spools and knots, warping-frame problems, toy-loom problems; and spools and knots, toy-loom problems, warping-frame problems. In both samples, the order of toy-loom problems and warping-frame problems was counterbalanced so as to provide a fair comparison of performance on the two types of problem. "Spools" and "knots"

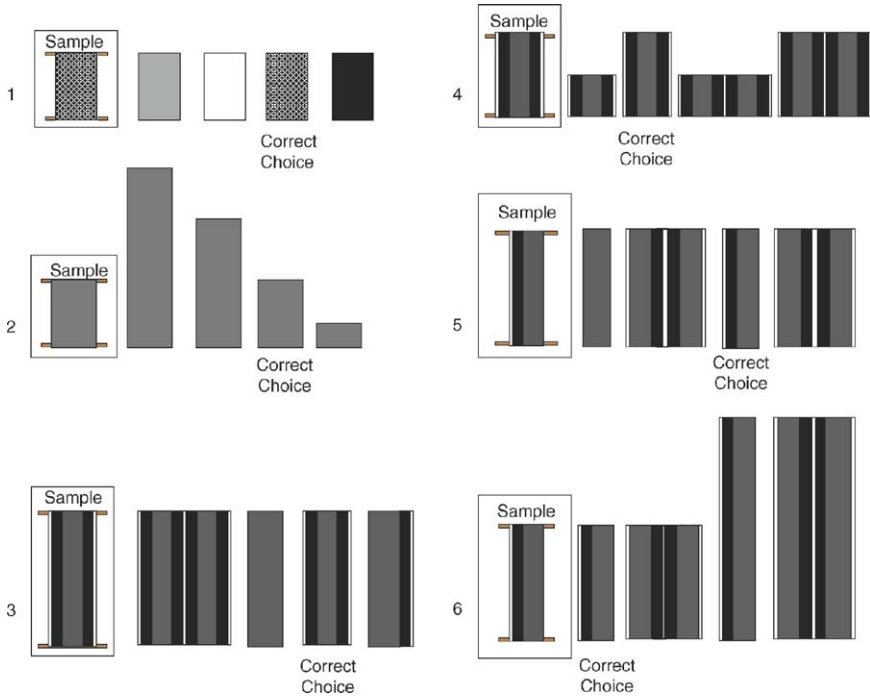


Fig. 2. Toy-loom problems. Problem 1 is a warm-up, color-matching problem (sample = 10.8 in. long). Length is the variable in Problem 2 (sample = 10.8 in. long). Pattern is the variable in Problems 3 (sample = 21.8 in. long) and 5 (sample = 16.75 in. long). Both length and pattern vary in Problem 4 (sample = 12.8 in. long) and Problem 6 (sample = 16.75 in. long). The samples for Problems 3–6 were patterns for actual Zinacantec clothing items.

were not counterbalanced because the preoperational “spools” problem was used primarily as a warm-up for the concrete operational “knots” problems; “spools” was not intended to be compared with “knots” or any other set of problems.

4.3. Materials

We presented the participants with two types of tasks: what we call our winding tasks and what we call our “knots” tasks. The winding tasks consisted of toy-loom problems and warping-frame problems. Toy loom problems consisted of six actual looms with thread wound directly on them, as one would do with a toy loom (the samples depicted schematically in Fig. 2). The correct solution of these toy-loom problems utilizes direct perceptual matching; no mental transformation is required.

There were also seven actual warping frames with thread wound on them (the samples depicted schematically in Fig. 3). This set included one simple warm-up task (Problem 1) and six requiring mental transformation. The warm-up task, not

