AN ANALYSIS OF LEARNING BY DISCOVERY

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In recent years learning by discovery has become a topic of much discussion among educators. One reason for its present prominence in educational circles is its close connection with the disciplinary structure projects described in <u>The Process of Education</u>.[1] Sand and Miller consider learning by discovery to be one of the three major characteristics of these projects.[2] Bruner, himself, the reporter for the Woods Hole Conference, attributes his own interest in discovery to these projects.

> The immediate occasion for my concern with discovery . . . is the work of the various new curriculum projects that have grown up in America during the last six or seven years. For whether one speaks to mathematicians or physicists or historians, one encounters repeatedly an expression of faith in the powerful effects that come from permitting the student to put things together for himself, to be his own discoverer.[3]

The relationship of learning by discovery to the curriculum projects was identified by the members of the Woods Hole Conference. They recognized that the mastery of the structure of a subject required that the learner develop certain attitudes about the structure. The instilling of the proper attitudes was viewed as an area about which little is known, but it was felt that encouraging learning by discovery was a major aspect in creating the desired attitudes. The mathematicians and scientists both believed that it was possible and desirable to teach the structure of a subject in a manner that would reflect the excitement that occurs when a student makes a discovery on his own. Therefore, as the various projects were developed they included experiences in learning by discovery.

A second reason for present interest in learning by discovery stems from a new emphasis in research on the psychology of learning. Around 1955 research activity on learning by discovery began to increase rapidly. Prior to that time there was little research activity on this topic.[4] Most of the current interest in this phase of the psychology of learning is concerned with the effects of learning by discovery on transfer, retention, and concept development.

These two events have served to reinforce each other and greatly stimulate interest in learning by discovery. As is so often the case, this sudden growth has resulted in confusion. The purpose of this paper is to make an analysis of learning by discovery in hopes of removing some of the confusion surrounding this term. The analysis will be sixfold:

1. to describe the essential characteristics of learning by discovery and to derive a definition therefrom,

2. to review briefly the rationale of learning by discovery,

3. to identify and describe the advantages claimed for learning by discovery,

4. to describe the purposes served by learning by discovery,

5. to identify some of the new curriculum proposals which utilize learning by discovery, and

6. to identify the different methods of instruction for discovery.

Characteristics of Learning by Discovery

Bruner stresses the importance of recognizing that discovery is a learning process, "not a product discovered."[5] It is essential that this distinction between product and process be made; otherwise confusion will exist about the use of the term and the relationship between product and process will be overlooked. Since learning by discovery is a method of learning, it is fundamentally concerned with the experiences and behavior of the learner. From the study of these factors several educators have identified a single essential characteristic of learning by discovery which distinguishes it from all other types of learning.

This essential characteristic of learning by discovery is succinctly stated by Ausubel:

> The essential feature of discovery learning is that the principle content of what is to be learned is not given but must be independently discovered by the learner before he can internalize it...The learner must rearrange a given array of information, integrate it with existing cognitive structure, and reorganize or transform the integrated

combination in such a way as to create a desired end product or discover a missing means-end relationship.[6]

Taba, in a recent article, practically paraphrases Ausubel's definition:

> The learner must construct his own conceptual schemata with which to process and to organize whatever information he receives. Teaching is directed to enable the learner to establish a relationship between his existing schemata and the new phenomena and to remake or extend the schemata to accommodate new facts and events.[7]

Bruner is in complete agreement with both Ausubel and Taba. He has stated that learning by discovery "is in its essence a matter of rearranging or transforming evidence in such a way that one is enabled to go beyond the evidence so reassembled to additional new insights."[8]

This essential characteristic of learning by discovery can be best understood by contrasting learning by discovery with expository or reception learning. According to Bruner, in reception learning "the decisions concerning the mode and pace and style of exposition are principally determined by the teacher as expositor; the student is the listener."[9] In discovery learning, however, Bruner continues to explain, the pupil is active. His behavior now helps set the mode, pace, and style of instruction. The pupil takes a part in the structuring of learning activities. He gathers evidence and tests hypotheses by manipulating data and questioning the teacher.

Additional insight into the differences between reception and discovery learning is provided by Ausubel.[10] Discovery learning differs from reception learning in that while the former requires that the learner discover new ideas or content for himself, reception learning presents the learner with the ideas or content in a predetermined final form. There is no reorganization or manipulation of data. The learner is told the concept to be learned; he does not discover it for himself.

Included in the above descriptions of learning by discovery is the idea of the acquisition of new information. Learning by discovery if carried to completion makes something which was unknown known. The product of the process is a new understanding or an extension of what was known before, at least insofar as the learner is concerned.

This does not mean that the product must be something unknown to others. Bruner's caution not to "restrict discovery to the act of finding out something that before was unknown to mankind"[11] stresses the fact that the discovery itself may be new only to the learner. In the case of most school work this would certainly be true, the ideas to be discovered by the students already being known to the teachers. In this sense learning by discovery results in what is called concept attainment.

