Education and The Need to Know

True growth depends upon
a dynamic match between
an individual and his culture

By Edwin H. Land and Stewart W. Wilson, '60

Teaching and learning within the framework of the school system are being studied and mastered by the largest and most competent group of creative scientists, engineers, and humanists in the whole history of education.

But intellectual growth and enjoyment also occur outside of school hours and outside of the school years; and the university must take the lead in the exploration of this new domain, because a large part of the knowledge, discernment, and technology required for instituting this new activity outside of the university resides within the university.

Our view is that one of the most powerful techniques whereby humans learn is to ask a question, hear an answer, ask another question, hear another answer and so on. The quality of what is learned depends on whether the answer is a good answer, and on the manner, tone, and responsiveness with which the answer is given. As our society ages and becomes more complex, there are fewer and fewer people proportionately who can give good answers and who can answer patiently and responsively. So we have had to resort to schools in which groups are instructed and in which the alternating sequence of question, answer, question, answer must be prohibited.

This newer process, the school process, varies in efficiency from the deplorable to the superb, but it operates only within the dimensions of its own evolution and is necessarily remote from the question-answer mechanism which is intuitive for the human mind. Our own view is that there never can be a revolution away from any major accomplishment, for every major human accomplishment so shapes the human race that it *is* the human race. Schools, and the kind of learning that is carried on in schools, are from now on inevitable components of our very being.

But this does not alter the fact that one of the most primitive and natural human drives has had to be inhibited nearly totally in the course of development of our mass society from its technological infancy. Now, happily, the time has come when it appears feasible to release that inhibition. The time has come when we can direct all the power of our technology to make it feasible for anybody to ask the questions he wants to ask of the distinguished person from whom he wants an answer, and immediately to follow the answer with still another question.

Our vision goes something like this. Imagine that, wherever you are, you are able to pick up a telephone and ask for, say (if it happens to interest and intrigue you at the moment), Edward M. Purcell's thoughts, insights, feelings about momentum, about what momentum is. And imagine that, having done this, Professor Purcells' *voice* comes back to you and starts speaking about momentum, with all the directness and freshness that only Purcell can give to Purcell's conception of momentum.

Now, you might have chosen a different voice, of equal interest and competence. But whichever voice you pick from the galaxy of voices at the other end of the line, you always get an authentic and competent one, you always get a *best* voice in the field you are interested in.

That is the first part of the vision: That the thoughts and insights, the way of seeing, of our very best men (the men, for example, who have contributed to the Physical Science Study Committee) will be instantly and directly available to every one of us; that their statements of what, through a lifetime, they have come to feel and the way, in their own voices, they express it, will be instantly on call.

The second part of the vision has to do with our part in the interaction, for we do have an interaction in mind. As we listen to Professor Purcell's statement we will not want to listen passively, for we will find out that just listening passively will permit us only the slightest appreciation and understanding of what he means, and means us to see; indeed, of the whole process of thinking about momentum that led up to the completed, accurate statement we are listening to. Really to appreciate and understand, we will have to be able to stop the voice, repeat the voice and ask it questions, and the voice will have to be able to respond to our questions and appreciate *them* in very much the same way that Purcell, in preparing the statement, throughout his whole lifetime, appreciated and responded to his own questions. For behind his statement about momentum lies a grand, complex, and sometimes bewildering process of understanding, a process of understanding that *he* had to live through, one which, if we are to get even a partial understanding of momentum from his statement, we will have to live through too, but in our own way.

So the voice must be divergeable, controllable. It must not rush on, however beautifully, when we don't understand; it must answer our questions. And it must also be prepared for questions, not only about specific confusions, but questions which shoot off from the main track because something Professor Purcell said, "If an atom lost . . . yeah, I mean if an atom lost its electron, . . . where would the electron go?"

something whose richness he hinted at, makes us want to go there

Thus the second part of the vision says that not only are the best and most accurate statements, not the watered-down statements of the earlier traditional education, available at the other end of the line, but also that these statements can be searched through and explored in exactly the way our own minds require, according to our own internal imperatives, logical, illogical, brilliant, or otherwise.

