IS A COMMON CURRICULUM POSSIBLE?

Oliver And because of the difficulty of education research, too often the content falls by the wayside. I recently met a fellow who studies instruction. Not instruction with respect to any domain. Not instruction with respect to any age or pupil set. He doesn't want to instruct anything particularly, just instruct in general. My own conviction is that nothing much will come of this.

Bob I share his interest. There's a profound question, in fact, of how much domain independence there can be in education. Is it possible to imagine creating a general curriculum for a wide diversity of people; one focused less on specific context than on ideas of proven power? Consider as a thought experiment designing education for colonies in space. For those strange new artificial worlds, which have to be completely designed, what sorts of minds and educations should people have in such an environment?

Oliver We don't need the space station as context to discuss the issue. Let's look at the question directly. What have you in mind?

Bob If then we think about the content fields of knowledge, we need to ask what are they? How stable are they? Are they independent of what we want to do? What is the nature of knowledge? And how can we imagine a way of people relating to one another in respect of the different fields of knowledge which will focus on the most important ideas, and how can we think about what people should know, what their minds should contain?

Oliver You used "should" several times. Exactly where does that should come from?

Bob Right at the heart of education is the question of freedom and individual choice; how do the goals of a teacher relate to those of a student? As we look at our own children, do we want our children to grow up to be the kinds of people we are—and the answer may very well be yes—or to be people who will most effectively adapt to the circumstances they find themselves in? Or do we want them to grow up to be people who have visions of their own to which they will try to make the world adapt? There probably is no single answer to any one of those.

Oliver There can't be, of course. I'd say that any vision of ours has to be with respect to those values and just those. At some level those values and decisions aren't right or wrong, at some level those are the way we are. It's not education to enforce values—because values will change with

knowledge—it's education to support them. It is not just a farcical idea to teach values; it can also be extraordinarily destructive—look at Hitler. I always say a pox on ideologies, but I have an ideology of my own which is very like yours, with your notions about freedom and so forth. Maybe we've spent enough time talking about this level of generality, but I think it always should be borne in mind that values are held with respect to a society and a culture, and, for me at least, without regard to any binary notion of good and evil.

CANTOR'S THEOREM

Bob Let's get specific then. Suppose we made a catalog of terrific ideas. My common curriculum would be such a collection, whether in music or athletics, or in language or mathematics. The issues are what should such a catalog contain and how do the contents relate to what a person knows. Let me give you an example. I think that Cantor's proof—

Oliver His Diagonal Theorem—

Bob If you will, his proof of the noncountability of the reals is one of the simplest and most elegant arguments I know. I would like students to run into that, see it with the same intensity I have to its power and beauty. So I would propose *that* proof as one straightforward enough to be accessible and exotic enough to be engaging, as an example of what might go into a common constructive curriculum (see Box 1).

Oliver I am not arguing that Cantor's proof is not beautiful and compelling. Indeed, the intensity of feeling that a mathematical fact may offer is as great as any. On viewing for the first time certain infinite series of Ramanugan, G. N. Watson (1936) says:

> [I felt] a thrill which is indistinguishable from the thrill which I feel when I enter the Sagrestia Nuovo of the Capella Medici and see before the austere beauty of the four statues . . . which Michelangelo has set over the tomb of Giuliano de'Medici and Lorenzo de'Medici.

But there could never be more than one citizen in a thousand who could appreciate that. I don't know that there are any ideas that should be part of everybody's education. I don't know whether that's a should, or a should not, or a never mind. Let's face it, Bobby Fischer, as a world-class chess master, probably related most of his life to playing chess. That's where his beauty was. He wouldn't give a damn about infinite sets—why should he? But I do think most kids are a little broader than that.

Are the real numbers countable? We start by assuming the opposite: That the real numbers, both rational and irrational, can be all put in one to one correspondence with the natural numbers, and are thereby countable. Let us consider only those numbers between zero and one, each one represented symbolically as a decimal. Write them in an array; by assumption, this array contains all the real numbers between *0* and *1*. If there is inevitably some decimal number not in this collection, then the numbers between zero and one are not countable. Here is an example of the array:

. **2** 6 0 1 1 ...
. 6 **3** 4 2 5 ...
. 1 9 **7** 0 3 ...
. 1 4 4 **8** 6 ...
. 7 9 5 5 **4** ...
...

