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Development of Young Children's Explanations: The Relationship between Domain Knowledge and Reasoning Schemata in Causal Systems Revisited

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Abstract

We activate complex psychological constructs in our explanations of biological and physical phenomena. In this research, two experiments were conducted to examine the relations between domain knowledge acquisition and reasoning schemata in explanations. In the first experiment, 3-, 4- and 5-year-olds, and adults (total N=120) performed "explanation tasks" consisting of 4 reasoning problems adapted from conditional reasoning tasks, and justifications of truth-value (yes-no) judgments involving familiar phenomena. These problems were embedded in familiar and realistic contexts. In the second experiment, child of ages 5:0 years and 5:6 years, and adults (total N=90) solved the same types of problems as used in the first experiment. These tasks were embedded in both familiar and unfamiliar contexts and participants also explained their judgments in detail in response to wh-questions. The results were as follows: (1) Throughout the tasks, young children's ability to make inferences was comparable to that of the adults; (2) Even 3-year-olds were able to make both deductive and inductive inferences; (3) Children's explanations were flexible and appropriate depending on differentiated domain knowledge, because young children already have domain knowledge of theories of mind, biology and psychics, and the level of this knowledge improved with age; (4) Chil dren's domain-specific knowledge acquisition promoted inductive and deductive inferences, based on domain-general reasoning schemata. There were two styles of adult explanations: highly elaborated through reasoning and a simple style through rote leaning. Results (1) and (2) imply that reasoning schemata are domain-general, while results (3) and (4) suggest that increasing scientific knowledge has a powerful effect on the activation of both inductive and deductive reasoning.

Key words : Development of explanation, causal systems, domain knowledge acquisition, reasoning schemata, cognitive development

Problem

In our attempts to explain everyday phenomena, the richer our correlating domain-specific knowledge is, the easier such explanations become. "Causality" is utilized to clarify the causative routes between cause and effect, in order that we might satisfy our listener with our explanation (Watanabe, 1998). Causality is a linguistic schemata used to express 'backward reasoning: why-because reasoning,' in other words the causal inference that allows us to trace backwards to surmise as to the original cause of an event. During childhood, it can be difficult to trace events back to their causes, and to the past, due to strong constraints on understanding of the temporal relationships between occurrences of phenomena. According to Uchida (1985) monitoring functions start to emerge in children once they reach around 5 and a half years old, in response to the expansion of their cognitive processing resources. At this age, children become able to utilize reversible operations, that is, "*the reversibility of operation*" by Jean Piaget, and replace the temporal relationship of the occurrence of a phenomenon with that of the relationship between cause and effect. The phrase that children use, from around 2 years old ("but that's because –"), to defend their behaviour, is diverted into a linguistic schemata for expressing rationale, and thus children become able to give explanations based on causality.

From this, I assume that there are various 'causal systems' at work when explanations are given. A causal system will consist of procedural knowledge such as 1) domain-specific knowledge (declarative knowledge), 2) reasoning schemata and 3) linguistic schemata used to express the reasoning schemata, and we can surmise that when these subsystems work together, coordinating with each other, the explanation itself will become appropriate. In what way, then, do explanations by young children develop, and how is this connected to qualitative and quantitative changes in knowledge, brought about by life experience and by learning, and to the development of reasoning schemata?

Existing knowledge of the development of naive theories presents certain implications for our discussion of the relationship between knowledge and reasoning schemata. It has been shown that once children come to hold naive theories about biology, physics and psychology, these theories become plausible, and the children thus able to give appropriate explanations for everyday phenomena. Inagaki & Hatano (1987) and Inagaki (1995) have shown that, within the domain of biology, pre-school children analogize through personification. Gelman & O'Reilly (1988) have found that 4- and 5-years olds distinguish between natural and artificial objects ontologically, from the perspective of the internal structure and functions of the objects in question, and furthermore that, at the most basic level, natural objects are able to produce more inductive reasoning. Moreover, Wellman, Hickling & Schult (1997) found that, by requiring 3- and 4-year olds to provide explanations for human behaviour and actions, children are able to provide psychological, biological and physical classifications of explanation, according to the nature of the stimulus with which they are presented. Analysis of the speech data collected though the Child Language Data Exchange System, or CHILDES, has shown that children begin to use diverse causal systems in their everyday conversation from around 2 years old, and that these are used according to domains that are related to their domain-specific knowledge.

There is also much knowledge about the conditions in which inductive reasoning can occur within categorizing processes. Children are able to ascribe items to certain categories and undertake inductive reasoning if they notice similarity in attributes with other category members (Gellman & Markman, 1986, 1987); Gelman & O'Reilly, 1998; Gelman, 1988; Gelman & Coley, 1990; Sumiyoshi, 2001). The success or failure of such inductive reasoning rests on the available knowledge on the attributes of category members. If there is sufficient knowledge about these attributes, then children are able to expand these attributes to relate to other subjects, engendering a greater possibility for generalization (Coley, 1995). Moreover, in order to make it easier to compare the attributes of corresponding items and phenomena, inductive reasoning becomes more likely when information is presented in a comparative form (Waxman, Lynch, Casey & Bear, 1977).

Oizumi & Hatano (1999) reviewed the knowledge gleaned thus far on the reasoning that occurs with regard to awareness of objects and of emotion. They showed that a distinction is made between the schemata and processes of reasoning in these two domains from a very early age, and suggested that a differing causal system is activated according to the domain.

No empirical research has yet been carried out to test this point, but methods suggested by Markovits, Venet, Janveau-Brennan, Mal-fait, Point & Vadeboncouer (1996) provide suggestions for a methodology that could be used to resolve this issue. They have shown that if a young child is given conditional reasoning problems, and asked to both make truth-value judgments on 4 logical expressions, and explain their rationale behind the judgments, then the truth-value judgments made by children do not differ from those made by adults, at least in those areas where children are able to activate knowledge. It is known that if adults are provided with contextual information to activate knowledge from related domains, such as in the everyday example of dividing up post to be delivered according to the addressee, their performance in both causal reasoning and conditional reasons improves (Tversky & Kahneman, 1973; Evans, 1989/1995). For children, however, contextual information functions as a guide, allowing them to make appropriate truth-value judgments regardless of whether the situation presented to them was real or imaginary. Tversky & Kahneman were primarily interested in conditional reasoning, and thus paid little attention to the question of development in causal systems. If we take into consideration, however, this knowledge that conditional information works as a clue that guides subjects towards appropriate truth-value judgments, then we can surmise that appropriate rational reasoning occurs in those situations in which existing domain knowledge, relevant to the attributes of the phenomena that is to be explained, can be easily activated.