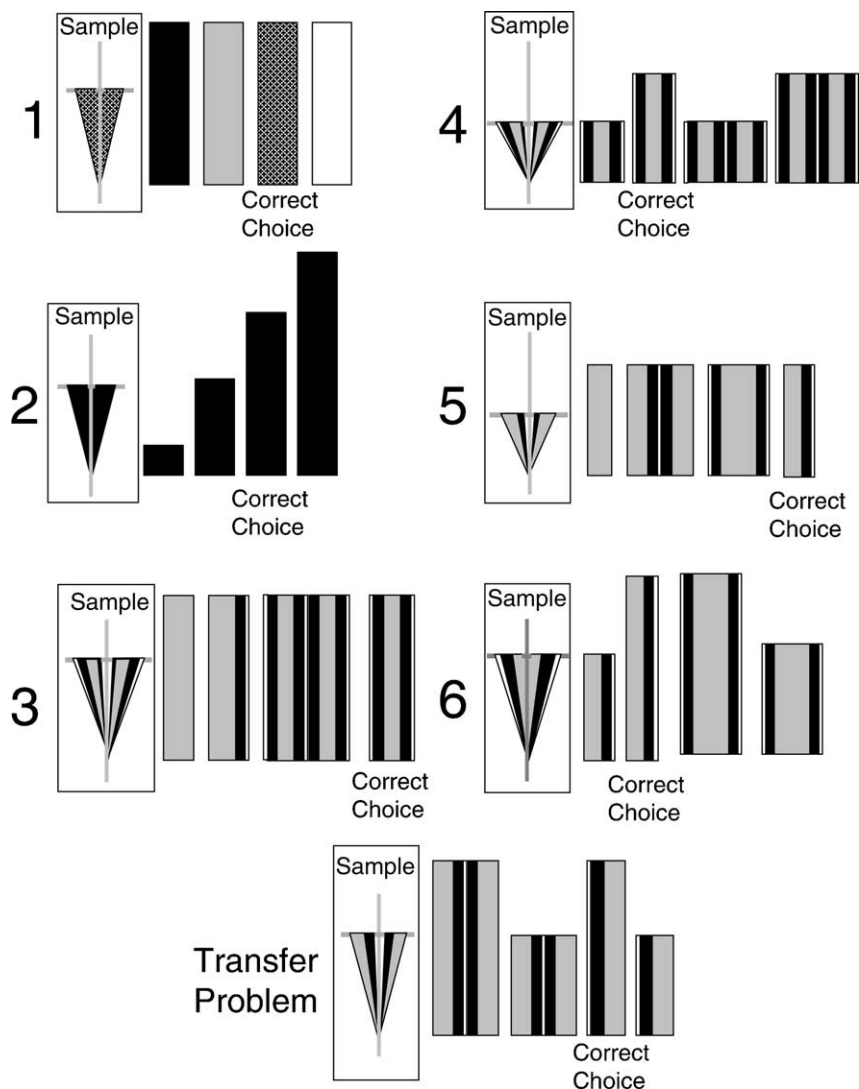


Fig. 3. Warping-frame (*komen*) problems. Problem 1 (sample = 7 in.) is a color-matching problem. Problem 2 (sample = 13.25 in.) is a problem involving only a size transformation. For Problem 3 (sample = 13.75 in.), the participants needed to make a pattern transformation to find the correct match. Problem 4 (sample = 9.25 in.) requires both a size transformation and a pattern transformation. Problem 5 (sample = 9 in.) involves a pattern transformation. Problem 6 (sample = 16 in.) requires a pattern transformation as well as a size transformation. The Transfer Problem (sample = $15\frac{3}{4}$ in.) requires both a size transformation and a pattern transformation. (Lengths of the samples include the warp threads in their wound configuration, but not the long wooden frames down the middle.) The samples for Problems 3–6 and the Transfer Problem were patterns for actual Zinacantec clothing items.



Fig. 4. Preoperational spools problem. A Los Angeles participant copies the model. Photograph by Patricia Greenfield.

included in the data analysis, was similar to the first toy-loom task and required simple color matching. This task was not included in our data analysis. There were four woven cloths to choose from in matching each warp sample. The correct (concrete operational) answers to each item shown in Fig. 3 require either a length transformation (Problem 2), a pattern transformation (Patterns 3 and 5), or both (Problems 4, 6, and Transfer). For a length transformation, the participant must realize that when the warp is unwound and placed on a loom, its length will almost double from its folded state on the warping frame. For a pattern transformation, the participant must realize that the stripes will be in a different configuration when they are unwound from the warping frame.