Let us construct the decimal number represented by the diagonal, that is, by the bold-faced digits, **.23784**... Now let us construct another number that differs from that one in every digit; it might be **.12673**... This new number will be different from every number in the collection in at least one digit and is therefore not in it. Consequently, the real numbers between zero and one are not countable.

Box 1. Cantor's Proof of the Noncountability of the Real Numbers

Bob That's the question I'm raising: Can one in principle imagine the existence of such a thing as a student-centered curriculum? . . . or do we have to look at education as a process of individual and personal negotiation between individuals who know each other? Can there be in principle such a thing as a common student centered curriculum?

Oliver Why would you ever imagine that such a thing might be possible?

Bob People have common interests. We're mainly interested in how things and people work in the world, how they got that way, and how they relate to one another. When I've seen kids—whether aged 6 or mature enough to be professors—communicate to each other with a sense of engagement and excitement, they usually say things such as "Have you seen this neat phenomenon?" and "Do you know this good trick for doing such and such?" My question is whether one might, in the hope of designing education materials that would have some chance of being intrinsically motivating for students—whether one might organize knowledge into a stable curriculum around "neat phenomena" and "good tricks."

Oliver But why do you think that might be possible? And if it is possible, why isn't it so easy that already it has been done frequently?

PSYCHOLOGY AND KNOWLEDGE

Bob First, it might be possible because the world is orderly and because people are able to see the forest as well as the trees—our single greatest gift may be that we can change perspectives and thus be sensitive to emergent phenomena.

Oliver Much of the world is orderly.

Bob And so are people and their mental processes.

Oliver A much harder argument to carry.

Bob Secondly, we have been able to learn as scientists that there is a fit level of description of the world; fit in the sense that we can understand the world if and only if reasonably simple levels of description work well enough to save appearances. Here's an example. You know how shot is made? Spraying out molten iron at the top of a high column, the metal shapes itself into little spheres under its own surface tension as it cools and falls to the bottom of the tower. Understanding the process depends on an abstract description in terms of physical laws that are not very obvious nor obviously applicable in the particular case.

We need theories of learning as simple as the notion of surface tension and as effective in application. Very simple theories are inadequate because they don't fit. Complex theories are useless because people can't make sense of them. Our friend Minsky talks about ideas in a way that has led me to the following suggestion. He describes dumbbell theories—those where a dichotomy of the world is proposed and phenomena are arranged along the connecting continuum. He recommends that if one's theories seem insufficient it may be because they focus on some single characteristic and order the world by some value assigned to that characteristic. Can we try to go beyond dumbell theories—such as that based on the innateness of intelligence? Moving away from "dumbbell" theories, I look for what I've come to call "pawnshop" models, taking the name from the symbol of a pawn broker.

Oliver Can you give me a serious example?

PEIRCE'S REFORMULATION OF LOGIC

Bob Let's try one from Logic. The observation, vis-à-vis dumbbell and pawnshop theories in this domain, is that for centuries in the West, logic has been taught as a system with two categories of reasoning,

deductive and inductive. Within the last century, Peirce developed a three-part categorization, based on his complete covering of the three terms of the syllogism with logical processes—deduction, induction, and what he first called "hypothesis" and later "abduction" or "retroduction." Abduction is the process by which one decides that such-and-such a particular instance is a case which can be subsumed under a specific rule. This three-part classification, a pawnshop model, is more balanced, satisfying, and fruitful in respect of fit to descriptions of human-reasoning capacities—because the mode of reason in which humans are most successfully logical is that of "abduction," the mode ignored by scholars for thousands of years. The distinction between abduction and other forms of reasoning (see Box 2[1]) is more important in psychology than it is in formal logic. Abduction is what people are good at. Abduction is the notion through which the logical possibility of multiple schemes of representation makes connection with psychology to provide a "should" that is functional, more than a matter of choice. One should have a multitude of representations of situations, because one can then function more logically in the way people do best.