Everyday reasoning does not make particular use of rational reasoning, and the causal reasoning (causality) referred to earlier, which is concerned with the relationship between cause and effect, is applied much more often. However, I assume when we examine an idea, or we persuade others, it is thought that rational reasoning schemata, such as rational and formal analyses, syllogism, or systematic induction, will play an important role. For example, after having made a truth-value judgment based on a logical expression, one would need, if requested to explain the basis of that judgment, to be able to carry out reasoning in a systematic way. Since we can assume that there are a number of differing reasoning schemata that could be applied in such a case, then I can also assume that it should be possible to discover the nature of the relationship between the knowledge used in an explanation, and the reasoning schemata applied It is not possible to conclude that children have no causal system for explanations simply because they are not able to rationalize the first and most basic problem in conditional reasons (If...., then....). Using "explanatory tasks', then, which consist of truth-value judgements based on conditional reasoning that have been adapted into a style of question comprehensible to young children[1], this research will look to clarify the developmental processes that occur in the explanatory skills of young children.

From these findings, as outlined briefly above, I assume that the following reaction would occur in the development processes for language and for cognition, as causality and other rational reasoning schemata are diverted from linguistic schemata that come into use from around 2 years of age. Firstly, knowledge and reasoning schemata in the explanatory domain need to be activated, and to come to work well together; without both functioning sufficiently, the explanation produced will itself be insufficient and inappropriate. Secondly, knowledge domains are differentiated from a very young age, and the quality of information (conceptual levels) is refined as age increases, moving from naïve concepts towards scientific concepts. Thirdly, in parallel with this improvement of conceptual level, rational reasoning schemata are activated. By combining these suppositions with the predictions of the response that will be gleaned during the experiment, in which subjects will be required both to make truth-value judgments on questions[2] that have been adapted to correspond to the logical expression of explanatory tasks, and to explain the rationale behind their answers, we are able to make the following hypotheses:

Hypothesis 1

The ease with which both young children and adults are able to make truth-value judgments will differ according to question type (which have been adapted to correspond with logical expression). Even young children will be able to solve the modus ponens (MP) and the modus tollens (MT) questions, but will find it difficult when the questions are concerned with either affirming the consequent or denying the antecedent.

Hypothesis 2

The knowledge upon which the explanation is based will be domain specific.

Hypothesis 3

Conceptual levels in knowledge increase with age, and knowledge itself is refined from naive concepts through to scientific concepts.

Hypothesis 4

There will be correlation between the knowledge and reasoning schemata used in explanations.

Hypothesis 5

As conceptual levels of knowledge increase, rational reasoning schemata, such as inductive and deductive reasoning, will grow.

In experiment 1, I will consider whether or not the explanatory tasks have been adapted so as to be capable of gleaning truth-value judgments from young children (hypothesis 1), and whether or not it is possible to identify knowledge domains through rationalization protocols (hypothesis 2). Based on the results of this, experiment 2 will look at hypotheses 3, 4 and 5, as we seek to clarify the relationship between knowledge in causal systems and reasoning schemata.

Experiment 1

Object

As well as examining the validity of the explanatory tasks (adapted from truth-value judgment tasks), we will investigate both truth-value judgment capability (hypothesis 1), and specialization according to knowledge domain (hypothesis 2), through causal protocols and truth-value judgments made according to the adapted tasks (adapted to logical expression).

Method

Experiment design: Three factor design: 2 domains (Biological / artificial) x 4 logical expressions (MP / MT / affirming the consequent / denying the antecedent) x 4 age groups (3 yrs / 4 yrs / 5 yrs/ university students). Factors 1 and 3 are within subject factors, and factor 2 is a between subjects factor.

Subjects

3 year olds (mean (m) = 3 : 7, range (r) = 3 : 1–3 : 11)
4 year olds (mean (m) = 4 : 6, range (r) = 4 : 1–4 : 11)
5 year olds (mean (m) = 5 : 7, range (r) = 5 : 0–6 : 2)

Thirty children of each age group (divided equally between the sexes), together with thirty adults (female university students), from whom control data is to be gleaned.

Materials

Four explanatory tasks were drawn up using phenomena related to goldfish (animate) and building blocks (inanimate / artificial) (The goldfish lives in the water / the building block floats in the water). Within the truth-value judgment paradigm, subjects are provided with conditional sentences as propositional pompts, designed to evince the relevant domain knowledge: "There is a living thing. If it is a goldfish....". This research, however, is concerned with the detection of domain-specific knowledge, and as such our pre-task prompts did not evince domain knowledge, and instead were provided in the following manner: "You know goldfish, don't you? They live in the water, don't they?"

Procedure

Picture cards were used as prompts (2 cards for each question, e.g. for the goldfish question, 1) picture of a goldfish; 2) picture of a goldfish swimming in water). These cards were shown, and after establishing the prompt ("You know goldfish, don't you? They live in the water, don't they?") in a normal adult voice, a puppet was then used (in those cases where the subject was

Table 1. Evaluation norms for protocol: (1) Knowledge Domain, (2) Conceptual Levels, (3) Reasoning Schemata.

Item	Definition	Example of protocol
(1) Knowledge Domain (Experiment 1)		
Psychological	Explanation deriving from psychological state, e.g. desire, hope, belief	"because the goldfish likes water" (4 : 1-, girl)
Biological	Explanation of biological functions and mechanisms	"if it's not in the water it's breathing will stop. It will die" (4 : 5, boy)
Physical	Explanation of mechanisms using biological concepts	"there's something like singing gasoline in there" (4 : 5, boy)
Source	Reference to the source of that knowledge in order to give the explanation authority	"because mummy said so" (3 : 8, girl) "they showed it on telly" (5 : 3, boy)
Other	No discernable meaning; knowledge domain unclear	(pointing at the picture) "it's floating" (3 : 8, girl)
(2) Reasoning Schemata (Experiment 1, 2) (a)		
Deductive	Generalizing rules from individual examples	"fish breathe through their gills so they live in the water. A goldfish is a kind of fish, so it lives in the water" (6 : 1, boy)
Inductive	Extracting rules from example	"salmon and squid ... if they come out of the water they can't breathe and they die, so that's why goldfish live in water too" (5 : 4, girl)
Unreasoned	Causal or circular argument/ explanation; attempts to apply knowledge; references to the source of knowledge	"because (someone) said that hemo (globin) makes blood" (6 : 1, boy) "radios are made so that sound will come out" (5 : 7, girl) "daddy told me" (4 : 6, boy)
Other	Not distinguishable	"the goldfish is in the water" (4 : 8, boy)
(3) Conceptual Level of Knowledge (Experiment 2) (b)		
Scientific	1) scientific concepts 2) precursory stage to scientific concept	"because the molecular density of the part of the building block beneath in the water, and the molecular density of the building block that is displacing the water are the same, a buoyancy effect is generated" (university student) "the water is holding up the building brick" (5 : 4, girl)
Naïve	Naïve biology & naïve physics	"the building brick has air in it, and air is lighter than water. That's why balls float too, you know" (5 : 8, boy)
Final cause & effect	Objective and causal explanations of phenomena	"if the fish comes out of the water it will die" (4:6, girl) "sound comes out of radios because they have batteries in them" (5 : 5, boy) "building blocks are made so that they float" (4 : 7, boy) "because radio's are made so that sound will come out" (5 : 6, girl)
Other	Source of knowledge; not distinguishable	"because I saw it on telly" (5 : 7, boy)

