段階的かつ連続的に発達する認知構造
Cognitive Structures can develop both gradually and successively

前田 洋士 MAEDA, Hiroshi
● 国際基督教大学教育研究所
Institute for Educational Research and Service, International Christian University

Keywords 認知構造，発達水準，コネクショニストモデル
Cognitiue structure, Developmental level, Connectionist model

ABSTRACT
ニュートン力学の概念に対する認知構造の発達過程について検討を行った．専攻領域の異なる 37 人の大学生を対象に，46 個の古典力学の単語をカテゴリー分けする作業を行った（実験 1）．その結果,実験参加者の水準は，専攻領域を反映して初学者，中間者，専門家の 3 つに分類ができた．この水準の違いが，同一の学習システムによって段階的かつ連続的に示されるかどうかについて，コネクショニストモデルにより検証した（実験 2）．シミュレーションの方法は，実験 1 で使用した単語の情報をネットワークに学習させて，カテゴリー化をさせるものであった．結果，学習の進行順に認知発達過程を示唆する急激学習期，停滞学習期，十分学習期の 3 つの局面が示された．このことから，3 つの質的に異なる認知構造の水準は，同一の認知構造から発生していることが示唆された．

Learning natural science and development of cognitive structures

Learning natural science requires the acquisition of a coherent body of knowledge as a related set has been emphasized as opposed to discrete concepts, skills, and so forth (Reif, 1985). It is considered that learners are constructing their own understanding (Champagne et al., 1981).

Learner's structural knowledge has been studied by eliciting a represented body of knowledge or the conceptions learners hold in their mind (e.g. McCloskey et al., 1983).

Experts v.s. Novices

The differences in knowledge structure between experts and novices about physics have been studied by several researchers. For example, experts represented structural knowledge more efficiently and effectively than novices, developing more elaborate structures that enabled them to reason more effectively (Simon & Simon, 1978; Larkin, McDermott, Simon, & Simon, 1980).

Naïve notion and its stubbornness

In science learning in school, despite extensive instruction and acceptable (even outstanding) performances on school examinations, many students cling tenaciously to their pre-existing, naive notions or naive theory. Naive theory seems interfering with acquisition of sophisticated scientific knowledge. Some students insist on an everyday homogeneity view even when they take chemistry courses in college (Bunce, Gabel & Samuel, 1991). From these considerations, it takes much time for learners to organize a sophisticated theory in mind because of the stubbornness of naive theory. In another words, learners have difficulty to learn the principles of the phenomenon in a fully abstract manner. This account suggests the consistency with representational redescription model (Karmiloff-Smith, 1992).

A connectionist account of conceptual development

Connectionism is a movement in cognitive science which hopes to explain human intellectual abilities using artificial neural networks. The term "Connectionism" is also known as "neural networks" or "neural nets". Neural networks are simplified models of the brain. As Brain composed of large numbers of conjunct neurons, the artificial neural networks are composed of large numbers of units together with weights that measure the strength of connections between the units. These weights model the effects of the synapses that link one neuron to another. Experiments on models of this kind have demonstrated an ability to learn such skills as face recognition, reading, and the detection of simple grammatical structure (e.g. Plunkett, K., et al. (1997); McClelland, J.L. (1991)).

In the most common type of connectionist model, the architectures of networks are composed of an input layer, several layers of hidden units corresponding to the network's continuous changing internal representations, and an output layer. In general, the hidden layers have fewer units than the input layer, which cause the representation of the information from the input to be compressed. In contrast with the previous work in artificial intelligence as described in a von Neumann architecture, connectionist networks have massively parallel systems. In connectionist networks, processing elements show nonlinear responses to their input information. This has consequences for both representation and learning (Karmiloff-Smith, 1992).

Hypothesis

In categorizing concepts, the results of the different level's subjects can be categorized into different developmental concept levels. Those developmental levels are from the same cognitive structural system.

Experiment 1

Method

Participants. Three groups of university students with different major are as participated in this study. Group 1 consisted of 17 university undergraduate or graduate students majoring in the humanities or the social sciences (3 in literature, 2 in history, 8 in psychology, and 4 in sociology). Group 2 consisted of 10 university undergraduate or graduate students majoring in natural science (2 in chemistry, 2 in information science, and 6 in biology). Group 3 consisted of 10 university graduate students majoring in physics.