Concept attainment occurs when the learner himself first became aware, either through discovery or reception learning, of a concept which was already known to the person responsible for his instruction. Concept formation, on the other hand, is the discovery of ideas or concepts not previously known by either the learner or the instructor. Thus, concept formation is a highly creative act, far more so than concept attainment.

Learning by discovery may lead to either concept attainment or formation. However, all studies of learning by discovery known to the author have so far been limited to concept attainment. At present little is known about fostering concept formation, so little, in fact, that the area is just beginning to be explored.[12] The new curriculum projects mentioned by the Woods Hole Conference, for instance, use learning by discovery to foster concept attainment. In these cases the concepts to be attained are aspects of the disciplinary structure that have been identified by the scientists or scholars.

Other characteristics of learning by discovery have also been identified, but these are either shared by other learning processes or are limited to one or two of the various forms of learning by discovery. Taba,[13] for example, states that learning by discovery is characterized by inductive processes. Reception learning may also proceed through inductive processes.[14]

Another important but not unique characteristic of learning by discovery is the fact that it begins or is initiated by a problem situation. In this sense, learning by discovery is a type of problem solving. Indeed, Taba[15] traces the history of modern learning by discovery through Dewey's work on inquiry and problem solving.

Attention is called to the fact that only one of the three major characteristics of learning by discovery identified above is an essential element: the independent reorganization or extension by the learner of his own cognitive structure. From this essential characteristic it is now possible to derive a working definition of learning by discovery. Thus, learning by discovery may be defined as the process of the independent reordering or extension of cognitive structure by the learner which culminates in the learner's acquisition of one or more new concepts.

The Rationale of Learning by Discovery

There has not yet appeared a definitive study of the rationale of learning by discovery. In order to develop an understanding of this rationale it is necessary to draw upon many separate sources and to attempt to synthesize the various points of view into a coherent framework. Only one detailed explanation of discovery rationale was located. Even in this case, the treatment is confined to only one specific approach to discovery learning, the Illinois Studies of Inquiry Training. Since so little has been written on the rationale of discovery learning, this section will present the rationale of inquiry training.

Illinois Studies of Inquiry Training

The purpose of the Illinois Studies of Inquiry Training "has been to help children develop a set of skills and a broad schema for the investigation of causal relationship.[16] The desired outcome of such training is to enable the learner to achieve greater independence and autonomy in concept development.

Two assumptions rest behind the rationale of inquiry training. First, it is assumed that there is a high degree of uniformity among the fundamental thought processes used in inquiry and that these fundamental processes are the same for all disciplines. A second assumption is that the rate of intellectual growth, as identified by Jean Piaget and Barbel Inhelder,[17] can be accelerated by teaching children the fundamental processes of inquiry.

According to Suchman the rationale of inquiry training consists of three tenets:

1. inquiry training frees the learner to formulate new ideas and relationships according to his individual ability and his own cognitive needs; thus, it promotes autonomy of learning;

2. motivation is intrinsic within inquiry, for children

enjoy self-directive activity that results in intellectual growth; and

3. concepts achieved through inquiry are more meaningful to the learner because they result from his own needs, behavior, and motivation.

The structure and function of inquiry. Four aspects of inquiry behavior have been isolated and studied by the Illinois Studies of Inquiry Training: searching, data processing, discovery, and verification. A description of each of these four aspects follows.

Searching is characterized by behavior designed to gather data according to a systematic plan. It is a selective process which allows the inquirer to adjust his data assimilation to the requirements of his purpose. Two aspects of searching account for much of its value as a device for the collection of data. The first of these is mobility. This permits the inquirer to capitalize on a wide range of data sources. Manipulation is the second aspect. Through manipulation the inquirer can subject the environment to selected changes to observe the effects and determine their relevance to the task. New data are often produced by this means. Whereas mobility provides new sources of data, manipulation increases the amount of data obtainable from a single source.

The searching behavior of inquiry has four basic characteristics. First, there must be a locus in which to search. Second, there must be freedom to explore the locus. Third, there must be a "set" to direct the searching activity. Finally, there must be a plan to follow in carrying out the search. Of these four characteristics that of set is of special importance. Sets direct the searching activity into certain areas while closing off other areas. Sets permit the inquirer to focus his efforts along selected lines without having to attend to all possible data sources. The problem is to retain enough richness and variety of sets as are possible without interfering with a systematic approach in the search for data. This is a variation on the theme of freedom within limits. The limits must give order to the search without severely limiting the variety of data sources available.

