



Chapter Title: THE IMPORTANCE OF STRUCTURE

Book Title: The Process of Education

Book Subtitle: Revised Edition

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Published by: Harvard University Press

Stable URL: <https://www.jstor.org/stable/j.ctvk12qst.6>

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THE first object of any act of learning, over and beyond the pleasure it may give, is that it should serve us in the future. Learning should not only take us somewhere; it should allow us later to go further more easily. There are two ways in which learning serves the future. One is through its specific applicability to tasks that are highly similar to those we originally learned to perform. Psychologists refer to this phenomenon as specific transfer of training; perhaps it should be called the extension of habits or associations. Its utility appears to be limited in the main to what we usually speak of as skills. Having learned how to hammer nails, we are better able later to learn how to hammer tacks or chip wood. Learning in school undoubtedly creates skills of a kind that transfers to activities encountered later, either in school or after. A second way in which earlier learning renders later performance more efficient is through what is conveniently called nonspecific transfer or, more accurately, the transfer of principles and attitudes. In essence, it consists of learning initially not a skill but a general idea, which can then be used as a basis for recognizing subsequent problems as special cases of the idea originally mastered. This type of transfer is at the heart of the educational process—the continual broadening and deepening of knowledge in terms of basic and general ideas.

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The continuity of learning that is produced by the second type of transfer, transfer of principles, is dependent upon mastery of the structure of the subject matter, as structure was described in the preceding chapter. That is to say, in order for a person to be able to recognize the applicability or inapplicability of an idea to a new situation and to broaden his learning thereby, he must have clearly in mind the general nature of the phenomenon with which he is dealing. The more fundamental or basic is the idea he has learned, almost by definition, the greater will be its breadth of applicability to new problems. Indeed, this is almost a tautology, for what is meant by "fundamental" in this sense is precisely that an idea has wide as well as powerful applicability. It is simple enough to proclaim, of course, that school curricula and methods of teaching should be geared to the teaching of fundamental ideas in whatever subject is being taught. But as soon as one makes such a statement a host of problems arise, many of which can be solved only with the aid of considerably more research. We turn to some of these now.

The first and most obvious problem is how to construct curricula that can be taught by ordinary teachers to ordinary students and that at the same time reflect clearly the basic or underlying principles of various fields of inquiry. The problem is twofold: first, how to have the basic subjects rewritten and their teaching materials revamped in such a way that the pervading and powerful ideas and attitudes relating to them are given a central role; second, how to match the levels of these materials to the capacities of students of different abilities at different grades in school.

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The experience of the past several years has taught at least one important lesson about the design of a curriculum that is true to the underlying structure of its subject matter. It is that the best minds in any particular discipline must be put to work on the task. The decision as to what should be taught in American history to elementary school children or what should be taught in arithmetic is a decision that can best be reached with the aid of those with a high degree of vision and competence in each of these fields. To decide that the elementary ideas of algebra depend upon the fundamentals of the commutative, distributive, and associative laws, one must be a mathematician in a position to appreciate and understand the fundamentals of mathematics. Whether schoolchildren require an understanding of Frederick Jackson Turner's ideas about the role of the frontier in American history before they can sort out the facts and trends of American history—this again is a decision that requires the help of the scholar who has a deep understanding of the American past. Only by the use of our best minds in devising curricula will we bring the fruits of scholarship and wisdom to the student just beginning his studies.

The question will be raised, "How enlist the aid of our most able scholars and scientists in designing curricula for primary and secondary schools?" The answer has already been given, at least in part. The School Mathematics Study Group, the University of Illinois mathematics projects, the Physical Science Study Committee, and the Biological Sciences Curriculum Study have indeed been enlisting the aid of eminent men in their various fields, doing so by means of summer proj-

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ects, supplemented in part by year-long leaves of absence for certain key people involved. They have been aided in these projects by outstanding elementary and secondary school teachers and, for special purposes, by professional writers, film makers, designers, and others required in such a complex enterprise.

