
Should You Ask a Fisherman or a Biologist?: Developmental Shifts in Ways of Clustering Knowledge

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Should You Ask a Fisherman or a Biologist?: Developmental Shifts in Ways of Clustering Knowledge

Judith H. Danovitch and Frank C. Keil

Individuals can infer what others are likely to know by clustering knowledge according to common goals, common topics, or common underlying principles. Although young children are sensitive to underlying principles, that manner of clustering might not prevail when other viable means are presented. Two studies examined how a sample of 256 children at ages 5, 7, 9, and 11 decide how to generalize another person's knowledge when goals, topics, and principles are put in conflict. In both studies, younger children preferred generalizing according to goals and topics, whereas older children preferred clustering based on principles related to disciplines. The most naturalistic ways of envisioning how knowledge is clustered in the minds of others therefore seems to change significantly during the elementary school years.

Knowledge is distributed unevenly in social groups. It clusters in ways that reflect people's interests, activities, aptitudes, and environments. As a result, we often need to rely on others to find answers to questions of interest. This reliance, however, requires a sense of who would provide the most informed answer. Imagine the following scenario: You notice that fish who live at the bottom of the ocean eat different things from fish who live closer to the surface, and you are interested in understanding this phenomenon. Would you be more likely to get an accurate answer from a local fisherman or a university-trained biologist? In this case, both informants may know the correct answer, although they might use different terminology to describe it. The fisherman would know about different types of bait used to catch surface or bottom-dwelling fish, whereas the biologist would know that only certain types of prey can survive the rigors of living in the deeper, colder water.

The fisherman knows the answer to this question because understanding the feeding patterns of dif-

ferent fish is a necessary aspect of accomplishing his goal of catching fish. Conversely, a biologist is likely to study the relationships between organisms and their environment or the structure of the aquatic food chain to test existing biological principles more effectively. Although decisions such as this one may seem trivial, we select among diverse sources of information throughout our daily lives. To function in the world, it is important to be aware of the breadth and depth, as well as the limitations, of one's knowledge and to acknowledge when it is best to consult someone else (a task that is more difficult than it appears; see Rozenblit & Keil, 2002). To make the best use of limited time and resources, one must be able to judge accurately other people's relative knowledge to choose the most appropriate informant for each situation.

By predicting which individuals possess certain types of information, we lessen the burden of acquiring all of the information ourselves, leading to a division of intellectual labor. While a rough division of physical labor based on hunting and gathering existed as early as the Paleolithic Era, a much more dramatic division of labor began with the advent of agriculture approximately 10,000 years ago. A division of cognitive labor emerged, organized by different sets of goals, such as the creation of clay pots, forging metal, and growing crops. Thus, ancient people must have attributed distinct sets of knowledge to a potter versus a blacksmith versus a farmer and consulted them accordingly.

In the modern world, the division of cognitive labor according to goals remains ubiquitous and critical as each member of society chooses, or is

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assigned, a precise role with a set of goals to fulfill. We can understand such goal-clustered knowledge as any knowledge that helps move a person closer to achieving the goal. Thus, a pediatrician might be expected to know not just the biology of children relevant to treating illness but also the economic forces influencing treatment and the sociological pressures on children, among many other topics. The division of cognitive labor by goals permeates all aspects of human life, and as a result, it is likely to guide people's representations of knowledge (Teske & Pea, 1981).

Clustering knowledge by goals is not the only means of conceptualizing the distribution of knowledge among individuals. As early as classical Greek philosophy, there has also existed a notion of disciplines, branches of scientific or artistic knowledge defined (at least in theory) by a common set of beliefs or principles. However, the official division of knowledge according to disciplines arose relatively recently in human history, as is reflected in the structure of the modern university. Not until the late 1800s did university curriculums shift from teaching general skills such as rhetoric and logic to teaching mostly self-contained disciplines, such as history or physics (Lucas, 1984). Although there have been some shifts over the past 150 years in how these disciplines are viewed, most adults feel that certain fundamental principles unify each of the traditional academic disciplines, particularly with respect to the natural sciences (Keil & Rozenblit, 1997).

There are other ways of clustering knowledge. Consider a person who knows all about restaurants that are open at 2:00 a.m., college football teams, and the quality of recent movie releases. Although these bits of knowledge are not related in any deeply causal or systematic way, they are all things one would expect a typical college student to know. Purely as a function of location and status, any given person will have access to a unique set of information. Understanding a person's privileged access to a body of information allows us to predict knowledge clusters of this sort.

Another way of clustering knowledge is based solely on the topic or object in question, without relating it to the attainment of goals or describing its relationship to fundamental principles. For instance, a dinosaur fan can become an expert on different kinds of dinosaurs without necessarily understanding evolutionary history or paleontology. In general, experts on a certain topic would not be expected to possess knowledge about similar topics outside that domain even if they involve some of the same basic principles. Hence, one would not consult a basket-

ball fanatic to understand the movement patterns of a soccer ball that has been kicked toward the net. Because clustering knowledge according to topics can often be accomplished through a shared set of lexical items, it appears to be an easy way to structure one's thoughts (e.g., a person knows a great deal about anything concerned with basketball). However, topic-based knowledge may confer fewer practical benefits because it does not support powerful inductions.

Adults use all the diverse ways of clustering knowledge described here and they seem to do so strategically depending on the situation (Keil & Rozenblit, 1997). However, it remains unclear how children prefer to cluster knowledge. In the later school years, children are generally exposed to discipline-based clusters such as biology or history, but they can demonstrate a basic appreciation of such clusters much earlier in their lives. For example, children as young as 3 years old display a rudimentary understanding of the division of cognitive labor among familiar experts such as doctors and mechanics, and by age 5, they appear to link certain types of expertise with underlying principles related to biology or physics (Lutz & Keil, 2002).