The last warping-frame problem, Transfer Problem (Fig. 3), was designed to assess the effect of a brief instructional procedure. This procedure was given to anyone who made an error on any of the preceding six problems. It consisted of going back to any problem where an error was made and explaining the warping frame, diagnosing the cognitive process behind the error, making explicit the error-producing way of thinking, and then showing the transformation that would produce the correct answer. The transfer problem was given immediately after this learning procedure.

The “knots” tasks were based on work by Piaget and Inhelder (1956). The knots were loops (“necklaces”) of string with spools of different-colored thread on them. We turned the loops into figure-eight “knots,” thus creating a situation that requires mental transformation to predict what the color configuration will be once the “knot” or figure-eight is unlooped. (For Piaget and Inhelder, 1956,

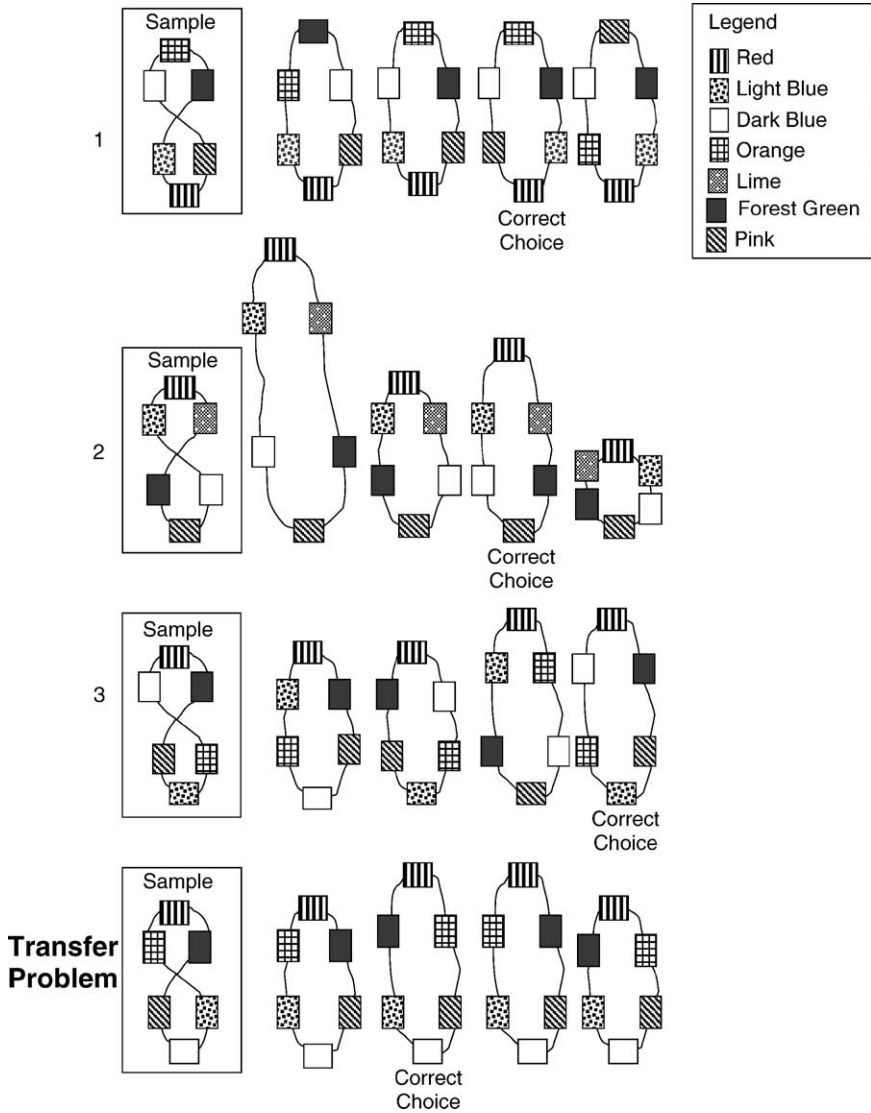


Fig. 5. Concrete operational “knots” problems. Problem 1 (sample = 21-in. circumference) requires only a pattern transformation. Problem 2 (sample = 46-in. circumference) requires a size transformation. Problem 3 (sample = 41-in. circumference) requires a size transformation as well as a pattern transformation. To solve the Transfer Problem (sample = 34-in. circumference), the participants needed to make both a size transformation and a pattern transformation.

a knot is any transformation that does not change the topology of a figure.) Following the pattern of the warping-frame tasks, we presented subjects with one pattern-matching task (Fig. 4) requiring no mental transformation, and four “knots” with choices for matching, all of which required mental transformation (Fig. 5). As in the warping-frame problems, the knots problems required either a pattern or a size transformation (see legend to Fig. 5 for details of pattern transformations). The instructional procedure followed the pattern described for the warping-frame instructional procedure.