Materials. Forty-six terms in Newtonian-dynamics were used as common concepts for these experiments. Each term was inscribed on small pieces which are shape like domino. A whiteboard (height × width=100cm × 140cm) was put on the table for experimental task area. Three colors (black, red, and blue) of marker pens were provided to descript explanations for categorization.

Procedure. The free sort task. A concept classification and categorization task was adopted in this research (e.g., Gorodetsky & Hoz, 1985). No criteria for categorization were suggested. The instructions emphasized the absence of a right answer, indicated that the words to be classified were on pieces on a whiteboard, asked that the words be classified into "categories that include words that you think belong together," and pointed out that any number of categories was possible and that any category could contain any number of words. Subjects classified the 46 terms into categories and provided a names and explanation for each category on the whiteboard. A maximum of 30 minutes was allowed for completion of the task.

Results

The differences among the three groups. The results could be categorized into four conceptual levels as follows:

Standard 1 on the basis of superficial resemblance

Standard 2 on the basis of textbook categorizations but with a logical fault

Standard 3 on the basis of textbook categorizations

Standard 4 as a sophisticated higher level categorization of items

Figure 1 shows the Mean and Standard Deviation of categories as a function of group. Considering the number of categories at Standard 2 and 3, it is suggested that students in Group3 have many numbers of categories with no logical faults. On the other hand, there are a small number of categories in Group 3 at Standard 1. And also, there are a small number of categories in Group 1 and 2 at Standard 4.

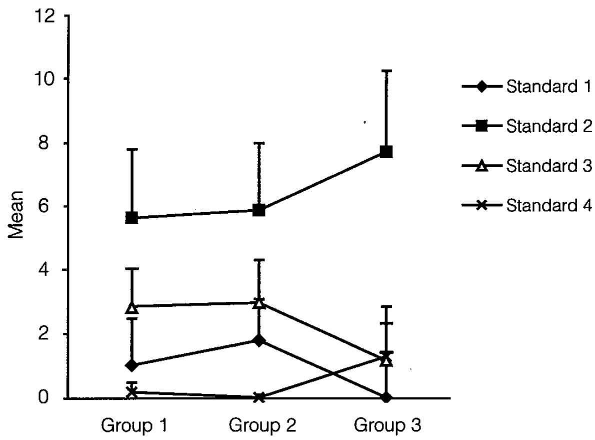

Figure 1. The Mean (and standard error) of categories as a function of group in Experiment 1.

Note. Standard 1 on the basis of superficial resemblance; Standard 2 on the basis of textbook categorizations; Standard 3 on the basis of textbook categorizations but with a logical fault; and Standard 4 as a sophisticated higher level categorization of items.

A Kruskal-Wallis test was conducted to examine whether there were differences among the three groups in terms of the number of categories used by participants. There could see significant difference from chance for all Standard except for Standard 2. Although the Standard 2 did not differ significantly, the score of Kruskal-Wallis test is enough large to suggest the tendency.

Table 1 *Differeces among the three groups in term of the number of categories used by participants*

Standard	*kw*	*df*	*N*
Standard 1	10.91**	2	37
Standard 2	6.28*	2	37
Standard 3	10.16**	2	37
Standard 4	7.03*	2	37

Note.kw = Results of the Kruskal-Wallis test.
* p ≤ .05 ** p ≤ .01

The categorization patterns. Considering the categorization patterns shown in Figure 1 and Table 1, it seems that there were differences in structural knowledge across the three groups. These differences reflect the degree of sophistication in structural knowledge. The results suggest that learners can be categorized into three groups - beginners, intermediates, and experts.

Experiment 2 (Simulation)

To determine whether these three levels came from a continuous entity, or the same cognitive structure system, a computer simulation was executed using a connectionist modeling.

Method

The simulation method was designed to train the network to be able to categorize those same concepts used in Experiment 1. The modeling results are based on a simple recurrent network (Elman, 1990) with 21 input units, 7 hidden units, 17 output units, and 7 context units (Figure 2). To model the learning process, 46 concepts were classified along with 7 input indices (Table 2). Those indices are consisted with several superficial resemblances, and 6 hierarchical semantics.