Notes:
a) the reasoning schemata used in explanations have been classified, from the perspective of linguistic schemata (c.f. not from a conditional reasoning perspective), into reasoning types (deductive, inductive) (1 point each) and non-reasoning types (0 points).
b) Conceptual levels decrease in score from scientific (3 points) , naive (2 points), objective - causal (1 point) and other (0 points).

a young child) to ask for the truth-value judgment in the voice of the puppet (in this case, Ernie from Sesame Street). The questions were either MP: Does that (goldfish) live in the water? Answer: Yes; affirming the consequent: Do you know what animal lives in the water? Is it goldfish? Answer: Not necessarily; MT: Do you know an animal that doesn't live in the water? Is it goldfish? Answer: no; and denying the antecedent: Do you know an animal that isn't a goldfish? Does it live in the water? Answer: some do and some do not live in the water. The questions on building blocks followed the patterns for the goldfish questions. On gleaning an answer, the puppet would 'ask' questions such as "why?" and "how come?", thus requiring the subjects to provide justifications for their truth-value judgments. The procedure was the same with university students, aside from the use of the puppets. For half of each age group, the order of the questions was MP a affirming the consequent a MT a denying the antecedent, and for the other half it was denying the antecedent a MT a affirming the consequent a MP. A total of eight truth-value judgments and corresponding rationales were thus requested from each subject in the experiment. Data was collected by the children being interviewed individually in a room at their own nursery or kindergarten, and the university students individually in a laboratory at the university.

Results

(1) The Reaction to each type of Conditional Reasoning

In order to consider the validity of the adaptation from the truth-value judgment tasks, we calculated the scores (correct answers) for each question, including the scores from the animate and artificial tasks, which were weighted equally. These have been shown according to logical expressions in Figure 1. To establish the frequency of correct answers given, we conducted a log linear analysis (an analysis of the SAS Catmod procedure) on the 4 logical expressions x 4 age groups. The results showed that the main effect of age ($\chi^2(3) = 63.42$, $p < .0001$) and the interaction of logical expression type and age group ($\chi^2(9) = 56.47$, $p < .0001$) were both significant, and that the main effect of logical expression ($\chi^2(3) = .60$, $p < .0001$) implied a trend toward significant. Having conducted a residual analysis to examine the appropriateness of the model and to establish any discrepancies between expected values in frequency bias, the results showed that 4-year-olds performed better than 3-year-olds, and that 5-year-old performed better than 4-year-olds, and that there was no significant gap in performance between 5-year-olds and university students, showing that children aged 5 years old are capable of performing truth-value judgment tasks to the same level as adults (to summarize: $3 < 4 < 5 =$ adult). Moreover, tasks that required subjects to affirm the consequent were performed better than those that required subjects to deny the antecedent, and results were strong for both MP and MT tasks. This shows that denying the antecedent is the most possible, just as had been with the original truth-value judgment tasks (antecedent < consequent < MP = MT). Looking at each separate type of question, only the MT type showed no significant differences between the age groups, the scores of all of which reached the very top of the graph in Figure 1. For the MP type, there was no significant gap between the ages, with the university students scoring the highest ($3 = 4 = 5 <$ adults). For 'affirming the consequent' the scores improved as age increased ($3 < 4 < 5 <$ adults), and for

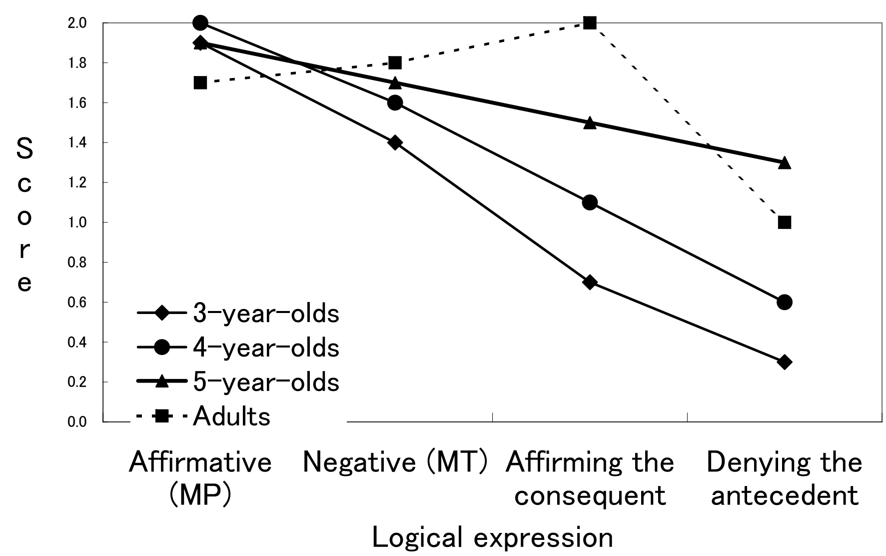

Figure 1. Results in truth-value judgment by logical expression type.

'denying the antecedent' the 4 years old scored better than the 3 years, the university students scored better than the 4 years olds, but the 5 year olds scored better than the university students (3 < 4 < adults < 5). 'Affirming the consequent' was difficult for all of the children, whilst 'denying the antecedent' was difficult for all subjects, including the university students. This supports the hypothesis 1.

(2) Domain-specific knowledge utilized in explanations

The protocols to be used to identify the domain-specific knowledge being used to rationalize explanations were divided according to proposition type (units taking 'agent + predicate' as one unit). Then, having identified the significance of each proposition, I drew up standards (Table 1(1)) for these, having also included the source from which the relevant knowledge is gleaned, according to the classifications made by Wellman et al. (1997). Both authors then carried out an analysis of the results separately. The rate at which the evaluations matched was $\kappa = 98.7$, and those items disputed were resolved through discussion.

Figure 2 shows the frequency ratios at which each source category of domain knowledge was used within explanations for responses to 'affirmative (MP)' type tasks, which were the least difficult for all age groups, by age and by domain. On carrying out a log linear analysis (domain field 5 x age group 4) (CATMOD PROCEDURE) on frequency, whilst the main effect of age ($\chi^2(3) = 3.59$, *n.s.*) was not significant, the main effects of domain knowledge ($\chi^2(4) = 161.53$, $p < .0001$) and of the interaction between age group and domain knowledge ($\chi^2(12) = 75.05$, $p < .0001$) were shown to be significant. The results of a residual analysis conducted on the appropriateness of the model and any potential gaps between expected values on distribution and bias showed a significant bias, regardless of the logical expressions applied in the task, towards "biology" in the animate domain, and "physics" in the artificial domain. On conducting a residual analysis taking logical expressions type into account, the most frequently used sources in the animate domain were as follows: "other" for 3-year-olds, "psychological" for 4-year-olds, "biological" and "source" for 5-year-olds and university students. Equally, for the artificial domain, "other" was the most frequently cited source for 3-and 4-year-olds, with a bias shown amongst 5-year-olds and university students towards "physics and source". These results affirm the conclusions reached by Wellman et al. (1997).