Several strands of work suggest that children's preferred ways of thinking about clusters of knowledge might shift during the elementary school years. For instance, accounts of the syntagmatic-paradigmatic shift (e.g., Nelson, 1977) suggest that younger children think about concepts in more script-like ways and do not produce predominately adult-like paradigmatic responses until age 9 or later. Script-like representations are often organized around goal structures whereas paradigmatic representations might be considered closer to taxonomies of the scientific disciplines. Although paradigmatic representations may be accessible at younger ages (e.g., Cole & Means, 1986), the reported shift may reflect a change with respect to the method of organizing knowledge that is most salient and that occurs as knowledge becomes more elaborated in a domain. Indeed, for novel categories, goal-directed organizations are often the first to spring to mind in adults (Barsalou, 1991; Ratneshwar, Barsalou, Pechmann, & Moore, 2001). Thus, as children are much more universal novices, we expect a greater tendency to favor goal-directed organizations.

In the context of understanding metaphors and analogies, young children often rely more on observable common object attributes and show less sensitivity to more complex relational properties. Thus, young children may have more difficulty with discipline-based knowledge as it involves sensitivity

to complex relational structures over surface attributes; consequently, discipline-based modes of clustering should emerge later than the less complex topic-based modes, again as a function of the degree of elaboration of knowledge in a domain (Ratterman & Gentner, 1998). Moreover, providing higher order common labels, or larger numbers of instances, for two distinct relational structures helps foster the shift (Gentner, 1988). With respect to clustering knowledge, the relational shift model might favor discipline-based categories by promoting sensitivity to deeper relational commonalities (Gentner & Namy, 2000; Namy & Gentner, 2002). During the elementary school years children may be exposed to an increasing number of terms and instances that suggest relational commonalities that organize disciplines.

Another developmental pattern of relevance is the characteristic-to-defining shift in word meaning (Keil & Batterman, 1984). When defining and characteristic features of words are pitted against each other, younger children often first rely on the most typical features associated with members of categories and only later start to place more emphasis on defining or more theoretically central features. This shift also occurs on a domain-by-domain basis, and it seems to represent a natural way of mastering the key dimensions that organize a domain (Keil, 1989). With respect to beliefs about clusters of knowledge in other minds, the characteristic-to-defining shift suggests that, when discipline is pitted against topic, children might initially cluster knowledge in other minds based on typical or characteristic features associated with various phenomena. Only later do children prefer clusters based on more defining or theory-like relations associated with disciplines.

The various proposals that differentiating knowledge might promote shifts in ways of construing information are also related to the notion of core knowledge, which proposes that skeletal theoretical frameworks for understanding domains such as physics, biology, and psychology are present early in development (Gelman & Wellman, 1992). At younger ages, these frameworks may be too loosely differentiated to allow discipline-based ways of organizing knowledge to dominate other forms, even though it may be possible to demonstrate the presence of such discipline-based knowledge in tasks where other ways of organizing knowledge are not available.

From different perspectives, each of these research traditions suggests a potential shift in the most salient way of thinking about knowledge in other minds during the elementary school years. Integrating

across these accounts, one developmental model would be that in each domain of knowledge, the child initially may be biased toward both goal- and topic-based ways of clustering knowledge when they are in competition with discipline-based ways. Early on, children might always have some access to discipline-based methods of clustering knowledge, but this method of clustering may seem less salient when other methods are also present. In addition, goals, disciplines, and topics often converge in real-world cases; therefore, the use of goals and topics may serve as a good heuristic for picking up on disciplines. As their understanding develops in each domain, children perceive increasingly rich discipline-based relations and the inductive power such relations provide; thus, they will gravitate more strongly to using this alternate method of organizing knowledge in other minds. This shift in default bias, similar to the characteristic-to-defining shift and the properties-to-relations shift, would be expected to occur on a domain-by-domain basis, emerging earlier in some domains than in others.

In this study, we examined how intuitions about knowledge clusters change with age and education by assessing the strength of children's preferences for a discipline-based method of clustering knowledge when put into conflict with goal- and topic-based methods. When there are no competing ways of organizing knowledge, young children are capable of clustering knowledge according to disciplines in carefully set-up cases, yet we predicted that when given a choice between discipline-consistent clusters and goal-centered clusters, younger children would gravitate toward a goal-oriented means of clustering knowledge. However, when given a choice between discipline-based clusters and topic-based clusters (containing no coherent goal), the tension between these competing ways of clustering knowledge may be alleviated and children should be more likely to opt for the discipline-based clusters. As they progress through elementary school, children should also show less reliance on topic-based clusters as the default, a fact that may be reflected in the quality of their explanations as well.

This study also addressed the related question of whether the natural sciences or the social sciences are better suited to discipline-based or goal-based knowledge clusters. Knowledge about the natural sciences appears to be qualitatively different from the social sciences or humanities, as has been reflected in recent debates about the nature of higher education (Searle, 1990). The more objective nature of scientific principles may lend itself better to discipline-based clusters. Therefore, concepts related to

the natural sciences may be easier to grasp and children may begin to cluster knowledge according to discipline in those domains at a younger age.

Experiment 1

Method

Participants. Participants were 128 children, including 32 kindergarteners ($M = 6$ years 0 months), 32 second graders ($M = 8$ years 0 months), and 32 fourth graders ($M = 10$ years 1 months), each of whom was interviewed individually by the experimenter in one session lasting approximately 20 min. Additionally, 32 sixth graders (ages 11 or 12 years) completed a pencil-and-paper version of the task. There were roughly equal numbers of males and females in each age group. Participants were predominantly European American from middle- and upper-middle-class backgrounds and they were recruited at elementary schools in Broward County, Florida.