The (preoperational) task in Fig. 4 is to put spools on the dowel, matching the sequence in the model (on the ground). The (concrete operational) task in Fig. 5 is to figure out which “necklace” the figure-eight on the far left would turn out to be if it were untwisted. As in the case of the warping-frame series, the last problem was a transfer item to test the effect of the learning procedure.

4.4. *Measure of winding and weaving experience*

Because the study focused on the relationship between the development of cognitive skill in spatial transformation and understanding how to wind, set up, and weave a warp, we asked Zinacantec girls about their experience in winding and weaving warps on both the toy loom and the warping frame. A nine-point scale from zero to eight of winding and weaving experience was developed. Zero was used to represent no weaving or winding experience of any sort. One could then get points for weaving on a toy loom (1 point), winding on a toy loom (1 point), weaving on a real loom (1 point), winding on a real loom (1 point). One could also get 1 point for winding and 1 point for weaving either of the two complex striped designs shown in Problems 3–5 in Fig. 2 and Problems 3–6 in Fig. 3. These designs are important because, as we have seen in Fig. 3, understanding pattern transformations from the warping frame to the loom is part of the array of mental transformations that are required to wind and weave complex striped designs.

5. Results

5.1. *Question 1a: Does the use of the winding tools correspond to actual cognitive development?*

We hypothesized that before age 6 children would be able to understand the connection between warp threads and woven cloth on the toy loom (theorized to require no mental transformation), but not on the warping frame (theorized to require mental transformation). Our results indicate that the children were performing in accordance with these hypothesized stages of cognition. Zinacantec children under the age of 6 successfully solved virtually all of the matching problems that did not require mental transformation ($m = 5.56$ out of 6), but they were completely unable to solve the warping-frame problems that did require such

transformation ($m = 0.56$ out of 5). In sharp contrast, Zinacantec children aged 6 and older began to solve warping-frame problems (aged 6–9, $m = 2.34$ out of 5; aged 10–13, $m = 4.13$). The difference between each of these age groups is statistically significant ($t = 4.68$, $P = .000$; $t = 5.19$, $P = .000$, respectively).

5.2. Question 1b: Do girls begin to use weaving tools at the appropriate level of cognitive development?

For the most part, the answer to this question is yes. In our sample, the earliest use of the toy loom is at age 4, an age where our toy-loom problems (Fig. 2), but not our warping-frame problems (Fig. 3), were successfully solved; in contrast, the earliest use of the real loom is at age 7, an age when a considerable number of girls can perform the mental transformations required by our warping-frame problems (Fig. 3). Winding on the real loom follows the same age pattern, with the earliest experience also reported at age 7. While winding on the toy loom does not occur among 4- and 5-year olds, as we thought it would, we do find the predicted developmental sequence: five girls in the 6- to 9-year age group have wound a warp on a toy loom, but not on a warping frame. In contrast, the reverse does not occur once in this age group. That is, in the age period where they are transitioning into concrete operations on our weaving problems, girls generally learn to wind on the toy loom before they begin winding on the warping frame, as one would predict from our cognitive analysis and findings with the toy-loom and warping-frame problems. Clearly girls do wait for the development of the cognitive skills required by our transformational warping-frame problems to begin using the real loom. In contrast, they begin using the toy loom at the time when they apply perceptual matching to all weaving problems, whether or not they can be correctly solved by this strategy.

