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# The Developmental Progression of Children's Knowledge Constructions for Heating and Cooling

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ABSTRACT. We explored the cognitive development of physical knowledge for heating and cooling in a cross-cultural, mixed-gender sample of 270 children. Subjects were drawn from five age groups ranging in age from 4 to 13 years. Subjects were individually exposed to heating and cooling demonstrations, whereafter they were interviewed and assessed for their understanding of the phenomena in question. Results showed a clear developmental progression. The youngest children gave relatively unsophisticated explanations that focused on the source of heat but failed to explain the process itself. Slightly older children gave explanations that were characterized by a notion of movement (without a kinetic basis). The oldest children gave more sophisticated accounts of the process of heat transferral, which employed notions of convection, radiation, and conduction. This progression was unaffected by population group or gender, although a significant interaction between age and population was observed in the case of heating. The implications of these results for neo-Piagetian research are discussed. Some parallels between the developmental progression observed here and the historical development of scientific concepts of heat are noted.

PIAGET'S (1970) WORK on the development of physical knowledge in children focused on the particular content domain of sugar-water solutions as the basis for a more general theory about the development of types of knowledge. His pioneering work has since been extended to a number of other content domains (Strauss & Klein, 1985; Strauss, Orpax, & Stavy, 1977). One domain about which very little is known is that of heat. Bearing in mind that Piaget was particularly adept at exploring the connections between phylogenetic intellectual development (particularly in scientific history) and ontogenetic development, and the fact that theories of heat have been prominent in the development of scientific thought, this is a striking gap in research on the development of children's knowledge. The present study represents an initial attempt to fill this gap.

Piaget (1970, 1971a, 1971b) distinguished between two types of knowledge: logico-mathematical and physical knowledge. His interest in the latter consisted mainly of delineating the developmental progression of children's understanding of physical phenomena. In the case of sugar-water solutions, for example, he showed that children progressed from an initial stage, at which they are unable to understand that sugar is preserved in water (nonpreservation), to a stage at which they are able to grasp preservation, and finally, to a summit stage at which they apply atomistic schemata to interpretations of the phenomena.

This developmental progression of constructions concerning the physical nature of sugar-water solutions has been further documented by Slone (1987). In addition, there is a growing body of evidence suggesting that examining specific content domains can significantly advance the understanding of cognitive growth (Brown & Campione, 1981; Feldman, 1980).

It is important for several reasons to examine the developmental progression of physical knowledge structures in content domains other than sugar-water solutions. First, both the Piagetian framework and recent research evidence point to the significance of charting the developmental progression of knowledge in other content domains. In this respect, several researchers have investigated the development of knowledge in a variety of content domains, such as material hardness (Strauss & Klein, 1985), temperature (Strauss, Orpaz, & Stavy, 1977), and density (Megged, 1978). Second, one of the underlying tenets of Piaget's theory is a notion of the universality of cognitive progress; it is important to extend research on physical knowledge by subjecting it to an examination of its universal aspects. This is most usefully achieved by examining physical knowledge across different cultures. Third, in line with Piaget's assumptions about the recapitulation of phylogeny in ontogeny, it is appropriate to match developmental progression with possible corre-

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sponding phylogenetic development, that is, with the history of scientific ideas about the phenomenon in question.

One particular content domain that has received little attention is that of heat. Although there is an identifiable body of research on children's conceptions of heat, it is largely concerned with their import for teaching physics. With reference to more current neo-Piagetian research, there is little more than a preliminary study reported by Shayer and Wylam (1981). Using a series of tasks developed by Piaget (1974) with a sample of 10- to 13-year-olds, Shayer and Wylam claimed that the development of physical knowledge about heat can be described according to the developmental meta-stages identified by Piaget. Thus, in the early to middle concrete stage, heat is associated with its effects (burning, melting, etc.) but is not modeled; that is, explanations offered do not conceptualize or explain the process. In the late concrete stage, heat is understood quantitatively (to the extent that children understand that thermometers use a multiplicative and not a linear scale) and causally but is not modeled as being extensive, nor is the causal understanding an adequate model. In the early formal stage, a caloric–liquid model of heat flow predominates, and children understand that the notion is extensive (it depends on both mass and temperature), but few children are able to explain heat transferral kinetically.