From the above results I am able to confirm that specialization in domain knowledge occurs from a young age in children, and that they utilize knowledge that is related to the domain about which they are being questioned. This confirms the hypothesis 2.

(3) Reasoning Schemata used in Explanations

The protocol for reasoning were divided according to proposition, and classified into four types (Table 1 (2)), namely 'deductive', 'inductive', 'unreasoned' and 'other'. Figure 3 shows the frequencies at which these by used according to age. The rate at which our evaluations matched was $\kappa = 94.8$, and those items disputed were resolved through discussion. We conducted a log linear analysis (reasoning schemata 4 x age group 4) (CATMOD PROCEDURE), the results of which showed

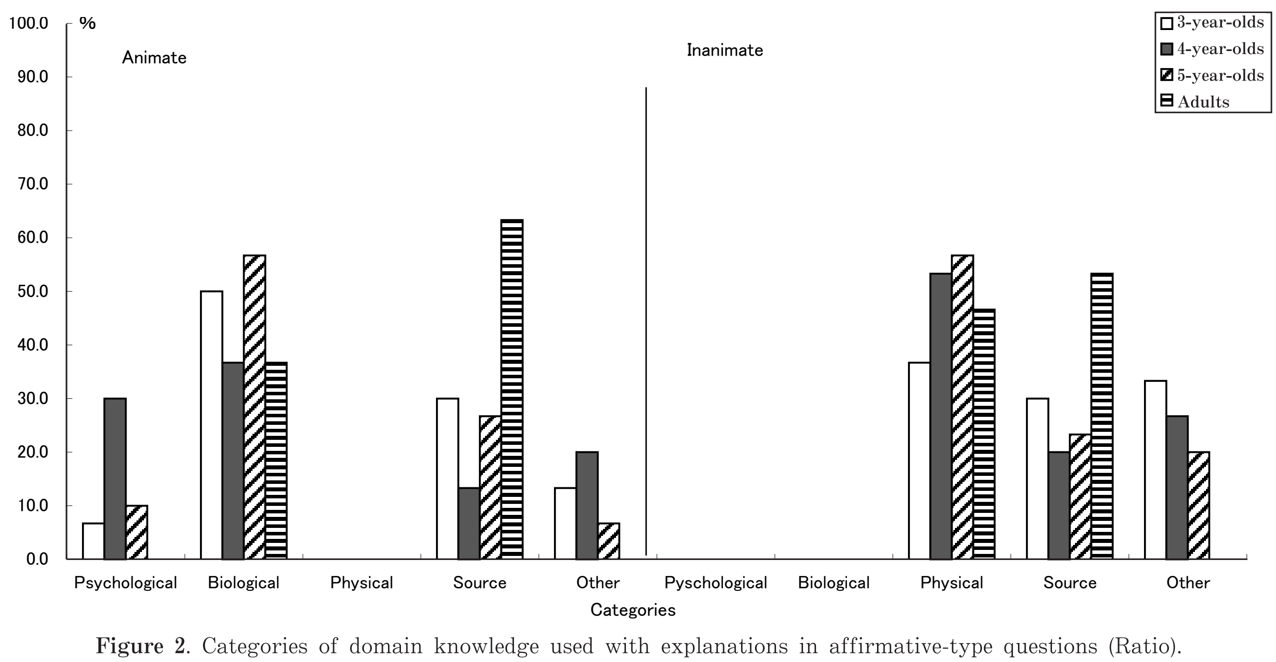

Figure 2. Categories of domain knowledge used with explanations in affirmative-type questions (Ratio).
Axis : Pyschological / Biological / Physical / Source / Other

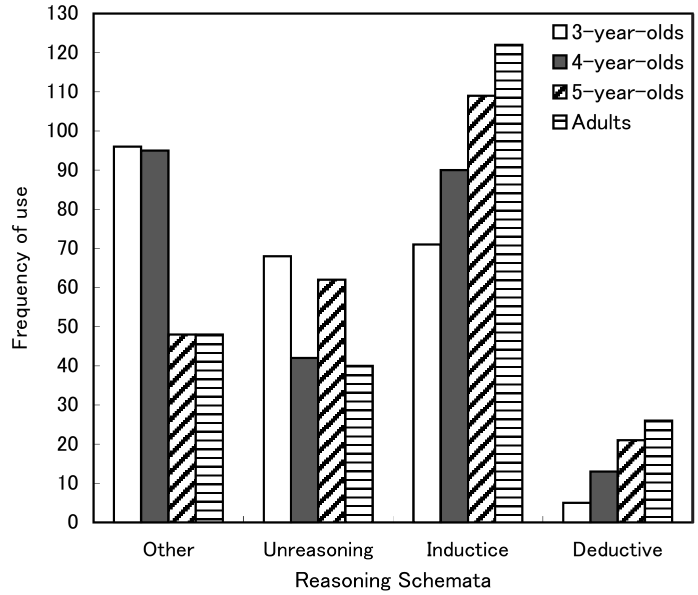

Figure 3. Frequency of types of reasoning schemata used.
(Frequency Total; 240 = 30 per age group x 8 questions)

that whilst the main effect of age was not significant $\chi^2(3) = 4.26$, n. s.), the main effect of reasoning schemata ($\chi^2(3) = 170.74$, $p < .0001$) and of the interaction of age group and reasoning schemata ($\chi^2(9) = 67.66$, $p < .0001$) were significant. The results of a residual analysis conducted on any potential gaps between expected values on distribution and bias showed that 5-year-olds and university students made frequent use of 'deductive' and 'inductive' reasoning, whilst 3-and 4-year-old made more frequent use of those schemata classified as 'unreasoned' or 'other'. The fact that both inductive and deductive reasoning was observed in 3 year olds, despite the frequency being low, and the fact that once children reach 5-years-old they are able to use inductive and deductive reasoning to the same level as adults, both allow us to surmise that reasoning schemata represent procedural knowledge, common to all domains, which is possessed even at the early stages of development, when domain-specific knowledge is not sufficient enough to allow reasoning. Reasoning, therefore, is limited at those stages where the level of domain knowledge is low. There appears, however, to be a relationship in which rational reasoning schemata are activated as and when knowledge increases.

The validity, then, of the explanatory paradigm has been confirmed. This leads me onto Experiment 2. Firstly, the task was manipulated so as to exaggerate the familiarity or unfamiliarity of the explanatory tasks in hand. Secondly, based on Uchida (1985), current thinking estimates that changes in domain knowledge and reasoning schemata occur at around 5-years-old. In order, then, to examine this critical age more closely, the subjects were split into between 5 : 0- and up to 5 : 6-years-old, and between 5 : 7- and 6 : 0-years-old. Thirdly, the experiment was amended so that wh-questions (asking subjects the rationale behind their answers using the questions why? and how?) would be repeated *twice*, in order to gain more detailed information on protocols. The takes of the Experiment 2 imposed only two task : 'affirmative (MP)', which showed high scores and 'denying the antecedent', which showed low scores in the Experiment 1.