5.3. Question 2a: Do children structure the real-world weaving tasks in line with our hypothesized stages of cognition?

The nature of children's errors reflects a transition from preoperations to concrete operations. The pattern of errors illustrates that children were not giving just "random" answers, but rather answers that reflected a perceptual match and some problem with transformation, such as failure to make a size transformation or failure to make a pattern transformation. A binomial test for Problem 3 with two random answers indicates that children chose the random answers significantly less than chance (binomial test, chance probability = .66, observed proportion = .33, $P = .000$). (A random answer involved neither a perceptual match nor a transformation. In Fig. 3, the two random answers to Problem 3 are the two left-most alternatives.) For the two other warping-frame problems with random answers, the binomial test also indicates that children chose the random answers significantly less than chance would predict; this was true for the warping-frame problem involving only a size transformation where color is held constant (Problem 2; binomial

test, chance probability = .66, observed proportion = .13, $P = .000$), and for the warping-frame problem involving only a pattern transformation (Problem 5; binomial test, chance probability = .66, observed proportion = .37, $P = .000$). (For Problem 2, Fig. 3, the random answers are found on the far left and the far right of the answer choices. For Problem 5, Fig. 3, the random answers are the first and third alternatives to the right of the match.)

Fig. 6 summarizes the pattern of results on the three warping-frame problems that included random choices. If errors were randomly distributed, perceptual matches should have occurred half as often as “random” responses. Instead, the reverse was true; perceptual matches occurred more than twice as often as “random” responses. Thus, the overall pattern indicates that children’s errors reflect our hypothesis about the preoperational structuring of thought.

Pattern of answers in winding board problems with random choices

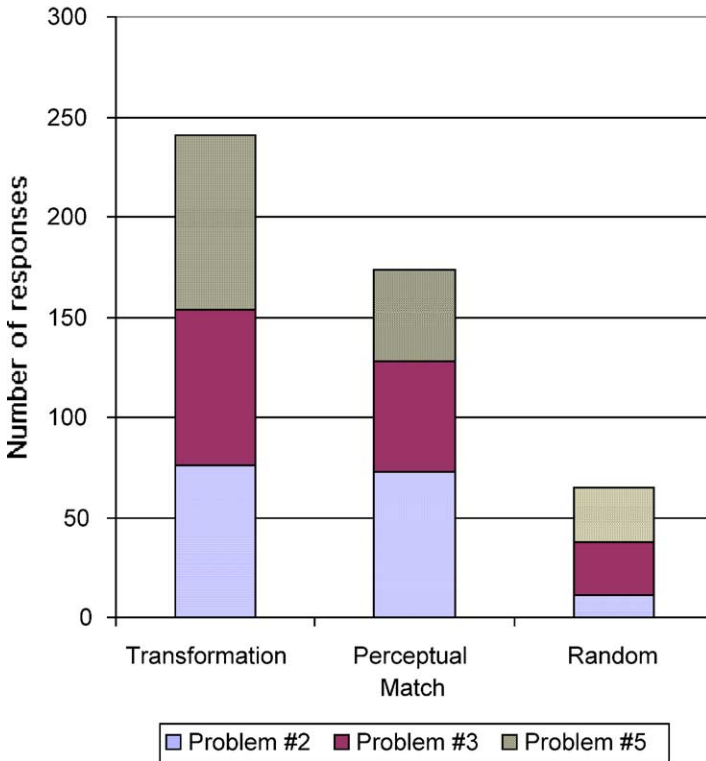


Fig. 6. Distribution of answers on warping-frame problem with “random” choices.

5.4. *Question 2b: Are these modes of cognitive structuring the same as those revealed by more traditional piagetian spatial tasks?*

Similarly, the pattern of errors on the knots tasks indicated that, as Piaget and Inhelder (1956) had shown, improved performance reflected a transition from pre-operational matching to concrete operational transformation. Again, children did not make random errors; their errors focused on the preoperational strategy of making a perceptual match. There were two knots problems with opportunities for a “random” error (neither a perceptual match nor a transformation). For Problem 2, random errors (choosing the far left or the far right), were made at a rate significantly below the chance probability (binomial test, chance probability = .66, observed proportion = .22, $P = .000$). For Problem 3, random errors were made at a rate significantly below the chance probability (binomial test, chance probability = .66, observed proportion = .12, $P = .000$). Overall, responses tended to be either preoperational (perceptual match) or concrete operational (spatial transformation), with relatively few random responses.