Data processing serves to organize the results of the search into patterns that reveal regularities in the data. Briefly it is the means of developing relationships among the data collected. The processing of data falls into four divisions:

1. Analysis--subdivision of data into their parts.

2. Comparison--identification of similarities and differences of the data.

3. Isolation--selectivity of variables for intensive examination.

4. Repetition--continuous presentations of data to increase opportunities for selection as subjects of investigation.

Discovery is achieved when the data processing is culminated by a synthesis leading to an explanation or understanding of the inquirer's problem. Specifically discovery occurs when previously noted conflicts, dissonance, or discrepancies are resolved by additional insight. There are at least two ways in which solution can occur. A synthesis may be developed from data that originally appeared to be incompatible. Sometimes the divergent data fall into patterns that match other concepts previously learned. Discovery may also result from a conceptual shift, the development of a new concept which fits the data. However, inquiry training does not attempt to teach the learner to develop or invent new conceptual schemes. This is considered beyond the intent of the program.

Verification is the process of checking the discovery against reality to ascertain its soundness. Most often this is accomplished by testing the concept against specific instances to see how well it allows prediction.

Inquiry training.--The training program begins with the presentation of a short motion picture which establishes a problem situation. The learners are encouraged to seek the solution to the problem posed. This they may do by questioning the teacher about the motion picture. They may not, however, ask for generalizations or explanations. By this process of inquiry an analysis is made of the presentation and hypotheses are offered as explanations of the phenomena observed. This process consists of two phases: "(a) interpreting data in terms of pre-existing concepts and (b) modifying concepts to correspond to the data...."[18] These two phases are known as assimilation and accommodation, respectively. One of the major purposes of inquiry training is to help children learn to carry out these two phases more autonomously and efficiently.

Assimilation and accommodation are mutually dependent upon each other in promoting conceptual growth. The learner must effectively use first one and then the other. He must assimilate new data and, at the appropriate time, accommodate previously existing cognitive structure to these data. Once the cognitive structure has been modified to incorporate the new data, the learner again sets out to assimilate additional data. This process continues until the explanation is discovered.

Inquiry training attempts to make discovery more efficient by providing the learner with a better strategy for seeking solutions to problems. In other words, it attempts to teach the learner a strategy for inquiry. There are four key elements involved in setting up a program for inquiry training. The first of these is the problem episode. The purpose of this episode is to present the learner with a problem on which to work. The short physics films spoken of earlier are used for this purpose. These films serve as stimuli for inquiry.

The second element, the responsive environment, provides the sources of data needed to discover the explanation for what was observed in the film. No attempt is made to structure the form or sequence of the data. The learner determines both of these by the questions he asks. There are, however, certain limitations imposed on the questioning. All questions, for instance, must be phrased so that they can be answered by either "yes" or "no." Other questions must be recast until they fit this pattern.

The third element changes the focus of the inquiry from content to process. This change is accomplished (1) by providing opportunities for directed inquiry practice, (2) by developing the plan for analysing causality, and (3) by mastering a method for investigating causal relations.

Practice in more efficient inquiry is developed mainly through two methods. First, the teacher helps the learner realize why he runs into trouble when following inappropriate lines of inquiry. Second, tape recordings are made of inquiry sessions and later criticized to point out weaknesses and strengths. From this the learners are able to ask better and more germane questions.

Teachers help the learners to analyze causality by seeking information about the following five facets of the problem episodes:

1. the objects contained in the episodes;

2. the systems, interrelated assemblies of objects, presented by the episodes;

3. the conditions existing, especially those which change, during the episodes;

4. the events which occur during the episodes: and

5. the properties of the objects identified in the episodes.

The learners are assisted in identifying and describing these five facets and in noting the relationships that exist among them.

The last aspect of focusing inquiry on process entails the learning of a schemata for inquiry. Although there are various approaches to strategies of inquiry, the Inquiry Training Program has settled on three phases: episode analysis, the determination of relevance, and the induction of relational constructs.

Episode analysis consists of routine checks made on the objects and systems identified in the problem episode. This is done in order to determine the properties of the objects and systems. The learner may do this by asking the teacher if an object is a certain thing or has specific characteristics. Another method is to ask if a certain thing would happen if the object were subjected to specific conditions. In addition the analysis includes determining the state of the objects and systems at the episode's beginning and at the completion of each successive distinct event. The last aspect of the analysis consists of having the learners present their data in organized chart form. A standard form for this chart has been developed by the Inquiry Training Program. Its purpose is to aid the learner in recognizing patterns and relationships among the data.

The determination of relevance characteristically involves two goals. The first is to establish the relevant variables of the episode and the conditions necessary for their operation. This goal is achieved by changing one variable at a time while holding the others constant. The second is to identify the conditions relevant to the results of the episode. Questions are used to gather the information needed to satisfy both goals.

Phase three, the induction of relational constructs, is designed to help determine why certain conditions must be present for the results to occur as observed. Unfortunately, attempts to identify a standardized procedure for this phase have failed. Previous experience, intuition, and creativity all seem to influence the effectiveness of the learner's behavior. "Here is where the individual brings to bear his existing conceptual systems in hypothesizing causal relationships and testing them."[19]

An example of a typical session of Inquiry Training is given in Appendix 1. Much of the rationale described above is easily identifiable in this example.