Experiment 2

Object

I examine the hypotheses 3, 4 and 5.

Method

Experiment Design Four factor experiment: Logical expressions 2 (MT / denying the antecedent) x knowledge levels 2 (familiar / unfamiliar) x domain knowledge 2 (animate / inanimate) x age group 3 (4 : 5-5 : 5 years / 5 : 6-6 : 6 years / adults＜university students＞). The first, second and third factors are within subject factors, the fourth is a between subject factor.

Subjects 90 subjects. 30 each from the following groups: children in the first half of their fifth year ($m = 5:3$, $r = 4:10\text{-}5:6$), children in the second half of their fifth year ($m = 6:3$, $r = 5:10\text{-}6:6$)[4].

Materials

4 tasks were drawn up. For the 'familiar' tasks, 'goldfish' and 'building blocks' were chosen as subjects with which the children were likely aware (through

direct manipulation), while 'bear' and 'radio' were chosen as subjects which the children were unlikely to have directly come into contact with or operated themselves[5]. In the unfamiliar tasks, little known nouns or nonsense words with no meaning were used for the subjects, and 2 tasks were drawn up for both categories (animate: "MANATEE eat seaweed" / "HAEMOGLOBIN makes red blood"; inanimate: "ROENTGEN copies the inside of bodies" / "NEUROM burn in water"), making a total of 4. There were 8 familiar and unfamiliar tasks in total. In order to lessen the burden on subjects, each subject was asked one MT and one 'denying the antecedent' question for each task, making the total number of questions asked to each subject 16.

Procedure

For each task, two questions (MT & denying the antecedent) were asked, with wh-questions asked twice in order to glean detailed protocols for responses given with which to build detailed reasons for explanations.

A puppet was used (Curious George, who tends to repeat questions) to ask the subjects to "explain things in detail so that others can understand", thus conveying the experiment objective. The conductor of the experiment then showed a picture card before asking MT questions. For the familiar tasks, the subjects were asked the questions having been given a prompt, as in the Experiment 1. For the unfamiliar tasks, the subjects were asked by the conductor of the experiment, in his or her real voice, "do you know what NEUROM are?". Once it had been established that the subject was unfamiliar with the agent in the question, the conductor then gave the prompt precondition of "NEUROM burn in the water" in his or her own voice. Then, if the subject was a child, the conductor would then change to the 'voice' of the puppet, and ask : "Do NEUROM burn in the water?". Then, he or she asked "Do you know anything that's not a NEUROM? Does it burn in the water?", thus prompting a truth-value judgment. The truth-value judgment having been given, the conductor would then ask two wh-questions in the voice of the puppet ("why?" "I don't understand why? Please tell me"), thus prompting detailed rationale. All other questions were also asked in this format. Counterbalance was used in determining the order of familiar and unfamiliar questions. The puppet was not used if the subject was a university student, and more formal language was used to ensure that the instructions were understood in the same way.

Evaluation Norms

The explanatory protocols were divided according to the unit of proposition. According to the cognitive levels shown in Table 1 (3), and the reasoning schemata shown in Table 1 (2), I and a research assistant independently judged the content meaning of each proposition, and represented individual performance for the propositions evaluated as being of higher levels on the evaluative standards. The rate at which the evaluations matched was $\kappa = 94.7$ for conceptual levels, and $\kappa = 98.6$ for reasoning schemata, and those items disputed were resolved through discussion.

Results

(1) Conceptual Levels used in Explanations

We calculated the frequency at which the various conceptual levels, as laid out in Table 1 (3), were used in rationale (the maximum scores = 32). The results are shown in Figure 4. No difference was shown in the frequencies used for the animate and inanimate categories, so the overall frequency was examined through a log linear analysis (CATMOD PROCEDURE) which looked at the basic effect of conceptual level 4 x age group 3 for both familiar and unfamiliar tasks. The main effect of age group ($\chi^2(2) = 0.71$, n. s.) was not significant, but the main effect of conceptual level ($\chi^2(3) = 320.39$, $p. < .0001$), and of the interaction between logical expressions type x age group ($\chi^2(6) = 244.00$, $p. < .0001$) were both shown to be significant.

Next, I carried out the same analysis, having separated the results into those for familiar and unfamiliar tasks. This showed that both the main effect of cognitive levels (familiar : $\chi^2(3) = 177.08$, $p < .0001$, unfamiliar : $\chi^2(3) = 67.35$, $p < .0001$) and of the interaction between cognitive levels and age group (familiar: $\chi^2(6) = 205.99$, $p < .0001$, unfamiliar : $\chi^2(6) = 85.17$, $p. < .0001$) were significant. The main effect for age group was only significant for unfamiliar tasks (familiar : $\chi^2(3) = 0.71$, *n.s.*, unfamiliar : $\chi^2(3) = 5.92$, $p < .06$) The results of a residual analysis conducted on any potential gaps between expected values on distribution and bias showed that : 1) for familiar tasks : there was no difference in the frequency with which 'scientific' reasons were used by children in the first and second halves of their fifth year, and adults showed a significantly higher frequency of utilization (early = late < adults). 'Early' 5-year-olds used 'naive concepts' more than adults, and 'late' 5-year-olds used them significantly more than 'early' 5-year-olds (adults < early < late). For the 'object - causality' and 'other' categories, these were used by 'late' 5-year-olds more than by university students, and by 'early' 5-year-olds more than by 'late' 5-year-olds (adults < late < early); 2) there was no significant difference in the frequencies with which 'scientific' and 'objective causality' reasons were used by 'early' 5-year-olds, 'late' 5-year-olds and university students, but for 'naive' reasoning, the scores increased with age (early < late < adults). 'Other' reasons were given by adults the least, and significantly more so by 'early' rather than 'late' 5-year-olds (adults < late