These results are interesting, but they constitute an insufficient exploration of physical knowledge about heat. In the first place, the method employed in the study did not replicate that used by Piaget in his study of knowledge about sugar-water solutions. Thus, there is no systematic and comparative account of the developmental progression of physical knowledge about heat. This problem is compounded by the fact that only a very limited developmental spectrum was sampled. Shayer and Wylam's (1981) subjects ranged in age from 10 to 13 years, whereas children in Piaget's study of sugar-water solutions ranged in age from 4 to 12 years (Piaget & Inhelder, 1974, p. 68).

Some of these problems were addressed in the present study. The developmental progression of physical knowledge about heat was explored with a procedure very similar to that used by Piaget in his sugar-water solution work. This was further extended by the use of a developmentally representative sample, and the universality of the developmental progression of physical knowledge about heat was examined by sampling from different population groups.

Because the study was exploratory, no clear hypotheses about the developmental progression of knowledge about heat were entertained. We hypothesized that knowledge about heat would show developmental change, but the exact nature of this change was left to be empirically ascertained.

## Method

### *Subjects*

The sample for this study consisted of 270 children drawn from schools in the Cape Peninsula of South Africa. Because three independent variables of particular importance to the study were age, gender, and population group,[1] equal numbers of children from within each of the categories constituting these latter two variables were drawn. There were 135 boys and 135 girls; 90 children were White, 90 were "Colored," and 90 were Black. Children were not drawn equally from age categories: 60 were between 4 years and 5 years and 11 months old; 63 were between 6 years and 7 years and 11 months old; 60 were between 8 years and 9 years and 11 months old; 56 were between 10 years and 11 years 11 months old; and 31 were 12 or older. Children were also matched (as far as possible) for socioeconomic status.

Lists of children were compiled in liaison with class teachers at the schools from which they were dawn. Children were drawn from three schools in the Cape Peninsula area: a White school, a Colored school, and a Black school.

### *Materials*

A developmental task was devised to assess children's knowledge of heating and cooling. The method was much akin to that used by Piaget for the assessment of children's knowledge about sugar-water solutions. The task involved placing a lighted candle underneath a beaker of water, or removing the candle from underneath the beaker, both eventualities being followed by a questionnaire intended to assess the level of the child's understanding of the process of heating and cooling. The questionnaire appears in Figure 1 and was devised as a structuring aid to the semi-clinical interview, which was the primary method of data collection in this study.

### *Procedure*

Each child was seen individually in a quiet, private classroom by one of three interviewers. The child was shown both the heating and the cooling demonstration, as previously described, and then assessed with the interview schedule shown in Figure 1. The order of presentation of the demonstrations was

[1]The population groups referred to here are those recognized and given differential treatment (including education) under South African law (particularly in the Population Registration Act of 1950, and the Separate Amenities Act of 1953). We do not agree with the legislated differences between these groups, but the differences must nevertheless be recognized in research that compares them.

**Part I**

Instructions

Light and place a candle underneath a cup of water, and wait for several seconds, drawing the subject's attention to these actions. Leave the cup and candle in front of the subject. The following questions are asked, with exploration of any additional concepts or explanations advanced by the subject, which should be recorded verbatim.

Questioning format:

1 What happens to the water in the cup when the lit candle is put underneath it and left for a while?..........
..........................................................
..........................................................

2 What does it mean "to heat"?........................
..........................................................
..........................................................

3 How does the water get hot?.........................
..........................................................
..........................................................

**Part II**

Instructions:

Remove the candle, drawing the subject's attention to this. Leave the cup in front of the subject. The following questions are then asked, with further exploration as above.

Questioning format:

1 What is going to happen to the water now that the candle has gone?
..........................................................
..........................................................

2 What does it mean "to cool"/ "to get cold again"?.....
..........................................................
..........................................................

3 How does water cool?................................
..........................................................
..........................................................

4 What happens to the heat?...........................
..........................................................
..........................................................

**FIGURE 1. Questionnaire/interview schedule.**

counterbalanced across subjects. Each child was interviewed in his or her home language, and responses to questions were recorded verbatim for later scoring.

