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Practical Work and Problem Solving by Children

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初等教育段階の理科教育のカリキュラムやその目標は，その時代の変化と社会的な要請に基づき変容してきた。情意的側面として関心や意欲，プロセススキル，知識理解，科学的態度の形成は，重要な理科の目標である。理科の授業を構成するとき，子どもの観察・実験などの直接経験と話し合いやまとめる活動などを，子どもの主体的な問題解決の過程に組み込みながら目標の達成を図ることが必要である。構成主義学習論は子どもの認知活動を基盤とする立場から，科学的概念の構成に至るまでのプロセスを提案している。理科の学習指導を通して，子どもの概念の変容を図ることが求められる。

キーワード：理科カリキュラム，初等理科学習，構成主義，問題解決

Introduction

Up to now, various objectives have been set from the demand of the society or the demand of children-centered education in the history of science education. There are various demands for science education at present with the development of science and technology. To support the development of science and technology, scientific thinking skill and creativity have been emphasized. The scientific knowledge for life and the custom for health were emphasized to improve life and health. Interrelationships among science, technology and society are emphasized for the society in the future. Science education as general education has been valued. The science curriculum in each country has variously revised for social needs.

As for the curriculum of science, various aspects have been emphasized. Douglas A. Roberts (1982) characterized and classified the current curriculum into the following seven emphases;

1) The "Everyday Coping" Emphasis : The selected set of messages constituting this emphasis declares, in sum, that science is an important means for understanding and controlling one's environment- be it natural or technological.
2) The "Structure of Science" Emphasis : The substance of this emphasis is a set of messages about how science functions intellectually in its own growth and development.
3) The "Science, Technology, and Decisions" Emphasis : Unlike the Everyday Coping emphasis, this one concentrates on the limits of science in coping with practical affairs. The substance of the Science, Technology, and Decisions emphasis is a set of messages which distinguishes science from technology, first, and subsequently scientific/technological considerations from the value-laden considerations involved in personal and political decision making.
4) The "Scientific Skill Development" Emphasis : A clear example of materials which embodies this curriculum emphasis is found readily in the "Science - A Process Approach" materials developed under the sponsorship of the AAAS Commission on Science Education. In discussing these materials, Gagne pointed out that they "are directed toward developing fundamental skills required in science activities... The goal is not accumulation of knowledge about any particular domain, ... but competence in the use of processes that are basic to all science".
5) The "Correct Explanations" Emphasis : This curriculum emphasis stresses science "products" as heavily (not exclusively) as the former one stresses "processes". The practitioner encounters the messages constituting this emphasis simply because, in his own scientific training, some ideas (products) are accepted by the scientific community while others are not.
6) The "Self as Explainer" Emphasis : The messages constituting this emphasis deal with the character of science as a cultural institution and an expression of one of man's many capabilities. The story is a long and interesting one, but to simply call it "history of science" likely to mislead ; probably the most common image of the history of science is one that examines growth and change in scientific ideas as a function of human purpose and of the intellectual and cultural pre-occupations of the particular setting in which the idea was developed and refined.
7) The "Solid Foundation" Emphasis : This curriculum emphasis has it that science

instruction should be organized to facilitate the student's understanding of future science instruction. Thus science in the elementary school is seen as preparation to learn science in the secondary school, which in turn is preparation for some future purpose. The set of messages communicated to the student is reassuring: that what he is learning fits into a structure which has been thought about and planned. Immediate and nonesoteric answers can be given to questions such as "Why should we learn this?"

Thus, there are various curriculum in science education. What are the differences in teaching-learning activities? Though each country has original characteristics of the science education, all science classroom activities have a teacher, children and teaching materials. It is thought that the learning ability of the students in the elementary school does not vary much among different countries. There are big differences in teachers' qualifications, objectives and teaching material of science education and teaching methodology. The development of science education depends to a great extent on the teacher's ability to devise appropriate teaching materials and improve the teaching methodology in the science classroom.