Up to this point the rationale presented has been limited to a single approach to learning by discovery, inquiry training. Now attention is focused on the general rationale of all approaches to learning by discovery, including inquiry training. As mentioned earlier this rationale is derived from a synthesis of many separate sources on learning by discovery.

General Rationale of Learning by Discovery

The basic tenet of learning by discovery challenges the assumption that the process of learning can best be controlled by some person other than the learner himself. Expository learning, according to Suchman, provides no place "for search, for data gathering and processing or for discovery. The learner is reduced to the level of the machine itself, and only the most menial of human cognitive functions are called into play. The creative and divergent aspects of human intelligence are for the most part ignored and neglected."[20] It is largely to overcome these drawbacks that learning by discovery has been advanced as an improved technique for promoting learning. The first assumption of learning by discovery, then, is that the learner himself is best able to direct his own learning and that learning by discovery is the most effective means yet developed to foster the learner's self-direction.

A second tenet of learning by discovery is that it provides a concrete basis for the development of abstract ideas. This tenet is based upon the research of Barbel Inhelder and Jean Piaget. Their research indicates that, prior to the upper elementary grades or junior high school, learning should be based more upon concrete activities, such as those afforded by discovery and other largely nonverbal experiences, rather than upon more formalized and high verbal activities.[21] Thus developmental considerations have influence on the interest in learning by discovery. Adding to this line of reasoning Ausubel states:

> Furthermore, for children who are still functioning at Piaget's level of concrete operations, nonverbal, intuitive discovery and application of

principles, prior to formal verbalization, is often desirable, in addition to the use of concrete-empirical props. In learning more complex and abstract ideas far removed from everyday experience, it is plausible to suppose that subverbal insight acquired through discovery experience may serve as a facilitating transitional phase in the achievement of full verbal understanding.[22]

Ausubel's comments on subverbal insight lead to a third tenet of the rationale of learning by discovery. This tenet holds that subverbal understanding precedes the ability to verbalize what is understood. Thus, the discovery is made and understood before it can be expressed verbally. "The separation of discovery phenomena from the process of composing sentences which express those discoveries is the big new breakthrough in pedagogical theory."[23] Discovery of the generalization occurs before the learner is able to verbalize what he has found. In discovery learning subverbal insight later emerges as verbal statements. In reception learning the approach used is different. The learner is presented with a verbal generalization and expected to gain insight from it. The proponents of learning by discovery claim that providing a verbal generalization leads to rote learning because the learner can only memorize a generalization that he does not really understand. If, on the other hand, the learner had discovered the generalization for himself, he would have first gained subverbal insight and later verbalized his own understanding of the generalization. Such a process insures that the understanding and the verbalization are as nearly the same as possible.

Whereas the expository or reception techniques of teaching tended to divide learning into two aspects, content assimilation and the process for organizing and using the content, the "rationale of learning by discovery seems to bring process and content into a transactional relationship. The rationale stresses the need for a strategy for cultivating autonomous mental processes in relation to the requirements of the structure or the logic of the particular content."[24]

The transactional relationship between the content and the process is an outgrowth of the learner's need to process new content so that it is assimilated to his own conceptual schemata. In certain cases where the new content cannot be readily assimilated to the previous cognitive schemata, the schemata is reorganized so as to facilitate the new content. Thus each of these two aspects of learning transacts with the other. In fact, the content is learned as the result of a process, learning by discovery, which reveals the relationship between content and cognitive schemata. Stressing this important quality of discovery, Taba explains:

> The act of discovery occurs at the point in the learner's efforts at which he grasps the organizing principle imbedded in a concrete instance or in a series of instances and can therefore transform this information: the learner can see the relationship of the facts before him, he can understand the causes of the phenomenon, and he can relate what he sees to his prior knowledge.[25]

Taba also stresses the connection between discovery and the structure of the subject matter being studied. The discovery should reflect the logic or structure of the subject matter. This completes the transactional relationship between content and process, for the content itself has structure.

Strategies of Learning by Discovery

Taba also reports that all types of learning by discovery have a specific teaching strategy. Three aspects of strategy appear to be common to most types of learning by discovery. The first of these is the presentation of a problem situation which is designed to initiate the process of learning by discovery. A second aspect is the withholding of principles and generalizations in order to lead the learner into the discovery of these principles or generalizations on his own. The third aspect of strategy is the freedom given to the learner to direct his own actions in seeking and reorganizing data so that he may formulate additional insights for himself. Other aspects of strategy are found in specific types of learning by discovery, but the three given here are common to virtually all types.

Advantages Claimed for Learning by Discovery

The proponents of learning by discovery claim that there are several important advantages of this method of teaching. The most significant of these are (1) it strengthens and extends intellectual potency and cognitive skills, (2) it is intrinsically rewarding, (3) it teaches the heuristics of discovery, (4) it aids memory processes, (5) it makes learning more meaningful, and (6) it promotes transfer of learning.[26]

Bruner believes that intellectual potency and cognitive skills are improved by learning by discovery, for learning by discovery helps students develop effective means of problem solving. Three such means, strategies, are suggested.