*Scoring*

The entire sample of interview transcripts was content analyzed by the experimenter and two assistants to determine the global categories of understanding shown by children in the interviews. Five categories were identified and agreed upon (the categories are ranked from lowest to highest in terms of level of understanding shown). Explanations in the lowest category (no notion) showed no understanding of the phenomenon. Explanations in the second category (notion) showed only a rudimentary understanding of the phenomenon. In the third category (source), children's explanations focused on the source of the process (e.g., the candle) without explaining the process itself. The fourth and penultimate category (movement) contained explanations that focused on the movement of heat from one body to another, but in a theoretically rudimentary way. Explanations in the fifth category (transferral) substantiated the claim of movement of heat from one body to another by introducing a sophisticated explanation of the process of transferral of heat (i.e., conceptualizations that embodied notions of conduction, convection, or radiation, or that had kinetic bases, or both).

Once the categories had been established, each interview protocol was scored by three coders to identify the highest category of understanding reached by each child. Consensus among the scorers was very high, with a computed interscorer reliability coefficient of .98. The few cases of disagreement were discussed by the scorers and communally assigned to an agreed upon category.

Cases in which the interview was conducted in a language other than English were treated in a special way. The interview was translated into English by the interviewer, and both records were scored for physical understanding: the original by the interviewer, and the translated protocol by one of the other two researchers. Agreement between the two sets of records (original and translated) was very high.

## Results

There was a clear developmental progression in children's physical knowledge regarding the phenomena of heating and cooling. Moreover, the progression appears universal insofar as neither population group nor gender affected it.

The measure of chief interest was the frequency of each category of understanding in the five age groups, broken down by gender and population group. The method of statistical analysis used to assist exploration of the results was log-linear analysis, which is eminently suited to the analysis of complex frequency tables (Kennedy, 1983).

The log-linear analysis showed that there were no population or gender differences in children's understanding of heating or cooling. In the case of heating, however, an interaction between population, age, and level of understanding was observed. For heating, a strong Age × Heating effect was obtained, LR $\chi^2(26) = 90.2, p < .001$, and the Age × Population × Heating interaction was significant, LR $\chi^2(14) = 29.4, p > .05$, but no Population × Heating effect was in evidence, LR $\chi^2(8) = 10.9, p > .05$. In other words, the saturated model was required to describe the observed distribution of frequencies.

For cooling, however, the saturated model was found to be redundant as the Age × Population × Cooling interaction was not significant, LR $\chi^2(24) = 30.2, p > .18$. The most appropriate model to fit the cooling data as identified by the log-linear analysis was the much more elementary Age × Population and Age × Cooling model, LR $\chi^2(32) = 42.42, p > .05$.

*Heating*

Figure 2 provides a graphic representation of the relative dominance of modes of explanation of the heating phenomenon in the different age groups under study. Population group was included as a variable in the diagram because it was only significant in interaction with the age and heating variables. In other words, the population groups did not differ in terms of the progression of understanding for the heating phenomenon; they differed only with respect to the ages at which modes of understanding dominated.

The figure highlights very clearly the strong trend associated with explanations of heat transferral: transferral, as a means of explaining heating, develops from a relatively unfavored mode of explanation to the most popular form of explanation by age 12. This trend is supported statistically by Table 1, where the parameters for the log-linear model show a clear upward trend across the different age groups. A primitive mode of explanation, which directs attention to the source of heating, dominated in the youngest age groups (until about age 9) whereafter it gave way to a more sophisticated form of explanation, in which notions of heat transferral dominated.