The Objectives of Elementary Science Education

Elementary school education has a very important role for students' development. The six years of the elementary school correspond to the their development from pre-operational stage to concrete operational stage and according to the preparation period for the formal operational stage in the development theory by J. Piaget. Moreover, children improve their abilities of language and logical thinking in this stage. Therefore, there is naturally a big difference between the lower elementary school lower grades and the upper grades in term of the objectives, content , and method in science learning.

Jencks, Christopher (1979) commented; Science is basic to the elementary school curriculum because through it we can help children to learn to ask significant questions, to seek relevant answers, to apply problem-solving skills to everyday life, to think rationally, to test ideas, to make decisions, to investigate, to try and fail and try again. Through science we can and must help children sense the joy of making discoveries about their environment and about themselves. Through science we can heighten curiosity and excitement about learning and help children develop positive feelings about themselves. Through science we can help them to learn how to learn - for a lifetime. What could be more basic? Science learned in an environment that invites and supports critical thinking, curiosity, decision making, investigations and inquiry can provide a child with the knowledge of science content, thinking skills, and the attitudes that would be useful today, tomorrow, and throughout life.

Curriculum standards for the elementary school is prescribed in the Course of Education in Japan. The Overall Objective of the Course of Study in the elementary science is;
To develop the ability of problem solving and a rich sensitivity to love nature as well as the understanding of natural things and phenomena, by familiarizing pupils with nature and thorough observation and experiments, thereby fostering a scientific view and thinking.

The Courses of Study were provide the basic framework for the curriculum: the aim of each subject and the aims and content of teaching at each grade. Revised Courses of Study were issued in1989, and fully went into effect in elementary schools in April 1992.

Generally speaking, there are main three objectives in science education.

(1) Concern, motivation toward science and scientific attitudes is first objective that affects children to encourage and promote scientific inquiry. Concern and motivation toward science and scientific attitudes are related and important to affective and emotional development of students. The curiosity and concern toward science are influenced by their experiences. The more the student's experiences in science, the more the concern and curiosity are improved. The quality of the experience stimulates their curiosity. A good experience bears good curiosity. Concrete things and phenomenon of nature improve their concerns and motivation. The question by the teacher similarly improves their concern and motivation. To do an effective motivation, the teachers should investigate former daily experiences and the study their experiences. Scientific attitudes, for example the love of living things, objective view on the facts, are the results of their scientific investigation.

(2) Process skills is second objective in science education. Science educators have suggested that it is better for students to learn to do science than to learn the facts, concepts, generalizations, theories, and laws someone else has concluded; that it is far more important for them to master the process skills than to learn facts; and that they should do science the way scientists do science. Science process skills are "a set of broadly transferable abilities, appropriate to many science disciplines and reflective of the behavior of scientists" (Padilla). Elementary school students use process skills to find out how scientists think and work and to

investigate their own questions in a manner similar to the way scientists conduct their inquiries. They use the process skills to construct knowledge by asking questions, taking measurements, collecting data, organizing and interpreting the data, predicting the outcomes of manipulating one variables while keeping the others constant, formulating and testing hypotheses, developing experiments, inferring reasons for what they observe, and communicating their models to others. These activities "lead children to facts, principles, laws and generalizations which scientists have established". Doing science means applying the processes. Process skills form the core of inquiry-based, hands-on, science learning. In order to apply the processes, children first have to master them.

(3) Understanding and knowledge of science is third and final objective in science education. Everyone admits that the understanding in science education is the most important for students to be evaluated. Scientific knowledge is not used so that the student may memorize them. Scientific knowledge is a culture which the human race has been developing in a long history. Each knowledge has developed by the enormous effort of many scientists. In science education, there is the tendency that students are forced to memorize the knowledge as results of scientific investigations. Therefore, they do not necessarily understand them though the teachers always explain scientific knowledge that they memorize. It is necessary to clarify the relation between new concepts and some concepts that they have, so that they may understand scientific knowledge effectively. That is, the framework of concepts is required learn scientific knowledge.
Knowledge and understanding in science education are limited by the content of curriculum and the number of classes in a year. The content of curriculum should be constructed based on social needs and the abilities/capacities of students who learn science. The more and greater content as required by social needs, the harder it will be for students and the lesser their interest will be in science. The National Standard and science textbook should be balanced in term of social needs and students' learning abilities.