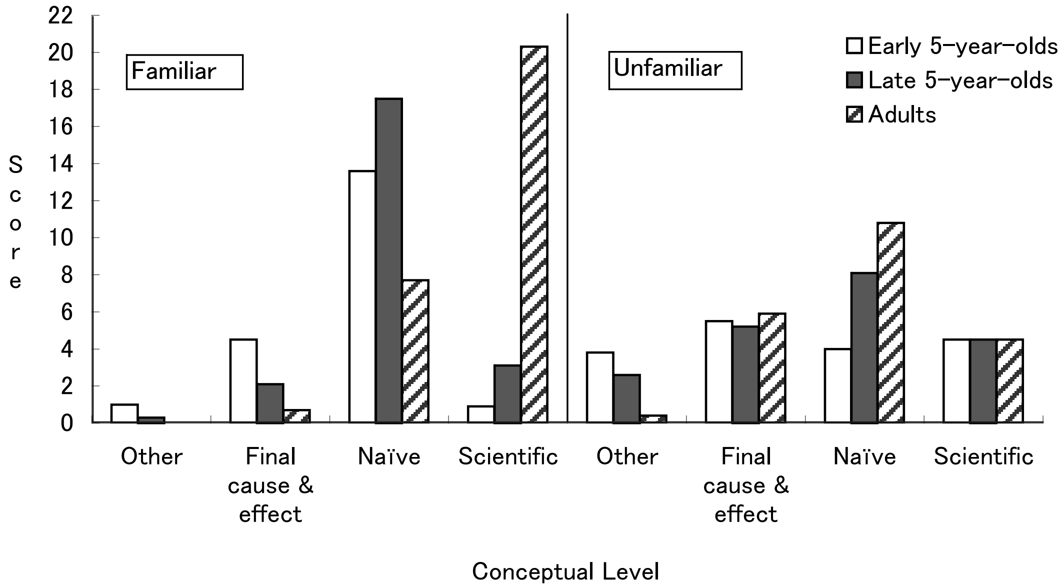

Figure 4. Mean scores in conceptual levels of domain knowledge used in explanations.

< early).

From the above results, I can see that for familiar tasks, just as had been expected, reasoning develops gradually from objective-causality to naive concepts, through naive and pre-scientific concepts and finally onto scientific concepts. This supports the hypothesis 3. For unfamiliar tasks, however, the no increase in conceptual levels was seen with age, and furthermore it was shown that for each age group the conceptual level of the explanation given within these unfamiliar tasks was extremely low when compared to that used within explanations given for familiar phenomena.

(2) Reasoning schemata in explanations

In order to establish which reasoning schemata were being used, results were classified and evaluated according to the evaluative standards for reasoning schemata laid out in Table 1 (2), and a log linear analysis (CATMOD PROCEDURE) (reasoning schemata 4 x age group 3 (5 : 0-5 : 6-years / 5 : 7-6 : 0-years / adults)) was carried out to determine the frequency with which reasoning schemata were applied to both familiar and unfamiliar tasks. The results showed that the main effect of age group was not significant ($\chi^2(2) = 1.70$, n.s.) but that the main effect of reasoning schemata ($\chi^2(3) = 266.11$, $p < .0001$) and of the interaction between reasoning schemata and age group ($\chi^2(6) = 107.15$, $p < .0001$) were significant. The results of a residual analysis conducted on any potential gaps between expected values on distribution and bias showed that 'deductive' reasoning was observed among adults much more than children (early = late < adults), whilst for 'inductive' reasoning, there were significant difference between the 'early' 5-year-olds and adults, and again between the university students and the 'late' 5-year-olds (early < adults < late). The results show that after the later stage of one's fifth year, there is an increasing strong tendency to search for specific examples and make analogies, and that inductive reasoning can be observed more often among children than adults.

(3) Reflectives and resource savers

The use of 'unreasoned' reasoning increased with age, from early to late 5-year-olds, to adults (early < late < adults), showing that adults tend to reason less than children. In both the familiar and unfamiliar tasks, uniformity in individual answers to questions was sought. With the aim, then, of examining such individual difference, I classified the subjects into 'reasoning type' (explained more than 80% (13 out of a total of 16 questions) of their answers using reasoning (inductive, deductive), 'unreasoning type' (explained using random application of knowledge and reaction to instructions, without using reasoning) and 'combination type' (both used and did not use reasoning) (Table 2). An χ^2 test on the number of subjects in each category showed that a significant bias in distribution at the 5% level ($\chi^2(4) = 11.07$, $p < .05$) The results of a residual analysis showed that whilst many university students fell into the 'unreasoning' category, few 'later' 5-year-olds did. Amongst the children, some did choose not to consider their response, answering only "I don't know"; the number who chose this option, however, was significantly higher among adults. The fact that very few university students fell into the 'combined' classification implies that cognitive style becomes polarized, falling into either a 'reflective and considerative' or a 'resource saver' strategy.

Table 2 Polarization between reasoning and unreasoning types.

Number of subjects (%)

	n	Reasoning type	Unreasoning type	Combined[a]
4 years	30	14 (46.7)	6 (20.0)	10 (33.3)
5 years	30	18 (60.0)	3 (10.0)	9 (30.0)
Adults	30	15 (50.0)	12 (40.0)	3 (10.0)

Notes : a) Reasoning type: at least 13 out of 16 questions answered using 'deductive' or 'inductive' reasoning. Unreasoning type: those subjects evaluated as unreasoning. Combined type: a mixture of the two.

(4) The Relationship between cognitive conceptual levels and reasoning schemata

In order to examine the relationship between the conceptual levels and the reasoning schemata (4 x 4) used in explanations in greater detail, the relationships between conceptual levels and reasoning schemata for both familiar and unfamiliar tasks have been depicted in Figure 5. From these, we can see that inductive and deductive reasoning increases in parallel with increasing conceptual levels.

Point values were given to both 1) the sophistication of the conceptual level used in explanations (3 : scientific, 2 : naive, 1 : final cause and effect, 0 : unreasoned; See Table 1 (3)) and 2) the rationality of the reasoning used (3 : deductive, 2 : inductive, 1 : unreasoned; See Table 1 (2)). The scores for each individual were then calculated. Looking at the correlation between 1) and 2) for all three age groups, the figures were as follows: 'MP': $r = .43$, $p < .01$; 'denying the antecedent' : $r = .64$, $p < .01$, thus showing a significant relativity between the two. Looking at the correlations between each age range and reasoning schemata separately, the following figures were gleaned : 'early' 5 year olds: 'MP' : $r = .53$, $p < .01$; 'denying the antecedent': $r = .72$, $p < .01$; 'late 5 year olds: 'MP' : $r = .44$, $p < .01$; 'denying the antecedent': $r = .40$, $p < .01$; university students : 'MP' : $r = .41$, $p < .01$; 'denying the antecedent' : $r = .51$, $p < .01$. These showed significant correlativity between conceptual levels in knowledge and reasoning schemata, supporting hypothesis 4.