Test items. The experiment consisted of two conditions of a set of 12 questions with 8 test questions in each condition, plus 4 distracter questions that remained constant (see the Appendix). Each question was presented in the following format: "This expert knows all about X. Would they know more about Y or Z?" The initial statement (X) always included a topic and an implicit goal that could be achieved through knowledge of a specific discipline and its underlying principles (in this experiment, the discipline was either social psychology or physics). One of the two facts that the participants chose between (Y) involved the same discipline as the original statement but not the same topic or goal. The other option consisted of a statement involving the same topic and the same goal but a different discipline (Z_1), or a statement containing the same topic word but not associated with the same goal or discipline (Z_2). For example, in one condition, participants were presented with the following question:

This expert knows all about why sidewalks are taken care of by people who want to be nice to others (topic: sidewalks; goal: keeping sidewalks clean; discipline: social psychology). Do they know more about (Y) why people get angry if someone else is mean to them (–topic, –goal; discipline: social psychology) or (Z_1) why salt melts ice on sidewalks but sugar does not (+topic, +goal; discipline: chemistry)?

In the other condition, the question remained identical but the +topic/+goal option (Z_1) was re-

placed with a +topic/–goal option (Z_2): "why sidewalks are divided into square sections" (+topic, –goal; discipline: unspecified). The +topic/+goal option (Z_1) always involved a contrasting discipline (chemistry contrasted with social psychology or cognitive psychology contrasted with physics), whereas the +topic/–goal option (Z_2) consisted primarily of mundane facts that bore no obvious connection to the goal or discipline (e.g., why sidewalks are divided into square sections). As some linguistic analyses have argued that no two words in a language are true synonyms (e.g., Lyons, 1977), the exact same topic words were used in each statement. The triads were also edited to avoid syntactic cues, and statement lengths were standardized as much as possible.

To verify that the +topic/+goal option would be more salient to children than the +topic/–goal option, this pairing (with no discipline-based option included) was presented to 12 kindergarteners ($M = 6$ years 3 months) who did not participate in the primary experiment. For both the physics and social psychology domains, kindergarteners chose the +topic/+goal option 78% of the time, significantly more often than chance, $t(11) = 6.413$, $p < .001$. Thus, goals used in this experiment had an important effect on knowledge clustering beyond any effect given by topic alone.

Each condition of the experiment used consistent sets of triads for each discipline. In Condition A, all the physics-based discipline options were pitted against +topic/–goal options and all the social psychology-based discipline options were pitted against +topic/+goal options. In Condition B, the opposite pairings occurred. Participants were randomly assigned to Condition A or Condition B only. Thus, each participant encountered an equal number of goal-centered and non-goal-centered options. All triads were also piloted with adult participants to ensure that the discipline-consistent option (Y) was most salient for adults ($N = 14$), who chose it more than 83% of the time.

Social psychology and physics items were presented in an intermixed pseudo-random order with the constraint that no more than two items from each discipline (e.g. social psychology) appeared together. The presentation of the two options (Y and Z_1 or Y and Z_2) was counterbalanced across participants. Each participant also encountered the discipline-oriented option (Y) first or the other option (Z_1 or Z_2) first an equal number of times.

Each statement in the triad was accompanied by a line drawing of the phenomenon it described. The drawings controlled for the number of people present and often showed the same person in the same

position in all three pictures. Additionally, neither of the topic-based clustering options (Z_1 or Z_2) depicted the topic item mentioned in the initial statement (X), decreasing the possibility of choosing an answer according to perceptual cues.

Procedure. Before the experiment began, children were trained on what it means to be an expert. As part of this training, children were first asked if they knew what an expert was and, if they said “yes,” they were asked to give an example of an expert. Children who said “no” were instructed that an expert is “someone who knows a whole lot about something or is really, really good at something, but experts don’t know everything” and were subsequently asked to think of a person who would fit that description.

The experimenter continued with examples of a doctor and a mechanic as experts, explaining that each one has a specialized realm of knowledge. Children were then asked to distinguish between the two areas of expertise by answering the question: “If you had a cut on your knee, would you go to the doctor or the car mechanic?” and the experimenter again emphasized that “experts know a lot, but they only know about certain things, not about everything.”

Children then completed two example items to ensure that they understood the format of the questions. The example items dealt with very simple domains of expertise: adding numbers and drawing pictures. If the child answered the first one incorrectly, the experimenter corrected him or her by providing another opportunity to answer the question and emphasizing the correct answer. The first example also illustrated that it is possible for the expert to know multiple things (e.g., knowing both how to count to a high number and say the alphabet) and that the participant should choose the fact that the expert is more likely to know based on the initial statement. Before beginning the test questions, children were also told that there were no right or wrong answers on this task, and that the line drawings did not contain any clues as to the answers.

Child participants were asked to explain their choices for a few test questions chosen randomly by the experimenter. They were not asked to provide an explanation for each question to avoid inadvertently reinforcing one way of clustering knowledge by generating verbal explanations.

The sixth-grade pencil-and-paper version included a set of written instructions and the second example from the experimenter script. Each of the questions was presented on a separate page, along with a small version of the corresponding line

drawing, and participants indicated their response by checking off a box next to one of the statements.

Results

If participants chose the discipline-consistent option over a +topic/–goal or +topic/+goal option, their response was coded 1; otherwise, it was coded 0. Thus, a total score of 0 to 4 was calculated for each participant for each of the two disciplines presented in the triads.

To determine the overall effect of grade level on performance, each child’s score on the social psychology and physics conditions was summed for a total score of 0 to 8. An analysis of variance (ANOVA) showed a significant overall effect of grade level, $F(3, 124) = 13.87$, $p < .001$, $\eta^2 = .251$. Collapsing across grade levels, an omnibus test (general linear model [GLM]) displayed a significant overall effect, $F(3, 252) = 3.00$, $p = .031$, $\eta^2 = .035$, with two main effects approaching significance: discipline, $F(1, 252) = 3.85$, $p = .051$, $\eta^2 = .015$, and condition, $F(1, 252) = 3.49$, $p = .063$, $\eta^2 = .014$.

