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Learning for Discovery: Establishing the Foundations

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Abstract—This article examines the prospect of facilitating the discovery process. The approach to learning for discovery which this article takes is called anticipatory learning. Anticipatory learning seeks to facilitate the discovery process by enhancing abilities in pattern recognition, empathy, and collaboration among researchers. Pattern recognition is developed in researchers through intuitive and metaphorical thinking. Metaphors which emerge from general systems thinking and aesthetics are especially useful for enhancing pattern recognition abilities.

Introduction

Is it possible to facilitate the discovery process? Can people learn to make discoveries? What would learning for discovery look like?

I believe that the discovery process can be facilitated. Discovery can never of course be guaranteed. The discovery process cannot be reduced to a series of mechanistic steps or simple recipes. However, people can learn skills and attitudes which enhance their ability to make discoveries. This process is called learning for discovery.

Learning for discovery is a collection of skills, abilities, and attitudes which are designed as a whole to help individuals make discoveries. Learning for discovery is designed to help provide some guidance to individuals in situations where the answers are not known. In much of traditional education a student is taught something which someone else already knows. Learning for discovery is designed for those situations when the answers and indeed the proper questions are unknown.

Learning for discovery is not meant just for university students. It is designed for anyone involved in research. Research is a type of learning. The researcher is often seeking to learn something which no one else knows. This is a qualitatively different kind of learning. Many times the researcher acts as his own learning facilitator.

Blocks to Discovery

One of the most far reaching theories related to discovery is that of Paradigm Change by Thomas Kuhn (1970). Kuhn's key concept is that of paradigm, an accepted model which organizes beliefs. The paradigm organizes a common community of researchers who take the paradigm for granted. It forms implicit rules for conduct. When a researcher acquires her content knowledge she also acquires a model for determining what the 'proper' problems are in that field.

Nothing can block our access to discovery more effectively than our preheld assumptions about the way things are supposed to be. We often do not even see phenomena that are not included in our working paradigm. Kuhn felt that in order for genuine discoveries to take place the paradigm must break down.

Paradigms break down because some anomaly is noticed which violates expectations. The perception that something has gone wrong is the prelude to discovery. The shift to a new paradigm occurs after the anomaly has been investigated and a new synthesis which adequately explains the anomaly has been formed. It should be noted that new paradigms do not need to answer all of the questions—in fact they often bring problems as well as solutions with them.

Anomalies then, act as signposts for the examination of our unquestioned assumptions. If we have the courage to examine our own assumptions then anomalies can be very valuable tools. They are valuable in another sense as well. Few anomalies fall within the confines of only one discipline. The investigation of anomalies forces us to take a broader multidisciplinary perspective, and counteracts the current trend towards fragmentation of knowledge (Wescott 1980).

We must always be on guard against the limits imposed by our disciplinary thinking. Learning for discovery can counteract some of these limits by enhancing process skills which can facilitate the discovery process. It also expands our tolerance for ambiguity.

Anticipatory Learning

One approach to learning for discovery is called anticipatory learning (Domaingue 1990). Anticipatory learning is a collection of skills and attitudes which are designed to prepare a person for facing the unknown. The critical component associated with facilitating discovery in anticipatory learning is pattern recognition.

A great deal of scientific and artistic effort is spent in the search for patterns. We may understand something by understanding its pattern. The more obvious manifestations of patterns include regularities and cycles. The search for regularities and cycles has been going on for a long time and is deeply embedded in our way of knowing. But patterns can come in many forms.

Patterns can be quite subtle and may be hidden from us by the 'noise' of other phenomena. Patterns can also be blocked from our understanding by our own preconceived ideas of what should be. In this case we create our own 'noise'. Creating our own 'noise' may be one of the single most important blocks to the discovery process.

Pattern recognition abilities are enhanced through the use of intuition and metaphor. Intuition plays a significant role in the discovery process. "It is often said that the role of intuition is a common factor in art and science. There is rarely a progress made in science without an intuitive perception of some hidden relations. . . more often than not, scientific intuition comes from an unconscious or half-conscious awareness of existing knowledge or of connections between concepts that have not yet been consciously realized (Weisskopf 1979: 106–7)."

Metphorical thinking also plays a critical role in facilitating discovery. It provides the researcher with the tools for breaking through habits and seeing subtle patterns. Two types of metaphorical thinking especially useful for the discovery process are inspired by general systems thinking and aesthetics. General systems thinking allows a researcher to examine the subtleties of complex problems. The reliance on aesthetics has guided researchers in examining patterns and integrating those patterns back into a knowledge system.