Another and fully equivalent way of stating this vision is to ask: Why can't we make these life-generated and life-filled statements available to students in a way, through a link, that is more vital, more human, and more responsive than the printed page? And why can't we make these men's statements available through a link which mitigates the enormous task of finding and training people who can competently resay them? In short, why can't we make the link direct?

There are very pressing reasons of a social, demographic nature—the shortage of teachers, for example—to encourage this effort. But more important still, we should create this direct link because its existence will extend and amplify, by a quantum jump, every person's appreciation and understanding of the world.

Problems for Both Engineering and Science

To make the link a reality will mean solving some engineering problems of great but not insuperable magnitude. In fact, the engineering problems should be a joy to work at because the goal is so human. But there is another whole area of investigation, an area more properly scientific than engineering, that will have to be explored. For, when we place any student—including indeed ourselves—in an environment in which his intellectual reach is enormously extended and in which he has, for the first time, the chance to draw the culture to himself, we should not be surprised to observe whole new patterns of behavior on his part, whole new ways of relating to that culture.

In plain terms, what happens to you when you can ask and can get what you ask for? What happens when the answer to the urgent question which has *just* emerged from your unconscious is *immediately* available from the environment?

Matching Cultural and Student Circuits

We sometimes think of the link we have been talking about as a good impedance match: The cultural circuit delivers its power when the student circuit is most ready and willing to absorb it. And when the student circuit delivers *its* power, in the form of an urgent question, the cultural circuit is not absent, or deaf, or insisting on its own signals; the cultural circuit listens and responds maximally.

So the scientific question can be stated: What happens when the impedance match is good? What kinds of questions and sequence of questions does the student ask? What structures, through the impedance match, take root and unfold in his mind? And what is the pattern of their unfolding? In a larger sense, what does the well-matched availability of the structures of the culture mean to the human mind? What kind of availability—precisely what kind—does the individual require in order that the cultural structures become a part of him?

This is a new intellectual realm and wants a new science for its investigation. This science today is almost nonexistent, but it has been begun; and this report describes some concrete experimental steps in which we* attempted to create the relationship which we have described.

For students we used a small group of 13- and 14-year-old boys from the Roxbury section of Boston. They were selected for us on the basis of our request for individuals who would be open and interested.

The boys came, usually one at a time, to an apartment in Cambridge in which there was a pleasant, comfortable room in which they would feel private and relaxed. Each boy came approximately once a week for as many as 10 weeks, and there was no compensation for participating other than bus fare.

The student room was equipped for the experiment with an audio and a visual channel. The boy listened by way of a small loudspeaker and voiced his questions into a microphone. The visual channel consisted of an analog device having a pen which could be made to write and draw sketches by remote control. Any graphical information which the boy received came to him on this device, the Electrowriter.

The boys were met when they arrived by a receptionist who told them they were to use an experimental machine, designed to allow them to explore a subject freely. She explained that the voices they would hear came from tape recordings, and that the machine was capable of receiving a question and switching to a tape containing an appropriate answer. The boys could stop the machine and ask a question at any point, and they had a small control panel which let them signal for repeats, skips, and so on.

The boys were told they could use the machine as long as they liked and in any way they liked. The receptionist was available in another room in case the "machine" failed to operate correctly.

The other end of the link was housed in a third, concealed room in the apartment. There we had tape playback equipment, an operator, and—according to our technical term—an expert. The boy's questions were heard by the operator and the expert, and between them they decided whether to answer "live" or by using a passage from a previously recorded set of tapes. The subject of these tapes was atomic physics, mostly descriptive and without the mathematics, though the conceptual content was fairly rich. The style of the atomic

*The project began some years ago when one of the co-authors (Land) had the essence of the dream and stated its basic questions to the other, who undertook to bring concreteness through a long series of studies and experiments.

physics tapes was relaxed and informal but without loss of rigor in any important sense.