There is at least one major matter that is left unsettled even by a large-scale revision of curricula in the direction indicated. Mastery of the fundamental ideas of a field involves not only the grasping of general principles, but also the development of an attitude toward learning and inquiry, toward guessing and hunches, toward the possibility of solving problems on one's own. Just as a physicist has certain attitudes about the ultimate orderliness of nature and a conviction that order can be discovered, so a young physics student needs some working version of these attitudes if he is to organize his learning in such a way as to make what he learns usable and meaningful in his thinking. To instill such attitudes by teaching requires something more than the mere presentation of fundamental ideas. Just what it takes to bring off such teaching is something on which a great deal of research is needed, but it would seem that an important ingredient is a sense of excitement about discovery—discovery of regularities of previously unrecognized relations and similarities between ideas, with a resulting sense of self-confidence in one's abilities. Various people who have worked on curricula in science and mathematics have urged that it is possible to present the fundamental structure of a discipline in such a way as to preserve some of the exciting sequences that lead a student to discover for himself.

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It is particularly the Committee on School Mathematics and the Arithmetic Project of the University of Illinois that have emphasized the importance of discovery as an aid to teaching. They have been active in devising methods that permit a student to discover for himself the generalization that lies behind a particular mathematical operation, and they contrast this approach with the "method of assertion and proof" in which the generalization is first stated by the teacher and the class asked to proceed through the proof. It has also been pointed out by the Illinois group that the method of discovery would be too time-consuming for presenting all of what a student must cover in mathematics. The proper balance between the two is anything but plain, and research is in progress to elucidate the matter, though more is needed. Is the inductive approach a better technique for teaching principles? Does it have a desirable effect on attitudes?

That the method of discovery need not be limited to such highly formalized subjects as mathematics and physics is illustrated by some experimentation on social studies carried out by the Harvard Cognition Project. A sixth-grade class, having been through a conventional unit on the social and economic geography of the Southeastern states, was introduced to the North Central region by being asked to locate the major cities of the area on a map containing physical features and natural resources, but no place names. The resulting class discussion very rapidly produced a variety of plausible theories concerning the requirements of a city—a water transportation theory that placed Chicago at the junction of the three lakes, a mineral resources theory that placed

it near the Mesabi range, a food-supply theory that put a great city on the rich soil of Iowa, and so on. The level of interest as well as the level of conceptual sophistication was far above that of control classes. Most striking, however, was the attitude of children to whom, for the first time, the location of a city appeared as a problem, and one to which an answer could be discovered by taking thought. Not only was there pleasure and excitement in the pursuit of a question, but in the end the discovery was worth making, at least for urban children for whom the phenomenon of the city was something that had before been taken for granted.

How do we tailor fundamental knowledge to the interests and capacities of children? This is a theme we shall return to later, and only a word need be said about it here. It requires a combination of deep understanding and patient honesty to present physical or any other phenomena in a way that is simultaneously exciting, correct, and rewardingly comprehensible. In examining certain teaching materials in physics, for example, we have found much patient honesty in presentation that has come to naught because the authors did not have a deep enough understanding of the subject they were presenting.

A good case in point is to be found in the usual attempt to explain the nature of tides. Ask the majority of high school students to explain tides and they will speak of the gravitational pull of the moon on the surface of the earth and how it pulls the water on the moon's side into a bulge. Ask them now why there is also a bulge of less magnitude on the side of the earth opposite to the moon, and they will almost always be without a satisfactory

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answer. Or ask them where the maximum bulge of the incoming tide is with respect to the relative position of the earth and moon, and the answer will usually be that it is at the point on the earth's surface nearest to the moon. If the student knows there is a lag in the tidal crest, he will usually not know why. The failure in both cases comes from an inadequate picture of how gravity acts upon a free-moving elastic body, and a failure to connect the idea of inertia with the idea of gravitational action. In short, the tides are explained without a share of the excitement that can come from understanding Newton's great discovery of universal gravitation and its mode of action. Correct and illuminating explanations are no more difficult and often easier to grasp than ones that are partly correct and therefore too complicated and too restricted. It is the consensus of virtually all the men and women who have been working on curriculum projects that making material interesting is in no way incompatible with presenting it soundly; indeed, a correct general explanation is often the most interesting of all. Inherent in the preceding discussions are at least four general claims that can be made for teaching the fundamental structure of a subject, claims in need of detailed study.