The objectives in science education have correlation among each other in the way of the learning cycle. The structure of objective in science is shown in Fig.1.

Teachers should understand the learning cycle in science teaching. The objectives should be accomplished through the learning cycle.

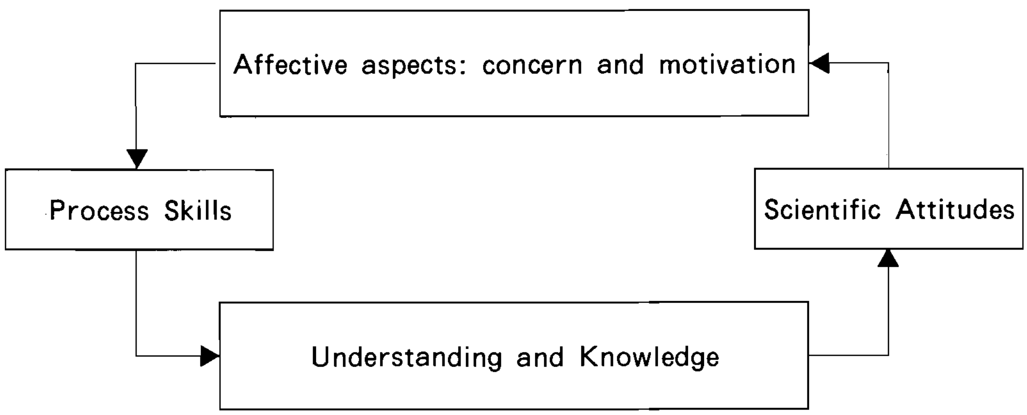

Fig. 1 The structure of four objectives in science education

Characteristics of the Process of Cognition of Science

In order to understand the characteristics of the process of cognition of science and nature, you should study human memory. Richard T. White(1988) described elements of memory as follow;

1. "Strings": A sequence of words or symbols recalled as a whole in an invariate form. Strings are units that are not readily paraphrased. They are usually verbal, but can be composed of other forms, such as musical notes. Examples of strings are memories of telephone numbers, lines of poetry, proverbs, addresses. Strings are learned as a whole , by repetition.

2. **"Propositions"** : A description of a property of a concept or of the relation between concepts. Like strings, propositions are generally expressed in words. They are descriptions of the properties of concepts, or statements about relations between concepts. Examples are : the sun shines, birds fly, glass is transparent, the orangutan is a primate, dogs chase cats, Milton wrote poems, acids neutralize bases.
3. **"Images"**: A mental representation of a sensation. The simplest way of describing images is to call them mental pictures. The mention of pictures is misleading, because it implies that images are solely visual, when they can related to any of the five senses. We are capable of inventing images for ourselves, as well as acquiring them from others. If I say 'Think of a chimney with a knot in it' you probably can create an image for it even though no one has shown you such a thing. I included the word 'probably' because people differ in their propensity and ability to form images.
4. **"Episodes"**: Memory of an event one took part in or witnessed. Episodes are our records of experience, memories of event, occurrences we took part in or witnessed. The distinction between episodic and semantic memory is an important one to consider in the learning of science. Example are an accident in the laboratory or the setting up a microscope.
5. **"Intellectual skills"**: The capacity to perform a whole class of mental tasks. Many theorists have overlooked the distinction between 'knowing that' and 'knowing how'. Where propositions are unitary, each learned separately as a single fact, each intellectual skill is the capacity to perform a whole class of tasks. For example, once students learn how to solve Ohm's Law exercise, they can apply the procedure to any exercise of the type, even ones not seen before; or once they have learned to recognize liverworts, they can class new objects as liverworts or as not-liverworts.
6. **"Motor skills"**: The capacity to perform a whole class of physical tasks. Science could be learned as an abstraction, but it has always been a typically human activity in which the hand has had a part, as well as the brain and the eye. In the course of studying science people are likely to acquire some specialized physical skills such as making sections for microscope slides, using a pipette, ruling tangents to graphs. Also, the practice of science may promote other motor skills which are useful in non-science applications, such as the pouring of liquid to a mark.
7. **"Cognitive strategies"**: Cognitive strategies are the last of the seven types of elements in memory that I propose in this model of learning. In contrast to the highly specific intellectual skills, these are very general skills, each frequently activated in diverse acts of learning and doing.