*Cooling*

Figure 3 provides graphic representation of the relative dominance of modes of explanation of the physical phenomenon of cooling in the five age groups under consideration. Two strong trends, substantiated by the log-linear anal-

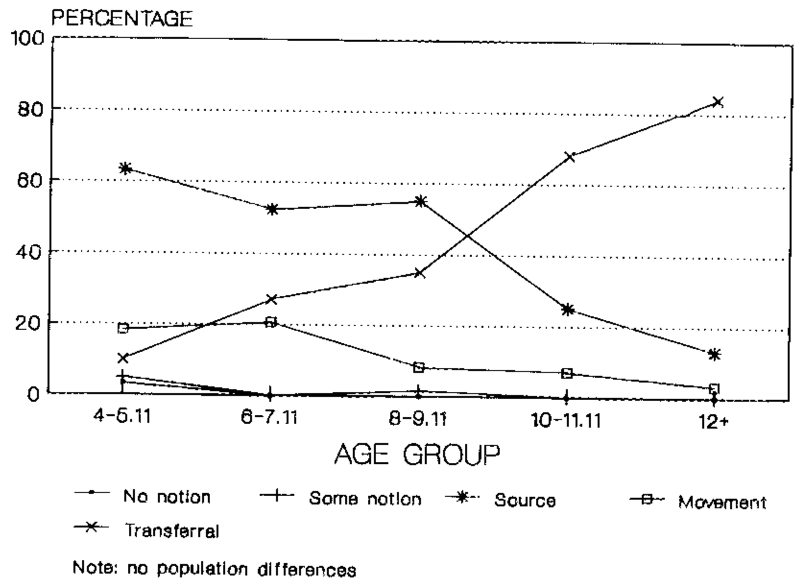


**FIGURE 2. Development of constructions for heating in different age groups.**

**TABLE 1**
**The Development of Knowledge About Heating Across Five Age Groups: Estimates of Log-Linear Parameters Based on the Saturated Model**

| Developmental level | Age group 4–5 | 6–7 | 8–9 | 10–11 | 12+ |
|---|---|---|---|---|---|
| No notion | 0.96 | −0.78 | −0.63 | −0.28 | 0.78 |
| Notion | 1.88 | −1.39 | 0.29 | −0.89 | 0.11 |
| Source | −0.48 | 0.72 | 0.73 | 0.37 | −1.24 |
| Movement | 0.26 | 1.77 | −0.46 | −0.33 | −1.24 |
| Transfer | −2.62 | −0.32 | 0.06 | 1.13 | 1.75 |

*Note.* The figures in the table are estimated effects that sum to zero in each row and column (rounded to nearest digit).

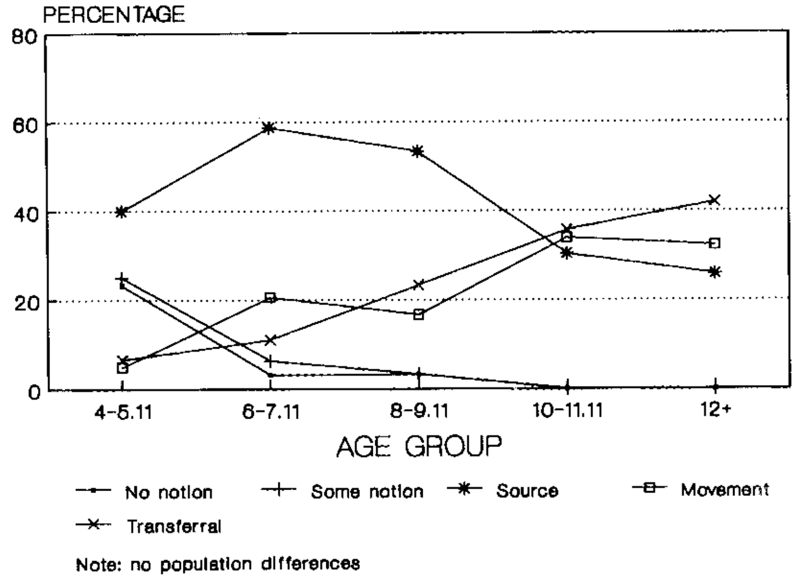


**FIGURE 3. Development of constructions for cooling in different age groups.**

ysis for heating, are evident. Table 2 presents the log-linear analysis for cooling.

Both movement and transferral, as forms of explanation, increased from rather insignificant levels in the youngest age groups to a position of relative dominance in the older age groups. Neither explanation dominated clearly, however, as transferral did in the case of heating. Moreover, source as a mode of explanation was still greatly in favor among older children, whereas it disappeared almost entirely in the case of heating.