5.5. *Question 3: What is the role of cultural learning in the development of piagetian stages of spatial representation?*

Regarding this question, we found that there were effects of experience. To show this, we first carried out a two-way analysis of variance (ANOVA) using culture (Zinacantán vs. Los Angeles) and gender (girls vs. boys) as independent variables and number correct on the warping-frame tasks as the dependent variable. Reflecting overall familiarity with weaving, Zinacantec children performed significantly better ($m = 2.70$) than children in Los Angeles ($m = .96$) on these tasks (main effect of culture, $F = 60.075$, $P = .000$).

A significant two-way interaction between culture and gender reflected the specific effect of weaving experience ($F = 5.75$, $P = .018$). Zinacantec girls performed significantly better on the warping-frame tasks than did the Zinacantec boys ($t = 2.54$, $P = .013$) or American children of either sex (Zinacantec girls compared with U.S. girls, $t = 7.12$, $P = .00$, Zinacantec girls compared with U.S. boys, $t = 6.62$, $P = .000$). Zinacantec girls got a mean number of 3.2 out of 5 problems correct on the warping frame, compared with Zinacantec boys' performance of 2.2, U.S. girls' 0.92, and U.S. boys' 1.0. The significant difference between Zinacantec girls and Zinacantec boys indicates an effect of active weaving participation, experienced only by Zinacantec girls.

However, even Zinacantec boys performed significantly better than U.S. boys ($t = 3.81$, $P = .00$) or U.S. girls ($t = 4.24$, $P = .00$). This finding indicates that passive exposure to weaving, experienced by Zinacantec boys but not by U.S. children, also had an impact. Indeed, in Los Angeles, a transformational approach to the warping-frame problems failed to develop. Even in the 10–13 age group, U.S. children correctly solved a mean of only 1.06 out of 5 warping-frame problems.

Another ANOVA, again using culture and gender as independent variables, showed that American children ($M = 2.00$) performed significantly better on the knots tasks, the task less familiar to the Zinacantecs ($M = 1.14$, $F = 25.05$, $P = .000$). As expected, gender did not come into play.

There was also evidence that performance on the knots task reflected a transition from preoperations to concrete operations for both U.S. children and Zinacantec children, but to a lesser extent for the Zinacantec children. Whereas 62% of the 4- and 5-year olds in Los Angeles answered the preoperational problem correctly, they answered only 16.67% of the concrete operational problems correctly. In the 6–9 age group in contrast, U.S. children answered 66% of the concrete operational knots problems correctly; this percentage rose to 93% in the 10–13-year-old group. Performance in each successive age group improved significantly.

In Zinacantán, 31.2% of 4- and 5-year olds got the preoperational “knots” problem, but virtually no one in this age group could correctly solve a concrete operational knots problem. At later ages, a smaller proportion of Zinacantec children made the transition to concrete operations on the knots problem. Even among the 10–13-year olds, children correctly answered only 61% of the problems correctly.

Summarizing these results, we carried out a repeated measures analysis for the combined sample of Zinacantec and U.S. children with age and culture as independent variables and the preoperational and concrete operational tasks as the repeated measure. This analysis showed task type (preoperational vs. concrete operational), age, and culture to exert significant main effects ($F = 78.22$, $P = .000$; $F = 80.44$, $P = .000$; $F = 45.66$, $P = .000$, respectively). A significant two-way interaction between culture and task type reflected the relatively greater difficulty of the concrete operational tasks for the Zinacantec children ($F = 14.86$, $P = .000$). A significant two-way interaction between age and task-type reflected the fact that younger children could do only the preoperational problems, whereas older children could do both ($F = 36.44$, $P = .000$).

This pattern of results reflects the greater general familiarity of children in the United States with stimuli and problems that are decontextualized from any cultural activity. Thus, we find that each group is acquiring the ability to mentally transform spatial stimuli in activities where they have had the most cultural experience.