Examples are determining goals, working out options, judging likelihood of success, reflecting on the meaning of new knowledge, searching out associations between elements of knowledge, generalizing and deducing. Cognitive strategies are general skills that we apply in our thinking and learning. They are so general they tend not to be linked with individual bits of specific knowledge. In contrast, bits from the other six types of memory elements can be linked together into conglomerations of knowledge that we call our concepts.

Shawn M. Glynn et. al.,(1991) explained it in the following way;

> Students are selective in their cognitive processing of information-processing because their minds, which can be conceptualized as information-processing systems, are quite limited in the ability to learn large amount of unfamiliar information quickly. When performing cognitive processes and constructing conceptual relations, students must work within the limitations imposed by their information-processing systems. The human information-processing system includes our conscious mind, or working memory, where mental work is done, and our long-term memory, where the products of learning are stored. Working memory is analogous to a cognitive workbench. Mental operations are performed in this workbench, but it is a relatively small workbench on which only a few operations can be performed concurrently. If working memory is asked to process too much information too fast, learning breaks down: for this reason, working memory is often referred to as the "bottleneck" of the human information-processing system. Ideally, the information in working memory is rehearsed, integrated in various ways with the information in long-term memory, and stored in long-term memory for future use. Long-term memory is analogous to a set of file cabinets or a computer hard disk. Long-term memory is virtually unlimited in its storage capacity and its information storage and retrieval functions are enhanced by the processes of organizing and elaborating information. The executive control coordinates the learning and reasoning that is taking place in the information-processing system. The executive control monitors the interaction between the working memory and long-term memory. Under the supervision of the executive control, intellectual products are crafted on the cognitive workbench of working memory,

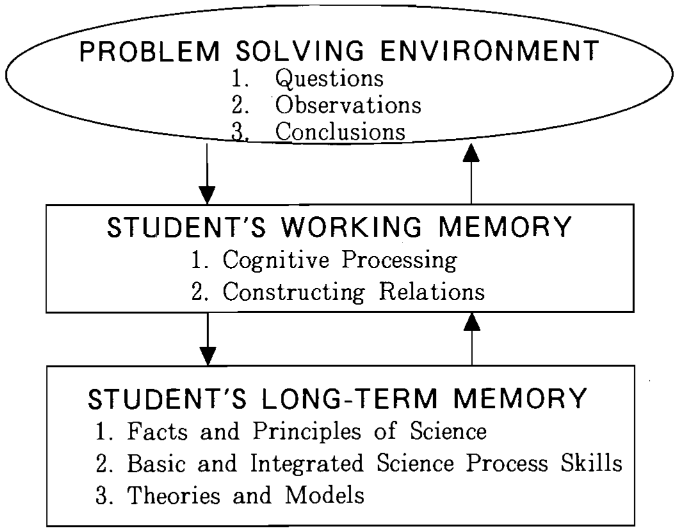

Fig.2. Cognitive model of scientific reasoning

conceptual information and tools are retrieved from long-term memory, and the products of reasoning are stored in long-term memory for the future applications.