Intuition

The importance of intuition in scientific discovery is referred to repeatedly. The basic message is that logic is not enough. "Intuitions are only signs, faint and flickering, but they cast a light on reality which can never be cast by intellect alone (Westcott 1968:10)." Einstein repeats the message. "Speaking of his own creative leaps, Einstein observed that 'to these elementary laws there leads no logical path, but only intuition', adding that the latter is 'supported by being sympathetically in touch with experience' (Holton 1971:97)."

The intuitive researcher seeking discovery must maintain a flexible approach. She must be open to considering a number of alternatives at the same time while maintaining a view of the whole project. In addition, she must live with the ambiguity of not knowing or not judging for periods of time. "The quest for understanding establishes a direction in the intuitive mode, but this direction is at once both sure-and-clear and continually open to change. We know where we are headed but must constantly tack to stay on a course we cannot chart beforehand. Frost's comment about 'giants hurling experience ahead of us' seems to describe what we are doing in an intuitive mode: hurling ahead of us the very directional signs that will lead us (Noddings and Shore 1984:81)."

Intuition is important for pattern recognition and discovery but, how can it be developed in the researcher? Zoa Rockenstein (1985) has developed educational objectives for the intuitive domain. She recommends the development of meditation, relaxation, and visualization skills. Mental imagery has played a critical role in the progress of science. Developing skills in vivid imagining can strengthen the ability of forming and recognizing patterns. "Visual discovery, in the scientific laboratory, on the artist's canvas, and in human relationships, occurs in relation to a form of inner vision that is far freer of mortal limitation than is sensory perception (McKim 1980:91)."

Philip Goldberg (1983) believes that expanding a person's information base will assist the development of intuition. A strong liberal arts program can serve this purpose. An expanded information base gives the researcher access to a larger amount of raw material from which to build connections and recognize patterns. The expanded information base serves two main functions. One function is a diverging function which opens up new possibilities. The second function is a saturation function.

During saturation the researcher is trying to learn as much as possible about the problem or opportunity. If discovery is to take place, the researcher must have a mind prepared with knowledge. All of the techniques and models for discovery are useless without a prepared mind.

Intuition can also be developed through the proper design and use of feedback. Rapid feedback is a crucial component for developing tacit knowledge and in turn intuitive thinking. Our tacit knowledge is made up of a repertoire of patterns which we find difficult to describe in a verbal way. Michael Polanyi (1966) illustrates the fact that we can know more than we can tell by giving the example of our ability to recognize a single face among thousands and yet remain unable to describe how we recognized the face.

I have described the Rapid Evolution Envelope (Domaingue 1990) as a design technique for enhancing learning through rapid feedback. The Rapid Evolution Envelope (R.E.E.) is made up of a bounded system in which an individual can receive clear and rapid feedback. In addition the individual can respond very quickly and receive additional feedback. Several 'generations' of exchange happen very quickly allowing an idea or operation to evolve at a fast rate. The envelope can contain an individual or a group of individuals who are mutually influencing one another as well as the evolving operation.

Developing intuition is vital for anticipatory learning. Unfortunately, intuition is severely neglected in traditional approaches to education. "We are likely to continue to encourage the function of sensation and suppress the function of intuition in our highly communicative and conforming society. Both communication and conformity require fairly strict adherence to conventions, and it will probably always be more common to find a parent or teacher helping a child draw a cow that looks like a cow than helping a child draw the implications of a cow. We should, however, be able to do both (Westcott 1968:188)."

An important influence on pattern recognition is problem framing. Solving problems is implied by the way they are posed. **A** researcher relies on a repertoire of understandings and approaches for framing problems based on his tacit knowledge, intuitive abilities, and his guiding metaphors.

Metaphor

Metaphorical thinking is very important in the discovery process. Metaphors are not just limited to use in literature. "We have found on the contrary, that metaphor is pervasive in everyday life, not just in language but in thought and action. Our ordinary conceptual system, in terms of which we both think and act, is fundamentally metaphorical in nature (Lakoff and Johnson 1980:

3)." Metaphors influence how we structure our everyday reality. We understand one concept by placing it into a relationship with another.

Metphpors influence how we organize our thinking. George Lakoff and Mark Johnson (1980:6) believe that our human conceptual system is metaphorically structured. If this is the case then metaphorical thinking is involved in the very process of knowing. "Viewed internally, metaphors operate as cognitive processes that produce new insights and new hypotheses. Viewed externally, metaphors operate as mediators between the human mind and culture. New metaphors change both the ordinary language we use and the ways in which we perceive and understand the world (MacCormac 1985:2)."