The first is that understanding fundamentals makes a subject more comprehensible. This is true not only in physics and mathematics, where we have principally illustrated the point, but equally in the social studies and literature. Once one has grasped the fundamental idea that a nation must trade in order to live, then such a presumably special phenomenon as the Triangular Trade of the American colonies becomes altogether simpler to

understand as something more than commerce in molasses, sugar cane, rum, and slaves in an atmosphere of violation of British trade regulations. The high school student reading *Moby Dick* can only understand more deeply if he can be led to understand that Melville's novel is, among other things, a study of the theme of evil and the plight of those pursuing this "killing whale." And if the student is led further to understand that there are a relatively limited number of human plights about which novels are written, he understands literature the better for it.

The second point relates to human memory. Perhaps the most basic thing that can be said about human memory, after a century of intensive research, is that unless detail is placed into a structured pattern, it is rapidly forgotten. Detailed material is conserved in memory by the use of simplified ways of representing it. These simplified representations have what may be called a "regenerative" character. A good example of this regenerative property of long-term memory can be found in science. A scientist does not try to remember the distances traversed by falling bodies in different gravitational fields over different periods of time. What he carries in memory instead is a formula that permits him with varying degrees of accuracy to regenerate the details on which the more easily remembered formula is based. So he commits to memory the formula $s = \frac{1}{2} gt^2$ and not a handbook of distances, times, and gravitational constants. Similarly, one does not remember exactly what Marlowe, the commentator in *Lord Jim*, said about the chief protagonist's plight, but, rather, simply that he was the dispassionate onlooker, the man who tried to understand without judging what had led Lord Jim into

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the straits in which he found himself. We remember a formula, a vivid detail that carries the meaning of an event, an average that stands for a range of events, a caricature or picture that preserves an essence—all of them techniques of condensation and representation. What learning general or fundamental principles does is to ensure that memory loss will not mean total loss, that what remains will permit us to reconstruct the details when needed. A good theory is the vehicle not only for understanding a phenomenon now but also for remembering it tomorrow.

Third, an understanding of fundamental principles and ideas, as noted earlier, appears to be the main road to adequate “transfer of training.” To understand something as a specific instance of a more general case—which is what understanding a more fundamental principle or structure means—is to have learned not only a specific thing but also a model for understanding other things like it that one may encounter. If a student could grasp in its most human sense the weariness of Europe at the close of the Thirty Years’ War and how it created the conditions for a workable but not ideologically absolute Treaty of Westphalia, he might be better able to think about the ideological struggle of East and West—though the parallel is anything but exact. A carefully wrought understanding should also permit him to recognize the limits of the generalization as well. The idea of “principles” and “concepts” as a basis for transfer is hardly new. It is much in need of more research of a specific kind that would provide detailed knowledge of how best to proceed in the teaching of different subjects in different grades.

The fourth claim for emphasis on structure and prin-

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ciples in teaching is that by constantly reexamining material taught in elementary and secondary schools for its fundamental character, one is able to narrow the gap between "advanced" knowledge and "elementary" knowledge. Part of the difficulty now found in the progression from primary school through high school to college is that material learned earlier is either out of date or misleading by virtue of its lagging too far behind developments in a field. This gap can be reduced by the kind of emphasis set forth in the preceding discussion.