Social psychology data. When social psychology was the discipline in question, an ANOVA showed a significant shift in performance among the four age groups for both discipline versus +topic/–goal, $F(3, 60) = 2.77$, $p = .049$, $\eta^2 = .122$, and discipline versus +topic/+goal, $F(3, 60) = 3.81$, $p = .014$, $\eta^2 = .160$ (see Figure 1). Post hoc analyses revealed that in both conditions these effects were driven by the sixth graders, who performed significantly better than the other three grades. There were no differences among the kindergarteners, second graders, and fourth graders.

Examining each grade and condition individually, the sixth graders in the +topic/–goal condition were the only group that approached performance at above-chance levels, $t(15) = 2.08$, $p = .055$. The sixth graders in the +topic/+goal group performed at chance, as did the +topic/–goal kindergarteners, and all other groups performed below chance. Thus, the +topic/+goal kindergartners and both sets of second and fourth graders actually exhibited a significant preference for non-discipline-based answers. A t test revealed that there was no overall effect of condition, $t(126) = .42$, $p = .676$, demonstrating that participants were equally likely to select a discipline-based option regardless of whether the other option included a topic only or a topic and a goal.

Physics data. For physics as the discipline, performance showed improvement with increased age (see Figure 2). An ANOVA indicated that performance significantly improved between each of the

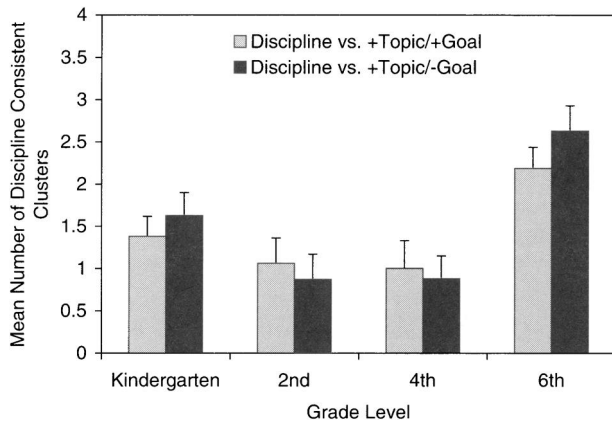


Figure 1. Mean number of discipline-consistent clusters for social psychology conditions in Experiment 1.

grades for both discipline versus +topic/-goal triads, $F(3, 60) = 5.35$, $p = .002$, $\eta^2 = .211$, and discipline versus +topic/+goal triads, $F(3, 60) = 6.78$, $p = .001$, $\eta^2 = .253$. Post hoc analyses revealed that in the +topic/-goal condition, the sixth graders, who differed from each of the other grades, drove this effect. However, in the +topic/+goal condition, post hoc analyses revealed that the second graders differed from the kindergarteners ($p = .042$), fourth graders ($p = .013$), and sixth graders ($p < .001$). The sixth graders also differed from the kindergarteners ($p = .019$) but not from the fourth graders. Thus, there are significant shifts between kindergarten and second grade, and between second and fourth grades with respect to rejecting +topic/+goal options.

Likewise, the only group that fell below chance in the domain of physics was the second grade +topic/+goal condition, $t(15) = 5.75$, $p < .001$. All other groups were at chance, except the sixth graders who

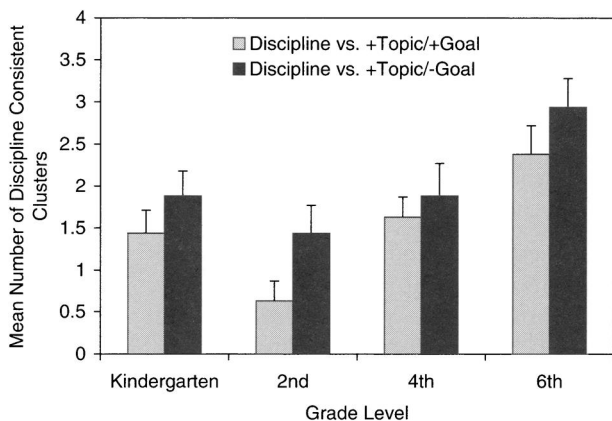


Figure 2. Mean number of discipline-consistent clusters for physics conditions in Experiment 1.

were above chance on the +topic/-goal condition, $t(15) = 2.80$, $p = .014$.

With respect to the role of condition in the domain of physics, collapsing across grades, a t test revealed a significant effect of condition, $t(126) = 2.17$, $p = .032$. Thus, participants in all grades were more likely to select a discipline-based option when faced with +topic/-goal option in physics than when faced with a +topic/+goal option.

Discussion

When assessing children's developing knowledge clusters, several patterns emerge. First, the frequency of clustering knowledge according to discipline generally increases with age, particularly in the domain of physics. As they mature, children begin to acknowledge that it is not always best to cluster an expert's knowledge according to topics only. However, this realization is by no means complete, and even in the sixth grade, some children maintain topic-based clusters. The distribution of individual scores in a linear, rather than bimodal, pattern also suggests that this ability develops gradually, as opposed to being an all-or-nothing trait.

Second, the set of principles associated with the domain of physics appears to become salient at an earlier age than principles associated with social psychology. This change is demonstrated by the major improvement in performance between second and fourth grades on the physics items, whereas a similar improvement does not occur for social psychology items until the sixth grade. It may be easier for children to grasp underlying principles associated with physical mechanics because those principles form a smaller and more compact body of relations than those governing psychological states and interactions, although any firm conclusions along these lines require a much larger set of items from both domains to be tested in future studies.

