Towards a Theory of Science Teaching

Inherent in all individual is an impulse to grow. Human growth has additional dimensions, that is, to develop a more adequate structure and the ability to function better. Piaget (1973) argued that children do not receive knowledge passively, but rather, discover and construct knowledge through activities. Malcom Knowles suggested that the educators as a result of accelerated social change must rethink their roles and concentrate on teaching students the skills and attitudes needed for self-directed inquiry (cited in Meyers, 1986).

According to Roger, the question of what to teach is based on the assumption that "What is taught is what is learned; what is presented is what is assimilated" (cited in Roberts, 1977). What to teach and how to teach are the apt questions that are to be probed into. Here, only "how" of the process is analysed. The concern of the process is to foster optimum growth in each individual. Aptitude-Treatment Interaction (ATI) studies are loaded with the problem of 'optimum' (Cronbach & Snow, 1977). One environment will encourage growth in one individual whereas another will hinder the growth.

Teaching strategies need to be devised on the basis of a theoretical framework which takes in both principles of learning and structure of content. The teacher must have two cognitive maps - one of the logic of the content and one of the psychologies of the cognitive processes involved in learning the content. Hence, there is no universal method that can be adapted to different situations. Typically, there are multiple conceptual frameworks that can be applied to a particular problem, and applying a few of these frameworks may make the problem dramatically easier to solve. All knowledge has a tool-like character (Perkins, 1986). This is the dimension that makes the educational process complex. Knowledge is designed to manipulate other knowledge and facilitate thinking and problem-solving activities of various sorts.

It is necessary that students be exposed to different models that provide for divergent thinking and alternative models, which scientists themselves used in their endeavor. In the course of trying to solve practical problems, children spend time reorganizing their levels of understanding. In real situations, children develop multiple access routes to their knowledge (Duckworth, 1987). Works of Bruner (1964) and Piaget (1973) suggest logical system for operating the process.

Theories of Conceptual Development

According to Bruner (1964) there are two kinds of teaching - - expository mode, and the hypothetical mode. In the expository mode, the decisions are principally made by the teacher as expositor; the student is the listener. In the hypothetical mode, the teacher and the students are in a more cooperative position with respect to what in linguistics would be called "speaker's decisions." It is the hypothetical mode that tends to increase the intellectual potency and helps to move from extrinsic to intrinsic rewards. Hypothetical mode characterizes the act of teaching that encourages discovery. Concepts discovered in a hypothetical mode are valuable, in the sense that they form the working capital of the individual.

According to Piaget (cited in Meyers, 1986), because of the child's inborn drive to interact with his environment, he meets contradictions, that is, things that do not 'fit' in his mental structures. The contradictions produce a state of disequilibrium. In other words, child's present mental structures are found to be inadequate and must be altered or replaced. Cognitive conflicts probably represent the best means of stimulating learning (Rowe, 1973). Teaching critical thinking involves intentionally creating an atmosphere of disequilibrium, so that students can change, rework, or reconstruct their thinking process. According to Piaget a student who receives certain knowledge through free investigation and spontaneous effort will later be able to retain it; he will have acquired a methodology that can serve him for the rest of his life, which will stimulate his curiosity without the risk of exhausting it.

Gagne' in contrast to Piaget does not believe that learning readiness relies on internal biological factors. Instead, prior acquisition of skills and habits makes the learner ready to new and more complex skills. In the classroom, Gagne' would probably teach skills going from a mastery of the least complex on up to the higher levels in accordance with a hierarchy of learning skills. He would probably insure success by making certain that students master lower level knowledge and concepts before moving on to the next level. Learning task proceeds in cycle in which the simpler cognitive operations precede the more complex abstract operations, and teaching strategies include both an "upward spiraling" in the content and demands for cognitive functioning (Dunkin & Biddle, 1974).

According to Skinner it is possible to arrange contingencies which ensure that an organism will attend to one object and not to another. He asserts that abstract thinking is the product of a particular kind of environment, not of a cognitive faculty. A self is a repertoire of behavior appropriate to a given set of contingencies (Skinner, 1971). To Duckworth (1987) it is not the pressure of data that gives rise to the understanding; but on the contrary, the child's own struggle to make sense of the data. In no case the outside help, speeded up the learning process. Research brings out the fact that there are limits to the engineering one can do with children's understanding.