Consider now some specific problems that received considerable discussion at Woods Hole. One of them has to do with the troubled topic of "general science." There are certain recurrent ideas that appear in virtually all branches of science. If in one subject one has learned them well and generally, that achievement should make the task of learning them again in different form elsewhere in science much easier. Various teachers and scientists have raised the question whether these basic ideas should not be "isolated," so to speak, and taught more explicitly in a manner that frees them from specific areas of science. The type of idea can be easily illustrated: categorization and its uses, the unit of measure and its development, the indirectness of information in science and the need for operational definition of ideas, and so forth. With respect to the last, for example, we do not *see* pressure or the chemical bond directly but infer it indirectly from a set of measures. So too body temperature. So too sadness in another person. Can these and similar ideas be presented effectively and with a variety of concrete illustrations in the early grades in order to give the child a better basis for understanding their

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specific representation in various special disciplines later? Is it wise to teach such "general science" as an introduction to disciplinary sciences in the later grades? How should they be taught and what could we reasonably expect by way of easier learning later? Much research is needed on this promising topic—research not only on the usefulness of such an approach, but also on the kinds of general scientific ideas that might be taught.

Indeed, it may well be that there are certain general attitudes or approaches toward science or literature that can be taught in the earlier grades that would have considerable relevance for later learning. The attitude that things are connected and not isolated is a case in point. One can indeed imagine kindergarten games designed to make children more actively alert to how things affect or are connected with each other—a kind of introduction to the idea of multiple determination of events in the physical and the social world. Any working scientist is usually able to say something about the ways of thinking or attitudes that are a part of his craft. Historians have written rather extensively on this subject as far as their field is concerned. Literary men have even evolved a genre of writing about the forms of sensibility that make for literary taste and vigor. In mathematics, this subject has a formal name, "heuristic," to describe the approach one takes to solving problems. One may well argue, as it was argued at Woods Hole by men in widely differing disciplines, that it might be wise to assess what attitudes or heuristic devices are most pervasive and useful, and that an effort should be made to teach children a rudimentary version of them that might be further refined as they progress through school. Again, the

reader will sense that the argument for such an approach is premised on the assumption that there is a continuity between what a scholar does on the forefront of his discipline and what a child does in approaching it for the first time. This is not to say that the task is a simple one, only that it is worthy of careful consideration and research.

Perhaps the chief arguments put forward in opposition to the idea of such efforts at teaching general principles and general attitudes are, first, that it is better to approach the general through the specific and, second, that working attitudes should be kept implicit rather than being made explicit. For example, one of the principal organizing concepts in biology is the persistent question, "What function does this thing serve?"—a question premised on the assumption that everything one finds in an organism serves some function or it probably would not have survived. Other general ideas are related to this question. The student who makes progress in biology learns to ask the question more and more subtly, to relate more and more things to it. At the next step he asks what function a particular structure or process serves in the light of what is required in the total functioning of an organism. Measuring and categorizing are carried out in the service of the general idea of function. Then beyond that he may organize his knowledge in terms of a still more comprehensive notion of function, turning to cellular structure or to phylogenetic comparison. It may well be that the style of thought of a particular discipline is necessary as a background for learning the working meaning of general concepts, in which case a general introduction to the

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meaning of "function" might be less effective than teaching it in the context of biology.

As for "attitude" teaching or even the teaching of heuristic in mathematics, the argument runs that if the learner becomes too aware of his own attitudes or approach, he may become mechanical or trick-oriented in his work. No evidence exists on the point, and research is needed before any effort is made to teach in this way. Work is now going on at Illinois on training children to be more effective in asking questions about physical phenomena, but much more information is needed before the issue is clear.