First, the student can be aided in learning to ask questions which locate constraints in the problem. Constraints serve to progressively eliminate wide ranges of possibilities and aid in the reduction of hypotheses to be explored. For example, the student who asks, "Did the error result from incorrect division?" The second student might be fortunate in immediately finding the solution, but if he were wrong, the error could still result from inaccurate multiplication, addition, or subtraction. The first student, if he received a negative reply, could immediately explore other areas.

A second means of improvement is to teach students to ask questions which fully utilize previous information. By locating constraints in the problem the student can then use his knowledge of the constraint to help him formulate his next questions. In other words, each successive question builds upon the information gathered by previous questions.

The third element is persistence which, in turn, consists of two facets: sheer perseverance and an organized means of collecting and storing information. The student who has organized his search for information and its storage is able to succeed where a student who has followed an unorganized pattern of search and storage becomes confused and discouraged. Bruner labels the strategy of the first student cumulative constructionism; that of the second, episodic empiricism. Thus, he asserts that the intellectual potency of students is improved by having them utilize the strategy of cumulative constructionism. Practice in discovery leads the student to search for more effective methods of gathering and storing information.

The second advantage of learning by discovery, intrinsic motivation, is based upon the concept of competence as a motivating factor.[27] This concept holds that the child has an intrinsic need to explore and manipulate his environment. He will of his own accord seek to discover things around him without being guided by extrinsic rewards. Bruner believes that learning by discovery capitalized on this intrinsic motivation by allowing the learner to guide or direct his own behavior. As the learner discovers new ideas and facts about his environment he gratifies his need for greater competency. Thus learning by discovery is said to have intrinsic motivation.

Relying upon the intrinsic motivation of learning by discovery also helps to curtail the negative influences of extrinsic controls often used by both parents and teacher. "That is to say, learning that starts in response to rewards of parental or teacher approval or the avoidance of failure can too readily develop a pattern in which the child is seeking cues as to how to conform to what is expected of him".[28]

Teaching the heuristics of discovery can, according to Bruner, be accomplished only by utilizing problem solving or discovery methods. Practice in learning by discovery leads the learner to develop a style of work from which he can formulate principles to guide future attempts at discovery. If the principles are to be truly generalities that can be used in a wide variety of situations, then it is necessary for the learner to undergo extensive practice with many types of problem situations. At present very little is known about the methods of instruction which most effectively teach heuristics of discovery. Indeed, Bruner has no suggestions to make here. He merely affirms that heuristics of discovery can be taught only by engaging in discovery itself.

Practically all authorities who favor learning by discovery cite its influence in aiding memory as one of its advantages, especially Suchman,[29] Taba,[30] as well as Bruner, who explains that "the very attitudes and activities that characterize 'figuring out' or 'discovering' things for oneself also seem to have the effect of making material more readily accessible in memory."[31] These authorities agree that the processes by which the learner discovers the principles being sought are, in and of themselves, of such a nature that improved memory of the discovered principle occurs as a natural by-product.

Only Bruner explains how learning by discovery brings about the improvement in memory. Basing his conception of memory on the work of George A. Miller,[32] Bruner states that the problem of memory is one of retrieval, not storage. The problem, then, becomes one of how best to commit the information to memory so that it may easily and accurately by recalled to consciousness. This may be achieved by organizing the information in such a manner that it is integrated into the learner's cognitive structure. Learning by discovery does just this, for it permits the learner to direct his own learning according to his own interests and cognitive structure. Thus newly acquired ideas and facts are organized by the learner so as to be effectively related to previously existing ideas and facts. Since the new information is related to previously existing cognitive structure which can be readily remembered, the new information itself can be recalled upon demand.

The fifth advantage, that of making learning more meaningful is probably the widest proclaimed benefit of learning by discovery.[33] Central to this claim is what is meant by "meaningful." Taba recognizes this problem and offers the following explanation:

> The essence of meaningfulness seems to be centered in the penetration into the basic structure of whatever one deals with, the mastery of the regularities and principles that govern the relationships of the phenomena observed, and the ability to use this knowledge in explaining a wide range of phenomena.[34]

Much the same idea of meaningfulness is contained in an explanation that Kersh offers to explain why learning by discovery enhances meaning:

> Through the discovery process, in which the learner is forced to rely on his own cognitive capacities, he becomes cognizant of the relationships of the learning task to his previous experience, or to the pattern of relationships among the elements of the task.[35]

Suchman states that learning by discovery is more meaningful because it is intrinsically rewarding, builds the learner's self-confidence in his own abilities, improves cognitive skills, and teaches the learner to detect pattern and organization in data.[36]

Each of these explanations stresses that meaning is derived from the learner's awareness of the relationships between the principle discovered and his previous cognitive structure. Awareness of these relationships imbues the discovery with meaning.