INADEQUACY OF THE PROCEDURAL/DECLARATIVE DICHOTOMY

Oliver Let's discuss this in some area we're both familiar with.

Bob It was popular in the mid-1970s to cup up the world of knowledge into systems of procedural and declarative descriptions. Typically, one has knowledge *that* something works and one has knowledge *how* something works. What's left out is what something's *for*. A two-term description, such as what condition-action rules represent, is an impoverished one. You've pointed out that the notion of purpose was essential in the early days of cybernetics. As McCulloch said, "We can now make machines that have purposes."

Oliver Can you give me a down-to-earth example?

Bob Let's see . . . if you use a shoe as a hammer, a fit description of parts and functions would be in terms of a handle and a striker more than in terms of sole, heel, upper, tongue, and laces. Things, functions, and purposes are inextricably intertwined. You need a pawnshop model to describe things of interest in the arena of purposeful human action.

[1]The idea of abduction sketched above was introduced in Peirce's (1956) essay "Deduction, Induction, And Hypothesis." A technical analysis of his developing ideas of logical fundamentals may be found in "Peirce's Theory of Abduction," by K. T. Fann.

[Abductive inference] . . . is where we find some very curious circumstance, which would be explained by the supposition that it was a case of a certain general rule, and thereupon adopt that supposition.

DEDUCTIVE INFERENCE
the rule: All the beans from this bag are white.
the case: These beans are from this bag.
IMPLIED result: These beans are white.
INDUCTIVE INFERENCE
the case: These beans are from this bag.
the result: These beans are white.
IMPLIED rule: All the beans from this bag are white.
ABDUCTIVE INFERENCE
the rule: All the beans from this bag are white.
the result: These beans are white.
IMPLIED case: These beans are from this bag.

Peirce's terms rule, result, and case translate into a more concrete vision of the evolving mind as follows. The "rule" becomes a cognitive structure, a model of a situation, what is known in the mind. The "result" is the problem situation actually confronted. It present immediate data such as "these beans are white." The implied case is the interpretation of the problem throught the model.

Abduction is prior to deduction and induction. This formulation emphasizes that a primary aspect of problem solving is the adopting of a hypothesis about "what's what." The perspective from which you view a situation determines what problem you imagine you are attempting to solve. The core of abductive inference in human problem solving is the deformation of problems to fit the recognizing processes of models in the mind.

Box 2. Peirce's Three Types of Inference

WORLD, INDIVIDUAL, AND SOCIETY

Bob Another triplet, more immediately germane to our education, would be Rollo May's (1958) partition of experience into *World, Individual, and Society.* Education has to have three foci, on the individual, on the world such as we find it to be, and on the society the individual inhabits. The world is essentially value free. Society is the sphere from which springs the sorts of things such as values and our sense of what we learn from what we've done and what we've suffered, indeed, even the intuition that gives us some sense of what we hope will be valuable and worth while.

Oliver How is this useful? Try telling me something new about the world, since the sphere of values may be harder to discuss.

THE WORLD: STRUCTURES OF KNOWLEDGE

Bob My favorite reference for the traditional view I found many years ago in an article in *Science*, "Evolution as Tinkering," by François Jacob. In sum, he describes a hierarchy of knowledge as deriving at the most minute of scales from determinate local physical laws, but he argues that at levels of the larger-scale aggregation of objects, the accidents of context have a more profound influence on the realization of the actual from the range of what is possible (see Box 3).