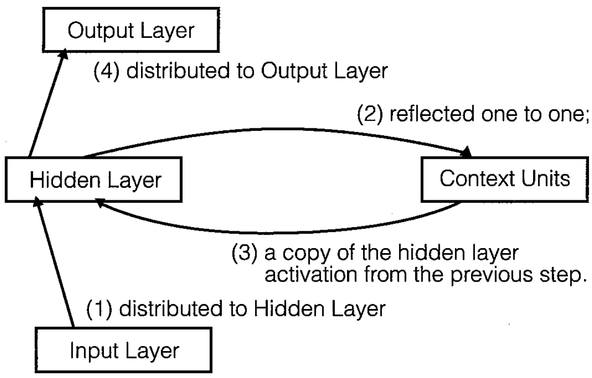

Figure 2. Schematic of Simple Recurrent Network in concept leaning.

Note 1. Distributed; All units from one layer are connected to all other unites in the next layer

Note 2. One to One; The first unit in one layer is connected only to the first unit in the context layer

Results

The results of the simulation broadly supported the proposal of three phases in cognitive development. In examining the Root Mean Square Error for the concepts learning, it is suggested that, as learning proceeded serially, developmental phases were as follows: a rapid learning phase, a stagnant learning phase, and a fully learned phase (see Figure 3).

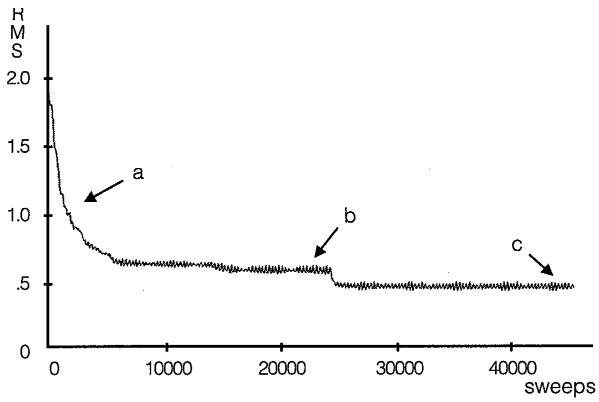

Figure 3. The Root Mean Square (RMS) Error for the concepts leaning with theoretical information over 40,000 sweeps in experimental group.

Note. a = arapid learning phase, b = a stagnant learning phase, c = a learned phase

Also, as learning proceeded serially, the network make categories gradually sophisticated are suggested for examining the cluster analysis of the output unit activation (Figure 4-6).