Improvement in the transfer of learning, the last advantage claimed for learning by discovery, was hypothesized by Hendrix in 1947: "For generation of transfer power, the unverbalized awareness (discovery) method of learning a generalization is better than a method in which an authoritative statement of the generalization comes first."[37] In the same article Hendrix states that the key to transfer is not the ability to verbalize the principle discovered. Indeed, she offers evidence that verbalization of the principle reduces the power of the subjects to transfer the principle to later situations. The key to transfer of learning, she states, "is a sub-verbal, internal process--something which must happen to the organism before it has any new knowledge to verbalize.[38] In a more recent article Hendrix39 reaffirms her belief that the nonverbal awareness of principles is, of course, attained by discovery learning; therefore, learning by discovery is credited with improving transfer power.

Purposes Served by Learning by Discovery

Three distinct purposes of learning by discovery can be identified in the literature dealing with this topic. These three purposes are (1) to teach subject-matter content, (2) to teach the heuristics of discovery and inquiry, and (3) to teach the nature of the knowledge discovered. In addition to these three distinct purposes, learning by discovery can also be used to serve a combination of any two or all three of these purposes. Taba recognized the unity of content and process, numbers one and two above, when she wrote that the rationale of learning by discovery "stresses the need for a strategy for cultivating autonomous mental processes in relation to the requirements of the structure or the logic of the particular content."[40] Bruner emphasizes the relationship among all three purposes. He believes that the "process and the goal of education are one and the same thing. The goal of education is disciplined understanding. That is the process as well."[41] In the same article Bruner developes the relationships that exist among subject matter, the nature of knowledge, and learning by discovery.

Although the discovery of subject matter content may be an important aspect of these studies, the emphasis is on learning how to develop skills of discovery and inquiry. Thus the focus of learning by discovery has switched from content to process. The work of Suchman[42] and of Bruner, Goodnow, and Austin[43] is of particular importance in studying heuristics. The research of Bruner, Goodnow, and Austin, especially, has influenced later studies of the heuristics of discovery.[44]

The third use of learning by discovery, teaching the nature of the knowledge discovered, received prominence because of its relationship to current thought about the nature of scientific knowledge. Glass states that one of the main objectives of science education is to teach "the nature of science."[45] To do this Schwab states that the student "needs to understand the conditional truth of scientific knowledge"[46]

The most extensive treatment of the ways to teach the nature of scientific knowledge is contained in a speech made by Schwab in 1961.[47] In this talk Schwab argues that today's citizen must understand the nature of science if he is to influence intelligently public policy dealing with scientific matters. This requires that the old pattern of teaching science as a body of truths be replaced by the modern conception of scientific ideas, "principles of inquiry--conceptual structures--which could be revised when necessary in directions dictated by large complexes of theory, and diverse bodies of data, and numerous criteria of progress in science."[48] Thus there is a continuous revision of scientific knowledge.

In explaining the rationale behind scientific inquiry, Schwab explains that scientific knowledge results from the interaction of two types of inquiry: stable inquiry and fluid inquiry. The first of these is characterized by its investigation of the ramifications of scientific principles. The principles themselves are not questioned; they serve instead as assumptions which guide further research. Fluid inquiry, on the other hand, challenges the principles themselves. It seeks to invent new principles and to test their feasibility. Fluid inquiry is characterized by frustration, failure, and lack of consistent direction. Yet, it is the source of major scientific advances.

Until the present century, fluid inquiry was overshadowed by stable inquiry. Now fluid inquiry has emerged to prominence. The importance of fluid inquiry has greatly increased, but the schools continued to emphasize stable inquiry. The need, then, is to teach science as inquiry so that the nature of scientific knowledge can be taught. By engaging the students inquiry they can learn about the nature of scientific knowledge.

One aspect of teaching science as inquiry is the utilization of learning by discovery. Learning by discovery is an important part of Schwab's inquiry curriculum. He suggests that laboratory work, for instance, be designed "to lead rather than lag the classroom phase of science teaching."[49] The student can engage in the investigation of scientific problems, attempting to discover new ideas and relationships. As he discovers these new ideas and relationships, the student will come to view all scientific knowledge as the result of discovery and inquiry. Principles and laws are seen as "formulations of the evidence made available by a series of inquiries."[50] It is in this sense that learning by discovery leads to an understanding of the nature of the knowledge discovered.

New Curriculum Proposals Utilizing Learning by Discovery

Learning by discovery has been incorporated into many of the new curriculum proposals. The National Council of Teachers of Mathematics reports that the "discovery approach is utilized in varying degrees by all the new programs (in mathematics) and is a central theme in the UICSM (University of Illinois Committee on School Mathematical) program."[51] Other than the UICSM, the programs spoken of include the School Mathematics Study Group (SMSG), the University of Maryland Mathematics Project (UMMP), the Boston College Mathematics

Institute, the Ball State Teachers College Experimental Program, and the Developmental Project in Secondary Mathematics of Southern Illinois University.