In contrast with this historico-hierarchical view, encyclopedists focus on the circle of knowledge. A reasonable contemporary description of this view is presented by Mortimer Adler in his introduction to the *Brittanica III:* his top-level organization of all knowledge is represented by a circle—a kind of pie chart—for the various domains of interest, being the physical world on different orders of magnitude (at first)

"Nature functions by integration. Whatever the level, the objects analyzed by natural sciences are always organizations, or systems. Each system at a given level uses as ingredients some systems of the simpler level, but some only. The hierarchy of complexity of objects is thus accompanied by a series of restrictions and limiations. At each level, new properties may appear which impose new constraints on the system. But these are merely additional constraints. Those that operate at any given level are still valid at the more complex level. Every proposition that is true for physics is also true for chemistry, biology, or sociology. Similarly, every proposition that is valid for biology holds true for sociology. But as a general rule, the statements of greatest importance at one level are of no interest at the more complex ones. The law of perfect gases is no less true for the objects of biology or sociology that for those of physics. It is imply irrelevant in the context of the problems with which biologists, and even more so sociologists, are concerned.

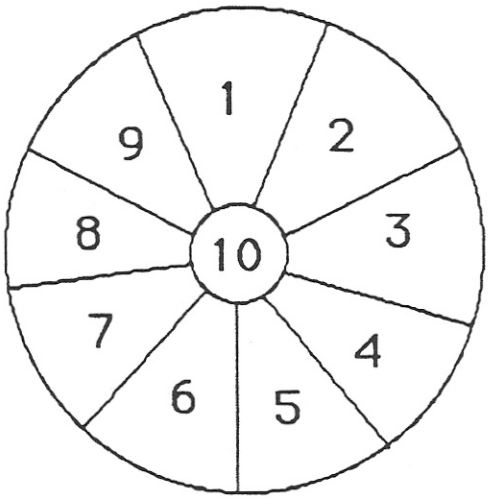
This hierarchy of successive integrations, characterized by restructions and by the appearance of new properties at each level, has several consequences.... (One) concerns the nature of the restrictions and limitations found at every step of increasing complexity. Can one explain why, among all the possible interactions at one level, only certain are observed at the more complex one?... There is no general answer to such questions, and it seems doubtful that there will ever by a specific answer for any one particular level of complexity. Complex objects are produced by evolutionary processes in which two factors are paramount: the constraints at every level control the systems involved, and the historical circumstances that control the actual interactions between the systems. The combination of constraints and history exists at every level, although in different proportions. Simpler objects are more dependent on constraints than on history. As complexity increased, history plays a greater part...."

Box 3. Francois Jacob (1974)

The Circle of Learning (from *Encyclopedia Brittanica III*, 1979)

The basic plan of the new Brittanica . . . aims to give its readers access to its contents by both the topical and the alphabetic mode. General and systematic access is provided by the Outline of Knowledge. . . . [T]he Outline of Knowledge is conceived as a circle of learning . . . The ten parts into which the outline of Knowledge is divided are disposed not along a finite straight line . . . ; they are disposed rather as a circle. . . . With the circular arrangement of parts, and with the rotatios of the circle, the reader can begin anywhere and go from thence to adjacent parts around the circle, or moving along iterior transecting lines, he can go from any part across the circle to parts that ae not adjacent on the circu ference . . . [T]he diagram below offers still another approach to the circle of learning. In this circle, Part 10 occupies the central position. . . . The reason fro this special placement of part 10 stems from the one organizing principle to which the editors were explicitly committed in planning and producing the new Brittanica. Briefly state, that principle involves a distinction between (a) what we know about the world of nature, man, and society by means of various brances of learning or departments of scholarship; and (b) what we know about teh branches of learning or departments of scholarship—the various academic disciplines themselves. . . . The special character of part 10 thus explains the diagram in which it occupies the centre of the circle of learning, but that must not be interpreted as attributing prime importance to it.

1. Matter and Energy
2. The Earth
3. Life on Earth
4. Human Life
5. Human Society
6. Art
7. Technology.
8. Religion
9. The History of Mankind
10. Branches of Knowledge



Box 4. Adler's Circle of Learning

then spreading out into issues of culture and historical significance as the arena of human concerns is reached. The mathematical sciences are given special status because of their reflexivity—represented as a circle within a circle—in the primary pie chart. The most interesting aspect of his graphical representation is the claim that one can treat the graph as

an object for which any slice may be a point of entry. If knowledge at this level were represented as a network, it would be equivalent to saying one could pick up the network at any node. I find this idea quite congenial, and I am now developing it in a concept chapter for some hypertext database access development work.