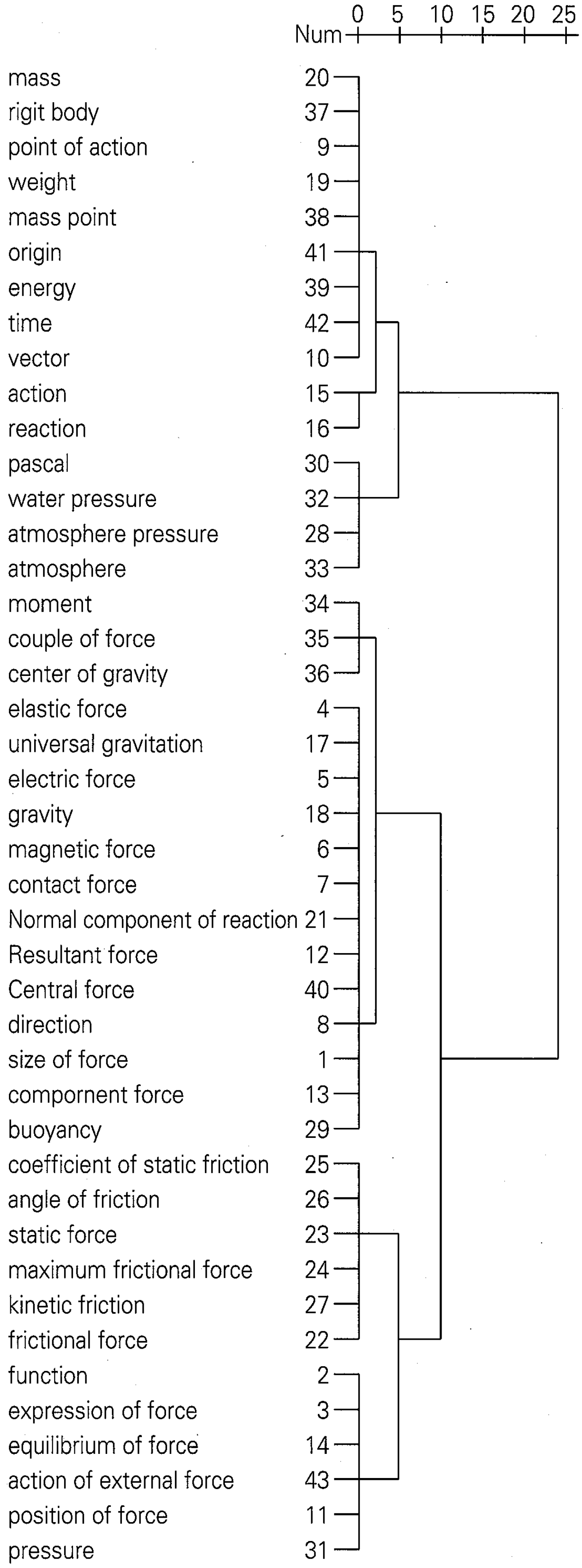

Figure 4. A dendrogram at an early learning phase on hierarchical cluster analysis

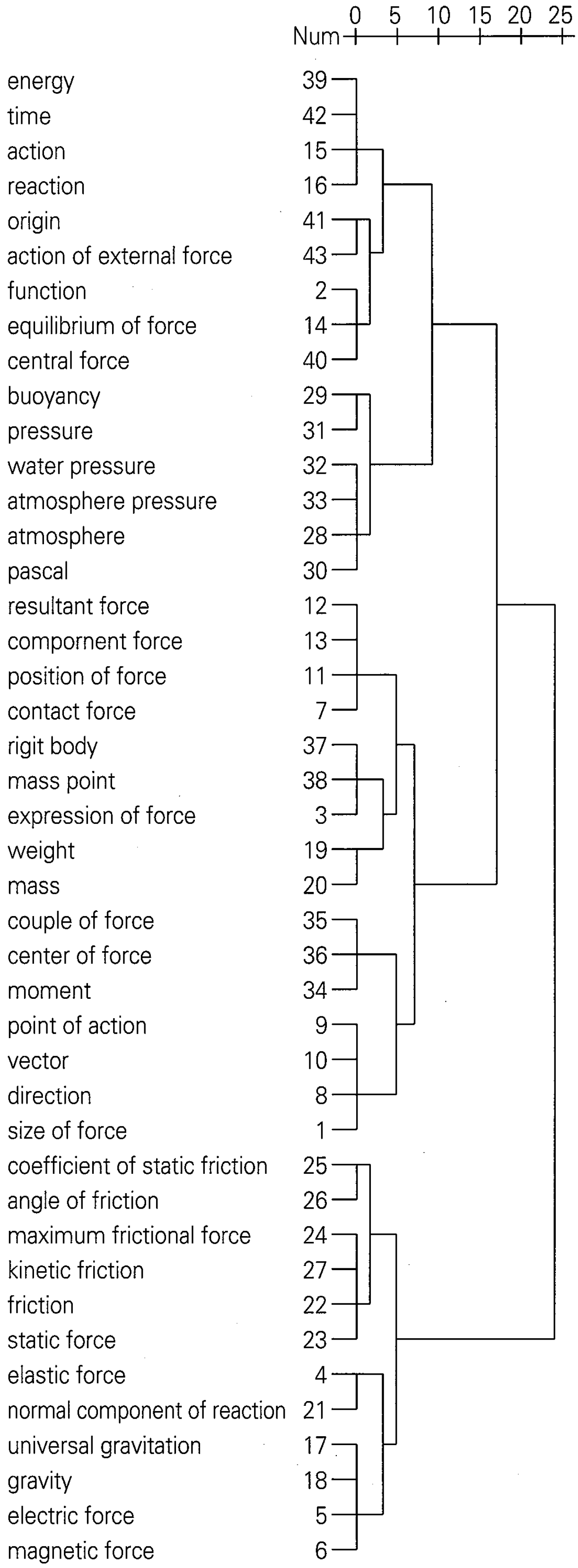

Figure 5. A dendrogram at a stagnant learning phase on hierarchical cluster analysis