One hears often the distinction between "doing" and "understanding." It is a distinction applied to the case, for example, of a student who presumably understands a mathematical idea but does not know how to use it in computation. While the distinction is probably a false one—since how can one know what a student understands save by seeing what he does—it points to an interesting difference in emphasis in teaching and in learning. Thus one finds in some of the classic books on the psychology of problem solving (such as Max Wertheimer's *Productive Thinking*) a sharp line drawn between "rote drill" and "understanding." In point of fact, drill need not be rote and, alas, emphasis on understanding may lead the student to a certain verbal glibness. It has been the experience of members of the School Mathematics Study Group that computational practice may be a necessary step toward understanding conceptual ideas in mathematics. Similarly one may try to give the high school student a sense of styles by having him read contrasting authors, yet final insight into style may come

only when the student himself tries his hand at writing in different styles. Indeed, it is the underlying premise of laboratory exercises that doing something helps one understand it. There is a certain wisdom in the quip made by a psychologist at Woods Hole: "How do I know what I think until I feel what I do?" In any case, the distinction is not a very helpful one. What is more to the point is to ask what methods of exercise in any given field are most likely to give the student a sense of intelligent mastery over the material. What are the most fruitful computational exercises that one can use in various branches of mathematics? Does the effort to write in the style of Henry James give one an especially good insight into that author's style? Perhaps a good start toward understanding such matters would be to study the methods used by successful teachers. It would be surprising if the information compiled failed to suggest a host of worthwhile laboratory studies on techniques of teaching—or, indeed, on techniques of imparting complex information generally.

A word is needed, finally, on examinations. It is obvious that an examination can be bad in the sense of emphasizing trivial aspects of a subject. Such examinations can encourage teaching in a disconnected fashion and learning by rote. What is often overlooked, however, is that examinations can also be allies in the battle to improve curricula and teaching. Whether an examination is of the "objective" type involving multiple choices or of the essay type, it can be devised so as to emphasize an understanding of the broad principles of a subject. Indeed, even when one examines on detailed knowledge, it can be done in such a way as to require an understand-

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ing by the student of the connectedness between specific facts. There is a concerted effort now under way among national testing organizations like the Educational Testing Service to construct examinations that will emphasize an understanding of fundamental principles. Such efforts can be of great help. Additional help might be given to local school systems by making available to them manuals that describe the variety of ways in which examinations can be constructed. The searching examination is not easy to make, and a thoughtful manual on the subject would be welcome.

To recapitulate, the main theme of this chapter has been that the curriculum of a subject should be determined by the most fundamental understanding that can be achieved of the underlying principles that give structure to that subject. Teaching specific topics or skills without making clear their context in the broader fundamental structure of a field of knowledge is uneconomical in several deep senses. In the first place, such teaching makes it exceedingly difficult for the student to generalize from what he has learned to what he will encounter later. In the second place, learning that has fallen short of a grasp of general principles has little reward in terms of intellectual excitement. The best way to create interest in a subject is to render it worth knowing, which means to make the knowledge gained usable in one's thinking beyond the situation in which the learning has occurred. Third, knowledge one has acquired without sufficient structure to tie it together is knowledge that is likely to be forgotten. An unconnected set of facts has a pitifully short half-life in memory. Organizing facts in terms of principles and ideas from which they may be

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inferred is the only known way of reducing the quick rate of loss of human memory.

Designing curricula in a way that reflects the basic structure of a field of knowledge requires the most fundamental understanding of that field. It is a task that cannot be carried out without the active participation of the ablest scholars and scientists. The experience of the past several years has shown that such scholars and scientists, working in conjunction with experienced teachers and students of child development, can prepare curricula of the sort we have been considering. Much more effort in the actual preparation of curriculum materials, in teacher training, and in supporting research will be necessary if improvements in our educational practices are to be of an order that will meet the challenges of the scientific and social revolution through which we are now living.

There are many problems of how to teach general principles in a way that will be both effective and interesting, and several of the key issues have been passed in review. What is abundantly clear is that much work remains to be done by way of examining currently effective practices, fashioning curricula that may be tried out on an experimental basis, and carrying out the kinds of research that can give support and guidance to the general effort at improving teaching.

How may the kind of curriculum we have been discussing be brought within the intellectual reach of children of different ages? To this problem we turn next.