Oliver What do you have in mind that's different?

Bob A fundamental image from Piagetian theory is that knowledge grows in a spiral of development. In my paper, "Coadaptation and the Development of Cognitive Structures" (1987), I argued that the spiral of development derives from reformulating knowledge between multiple systems of representation. Those are based on the primary modes of experience, visual, linguistic, and sensorimotor. The primary mechanism was argued to be based on the occurrence of surprising solutions to frontier problems. When an unanticipated solution was found, the representation in which the problem solving had gone forward could not explain its success. Consequently an explanation had to be sought in terms of other representations. In respect of the evolution of mind, it would seem most useful for any creature to be able to understand a surprising success.

I've recently tried to imagine how one might design an access scheme to a hypertext database that would avoid the problem of getting lost in space by creating multiple paths to knowledge reflecting the possible various modalities of experience. The paths would be based on variations of the models of representation. This system is rooted in hypertext database organization and accessed through principles of human psychological organization. On the other hand, it respects that very same spiral path of knowledge growth—not through the domains of external knowledge, but through the variations of human experience and its human representations.

Oliver The words of things entangle and confuse. Help me with some example that shows more clearly what you mean.

Bob Anything we know about the world must be represented in our minds in some particular way. What's important to notice is that it may be represented in several different ways. For example, a triangle may be described in words; it may be recognized as an object seen; or it may be traced by some action equivalent to walking its perimeter or tracing its outline with a finger.

Because memories often carry concrete details related to the circumstances of experience, one might imagine that schemes representing experience would also embody representational commitments derived

from the particular mode of modality through which one initially interacted in that experience.

Oliver Do you mean that the internal knowledge representation language in which a memory is embodied would reflect the modality which dominated the individual's specific experience?

Bob So I speculate. Some knowledge of things and their functions and purposes may be well described in any of these various modes of representation—others very definitely may not. For example, the meaning of a Jackson Pollock painting may be grasped primarily in terms of it visual dash—a cross fertilization of color and motion, thus visual and sensorimotor perceptions and conceptions—but you may not be able to say anything articulate at all about what it might mean in discursive prose.

Oliver But the extent to which such things qualify as knowledge needs to be discussed. We should also discuss the different kinds of knowledge that we have.

Bob Some of this has been elegantly discussed by Goodman (1978) in *Ways of Worldmaking*—but that would lead us too far astray—the point is that the categories of human representation are few, we may say four, approximately. Why cannot all knowledge then be multiply represented in an encyclopedia in each of those modes that are most natural for people?

Oliver Why should they all be, since some are more fit than others, at least to the extent that some are decidedly not fit?

Bob That's an epistemological question which has a psychological answer. People are different from one another primarily in their different commitment to the ways in which they choose to represent knowledge of their of experiences. Knowledge of the world is not merely "hard" (as in the "hard sciences") and "soft." That distinction marks a dumbbell theory. (For some people, the dimension of variation might be quantifiability, for others, replicability of experiments, and so forth.) Nor is knowledge for everyone primarily language-like, as some suggested (see Chapter 11, this volume). Knowledge is visual, symbolic (in the sense of language symbolizing generally) and kinesthetic—as well as being tactile, chemical, and heat and pressure sensitive. But the primary three are visual, linguistic, and sensorimotor. This trichotomy of human representations is more of a pawnshop theory.

Oliver How is it useful?

Bob One of the complaints in information science circles today is that hypertext has limited use because people get "lost in hyperspace." This means they don't understand the structure of the database organization, and so they can't relate the material they are examining to a specific node in that large-scale network structure. Some very good engineers are convinced that the limitation on the use of intelligent systems derives primarily from the limits of human intelligence. I've heard one claim that people simply aren't smart enough to understand and exploit the capabilities of computers.