The power of metaphors come from their ability to define reality. The metaphor focuses our attention on certain aspects and hides others from examination. In order to examine the hidden aspects we may need to change metaphors. The new metaphor of course will still have hidden aspects.

It is the very power of metaphors and of changing metaphors that William Gordon (1970) has used to form a creative problem solving technique. Gordon uses metphors to make the strange familiar, and to make the familiar strange. He calls his technique 'synectics', and it involves the use of different kinds of analogies. Gordon has demonstrated the usefulness of his technique for solving a variety of problems in fields ranging from medicine to oil drilling.

"One cannot overstate the importance of metaphorical thinking in creativity. It is simply and absolutely true that many, perhaps the large majority of our creative ideas and problem solutions are born in metaphorical thinking (Davis 1986:114)."

Besides being used for creative problem solving, metaphors have a role to play in guiding research. Philip Candy (1986:98) has suggested four areas where metaphors can be useful in research. These are: (1) identifying research problems, (2) suggesting possible research strategies, (3) representing potential solutions and insights, and (4) explaining results.

Metaphor has indeed been used in these four areas, and other areas, especially in the sciences. Metaphor has not only been described as useful, but necessary to science (Hoffman 1985:338). We can see why this is the case when we look at the range of uses of metaphor in science.

Scientific metaphors have been shown to serve a remarkable variety of functions:

(1) To suggest new hypotheses, hypothetical concepts, entities, relations, events, or observation terms,
(2) To predict and describe new phenomena or cause-effect relations,
(3) To give meaning to new theoretical concepts for unobservable or unobserved events,
(4) To suggest new laws or principles,
(5) To suggest new models or refinements of old ones,
(6) To suggest new research methods or ideas for experiments or hypothesis tests,

(7) To suggest choices between alternative hypotheses or theories, often a choice between more and less fruitful metaphors.
(8) To suggest new methods for analyzing data,
(9) To contrast theories or theoretical approaches,
(10) To provide scientific explanations in the form of metaphoric redescriptions,
(11) To suggest alterations or refinements in a theory,
(12) To suggest new theories, theoretical systems, or world views (Hoffman 1985:332).

There are two particular types of metaphorical thinking which have been associated with discovery. They are general systems thinking and aesthetics. Each of these metaphorical ways of knowing have additional metaphors embedded within them. However, these larger 'organizing' metaphorical structures have been associated with the discovery process.

It is likely that each of these metaphorical ways of knowing attunes the researcher to notice subtleties. I believe these approaches are useful tools for recognizing patterns which will aid discovery.

General Systems Thinking

General systems thinking is an attempt to look at the commonalities which different kinds of systems have. It is inherently a metaphorical process. A cell may be compared with a subway system and the generalities of inputs, outputs, information flow, boundary definition, feedback, etc., may be extracted from the comparison. These comparisons can be extremely useful. They provide a researcher with subtle concepts for examining very complex phenomena.

"General systems theory in the broadest sense refers to a collection of general concepts, principles, tools, problems, methods and techniques associated with systems. Although the name 'system' may have different meanings under different circumstances and for different people, it ordinarily stands for an arrangement of certain components so interrelated as to form a whole. Diverse types of components and their interrelations represent different systems (Klir 1972)." The key concept in Klir's definition is the forming of a whole. Systems cannot be understood by the classical approach of breaking things down into parts and examining the properties in isolation.

What are some of the commonalities of systems in general? All systems, whether physical, biological or socio-political have certain features in common. The following are their main characteristics.

(a) The components interact harmoniously with one another forming a network of interdependent elements comprising a whole.
(b) A system is more than just the simple sum of its parts.
(c) If one component is defective, not capable of interacting correctly with the others, not fulfilling its particular function, the whole system is affected.

(d) Systems that relate to other systems are called open systems.
(e) It follows that systems function in relation to their environment, on which they depend for support and which they affect with their outputs.
(f) Most systems are subject to external constraints imposed by the environment, and internal constraints due to their own inherent limitations.
(g) Many systems, especially in biology, sociology and industry, have a tendency to reach and maintain a dynamic equilibrium (homeostasis) (Beveridge 1980:70–71).

The metaphors which come out of general systems theory are powerful because they have wide application in several disciplines. They focus on essential features. By focusing on essential features it may be easier to recognize patterns and facilitate the discovery process.

The metaphors of general systems thinking can help the researcher in several ways. They can help her look at different levels of a problem. They provide a movement through multiple frames of reference. They can help break habits of thought, and they can provide a checklist for generating new ideas.