Next, in order to examine whether or not reasoning schemata varied according to conceptual levels in knowledge, I gave point values to the occasions when reasoning (inductive / deductive) had been called upon (1 point), and to the occasions when no reasoning had been made (0 point) (Figure 6). I carried out a bi-factorial repetition analysis *of variance* (knowledge levels 2 (familiar / unfamiliar) x age group 3), the results of which show that the main effect of knowledge levels ($F(1, 87) = 4.96$, $p < .0001$), the main effect of age group ($F(2, 87) = 9.85$, $p. < .0001$), and the interaction effect of knowledge level x age group ($F(2, 87) = 9.85$, $p. < .0001$) were all significant. The results of a post hoc comparison by *the Student-Newman-Keuls test* showed that the age range difference was not significant for familiar tasks, but that differences were seen with unfamiliar tasks, in which each range group were answering through inference. The difference between early and late 5-year-olds was significant at around 5%, although there was no significant difference between late 5-year-olds and university students. The fact that the interaction effect between the two factors is significant implies that the use of reasoning schemata is affected by whether the task is familiar or unfamiliar,

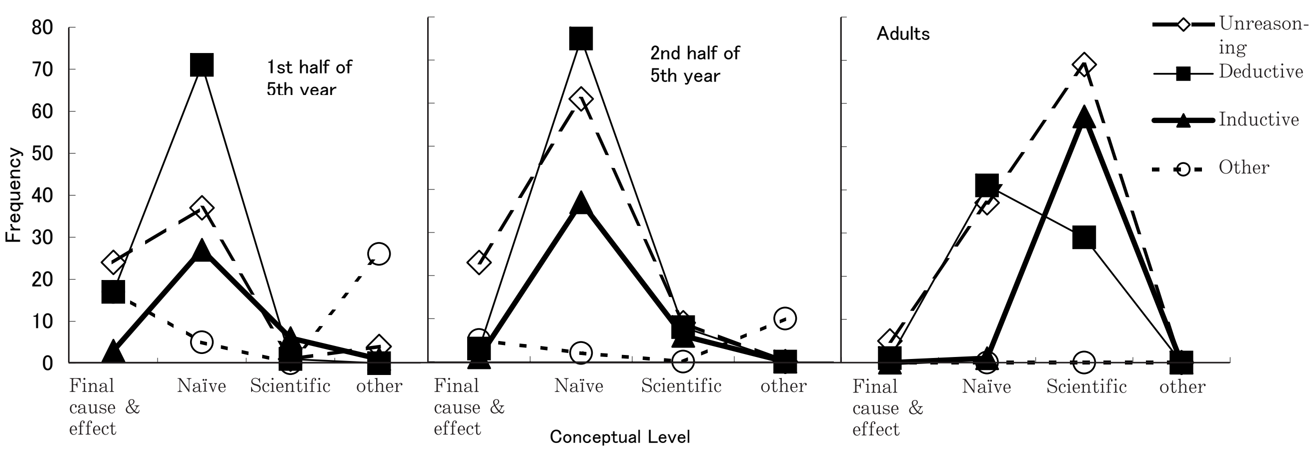

Figure 5. The frequencies of reasoning types in each conceptual level.

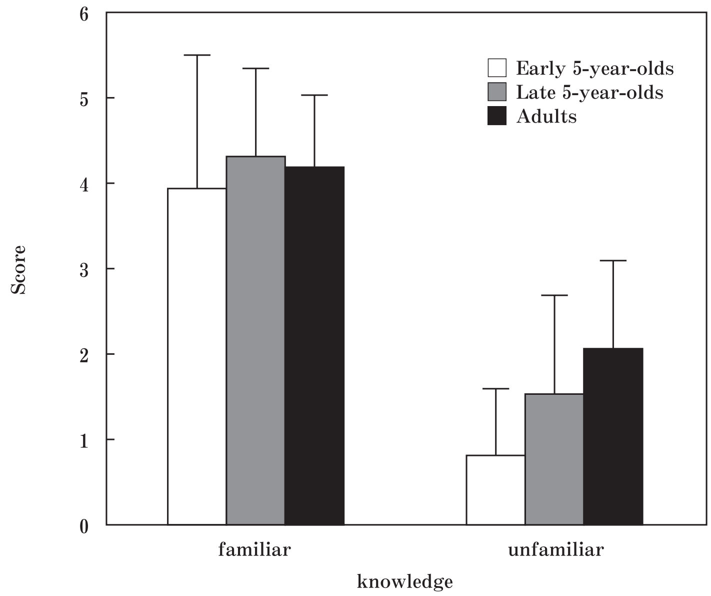

Figure 6. The mean scores of the reasoning types used in each familiar knowledge and unfamiliar knowledge.
(Maximum score is 8 points.)

and that the more familiar a task or subject is, the more easily rational reasoning schemata, such as inductive and deductive inference, become activated. This supports the hypothesis 5.

Looking at the order in which they appear, it can be surmised that the relationship between conceptual levels in knowledge and reasoning schemata is causally correlated. Inductive and deductive inference is possible from early childhood (Experiment 1). As children get older, knowledge and experience are built up through life experience, and on enrolling in school the qualitative aspects of knowledge, and conceptual levels, increase through curriculum based learning. As a result, the advanced rational reasoning schemata that children have possessed since an early age are activated, and explanations are refined into forms utilizing causality. Domain knowledge is increased via a different route to that of reasoning schemata. Through life experience and contact with media (the 'sources' in Experiment; "because I saw it on telly"), and curriculum based learning in schools, conceptual levels in knowledge appear to increase. In parallel with this increase in both the quality and quantity of knowledge, a tendency to try and apply retrieved knowledge to tasks, rather than to try and use inference to explain unknown questions or tasks, appears to be formed.

Discussion

(1) Summary of results

Through two experiments using explanatory paradigms, we established the following 5 points about the relationship between knowledge and reasoning schemata in causal systems. Firstly, the difficulty of the explanatory tasks varied, for both university students and children, according to the type of question. Good scores were achieved for both MP and MT type questions, with denying the antecedent questions being the most difficult (Hypothesis 1). Secondly, domain knowledge is differentiated according to theories of mind, biology and physics from a very early age, supporting findings from Wellman et al. (1997) (Hypothesis 2). Thirdly, young children make frequent inductive inferences, and there appears to be a trend toward the increasing utilization of deductive inference as age increases. However, even 3-year-olds are able to make use of rational reasoning schemata, such as inductive and deductive inference, thus suggesting that the reasoning schemata that represent one part of causal systems are inherent as domain general procedural knowledge. Fourthly, conceptual levels in knowledge improve with age (Hypothesis 3). Fifthly, it is the conceptual level of domain-specific knowledge that determines which type of reasoning schemata will be activated (Hypothesis 4), and the higher the conceptual level of knowledge, the more likely it is that rational inference will occur (Hypothesis 5). From these, it was detected a casual correlation between knowledge and reasoning schemata.

(2) The relationship between knowledge and reasoning schemata

Faced with questions on familiar topics with which they will have had little direct contact (bear, radio), children are likely to draw upon inductive inference based upon analogies with more everyday, familiar objects (person, television). At the first wh-question, children will try to explain the phenomena in question by personifying the topic, or likening it to a familiar object: "just like when we're cold we snuggle under a thick comforter, caves are warm and comfortable, so bears go to sleep in them" (5 : 2, boy), "it makes a noise when you switch it on, just like tellies or this tape (said whilst pointing at the tape recorder on the desk" (5 : 8, girl). These support the findings of previous research (e. g. Gelman & Markman, 1986, 1987; Gelman & O'Reilly, 1988; Gelman & Coley, 1990; Sumiyoshi, 2001), and suggest that when both children and adults attempt to explain objects and phenomena from the real world, there is a strong tendency to draw upon more familiar objects and phenomena, and make inductive inferences from them. With questions on unfamiliar phenomena, however, both children and adults find it increasingly difficult to make such analogical inferences.