Oliver The engineers need a deeper understanding of the human side of the "human interface"—

Bob And that is one of my objectives—to construct a hypertext encyclopedia with an organization which different people will find congenial to their own different ways of thinking. Let us play a game. Suppose a mind is made of four machines. One is a serial symbol manipulator—a kind of database machine that takes some character string as input and locates the address of a record.

Oliver Words are keys to more complex data structures. The language machine.

Bob Exactly so. A vector processor might be useful to capture the interrelationships of lines in 3-space.

Oliver The visual system.

Bob And a robotics control system.

Oliver For the sensorimotor knowledge.

Bob Could these machines communicate?

Oliver Of course, since there will be an algorithm for converting one scheme of representation into another—but programs run on one machine will be much more suitable for certain kinds of sensory mode-specific processing than the logically equivalent programs run with a different set of primitives on another machine. So this is your psychological pawnshop theory.

Bob But not merely that, that such components exist. People are different because their different experiences lead them to make representational commitments differently to one or another of these common systems.

Now for the epistemology—which also is psychological. Knowledge we count on comes from what we do (our methods) and what that inclines us to believe (our results). That knowledge is both about material things and about our thinking, and so we study are reasoning methods and theories as well as experimental methods and facts. The focus of a field is what the knowledge explains and how it may be used. The canonical core of scientific knowledge can be described in a very abstract and general form as a pyramidal network, with the focus of the field being the apex, and the four basal vertices being the methods of observation and reasoning, and the results (data and theory) they lead us to believe, as in Figure 1.

Purposes vary, however, and different purposes require different views of the field, flexible representations, and various paths of access to the data. Furthermore, new tools and new ideas create new subfields, as nuclear magnetic resonance technology created a new subfield of physical chemistry in which method is of primary importance. This shows that while a network best represents the knowledge of a field, for study in specific subfields, the information may be better organized and presented as a hierarchical tree. Hypertext databases provide the needed flexibility.

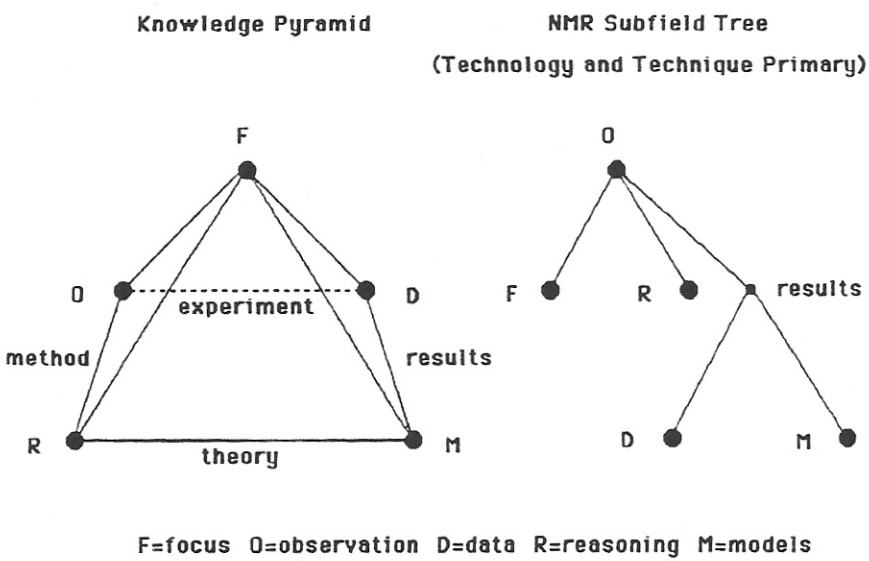


FIG. 1. This general scheme for organizing knowledge applies at different levels of knowledge—to the field as a whole, to subfields, and specialities also.

DOMAIN DETAIL INTERFACE: THE EPISTEMIC BODY

Bob In the arena of education, the nature of human representations and thinkable models (functional representations suitable for common-sense thought experiments) should be our central interest (see Chapter 1, this volume). This dimension will be the primary influence on the structure of the system and the user interface. Figure 2 shows a decomposition of knowledge for parts of the discipline of chemistry.