The picture that emerges overall is a clear progression from the relatively unsophisticated modes of explanation used by the younger children to the relatively sophisticated modes of explanation used by the older children. Particularly evident is the progression toward theories that embody notions of heat movement and transferral.

## Discussion

The results of the present study are notable for several reasons. First, the developmental progression of children's understanding of heat revealed here seems clear enough to claim that it extends Piaget and Inhelder's (1974) pio-

**TABLE 2**
**The Development of Knowledge About Cooling Across Five Age Groups: Estimates of Log-Linear Parameters Based on the Reduced Model**

| Developmental level | Age group | | | | |
|---|---|---|---|---|---|
| | 4–5 | 6–7 | 8–9 | 10–11 | 12+ |
| No notion | 1.92 | 0.27 | 0.06 | 0.00 | −2.24 |
| Notion | 1.93 | 0.81 | 0.34 | 0.00 | −2.74 |
| Source | −0.49 | 0.00 | 0.00 | −0.44 | 0.93 |
| Movement | −1.72 | −0.20 | 0.00 | 0.00 | 1.92* |
| Transfer | −1.65* | −0.87 | −0.06 | 0.44 | 2.13* |

*Note*. The figures in the table are estimated effects that sum to zero in each row and column (rounded to nearest digit).

*$p < .01$ (adjusted to control the experimentwise error rate).

neering work on physical knowledge to a new content domain. In addition, the observed progression was identical for different population groups, and for both sexes, supporting one of the tenets of Piagetian theory—namely, that these stages of cognitive development are universal.

The study of physical knowledge development supports a growing body of research that demonstrates that underlying knowledge structures are not equally accessible for all content domains (Chi, 1978; Flavell, 1970; Rozin, 1976), indicating the significance of knowledge of content domains in cognitive development. This research direction can be fostered by a reexamination of Piagetian notions and an attempt to reframe them within the perspective of current research.

The present results also hold implications for curriculum development and the teaching of physics to elementary and middle school children. Researchers have previously claimed that teaching the physics of heat to young children is an inordinately difficult task and that its difficulty is chiefly related to the cognitive readiness of the children (Albert, 1978; Erickson, 1979; Shayer & Wylam, 1981). The present study provides a rough age-based index of this readiness. The children we tested had not been formally taught the physics of heat at the time the study was conducted. A curriculum following the age guidelines identified here may make the task slightly easier. Piaget, as we pointed out in the introduction, was particularly fond of (and adept at) comparing ontogenetic cognitive development with the phylogenetic development of particular concepts. Thus, he often pointed to parallels between the history of a particular scientific concept and the stages of cognitive development that children pass through in their acquisition of a concept. Some tentative parallels can be drawn between the progression of knowledge about heat shown by children in this study and the development of the scientific understanding of heat.

The developmental progression identified in this study moved from unsophisticated, object-centered (or source-centered) explanations to explanations that embodied a notion of the movement or flow of heat from one body to another and, finally, to explanations that had kinetic bases. The history of scientific explanations of heat bears some striking resemblances. The following progression of scientific theories about heat is typically identified by historians of science (see for example Cardwell, 1970). An early theory, the famous Empedoclean division, postulated fire (and therefore heat) as one of the primary elements (along with air, water, and earth). This theory dominated Western thought until the 17th century, when it was superceded by the caloric–liquid theory of heat. In this theory, heat was postulated to be a weightless, subtle fluid that inhered in the gaps between the ultimate particles of nature and which transferred itself between objects in the process of heating (Considine, 1976). This theory was replaced in the 17th century by particulate and kinetic notions, which identified heat as a form of energy that could be transferred by one of three means: convection, conduction, and radiation.

The parallels between the development of scientific theories about heat and the ontogenetic development observed in this study are striking. It is tempting to conclude that each of the notions in the historical development corresponds to a stage in ontogenetic development. The ancient Greek idea of heat as one of the primary elements seems very similar to the object-centered understanding of heat in very young children. Similarly, the tendency of younger children to espouse explanations of heat transferral that are imbued with notions of the movement of a substance into a bordering body is strikingly similar to the caloric–liquid theory of Renaissance science. Much the same can be said for the final developmental stages as well.

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