Aesthetics and Discovery

The metaphorical use of aesthetics has played a significant role in scientific discovery. Scientists often refer to aesthetic criteria in their models of nature. They talk of elegance, simplicity, fit, and symmetry. When building a model these criteria often act as a heuristic. The scientist must make innumerable choices in research. Aesthetic criteria can act as an overarching guide for constructing their models. Universality is also referred to in the same sense as the other aesthetic criteria. It can be a driving force. Leo Kadanoff while studying phase transitions found that different phenomena all follow the same rules. "Kadanoff felt that he had taken an unwieldy business and created a world of extreme beauty and self-containedness. Part of the beauty lay in its universality (Gleick 1987:161)."

The aesthetic sense plays an important part in the validation of scientific models. "Bohr, Dirac, Einstein, Heisenberg, Poincare, and others acknowledge intuitive and aesthetic judgment as decisive factors in the the acceptance or rejection of a particular model (Wechsler 1978:4)." Aesthetic patterns carry a great deal of compressed information. These patterns can provide order to many elements which would not otherwise be perceived as being interconnected.

Aesthetic sense and imagery appear to be strongly linked. "The progress of science is linked with transformations of perceptions and imagery ... (Miller 1984:312)." Imagery has played a central role in facilitating creative insight. It played a significant role in the development of 20th-century physics. Henri Poincare has described our need for 'thinking in images'. This visual thinking may be necessary for the recognition of aesthetic patterns.

Metaphorical thinking helps researchers organize their thinking and guide their research. Metaphorical thinking can range from an analogy which solves a simple problem to a single all encompassing metaphor which guides an individual's life work. Howard Gruber calls the latter type of metaphor an 'image of wide scope'.

Images of wide scope can accommodate a range of perceptions and ideas. Gruber reports on Charles Darwin's image of wide scope (see Wechsler 1978). Darwin's image of wide scope, which was influenced by his theoretical work on the formation of coral reefs, was that of a branching tree. He kept returning to the tree metaphor throughout his work and he used it to help explain his theory of evolution.

The image of wide scope is flexible enough to allow the development of deeper and deeper insights. "Gruber believes that the total number of images of wide scope developed by any individual creator is very small, perhaps four or five over a lifetime. In addition there may be between fifty and a hundred subsidiary images 'that are used in the elaboration of these thematic organizers'. . . Images of wide scope change and evolve as vision evolves (Briggs 1988:194)."

Images of wide scope appear to be very personal to the researcher. They excite something within the researcher and provide him with vision and a feeling for achieving wholeness. It is probably not possible to choose or provide an image of wide scope for another person. The image must call to that particular person. We can see this in the fact that very similar theories can be motivated by very different images. While Darwin had his branching tree image, Wallace who was also developing a theory of evolution through natural selection, used the image of the steam engine (which we would now call a cybernetic model of regulation).

Images of wide scope may not be transferred to other people, but there are 'subsidiary' metaphors which not only can be transferred; but must be transferred to another person if a problem is to be solved or explained. A new theory may not make sense to a person without the accompanying new metaphors. There are also cases where a solution could not be arrived at by a researcher without her already having the needed metaphors in her experience.

Metaphors offer guideposts into the unknown. But training researchers in the use of particular kinds of metaphors is not without its dangers. I have already mentioned that metaphors can help reveal, but they also hide phenomenon from investigation. "Now it is clear that if one is too strongly attached to one's preconceived model, one will of necessity miss all radical discoveries. It is amazing to what degree one may fail to register mentally an observation which does not fit the initial image (Deutsch 1959:360)." Using metaphorical thinking is meant to promote flexibility and openness, and not reinforce narrowness of view.

Howard Gruber (1986) compares Thomas Huxley and Charles Darwin. Gruber feels that Huxley was more brilliant and versatile than Darwin, but it was Darwin who discovered a theory of evolution. "My belief is that Darwin and Huxley had fundamentally different views of science and of nature, and that for the task at hand, waiting for someone to take it up, young Darwin's vague and open receptiveness was a better beginning than young Huxley's hard-edge analytic objectivism, bordering on an early form of positivisim (Gruber 1986:249)."

I believe there is a message in the comparison of Huxley and Darwin that is quite relevant for us today. Strong hard-edge analytic objectivism is not enough to produce major discoveries. What is required is an openness and receptiveness to nuance and pattern. Certain kinds of metaphorical thinking can help develop that openness in the researcher.

Empathy and Collaboration

One final feature of anticipatory learning is the development of empathy and collaboration skills. Delores Gallo (1989) feels that empathetic understanding is related to open mindedness, tolerance for ambiguity and complexity, and an ability to defer judgement. She uses Carl Rogers' definition of empathy: "the state of empathy or being empathetic, is to perceive the internal frame of reference of another with accuracy and with the emotional components and meanings which pertain thereto as if one were the person, but without ever losing the 'as if' condition (quoted in Gallo 1989:101)." This requires a great deal of awareness and openness on the part of the empathetic person.