They describe a cognitive model of scientific reasoning. We should understand this in order to be able to improve science teaching for children's information-processing. It is possible to use the human information-processing system components to develop a model of what takes place in a science student's mind when he or she reasons about science phenomena. As can be seen in Fig.2, the science student typically responds to a problem-solving environment created either by the student, the teacher, the textbook, the lab manual, or a combination of these sources. The environment contains questions, observations, and conclusions, some of which may be provided by the student. Under the supervision of the executive control, the student carries out cognitive processes and constructs relations in working memory that have an impact on the questions , observations, and conclusions in the problem-solving environment. When reasoning in working memory about a science phenomenon, the student draws upon relevant facts, principles, and skills stored in long-term memory. These skills should include the basic and integrated science process skills routinely performed by scientists working in many disciplines. The basic skills include observation, classification, and communication, metric measurement, prediction, and inference; the integrated skills include identifying variables, constructing a table of data, constructing a graph, describing relationships between variables, acquiring and processing data, analyzing investigations, constructing hypotheses, defining variables operationally, designing investigations, and experimenting. The products of the scientific reasoning carried out in working memory are returned to long-term memory for future application. The final products of a student's scientific reasoning are theories and models.

Piaget J. suggested four stages of cognitive development commencing with birth: the sensorimotor stage, the pre-operational stage, the concrete operational stage, and the formal operational stage. Each stage represents more advanced capability for cognitive processing than the previous stage.

Elementary school students are mainly at the concrete operational stage, so the characteristics of their thinking are "Must see - feel - touch - smell - hear to know", "Thinking is reversible", "Some classification", and "Some conservation". Concrete operational children cannot think abstractly, and they do not wonder about abstract concepts. They are busy learning skills and how to manipulate things they can experience at first hand.

In the start of the sequence of cognition, how do learners select a useful or interesting event from many events that surround them? If a student has an experience similar to a previous event, he/she will give attention selectively to it. If the teacher focuses on an event, the student will also give attention to it. If the stimuli of the event is very strong for the student, he/she will be surprised and give attention to it. He/she will compare the event with other similar events that occurred at the same time or that are already stored in memory. Natural events or phenomena in the real world are concrete occurrences that are perceptible through the five senses. On the other hand, when words or sentences are presented to a child, he/she will accept the meaning in his/her own way. When the teacher presents words or sentences to children, they will always have their own interpretations of these. The words or sentences may have common meaning for teachers or scientists but these are too abstract to understand for young children. How do young children connect one event with another event? They will make connections in their own way first. But they do not make connection correctly. There are many ways in which students make connections. Some students can make relation between events in words (strings or propositions). Some students, especially young children relate events in term of images (mental pictures).

Mental images will be modified by children's own interests, motivations, previous experiences or knowledge, as well as by observations or information. However such mental images cannot be observed externally. But we can compare mental images to find relationships between them. For example, we want to distinguish a kind of leaf from other kinds of leaves, we will observe leaves in terms of shape, color, size, texture of leaf surface, and so on. We compare them in many different ways. If we know the features of a leaf, we can search similar images in the long-term memory. Another example: when we predict the changes of the air in the container where the candle burned out, we must compare many such phenomena in terms of cause and effect.

Mental images are modified by verbal (semantic) expressions. Semantic expressions require logical thinking/reasoning skills. Children may find the similarities or the differences between mental images at one time, or try to find new relations between them gradually through time by comparing mental images. Such reasoning skill is one of the logical thinking skills in science learning. Discriminating, classing, and rules are the intellectual skills.

Communication skill is required to connect students' ideas or expressions of events among students. Communication can be defined as any and all ways persons let others know their thought. When children observe something, they let others know what they observed by communicating. Children communicate their explanations for their systems of classification. When children discover something new, they let others know what they have discovered by communicating. Actually, the only way teachers can discover how children are understanding information is to ask them about it, and then accept to what they have to say. Communication includes verbal as well as non-verbal behavior; people communicate by talking, gesturing, writing, sharing, drawing, telling stories, giving oral presentations, play-acting, and so on. In the classroom, children communicate in small groups, in large groups, in individually with each other, in discussions or discourses with the teacher, and so on. Graphs, charts, diagrams, posters, symbols, maps, and mathematical equations are forms of communication of data gathered during an investigation.