Kersh[52] reports that both the Madison Project of Syracuse University and the University of Illinois Arithmetic Project UIAP) emphasize learning by discovery.

Many of the new science curriculum projects employ learning by discovery. Lee[53] reports that the Biological Sciences Curriculum Study (BSCS) uses laboratory work to lead students to make discoveries of their own. In addition many of Schwab's ideas on inquiry have been incorporated into BSCS materials.[54] The Physical Science Study Committee has also developed laboratory work which accentuates learning by discovery.[55]

Fraser[56] reports that both the Chemical Education Materials Study (CHEM Study) and the Chemical Bond Approach Project (CBA) utilize learning by discovery in their laboratory work.

Although all the curriculum projects mentioned above deal with either mathematics or science, Bruner states that discovery methods are not necessarily limited to "such highly formalized subjects...."[57] He cites some of the Harvard Cognition Projects' experimental work on social studies as evidence of the wide application that can be made of learning by discovery. At least certain aspects of English, as well as some forms of skill, can be taught by discovery methods. These studies, of course, give no idea of how widely adaptable learning by discovery may or may not be for these areas. All other attempts to locate additional examples of subjects or skills being taught by discovery were unsuccessful.

Instruction for Discovery

Much of the literature on learning by discovery is concerned with methods of instruction for discovery. However, not all of the methods described in the literature satisfy the two criteria of learning by discovery identified earlier in this chapter. These two criteria are (1) that the learner acquire a new idea or concept and (2) that the acquisition of the new information results from the learner's own manipulation and reorganization of data.

Evidence of the satisfaction of these two criteria was obtained by selecting from the literature surveyed statements that indicate that the criteria were met.

Thirty-six sources were identified. In attempting to identify the various methods of teaching for discovery an analysis was made of each of the different terms used in these sources to identify and differentiate among the various discovery methods. Although most of these sources used discovery in its generic sense, ten specialized terms were used to indicate different methods of teaching for discovery. These ten terms are autonomous discovery, concept attainment, directed discovery, guided discovery, independent discovery, individually derived principles, inquiry, open-ended experiments, self-discovery, and unverbalized awareness.

An analysis was made of the differences among the methods of teaching for discovery defined in each of ten sources. Perhaps the main result of this analysis was the finding that the different methods of teaching for discovery could be distinguished by a single factor, the amount of assistance given to the learner to aid him in making the discovery. This ranged from presenting the learner with some data which establishes a problem situation and asking him to seek an explanation to a very carefully controlled process in which the data is presented in a set pattern organized in such a way as to "lead" the learner to the discovery. The former provides little if any direction for the learner while the latter virtually insures successful discovery.

Instructional methods may be classified by the amount of assistance or direction that they provide for the learner. When classified in this manner, instructional methods may be conceived of as a continuum that ranges from the extreme of absolutely no assistance or direction for the learner to the other extreme of outlining in detail exactly what the learner is to do.

In the case of absolutely no direction the learner is left completely to his own devices. He determines his own problem, selects his own data, and reaches or fails to reach his own conclusions. The only direction is that which resides in the situation itself. In the case of the opposite extreme the learner is subjected to as complete direction by others as is possible. He is told when, where, what, why, and how to learn. No decisions are supposedly left to him.

All methods of teaching for discovery lie between these two extremes. Depending upon the various amounts of direction provided, they constitute a continuum of their own. The examination of the ten terms used to designate methods of instruction for discovery reveals that each of the ten terms may be classified into one of three basic methods. The three methods differ from each other in the amount of direction each provides for the learner. Each of the three basic methods of instruction for discovery is discussed below and a list of several examples is given.

The First Method--Autonomous Discovery

In this type of teaching for discovery the learner is presented with a problem situation and little else except instructions concerning standard procedures. The learner is asked to find an explanation or solution but is not told how to go about this task. The teacher or instructor does not attempt to encourage the learner to move in certain directions or adopt certain procedures or strategies.

The learner makes his own decisions about what kinds of evidence to gather, what lines of investigation are to be followed, and what the order of investigation will be. There is, however, some method of verification which the learner can use to determine how well he is doing and when he has made the discovery. These checks usually take the form of testing the relevance of new data to the discovery sought.[58] As the learner determines the relevance of these new data to the problem, he decides for himself what steps are to be taken next.

No attempt is made to arrange or control the learning environment in such a manner that the learner is led to certain conclusions. The environment, rather, is unorganized or, to use a statistical term, randomized. In other words, the learning environment is neutral as far as providing "hints" or suggestions for discovery is concerned.

The Second Method--Guided Discovery

Guided discovery differs from autonomous discovery in that the former involves processes which exert some influence over the decisions and, consequently, the actions of the learner as he attempts to discover an explanation or solution to the problem situation. "Hints" or suggestions are contained in the learning environment.