Relevance of Previous Experience

Young people have views on variety of topics that are currently taught in science classes, before formal teaching has taken place (Gilbert & Pope, 1986). People generally learn with the context of their previous experience. Concepts are developed from percepts - what they have seen or felt or heard. These previous experiences can remain uninfluenced, or be influenced in unanticipated ways, by science teaching. There is no right way to construct cognitive routines (Engelmann & Carnine, 1982). There are strategies that are acceptable and some that are better than the others. Some routines simply list the various steps the learner is to perform. Some routines deal with skills that are not conventionally taught. Dewey (1956) maintains that an educational experience which stimulates development is the one which arouses interest, enjoyment, and challenge to the immediate experience of the student.

Learning of a Concept as a Mental Model Transformation

To retain interest and develop students' critical thinking abilities to the fullest, the classroom environment should be highly interactive. "Students cannot be sponges, absorbing the 'wisdom' of the teacher's lecture" (Meyers, 1986). The learner must realistically engage in the subject matter and actively participate in the art of critical thinking. Meyers (1986) cites the argument of Hunt that human beings are "concept-making creatures" and that we use our innate thinking abilities to categorize, generalize, and in other ways make sense of the world.

The process of cognitive development is a dialogue between the child's cognitive structure and the structure of the environment (Kohlberg & Meyer, 1972). Piaget and Dewey claim that mature thought emerges through a process of development that is neither direct biological maturation nor direct learning, but rather a reorganization of psychological structures resulting from organism-environment interaction. Basic mental model is the product of the patterning of interaction between organism and environment, rather than a direct reflection of either innate neurological pattern or external environmental patterns (Kohlberg & Meyers, 1972).

The process of interaction involves three phases (Mizell, 1977). It starts with an awareness followed by the disequilibrium and resulting in the reforming phase. The concern of the teacher is to bring out the ideas of pupils and to cause them challenge their interpretation of events. Useful ways of challenging pupils' ideas can be built around specifically designed demonstrations.

Basic cognitive teaching involves presenting the learner with some examples that will induce a generalization to other examples (Engelmann & Carnine, 1982). Designing cognitive routines is difficult, because there are many decisions that must be made in designing these routines; and at each point there is more than one acceptable solution. Throughout the process of designing the routine, we must consider the routine in the perspective of other routines. "We should recognize that cognitive operations are not like physical ones, that the procedures people have developed for solving different types of problems are not necessarily the only ones possible" (Engelmann & Carnine, 1982).

Conceptual reorganization cannot be given to pupils; rather they can be led to discover ideas and conceptual structures of their own (Dunkin & Biddle, 1974). Individual differences exist in the amount of concrete thinking required before formal or abstract thought can emerge. Some concepts are internalized as habitual - by force of habit, whereas some concepts need logic and reasoning to be meaningful, so to form a frame. A frame is a complex information representation structure (Davis, 1985). The term frame was coined by Minsky, which is a stable and useful concept. "Not building frames" is a troublesome tendency in too many students. Students' difficulties in developing concepts result not only from misunderstanding in the presented material, but also from lack of knowledge that was never presented. Some students do not have a frame appropriate for the new concept.

From the above discussion it is evident that the structure in demand of a new concept should come from the learner. In most mathematical lessons, the whole difference lies in the fact that the student is asked to accept from outside an already entirely organized intellectual discipline, which he may or may not understand. This imposition of structure is the curse of the process of

education. The goal of intellectual education is not to know how to repeat or retain ready-made truths. It is learning to master the truth by oneself that is sound in the process of education. For the interactionist, experience is essential to stage progression, and more or richer stimulation leads to faster advancement through the stages (Kohlberg & Meyer, 1972). On the other hand, the maturational theory assumes that extreme deprivation will retard or fixate development, but that enrichment will not necessarily accelerate it.

Traditional approaches emphasize quantitative problem solving. This emphasis on learning quantitative methods and quantitative problem solving should be introduced after students have been given qualitative causal conception of the problem.

Teaching strategies

Teaching strategies are possibilities of interaction with the subject by the child. Analyzing what the students already knew that could be built upon, as well as what they knew that could cause difficulty is of prime importance (White, 1988). Determining which presupposition to introduce, in what order is a question of strategy. Decomposability of subject matter to learnable increments, building on students' correct previous knowledge, overcoming common misconceptions and incorporating correct subject matter in an appropriate form are all crucial points of interest. Student's individual purposes, interests, and background knowledge are all fixed variables and are beyond the realm of teacher manipulation (Macmillan & Garrison, 1988). Teaching tactics is possibly the only factor that the teacher can manipulate.