Third, the greater salience of physics-oriented clusters is also apparent in the quality of explanations given by children who chose the discipline-based options. Although statistical analyses of the explanations was not possible because of the small number of explanations available, selected explanations provide some insight into children's ways of reasoning about knowledge clusters. For instance, on an item comparing the transfer of force between two marbles with the transfer of force between a hammer and a nail, a fourth grader gave the following response: "It's not the size that would make the smaller marble move. ... It's the pressure and if you swing the hammer faster it puts more pressure and it

drives the nail." Likewise, a second grader responded: "Because when you play marbles, the big marble that you usually hit goes faster when you hit it so I was thinking that if you have a nail in wood then and you go faster, it will drive in." These children seem to be invoking a notion of a monotonic relation between forces and consequences in the domain of physical mechanics and assume that someone who grasped that principle for one phenomenon would naturally grasp it for others. Conversely, even when children clustered knowledge according to discipline on the social psychology items, explanations for their choices were generally vague. Consider the responses from some fourth graders: "It's similar because right here you get upset because someone did something and here you get upset because millions of people are watching." "Because they know what makes people happy."

Fourth, although there was no clear distinction between the +topic/+goal and +topic/-goal conditions, it is clear that younger children, particularly second graders, strongly prefer to cluster knowledge based on topics. Many second graders who unanimously chose either of the topic-based clusters would begin to answer almost by rote or claim that the questions were "easy," despite the experimenter's reminder about the training items where the topic-based choice was not necessarily the best answer. There may also have existed a possible confounding factor because of the distracter questions. Because they contained no implicit goals or principles, these questions may have skewed the results in favor of topic-based responses for lack of a better option. However, if that is true, the older children who successfully rejected the topic-based options on the actual test questions must have an even stronger preference for discipline-consistent clusters.

Finally, the performance of kindergarteners does not seem to fit the developmental trend for either discipline as their choice of clusters was usually at chance. It is possible that this group simply did not understand the questions or that aspects of the accompanying pictures distracted them too easily. It may also be that kindergarteners have not yet formulated any consistent way of clustering knowledge. These possibilities are addressed in Experiment 2.

Experiment 2

Experiment 1 showed that clustering knowledge according to disciplines emerges in the later elementary school years, yet it may not be the most

sensitive method of classifying an expert's knowledge. In Experiment 2, changes were made in the training procedure and format of the questions to emphasize the need to think about deeper causal principles. The term *expert* was eliminated and the question was made more realistic by using a first-person format. This format allowed the participant to feel more involved while emphasizing the "why" aspect of each statement. Likewise, the four distracter questions from Experiment 1 were removed to avoid any confounds they may have caused.

Method

Participants. Participants were 128 children, including 32 kindergarteners ($M = 5$ years 9 months), 32 second graders ($M = 7$ years 7 months), and 32 fourth graders ($M = 9$ years 9 months), each of whom was interviewed individually by the experimenter in one session lasting approximately 20 min. Additionally, 32 sixth graders (ages 11 or 12 years) completed a pencil-and-paper version of the task. There were roughly equal numbers of males and females in each age group. Participants were predominantly European Americans from middle- and upper-middle-class backgrounds, and they were recruited at elementary schools in the Greater New Haven, Connecticut area.

Test items. A new test statement was created for Experiment 2. In this experiment, the child was presented with the following scenario: I want to find out (X). Who should I ask? Should I ask someone who knows (Y) or someone who knows (Z)?" The experiment employed the same sets of facts and pictures as Experiment 1, in the same pseudo-random order, and using the same counterbalancing scheme, but without the distracter questions. Thus, there were only eight questions in Experiment 2, all of which presented a discipline-consistent option (Y) versus a +topic/+goal (Z_1) or +topic/-goal (Z_2) option. All triads were piloted with adult participants to ensure that the discipline-consistent option (Y) was most salient for adults, with adults ($N = 14$) choosing the discipline-consistent option 90% of the time.

Procedure. A new script was devised that emphasized the need to consider which of the two consultants would be best able to explain the phenomenon in question. The experimenter began by asking children if they ever had a question they did not know the answer to, and if so, how they went about finding out. Children who answered "no" were prompted to imagine what they would do if they did have such a question. The child then either

spontaneously suggested consulting another person or was prompted to do so by the experimenter. Children then provided a few examples of other people whom it would be suitable to ask.

Following this introduction, the experimenter provided two example situations of questions that one might choose to ask another, more knowledgeable, person (how to clean your room, how to fly an airplane). These questions emphasized that it is best to ask someone who is likely to know the answer because of their previous experience (e.g., a parent or sibling versus a pilot.) The experimenter also explained the importance of thinking about which person it makes sense to ask for help with the question.

The experimenter then provided two example questions. If children did not answer correctly (which never occurred on the first example and rarely occurred on the second), the experimenter prompted them to rethink the question and they subsequently chose the correct answer.

Before beginning the test questions, children were instructed that the purpose of the line drawings was only to help them remember the statements and that the drawings did not contain any clues. As in Experiment 1, participants were asked to provide explanations for their choices on a few randomly chosen test items.

Results

If participants chose the discipline-consistent option over a +topic/–goal or +topic/+goal option, their response was coded 1; otherwise, it was coded 0. Thus, a total score of 0 to 4 was calculated for each participant for each of the two disciplines presented in the triads.

Using a summed score of 0 to 8 for each child to compare across disciplines and conditions, an ANOVA revealed a significant effect of grade, $F(3, 124) = 42.81$, $p < .001$, $\eta^2 = .509$. Collapsing across grade levels, an omnibus test (GLM) displayed a significant overall effect $F(3, 252) = 5.10$, $p = .002$, $\eta^2 = .057$, with a significant main effect of discipline, $F(1, 252) = 10.29$, $p = .002$, $\eta^2 = .030$, but not condition, $F(1, 252) = .032$, $p = .859$, $\eta^2 < .0001$.