Imagine that every field and special study make a slice through the body of information in a discipline. These sections of the body of information can be seen as planar representational matrices, organized as follows. One axis specifies the general categories of representations which people can use in terms of their foundation in the various sensory modes (visual, manipulative, symbolic, somato-locomotive). The second axis specifies categories of thinkable models in terms of which a person can make sense of experience, ranging from the simplicity of a perspective (beginning with a decomposition of the domain into what things and features of things are important) through technical theories onto exploratory learning environments. (These categories are explained and exemplified in Chapter 1, this volume.) The cell contents of this organizing representational matrix are the

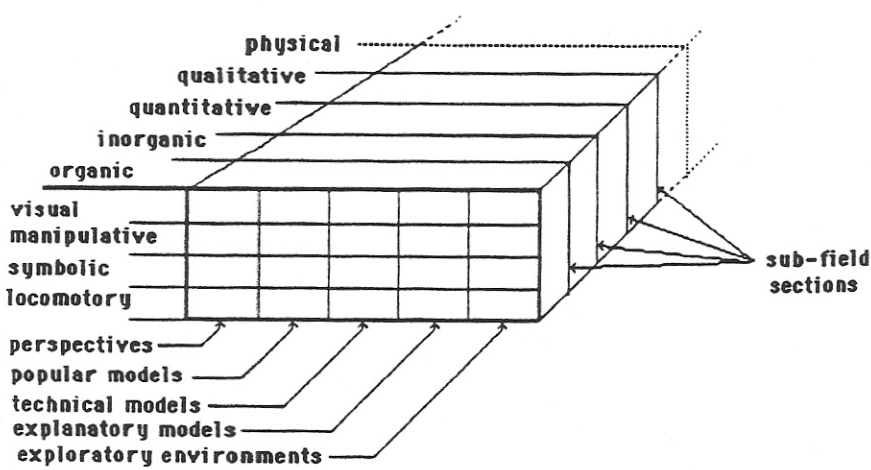


FIG. 2. Each cell of a subfield section matrix can be thought of as a mini-encyclopedia at a given level of technical depth and focused on a specific mode of representation. The data and programs of these database cells will overlap those of other cells and be linked to them.

domain information at various levels of sophistication and in various schemes of representation. Such cells can include alternative theories as well as multiple representations of the specific knowledge. Hypertext database organization should support in a natural fashion cross-representational correspondence links at the most detailed levels of the various models.

This is very general, in terms of the broad differences among systems of representation. But if you imagine that a real good for an individual is to have a mind which has a multitude of ways of viewing any particular situation, so that flexibility is a natural consequence of the human mind's abductive power, this focus on multiple descriptions applicable to common situations is a key to what it means for people to have effective and flexible minds.

Oliver Returning to the pyramidal access scheme to your multifaceted encyclopedia, I'm sure you realize how much thought and effort will be required to develop such a scheme to a point where its utility would be obvious and its worth determinable. Even if you could, in a pilot version of such a system, solve some of the technical problems of knowledge access for student-centered education, it doesn't help us approach values and how they relate to purposes.

MOTIVATION OF THE INDIVIDUAL

Oliver Let's assume, for discussion's sake, that such a view is worth advancing. Now let's ask how it relates to values and the should questions of education. My first criticism is that your proposal for a curriculum of neat ideas is focused on the "should" of the teacher, not that of the student. What do you think of the "should" of the student? What and where do you think interest comes from?

Bob Carl Rogers spoke on campus during my student days at Cal Tech. He described (1961) the process of natural growth with a phrase from Kierkegaard, as reflecting the effort of each individual to become that person which he most essentially is. He saw people as trying to bring their lives into some sort of coherent registration with the people they either perceived themselves to be or hoped that they would be someday. For young people, adolescents especially, I imagine that remains an abiding motivation.

Oliver I respect such objectives, even though I consider the expression too general to be very helpful. Let's take your example of Cantor's proof