What is the real understanding in science? And how do students understand in science? Edward L. Smith(1991) pointed out the mean of understanding. He proposed two criteria for understanding in science: Connectedness and usefulness in social contexts. The first criterion deals with the structure of a person's knowledge. An idea is understood to the extent that the learner has appropriately represented it and connected it with other ideas, particularly with the learner's own prior knowledge and beliefs. Learning with understanding can thus be contrasted to learning of isolated bits of information. Many students and even some teachers view the learning science as primarily the learning of many definitions and facts that are to be memorized and reproduced or recognized for testing purposes. Such learning fails to meet the connectedness criterion for understanding. The second criterion deals with the function of person's knowledge. An idea is understood to the extent that the learner can use that idea in successfully performing significant tasks appropriate to the social context in which they occur. This criterion incorporates three aspects: (1) The learner should be able to actually carry out various kinds of tasks; (2)The tasks should be generally recognized as worthwhile; (3)The learner should be able to perform the tasks in the social context where they are valued and in a manner judged appropriate by the participants in that context. Another way of expressing this criterion is that the learner should be able to participate successfully in a community of people who share, use, and value scientific knowledge.

Problem Solving Method in Elementary Science

Betty J. McKnight (1989) commented thus in "Problem Solving in Elementary School Science" :

Problem-solving skills should develop on a firm foundation built by each child's earliest experiences. The difficulty high school and college teachers encounter in teaching problem solving strongly suggests that most students' early education doe not create this ideal foundation. What does research suggest to the teacher of young children? Before a student can solve a problem, he or she must recognize that there is a problem to be solved. If teachers can introduce experiences that make students aware of discrepancies between what they expect and what they observe, students will learn to ask questions. Questioning will help students to define and ultimately to solve a problem. Such experiences can be both spontaneous events and teacher-planned activities. The natural world offers an inexhaustible supply of experiences for students:

experiences that will add general knowledge, stimulate curiosity, create a need to know. If young students are given hands-on experience with materials, they develop better language skills and better concepts of form - both of which lead to better problem-solving skills. Discrepancies - differences, inconsistencies, disagreements, disharmonies - can only be perceived by comparison with prior experience. Since some children have had more experiences than others, teachers must take care that the level of discrepancy is appropriate for the learners. Six general categories of discrepancies are identified in New York State's Elementary Science Syllabus. These are

- a goal to achieve without a means to achieve it
  Example: I want to raise this box, but it is too heavy to lift.
- a difference between what the student expects to observe and what the student actually does observe
  Example: I flip the switch, but the light does not go of.
- a missing fact and facts
  Example: I put seeds in soil, but they do not grow. (Student does not know that germination requires water and warmth)
- a difference between what students observe and what they've been told
  Example: I have seen wood float in water, but you tell me that this wood will sink.
- a conflict (internal or external) between interpretations , opinions, attitudes, or value
  Example: You call this nail heavy, but I call it light.

Problem-solving activities can be organized around the process skills of classifying, comparing, ordering, measuring, organizing data, shape and space, and seeing patterns.

F. Voss(1985) reviewed the literature in cognitive psychology to arrive at some characteristics of effective problem solving in practice. Competent problem solvers,

- possess a knowledge structure for the subject of their expertise
  1. arranged hierarchically, with key words and pointers(surface structures) at the lower levels, and fundamental laws and principals at the higher levels.
  2. including procedural knowledge, remembered experiences, and acquired skills
  3. open to continual modification by new information and new experiences
- know how to create a visual representation, to reconstruct a situation qualitatively (novices tend to combine familiar equations)
- acknowledge that "creating the internal representation" of the problem is the most challenging and crucial task
- know how to "chunk" information
- approach problems with a working-backward strategy; exercise by working forward
- monitor, summarize, reason, and evaluate as they progress through the problem-solving process (novices, lacking this skill, tend to confuse related issues and subproblems with solutions).

I would like to explain the process of problem solving for elementary science students. It consists of four steps as follows;

First step: The students find out and identify a problem.