Social psychology data. For social psychology as the discipline in question, an ANOVA showed a significant shift in performance among the four age groups for both discipline versus +topic/–goal triads, $F(3, 60) = 18.82$, $p < .001$, $\eta^2 = .485$, and discipline versus +topic/+goal triads, $F(3, 60) = 9.23$, $p < .001$, $\eta^2 = .316$ (see Figure 3). Post hoc analyses revealed that in the +topic/–goal condition, these

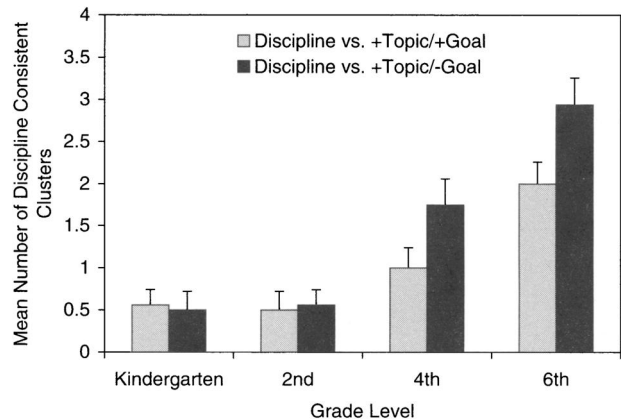


Figure 3. Mean number of discipline-consistent clusters for social psychology conditions in Experiment 2.

effects were driven by significant differences between the fourth graders and each of the other grades ($p = .002$ for all comparisons), and by the sixth graders whose performance was significantly different from the other three grades. In the +topic/+goal condition, the sixth graders drove the effect and there were no differences among the kindergartners, second graders, and fourth graders.

Examining each grade and condition individually, the sixth graders in the +topic/–goal condition were the only group that performed above chance, $t(15) = 2.91$, $p = .011$. The sixth graders in the +topic/+goal condition performed at chance, as did the fourth graders in the +topic/–goal group, and all the other groups performed below chance. Thus, the kindergartners, second graders, and fourth graders in the +topic/+goal condition actually exhibited a significant preference for non-discipline-based answers.

A t test revealed no significant difference between the +topic/–goal and +topic/+goal conditions overall, whereas within each grade, t tests revealed that the only significant difference between the two conditions was among the sixth graders, who were more likely to reject options that did not contain an implicit goal in favor of discipline.

Physics data. When physics was the discipline in question, performance showed an earlier movement toward disciplines (see Figure 4). An ANOVA showed a significant shift in performance between each of the grades for both discipline versus +topic/–goal options, $F(3, 60) = 19.05$, $p < .001$, $\eta^2 = .488$, and discipline versus +topic/+goal options, $F(3, 60) = 22.06$, $p < .001$, $\eta^2 = .524$. Post hoc analyses revealed that in the +topic/–goal condition, this effect was driven by differences between fourth graders and each of the younger grades

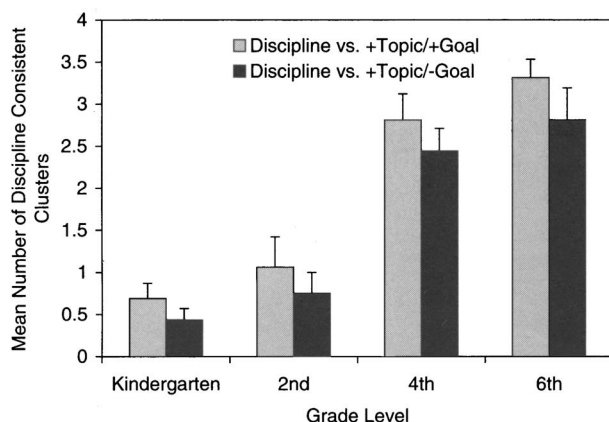


Figure 4. Mean number of discipline-consistent clusters for physics conditions in Experiment 2.

($p < .001$) and between the sixth graders compared with kindergarteners ($p < .001$) and second graders ($p < .001$). However, the fourth and sixth graders did not significantly differ. On the +topic/+goal condition, post hoc analyses revealed that the fourth graders differed from the younger grades ($p = .001$) but not from the sixth graders. The sixth graders also differed from the two younger grades ($p < .001$). Thus, there are significant shifts between second and fourth grades with respect to rejecting both types of topic-based options.

Likewise, the kindergarteners and second graders performed significantly below chance levels on both physics conditions. The +topic/-goal fourth graders were at chance, and the +topic/+goal fourth graders and both sixth grade groups performed significantly above chance levels. Thus, there was a shift toward discipline-oriented clustering between second and fourth graders in the domain of physics.

A t test revealed no significant difference between performance on the +topic/-goal and +topic/+goal conditions. Hence, on the physics-oriented triads, knowledge clusters were not affected by the presence or absence of an implicit goal along with the topic.

Discussion

Overall, the results of Experiment 2 support and strengthen the findings from Experiment 1. Younger children chose consultants according to topic- and goal-based knowledge clusters, but by sixth grade, discipline-based clusters prevailed. Clustering on triads involving physics principles also emerged earlier than those involving social psychology principles.

The manipulation in the phrasing of the question resulted in each of these shifts being more powerful

than in the previous experiment, suggesting that children's intuitions about how to cluster the information in each triad were more well defined and pronounced. Further evidence that children displayed a more concise notion of how to cluster knowledge is apparent in that kindergarteners were more consistent in their choices than in Experiment 1 and their performance more closely resembled the second graders. The improved performance of fourth graders on the social psychology questions also supports this notion.

General Discussion

Given a choice between two statements that describe what another person is likely to know, children as young as age 5 are capable of clustering knowledge according to consistent patterns. These clusters are often based on topics, but children are also capable of basing them on common goals or disciplines. However, when provided with two competing means of organizing knowledge, clustering in accordance with the principles that underlie the domains of physics and social psychology does not predominate until fourth grade or later.