Coley (1995) has suggested that there is a tendency towards generalization whenever there is enough information about category attributes to allow it. In this research also, inductive inference was the most frequent among the 'late' 5-year-olds, and a trend was shown towards more frequent deductive inferences as age increased, with adults using them extremely often. The findings of previous studies do not facilitate a discussion on why deductive inference increased with adulthood, but the results of this research suggest a dynamic relationship wherein rational inference is activated as conceptual levels increase, but rational inference is suppressed when conceptual levels of knowledge are low. This could well be one of the reasons why deductive inference increased with adulthood. As the quality and quantity of knowledge increased through curriculum based learning, so a tendency toward the principle of parsimony arises, in order to process information efficiently, making possible explanations utilizing a top-down form of deductive inference, rather than from the general route.

(3) Reflectives versus resource savers

The results imply that trends explanations in adults are polarized; consisting either of efforts of sufficient reasoning, or of the simple application of knowledge with no attempt at inference. For familiar phenomena and objects, and in particular inanimate objects, research carried out by Wellman et al. (1997) showed that explanations which referred to the source of knowledge (e.g. "mummy said so", "teacher said so just now", "I saw it on telly") were common throughout all age groups, and that children do not doubt that which they are taught by adults.

Konno (1990) showed that when university students were asked to explain "burning within water", a phenomenon which contradicts their experience, scientific concepts of burning were suppressed, and the students gave up trying to think about the question. In the same way, since university students possess high levels of conceptual knowledge, they are more likely to fail to undertake any critical evaluation, and apply acquired knowledge to the question instead; if pushed to provide further explanation, there was a strong trait towards the 'resource saving' cognitive style, with students ceasing their cognitive reasoning, claiming to "not know" the answer. Moreover, adults (university students) who cannot recall the scientific concepts that they doubtless learnt previously show a tendency toward intuitive judgment, based on the information displayed and their own experience. Evans (1989/1995) has proposed the 'dual process theory', namely that, within conditional inference, adult reasoning consists both of an intuitive and reflective process that is unconscious, and of a conscious, analytical process, leading to a stage of controlled monitoring. The results of this research suggest that the transition in both these processes does not necessarily occur automatically. Even adults, when they are not able to utilize knowledge about the attributes of the phenomenon in question, remain stuck at the first, intuitive stage, unable to transfer to the second, analytical stage. This then suggests that is would be difficult for meta-knowledge and critical thinking to occur.

How, then, is this sort of resource saving cognitive style brought about? I think that we cannot ignore the role of linguistic schemata in causal systems. If children and infants are asked to tell a story using picture cards, children who are native speakers of English tend to link scenes with causality, whereas native speakers of Japanese use more chronology, developing the scenes through "and then" conjunctions (Uchida, 1999). Watanabe (1998) analysed the speech of the history teachers, concluding that while Japanese teachers made regular use of chronological patterns, US teachers focused on encouraging students to consider the causes of events by using causal phrases and why-so, because reasoning in their classroom discourse. This trend having been shown, it was further reflected in an exercise that required children to write an explanatory report on a cartoon. The patterns shown were that the Japanese children tended to explain the story chronologically and and-then reasoning, ending their reports with a moral teaching or a precept, while the American children began their reports with the main topic of the cartoon, and developed scenes from therein, using causality, that is why-so-because reasoning. Based on an analysis of the explanatory sections in textbooks and the language used by teachers in elementary schools in Japan, Takeda (1998, 2001) has proposed that, unless given an appropriate question or task, children gradually lose the ability to critically perceive the language of teachers and textbooks, and, by the time they reach university level, have developed a tendency to take at face value everything said by textbooks and teachers.

Cognitive style, which begins to form as young children are influenced by the linguistic input of their native language, may well be reinforced by the classroom discourse that serves to suppress critical thinking to which children are exposed once they enrol in school.

What need to be considered in the future, then, are the questions of which aspects of the discourse structure that surrounds children in schools function to influence reasoning schemata and domain knowledge in causal systems, and how this resource saving cognitive style is produced. Moreover, there is also a need to developmentally clarify what kinds of relationship exist between these three declarative and procedural knowledge types.

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(Notes)

1 I carried out a preliminary experiment which indicated that truth-value judgment questions using conditional reasoning were not appropriate for children. As such, with reference to the task styles outlined for children as suggested by Markovits et al. (1996), we adapted the truth-value judgment questions that were based on this conditional reasoning. To test these, we randomly divided 30 university students into two groups of 15: the 'original task group', who were given the conditional reasoning-based truth-value judgment tasks to solve, and the 'adapted task group', who were given the judgment tasks as they had been adapted so as to be suitable for young children. There was no significant difference in the score patterns for either group, and similar trends were shown terms of difficulty according to question task, in that MP and MT questions were solved easily, with denying the antecedent and affirming the consequent being more difficult. Although this does not guarantee that the original tasks and the adapted tasks had entirely the same signifying content, from the fact that these results were reproduced with different subjects

in Experiment 1 (1), I determined that it would be appropriate to use these adapted tasks on the children.

2 The questions were adapted to correspond to the logical expressions of modus ponens (MP), modus tollens (MT), denying the antecedent, and affirming the consequent; their full terms should perhaps be used, but due to spatial limitations we have referred to them throughout the paper as they are referred to above.

3 It is likely that the reason that university students scored less well than 5-year-olds in denying the consequent lies in the capacity to process information. Adults will try to think of an example that satisfies both conditions, namely something that is both "an animal that is not a fish" and "[an animal that] lives in the water." Young children, however, will make their truth-value judgments whilst only paying attention to one or the other of these conditions, or placing more weight on one than the other. It is thought, then, that they can occasionally chance upon correct answers.

4 The explanatory paradigm tests linguistic capability and the capacity to process information. As such, children of around 5-years-olds were selected to undergo the experiment. Children in the first half of their fifth year were selected from a class of 4-year-olds, and children in the second half of their fifth year from a class of five year olds. 'Late' 5-years-olds is thought to represent the stage at which the qualitative developmental change of discourse construction ability occurs (Uchida, 1996), and at which there is an expansion of the capacity to process information, as measured by the WPPSI Intelligence Test.

5 Of the explanations given for the tasks on familiar items, those for 'goldfish' and 'building blocks', both of which the children were likely to have handled directly, and those for 'bear' and 'radio', neither of which the children were likely to have come into direct contact with, did not indicate any significant difference in terms of the levels of knowledge on these four items. For 'bea r' and 'radio', however, there was a tendency, however, to make analogies with more immediately familiar objects (such as 'person' and 'television') (inductive reasoning).

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