Normally these hints are provided in several ways. One commonly used method is to control the amount and type of data made available to the learner as he seeks the solution or explanation to the problem situation. The concept attainment studies provide an excellent example of this type of control in their use of positive and negative instances of a concept being sought.[59] Presenting all the needed data to derive a concept can effectively influence the learning process.

A second way of aiding discovery is to control the sequence of data presented. By doing this the teacher or instructor can arrange the data so that they provide a logical pattern of steps leading to the discovery. In other words, the sequence of data is organized so as to parallel the logical sequence of the subject being taught. The learner, of course, is unaware that the presentation of the data is carefully predetermined.

By these two methods the learner is guided toward the desired discovery. It is important, however, to note that the learning environment is manipulated, not the learner. The learner is, of course, indirectly influenced by this manipulation of his environment. Still, he reorganizes his own cognitive structure and reaches his own conclusions.

The Third Method--Directed Discovery

This method of teaching for discovery is extensively planned by the teacher or instructor. Not only is the learning environment carefully controlled but the learner is also told the nature of the concept he is to discover. Sometimes the learner is taught part of a principle and is then asked to discover the rest.

Generally both the type and sequence of the data presented to the learner are predetermined. The data to be used are carefully chosen to provide hints about the concept to be discovered. The sequence, likewise, is designed to lead directly to an understanding of the concept. Thus both the type and sequence of the data are programmed to direct the learner to the desired concept. These facets are so carefully planned that there is little chance that the concept will not be discovered.

When data are presented to the learner, he is informed that the data are, themselves, organized by either the concept being sought or by a related concept. This focuses the learner's attention on the data and directs his efforts toward the detection of relationships among the data. The other two methods of instruction for discovery do not assist the learner in this manner. He has to discover for himself that such relationships exist.

This method of teaching for discovery differs from expository or reception methods in degree rather than kind. Whereas expository methods usually commence with the generalization and then present evidence as support, the discovery method first presents the evidence and then builds toward the generalization. The learner must identify the generalization for himself; it is never identified for him.

The intent of directed discovery is to provide the learner with a carefully structured series of data that insures the efficient discovery of the concept. The decisions the learner must make about what steps to take next are limited to two or three possibilities by the data themselves. The learner is, in this sense, directed to the discovery.

Summary

The purpose of this paper was to analyze learning by discovery in order to clarify its present meaning and use in educational circles. The analysis revealed that interest in discovery stems from two main sources: its use in the new curriculum projects such as those described at the Woods Hole Conference, and the current interest in the psychology of learning.

Learning by discovery was found to have a single essential characteristic which distinguishes it from other forms of learning. The learner must acquire new insight by his own reordering or manipulation of data. In other words, he directs the course of his own learning. The definition of learning by discovery developed is it is a process in which the learner independently reorganizes data or extends his own cognitive structure so that he acquires new insight.

Three different methods of teaching for discovery were identified. The first is autonomous discovery, characterized by the learner's great freedom to conduct his own course of discovery. The second is guided discovery, characterized by the teacher's or instructor's power to control the type, amount, and sequence of data, the learner is told that the data are organized so as to illustrate the concept being sought.

Although no definitive study of the rationale of learning by discovery has yet been developed, several basic aspects of its rationale were identified. First, learning by discovery challenges the assumption that someone other than the learner himself can best direct the learning process. Second, discovery learning theory holds that the type of things a person can learn are determined, in large part, by his level of cognitive development. Third, the ability of the learner to verbalize an idea does not mean that the idea is understood. Discovery must precede verbalization. Fourth, learning by discovery establishes a transactional relationship between the content discovered and the process of dis-

covery itself. Thus learning by discovery, according to Taba, resolves the age-old problem of the relative importance of content and process. Each is essential to discovery.

Three common aspects of the strategy of learning by discovery were identified: discovery is initiated by a problem situation; the principle or generalization to be learned is withheld from the learner so that he must discover it for himself; the learner directs his own actions in seeking and reorganizing data to lead him to the discovery.

The proponents of learning by discovery make six claims for its superiority:

1. It increases intellectual potency and cognitive skills.

2. It possesses intrinsic motivation.

3. It teaches the heuristics of discovery.

4. It aids recall and memory.

5. It makes learning more meaningful.

6. It promotes transfer of learning.

A review of the literature discloses that learning by discovery has been used to serve three broad purposes: to teach subject matter content, to teach the heuristics of discovery and inquiry, and to teach the nature of the knowledge discovered. In addition learning by discovery can be used for any two or all three of the above purposes.

The paper ends with a review of the curriculum proposals which utilize learning by discovery. The proposals were limited to mathematics and science. However, the proponents of learning by discovery say it can be utilized with other types of content. Research studies of discovery learning have used it to teach aspects of English, social studies, and some forms of skill.

An annotated bibliography on discovery learning has been prepared by the writer. The bibliography describes over one hundred major sources on the general topic of discovery methods and is available from the writer on request.

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