Although we expected children to exhibit a preference for topic-based choices that incorporated an implicit goal, as opposed to topic-based choices that consisted of a random fact about the topic only, children generally did not show such a preference. That is, the presence of the same topic word seemed to be too powerful a lure for the younger children, regardless of whether an implicit goal accompanied it. In some cases, it may be that the +topic/-goal choices seem still to imply a distant relationship to the goal. When explaining +topic/-goal choices, children sometimes formulated elaborate, yet largely implausible, justifications. For instance, one child explained that the expert who knows why people want an ice cream cone when they see someone else eating one would also know why ice cream is called "gelato" in Italy because he must like to eat ice cream and, therefore, he would know how to order it when he goes abroad. Thus, even topic-only clusters may have seemed reasonable to some children if they thought about the statements in a sufficiently flexible way that invoked some sort of organizing goals. This finding also suggests that to influence the way children cluster knowledge, the goal-based options may need to be more explicit or avoid containing the same topic word. Thus, even though precise synonyms may be impossible to find in a language, it would be useful to see if the influence of topic is reduced when the nearest possible synonyms are used.

Although both types of discipline-oriented clusters became more salient among the older participants, clustering according to discipline on the physics questions emerged earlier and more powerfully than clustering according to discipline on social psychology questions. This supports findings from other research, where clustering in the domain of physics appears to be easier and to emerge at a younger age (Keil, McManus, Billings, & Rozenblit, 2002). The reason for this difference remains open to further investigation. One effective means of exploring this discrepancy may lie in the analysis of children's explanations for their choices. The explanations provided by children in these studies suggest that the principles underlying physics-oriented clusters were easier for children to verbalize. Likewise, overall, the older participants were able to provide richer, more descriptive explanations for their choice of discipline-consistent clusters, an ability that may have aided them in choosing the discipline-consistent options.

The quality of verbal explanations, even in young children, can be used as a way of assessing children's conceptual understanding (Hickling & Wellman, 2001). Because even adults have difficulty providing thorough explanations of common phenomena (Wilson & Keil, 1998), it is not surprising that no child in this experiment actually identified the clusters using the terms *physics* or *psychology*. However, the explanations that children provided for discipline-consistent clusters suggest several other strategies: (a) analogy, (b) likelihood of access, and (c) discipline-oriented ideas.

Analogy involves realizing that there is a relationship between two situations or objects, often by comparing one to the other and pointing out their similarities. For example, one child explained an item involving friction in a keyhole and in a bicycle wheel by stating that the expert would know why the wheel fails to turn "because the wheel is like the key." As Dunbar's (2000) work with professional scientists reveals, the use of analogies can actually be a powerful way of filling in gaps in current knowledge when other attempts are not fruitful. Similarly, when struggling to explain their intuitive notions of physics or social psychology, children may capitalize on familiar concepts by extending them to new situations. Thus, analogy may serve as a means of conceptual change that subsequently allows for clustering knowledge in a more sophisticated fashion (Inagaki & Hatano, 2002).

Children also explained discipline-consistent choices by recognizing that a person may be more familiar with the discipline-oriented phenomena or

by building on their own experiences with that situation or object. In this case, children appealed to personal experience to explain events such as the connection between cars sliding on icy roads and an empty shopping cart being easier to push than a full one. For example, one child explained that the expert would also know about the movement of the shopping carts "because people do that and when they ... go shopping and they don't have anything in their cart, they know it's easier." Thus, even though they did not explicitly acknowledge the underlying principles, some children accounted for their decisions based on personal experience with phenomena that demonstrate the principles in question.

Finally, a few children invoked discipline oriented terms such as *weight*, *force*, and *pressure* to explain the physics clusters and *emotions* or *feelings* to explain the social psychology clusters. Children younger than fourth grade rarely used these words, and even when the terms were employed, they were not necessarily used accurately. For example, one of the fourth graders explained the movement of marbles and a hammer and nail as being similar "because pressure usually gets it in faster ... and gravity pulls it down harder each time you swing." Because very few children have been explicitly exposed to the terminology of physics or psychology at these ages, it is not surprising that these terms are sometimes misinterpreted. What is impressive, though, is that children can apply them in the appropriate contexts and that they attempt to use them to explain physical or psychological concepts.

A full understanding of the mechanism underlying the shift from topic-based to discipline-based ways of organizing knowledge awaits further investigation. Younger children may possess a rudimentary understanding of discipline-based knowledge that becomes more fully differentiated as they mature and thereby allows them to apply it to a wider and wider range of situations. The younger children's bias toward topics may well be reflective of a novice-to-expert shift, similar to that described by Chi, Feltovich, and Glaser (1981). However, this is not all that takes place during development because once children advance past a certain point, they realize the general value of discipline-based clusters even in domains where they are still novices.

In addition to the differentiation of discipline-based knowledge, several other factors may promote a shift toward clustering by discipline. One may involve the use of higher order labels with expertise. Although it is plausible that a duck expert might know a great deal about ducks in a topic sense that includes both duck trivia and information from several domains, it

is much less plausible to be an animal expert in any way other than by discipline, namely, biology. There is simply too much trivia to learn about all animals to make a topic way of clustering feasible. Thus, as children encounter more and more higher level category terms with increasing age, the discipline point of view may become more salient.

A second mechanism may involve recognition that the same topic can be clustered in different ways depending on the kind of relations being described. For example, most adults will say that an expert on the inside parts of donkeys and horses knows more about the inside parts of zebras than pigs, whereas an expert on the prices of donkeys and horses is said to know more about the cost of pigs than zebras. As children get older and see more alternative uses of properties with the same words, they may start to appreciate further the disciplines that underlie topics and realize that topics are only rough indicators of more powerful deeper relations.