Second step: The students design their own investigation.

Third step: The students do observations and experiments.

Fourth step: The students make conclusions and re-construct their own scientific concept.

(1) The teacher should prepare a suitable natural event or phenomenon to motivate students. The new event or phenomenon should be related to events they have already experienced though it is a new one for them. More observations are required to find a problem. The student can find a problem to be solved because he compares the new phenomenon with his/her previous experience. For instance, when students study electricity circuits, they will be able to recall events related to electricity, like the pocket light, and the toy, etc., which used electricity . So, they will be able to find relationship between the unknown and known.

But many students have many ideas and problems individually because of their different experiences and knowledge. Students should classify, discuss and share their ideas to identify a common problem to have to solve. All students will be motivated through their discussion. Too much information from teacher robs students of their autonomous.

(2) Students will begin looking for their own ways to solve the problem. They want to find out ideas from their experiences, books, information from other persons. Their ideas for solving are various kinds. Some of their ideas (not many) can be realized. Some of ideas can not be realized. They will have to predict the result. However, some predictions will not be accurate. But they should predict before they try it. In this way, students learn to compare what actually happens with what happened without thinking about it. In science learning, identifying and controlling variables, formulating and testing hypotheses, defining operationally are very important activities for themselves to acquire as process skills. The teacher should give minimal suggestions or hints to support students' sense and decision toward solving problems.

(3) Experimenting is the scientific process which puts all the processes together. In experimenting, investigators ask questions about something they have observed or have wondered about. The question frequently takes the form of "I wonder why _______ ? "Often, but not always, this question is cast in the form of a hypothesis. Variables are identified, and most (those not being investigated but which may contribute to the outcome of the experiment) are controlled. If necessary or desirable, the variables to be investigated may be expressed in operational terms. An experimental plan is developed, and the procedure, the nature of the observation needed, and the data to be collected are specified. The experiment is carried out, and the data obtained. Modifications are often desirable, and these become part of a modified plan. After the investigation has been carried out and the data and observations have been recorded, the results are analyzed in term of the original question or hypothesis. Conclusions are made accordingly, and the results of the investigation are communicated to classmates or other individuals for their reactions.

(4) The first step in interpreting data is to decide what data they want to gather. This comes from the hypothesis they devise. Students may do the investigation mentally, visualizing what will happen, and deciding what kinds of information you will need to have in order to tell why it happened. Or they may want to " fool around " to see what happened. One of the best ways to organize data for interpretation is to put the data in visual form such as a graph, or a chart, or a histogram. Interpreting data is simple once decisions are made to collect the proper data.

Constructing models is very important and useful in the future learning. Models are concrete representation of things or phenomena we cannot readily see. Some good examples of models are those of atoms and molecules, that of the cross section of the earth, and that of sound waves. In these cases, models have been constructed to enable us to visualize what we cannot see. No one has seen the inside of an atom, no one has seen the inside of the earth, no one has seen a sound wave. Yet, the atom behaves in certain ways, the earth behaves in certain ways, and sound waves behave in certain ways - ways that permit scientists to devise replicas that represent what they ought to look like in order to behave the way they do.

" Constructivism " has recently become popular among science educators in the last ten years. It is based on the Metacognition of the child. Richard F. Gunstone(1994) described "conceptual change " as follows;

The term conceptual change is commonly used to describe contexts in which the learner holds existing ideas and beliefs which are in conflict with what is to be learned, and hence, learners are involved in changing ideas and beliefs if they are to embrace what is to be learned. This usage is quite consistent with my use of the term here, although I will argue for a broadening of the nature of the ideas and beliefs to be considered. ' Conceptual change' as it has been used in the literature for some time, has usually meant the abandonment of one conception and the acceptance of another. One of the issues which was developed and clarified in the workshop was the expansion of this meaning for conceptual change. Conceptual change may be replacement in the sense just described , or it may be the addition of the different conception. Addition here means an informed approach: an understanding of the value of the added conception in appropriate contexts.

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