We explored Question 3 further by examining whether levels of experience with winding and weaving in the case of the Zinacantec girls was correlated with performance on the concrete operational warping-frame problems. We found that experience in winding and weaving was significantly correlated with overall performance score on the warping-frame problems requiring mental transformation (Fig. 3, Problems 2–6; $r = .50$, $P = .0005$, two-tailed test). Knowing from the developmental results reported earlier that age would also be an important correlate, it was important to utilize age as a covariate to see if winding and weaving experience made an independent contribution to mental spatial transformation. Indeed, with age partialled out, our winding-weaving scale was still significantly correlated with performance on the transformational warping-frame problems (Fig. 3, Problems 2–6; $r = .31$, $P < .03$). We do not know whether stage of cognitive

development is cause or effect of weaving and winding experience; we strongly suspect that it is both.

5.6. Question 4: How does experience, both implicit cultural experience and explicit instruction, interact with maturation to develop cognitive skills in spatial transformation?

After a short-term instructional experience, participants who had made earlier errors showed significant improvement on the warping-frame transfer problem, compared with a similar problem (Problem 6) before instruction. This finding emerged from a repeated measures analysis with culture as the between-subjects variable ($F = 12.96$, $P < .001$, $N = 138$). Zinacantec children went from a 22 to a 69% rate of success; children in Los Angeles went from a 14 to a 55% rate of success after instruction. Children in both Nabenchauk and Los Angeles benefited from the instructional procedure, with no significant difference between the groups in amount of improvement. Nonetheless, as the final success rates (69% in Nabenchauk, 55% in Los Angeles) indicate, short-term teaching could not eradicate the effects of long-term cultural experience. A two-way ANOVA, incorporating culture and age as independent variables, indicated that, even after short-term teaching, Zinacantec children were still significantly better with a warping-frame problem than children from Los Angeles ($F = 14.37$, $P < .001$). As expected, age also posed some strong constraints on the effectiveness of the teaching procedure, and there was a significant main effect of age ($F = 54.77$, $P < .001$). Older children more often solved the transfer problem than did younger children.

Indeed, one way this superiority of the Zinacantec children manifested itself was in an age differential: Zinacantec children aged 5 and up and American children aged 7 and up were able to solve correctly the “transfer” warping-frame problem (Fig. 3) after an explanation of the device and their previous, incorrect answers. In other words, the youngest U.S. children were 2 years older than the youngest Zinacantec children who successfully learned the task. For the knots problem, there was no significant impact of the brief instruction on the transfer problem and no significant interaction with cultural group, which can be considered a stand-in for long-term experience.

6. Discussion

There is an interaction between cultural learning and maturational level; the notion of maturational readiness for cultural learning aptly describes our results. Most interesting of all, this developmental constraint has been built into cultural practices concerning the age at which each weaving tool is used for cultural teaching and learning. These practices constitute implicit procedural knowledge of development, rather than explicit conceptual knowledge (Hatano, 1982). This implicit

knowledge is then available as one component of parental ethnotheories of development. Such ethnotheories are often implicit, in contrast with the explicit nature of formal theories of development, such as that of Piaget. What we have shown here is a convergence between Piaget's explicit theory of operational development and the Zinacantecs' implicit theory of cognitive development. We have also shown how an implicit ethnotheory of cognitive development can be built into cultural tools.

We have shown that the implicit ethnotheory and explicit formal Piagetian theory of cognitive development actually converge in correctly predicting a developmental sequence of cognitive processes. Children who were at the age of using a toy loom used perceptual matching rather than spatial transformation in predicting how the wound-up warp threads would look when they were actually woven into cloth. Zinacantec girls who were at the age of learning how to use a real loom used mental transformation to figure out how a warp wound on the warping frame or *komen* would turn out as woven cloth. Girls who decide to wind on the *komen* appear to have accurate implicit knowledge of their own cognitive level and its match with the cognitive requirements of the task. Weaving can be seen as an activity that actualizes concrete operations in a culture-specific form. Children exhibit operational representations of space above the age of 5 in a domain where such operations are required by their everyday activities. Perceptual exposure to the stimuli (experienced by Zinacantec boys) also has an impact, but it is smaller. Implicit procedural knowledge is constructed out of mere exposure (Zinacantec boys), preparation for actual practice (the younger Zinacantec girls), as well as the practice itself (the older Zinacantec girls, many of whom have been winding and weaving). Short-term instruction, while beneficial to both groups in the weaving domain, was less powerful than long-term cultural experience.

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