These same skills are required to facilitate discovery. We can see this more clearly when we look at the effect of intolerance for ambiguity on problem solving. Ross (1982) reports that an important source of error with respect to causal judgements is a lack of deferred judgement. When individuals find one satisfactory explanation for a phenomenon they stop looking for others. This premature closure can prevent the discovery of more comprehensive explanations for the phenomenon.

Another factor mitigating against discovery is belief perseverance. Beliefs can be very tenacious. Ross (1982) reports that when the less effective problem solver is given information that opposes his values, he will consider it very critically and will reformulate it so as to maintain his beliefs. The same person when given information which is ambiguous as far as his values go, will accept the information unquestioningly and feel that it supports his current beliefs. Given this, ". . . what separates the less successful reasoner from the more successful one is the rigidity with which beliefs are held and maintained. I believe that the cognitive flexibility needed to modify beliefs and theories will not be available unless supported by a tolerance for deferred judgement and ambiguity (Gallo 1989:109)."

Another important feature in facilitating discovery is collaboration. People who have learned how to collaborate on a project are able to create and discover more than they could as isolated individuals. The collaboration of

James Watson, Francis Crick, and Maurice Wilkins, in the search for the structure of DNA is an important example. "It's evident from Watson's book that the dissonance among the visions and the differences in style, knowledge and talents allowed the team to propose and dispose of a great many possibilities, constantly shifting the elements of the context their data formed—until the whole fell into proper place (Briggs 1988:319)." Each of the men brought particular strengths and orientations to the team. By learning to collaborate with each other Watson, Crick, and Wilkins used the synergy of the group to make their successful discovery.

In order to develop abilities in collaborative learning the participants must have several skills. "In effective collaboration, participants will become able to perform task and maintenance leadership functions appropriate both to inquiry-oriented and to decision-oriented discussions and make effective group decisions by consensus, that is, decisions that evoke optimal commitment of the members to implement the decision (McKinley 1983:16)."

Consensus decision making is important in helping to form the group identity. One of the features of this identity is that the group maintain its own autonomy. "In group autonomy, participants will become able to determine and articulate their norms, generate appropriate feedback, assess their process, and diagnose and eliminate their group problems of collaboration without the assistance of an outside authority (McKinley 1983:16)."

The main purpose behind developing group autonomy is to ensure that there is a spontaneous and free flow of information among the group members. If synergetic relationships are to be formed then there must not be anything which inhibits the sharing of ideas and opinions. "A free exchange of ideas, opinions, and feelings is the lifeblood of collaborative learning. Making sure that messages are both sent and received as intended must become the mutual responsibility of all group members, not just of the leader (McKinley 1983: 16)."

The important elements of collaboration then become trust, rapport, and group autonomy. Certain aspects of these elements can be developed in individuals. But it is the interactions of individuals in groups where these elements take on their true significance. It takes time for groups to come together. When the groups do come together they produce synergetic results and they are fun for the individuals involved. "In the best work groups, the one in which people have the most fun and perform at their upper limits, the team interactions are everything. They are the reason that people stick it out, put their all into the work, overcome enormous obstacles (DeMarco and Lister 1987:121)."

A well developed team can create an environment which facilitates the discovery process. The other important aspects of anticipatory learning include the development of intuitive knowing, the design and use of feedback, the use of general systems and aesthetic metaphors, and the development of empathy. All of these elements facilitate the discovery process. Combined they form the foundations of anticipatory learning.

Conclusion

If we are to avoid what Thomas Gold (1989) has described as the 'herd instinct' in science, we need new approaches to learning. This applies to learning at all levels and includes the on-going professional development of researchers. Scientists may stick to the herd or never challenge their working paradigm because of the traditional education they receive. This education, from high school through graduate school, focuses on conformity and the skills of information retrieval at the expense of originality and risk taking.

One new approach is learning for discovery. The purpose of learning for discovery is to develop creativity and other traits which will lead to the generation of new knowledge. This is accomplished by helping the learner develop a tolerance for ambiguity.

The approach to learning for discovery which I have described is called anticipatory learning. Anticipatory learning seeks to facilitate the discovery process by enhancing abilities in pattern recognition. This is developed through the use of intuitive and metaphorical thinking. Skills in empathy and collaboration are also developed in anticipatory learning.

Education, as well as other social features, has mitigated against discovery in the past. It is time that new approaches to learning be established which can facilitate the discovery process. We can learn to break out of our old habits and face the world in an open manner.

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