Paoni (1983) investigated the teaching methods used by full-time faculty at Brookdale Community College and reported that the two factors that most influenced the selection of teaching methods were course objectives and the personal teaching style. Zeitun (1984) researched the teaching practices of 32 secondary school biology teachers in Amman, Jordan, and concluded that there is a significant correlation (0.64) between biology teachers' understanding of modern concepts in science teaching and their teaching practices.

In Thinker Tool system (White, 1988), the instructional approach is to:

1. Get the students interested in the subject.
2. Enable them to build gradually on what they already know.
3. Transform their knowledge into a generalizable form.
4. Teach them to transfer this knowledge to new situations.
5. Make them aware of the process of theory formation.

Mental model approach adopted in QUEST (White & Fredricksen, 1985) is a combination of the interactionist and Piagetian disequilibrium. According to their method, learning is a process of transformation of one model to another on the demand of situations. Transformations may involve additions, modifications, differentiation, or generalization of model features, or even construction of alternate models. Complete rewrites of aspects of the model are likely to be more difficult for the student to achieve than model refinements. Creating a discrepancy is effective

than requiring cancellation; the latter will create a vacuum and is not often educative. The process starts with stimulation of the equilibrium followed by logical revision of 'schema.'

Role of Teacher

The role of teacher is in bringing the students into interaction with the instructional material and to maximise the time on academic learning. In other words, the effective teacher becomes a facilitator of student interaction with the instructional material. The Thinker Tool (TT) approach developed by White (1988) was based on enabling students to construct an understanding of the subject matter for them via guided discovery. As the curriculum progressed, more and more of the inquiry process were turned over to students. This is identical with the description of teacher as a generic scaffolder (Perkins, 1986). The teacher supports the thinking process of the learner by judiciously prompting him/her at the task. The support is gradually withdrawn to help the student to be independent. The art of scaffolding is complex, and it depends on the ingenuity of the instructor.

The role of teacher is to provide a facilitative climate for learning (Roberts, 1977). The teacher is a leader, and he/she does not set lesson tasks, assign readings, lecture or evaluate; rather he/she helps to elicit and clarify the purpose of the members of the class. He/she relies upon the student desire to implement these purposes as motivational force behind learning. Structures of knowledge, sequencing the learning experience, arranging the environment to facilitate interaction are all concerns of teacher in any planning.

The Concept of Chemical Equilibrium

As described in the preceding pages, teaching of a concept includes three phases - an awareness phase, disequilibrium phase, and the refinement phase. Each phase is briefly discussed below.

Awareness phase

Awareness phase is intended to arouse the apperception mass of the student by demanding relevant response, on which the new concept is to be built upon. The previous experience of the student, the concepts developed in an earlier class, a suitable learning experience provided in the class can also be used to activate the mental model of the student. The knowledge structure that an individual possesses by himself/herself helps to base an intelligent learning environment. This is important because of the fact that the orientation of mental model will be more aligned to the new concept being presented. The concepts like forward reaction, backward reaction, and closed system are the functional capital (White & Fredericksen, 1985) desirable as the knowledge base.

Disequilibrium phase

Disequilibrium phase is the state of mind of the learner in which the current mental structure (*Schema*, Johnson-Laird, 1983; *frame*, Davis, 1985) of the student is inadequate to understand the new concept. The student conceives a reaction between Zinc and Sulphuric acid, giving Zinc Sulphate and Hydrogen gas to be a typical case. In the event of a reaction between Ferric Chloride and Potassium Thiocyanate, disequilibrium is mobilised. The demonstration of the

above reaction will demand for a qualitative reasoning for which the energy content of a molecule should be viewed as the causal agent.

$$Fe^{+++} + SCN^{-} \longrightarrow FeSCN^{++}$$

(Light yellow) (Colourless) (Blood red)

Refinement phase

Refinement is the result of the dialogue between the existing mental structure and the environment. Both the existing structure and the environment created for interaction are equally important. A reaction, which was conceived to be irreversible, uni-directional and static is replaced as a result of the new learning experience. Alternate examples or extension of earlier experiences can be profitably be manipulated to develop the concept of the dynamic nature of equilibrium.

In the light of the above discussion, issues related to cognitive development, individual difference, previous knowledge and teaching strategies are to be critically evaluated before making decisions about instructional practices. Also, the role of teacher in science education may have to be redefined.

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