These findings suggest several implications for education. First, younger children may find it easier to grasp sets of facts revolving around the attainment of goals related to a specific topic rather than facts grouped according to underlying disciplines. Although this study suggests that teaching according to topics (e.g., everything about bees) would echo the simplest way of organizing knowledge among young children, topic-based curriculums may be misleading if they fail to provide students with a solid understanding of basic causal principles. Likewise, understanding the component steps of accomplishing a goal is likely to involve the causal structures that form the basis for disciplinary knowledge. As indicated earlier, however, there is one caveat to this claim: When the topic involves a high-level category (e.g., living kinds or mammals), the relevant information is likely to overlap largely with an academic discipline (e.g., biology) regardless.

Additionally, this study raises the issue of when it is most beneficial to cluster knowledge according to goals or disciplines. Initially, it may seem as if discipline-based clusters entail the deepest or most thorough understanding of a question, yet there may be cases when it would be preferable to cluster knowledge based on attaining a specific goal. For example, when choosing the best person to design a new clock radio, you would seek someone who knows not only about electrical engineering but also about the economics involved in making the radio cost effective and the cognitive psychology principles determining which type of display is easiest for people to read. Moreover, because it is often difficult to find one person who commands such a wide

range of expertise, the most effective solution may be to assemble a group of people, each of whom represents a different realm of knowledge. Studies of scientific investigations have found that one of the ideal ways to solve highly specialized scientific problems is to engage in distributed reasoning with people from different backgrounds. However, for this type of group to succeed, it is essential that all the members focus on an explicit goal (Dunbar, 2000). Consequently, the power of human cognition depends on our ability to construct functional systems that coordinate different bits of knowledge and structure to accomplish goals (Hutchins, 1995).

As Waks (1987) suggested, knowledge is constructed in society. It is made by people and grounded in human interests, and consequently, knowledge is inextricably linked to human projects and the division of cognitive labor. To acquire and use knowledge most effectively, children must not only develop an accurate representation of the minds of others, often known as a theory of mind (see Wellman, Cross, & Watson, 2001, for a review), but also of how knowledge is likely to be clustered within them. The studies presented here suggest that the understanding of knowledge clusters develops during childhood in ways that may recapitulate aspects of the development of formal knowledge structures in human history. Thus, long before people explicitly conceived of academic disciplines as such, they frequently talked about differing domains of expertise revolving about topics and goals, such as those of carpenters, healers, and blacksmiths. Only over time, as those areas of expertise began to highlight more and more a cluster of underlying principles (e.g., mechanics, biology, and chemistry) did a more explicit focus on disciplinary knowledge emerge. At a more implicit level, a sense of discipline-based forms of expertise may always be present, but it is much less salient when put into tension with goal- and topic-based forms. The younger children's topic-based choices for expertise, however, may have never reflected a dominant adult way of organizing knowledge but rather they may be linked to a uniquely developmental strategy early on to see entities with common labels as likely to be closely related. Finally, it is important to keep in mind that, regardless of the method children use to cluster knowledge in other minds, even the youngest children in this study found the notion of a division of cognitive labor itself to be immediately compelling. A very early emerging and compelling sense of the importance of knowing who knows what may drive the need to understand further the division of cognitive labor and thereby cause the patterns of development found here.

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Appendix

Study 1 Stimuli (Participants Received Condition A or Condition B Only)

"This person knows all about why ..."		"Do they know more about why ..."	"Or do they know more about why ..."	
Social psychology triads				
Opening statement (+topic/+goal/discipline: social psychology)	Y option (-topic/-goal/discipline: social psychology)	Condition A: Z ₁ option (+topic/+goal/discipline: chemistry)	Condition B: Z ₂ option (+topic/-goal/ discipline: unspecified)	
Sidewalks are taken care of by people who want to be nice to others	people get angry if someone else is mean to them	salt melts ice on sidewalks, but sugar does not	sidewalks are usually divided into square sections	
Mean people laugh when a person spills glue and makes a mess	you like to do some of the same things your friends like to do	glue can make people's fingers stick together	glue comes in bottles with orange caps	
People get upset when paint drips on their pictures	you are nervous when talking in front of a large group	paint sticks better to paper than to plastic	paint is usually measured in gallons	
If one kid in a park has an ice cream cone, then other kids will want one	people smile when they see an old friend	ice cream has to be stored in special freezers so it won't melt	ice cream is called "gelato" in Italy	
Physics triads				
Opening statement (+topic/+goal/discipline: physics)	Y option (-topic/-goal/ discipline: physics)	Condition A: Z ₂ option (+topic/-goal/ discipline: unspecified)	Condition B: Z ₁ option (+topic/+goal/discipline: cognitive psychology)	
Keys don't work as well if they are old and worn out	it's hard to turn the wheels on a bicycle if they are rusty	keys were first used in ancient Rome	people sometimes forget which keys open the car door or the trunk	
Tennis balls bounce better on the sidewalk than on grass	bubble wrap keeps glass things from breaking	tennis balls come in cans of three	orange tennis balls are easier to find in the bushes than green ones	
Large marbles make small marbles go farther when they bump into them	a hammer drives a nail better if you swing the hammer faster	marbles were first made in ancient Egypt	it's hard to keep track of marbles while they are moving around	

Appendix (Continued)

Cars slide more on icy roads than on sandy ones	it's easier to push an empty shopping cart than a full one	cars that are old get crushed into a metal square	cars dim their lights when they pass other cars at night
<i>Distracter items (for Conditions A and B)</i>			
"This person knows all about why..."	"Do they know more about why ..."	"Or do they know more about why ..."	
Airplanes need one wing on each side to fly	airplanes are usually made in the United States	birds build their nests in the spring	
Telephones used to have a dial that you had to turn	ants send messages to each other about where to find food	telephones ring loudly so people will wake up if they are asleep	
Flowers need sunlight to grow	flowers make sick people feel happier	icicles form when water that is dripping freezes	
Penguins live in very cold places	submarines are made out of strong steel	penguins are fast swimmers	