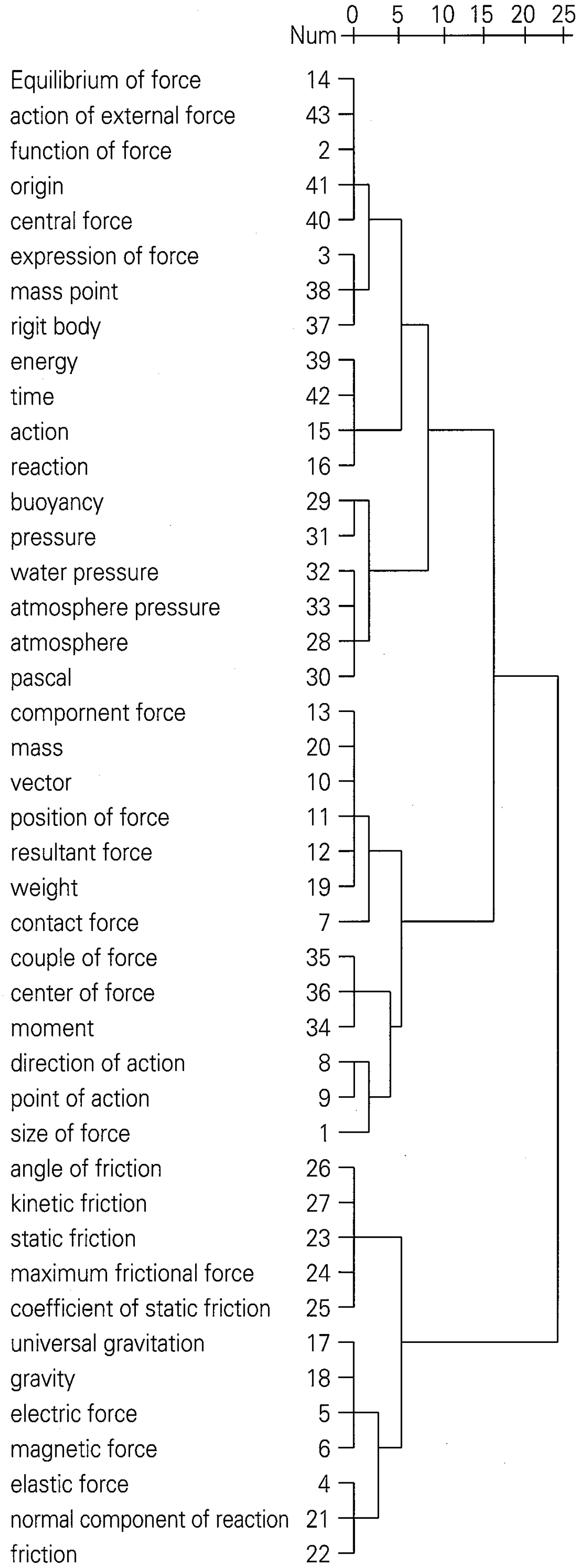

Figure 6. A dendrogram at a rather enough leaning phase on hierarchical cluster analysis

Discussion

These results suggest that learning these kinds of concepts may have stage-like developmental characteristics. It is possible to suggest that these three levels came from a continuous entity, or the same cognitive structure system. Individual differences in structural knowledge may reflect varying degrees of sophistication in learning a systematic set of scientific concepts.

In the present research, a simple recurrent network (Elman,1990) was adopted in studying the sophistication of structural knowledge. It is suggested a succession of learning with a decreasing RMS error. Also, apparently, concepts are categorized hierarchically. Concerning those results, it seems that supporting tendencies has observed. But detailed studies about the reliability of the network are left for further study.

"This paper forms part of a Ph.D. dissertation at International Christian University, Tokyo, Japan, 2003"

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