Atomic physics was the subject of the majority of the sessions, and one of us (Wilson) who had made these tapes acted as expert, selecting from the recordings or giving live answers as needed. When it became evident that two of the boys had a strong interest in astronomy, the machine became capable of talking about astronomy through the expert knowledge of Professors Purcell and Carl Sagan of Harvard, who knew that field and volunteered to participate in this work and to whom we are very grateful.

The boy never saw what was in the expert room, the expert or the operator. And the operator and the expert never saw the boy. There were no one-way windows. The boy was told he would be speaking and listening to a machine, because we wanted him free of any feeling of being watched or judged. And we wanted him to be uninhibited about stopping and questioning the voice.

We felt that if the impedance match were really to exist between the boy and his culture, then the boy's interaction with the expert who represented and expressed that culture should avoid the special and perhaps irrelevant interaction of their peculiar or special personalities; we feel that the interaction between the boy and the culture should be human, but not personal.

Of course, we were also curious to see how the boy took to a machine which could understand and talk to him. What would his attitude be? And then we also had in mind the fact that any widespread implementation of this arrangement is not going to be person-to-person—at least not very often. The boys may have suspected that there was someone in another room, but they never asked about it.

So the boys came and were told that the day's subject would be atomic physics or astronomy. They started the machine by asking a question or by just asking it to start where it left off—and then they and the expert began to explore.

Let us restate our motivation in doing these experiments and then go on to the results. Our first hypothesis, very simple but fundamental at this point, was that these students would react positively to the machine and would value the opportunity to use it. Our second hypothesis was that beyond just liking the machine they would interact with it in a serious, confident, and earnest way. Our third hypothesis was that if the impedance match was good, the questions the students asked—remember that these were not specially selected, brilliant students—would be interesting and exciting, the kind that make teachers happy and joyous.

The evidence suggests that our first hypothesis is correct, that these students valued—indeed prized—the opportunity to use the machine.

Hard Listening to Hard Subjects

The sessions lasted an average of *two hours* each, with a range from one hour to as much as three. During this time the machine was in continuous operation, with the student either listening or asking a question. All our ordinary ideas about a 13-year-old's span of attention in listening to hard subjects are shaken by this result.

Not only did the students spend a long time in the room, but they concentrated. Their absorption in what they heard is shown by the fact that their questions were, most of the time, either related to or clearly suggested by what they had just heard. And most of them took notes, in one case overflowing notes, straight through the session. (We might mention also that getting to the apartment and back to Roxbury was a one-hour bus ride each way, and that the students came after a full day in school.)

And, finally, they *told* the receptionist how very much they liked it!

Demands and Disappointments

Our second hypothesis—that they would use the machine confidently and with a sense of the importance to themselves, of entering into the interaction—was quite dramatically confirmed. Questions were exacting, even demanding at times, and there was often considerable disappointment if the machine could not answer. (This sometimes happened, and the fact was signaled to the student by a light on his panel.) Here are some examples of the questions, showing how earnestly the 13- and 14-year-old boys questioned the machine.

Q. *Now! Could you explain to me the first dimension, the second dimension, the third dimension, the fourth dimension, and the fifth dimension, and the sixth dimension—all in detail; and, if you could write it on your Electrowriter, please do. Thank you.*

Q. *Explain to me please . . . and don't say "no answer available" . . . explain to me the theory—Einstein's theory—of relativity, sumpin' like that, you know,* relativity.

Q. *Could you tell me what is beyond Pluto, or what do scientists theorize is beyond Pluto, or if they have any hard knowledge . . .* fact *. . . of what is beyond Pluto?*

Q. *What does "geophysics" really mean?*

Q. *Could you tell me all about astronomy? And show me on the Electrowriter too please. All about the stars, every star in the universe, all over the universe, every star in any other universe. Just mainly stars and planets and show me on the Electrowriter please. Thank you.*

Exciting Intellectual Moments

Our third hypothesis, if you recall, was that if the impedance match is indeed good, exciting intellectual moments will occur. Here is an example.

Q. *Why doesn't the match light in the carbon dioxide? You said before that oxygen helped to make . . . helped to . . . that (cancel) Why doesn't the ox . . . why doesn't the match light in the carbon dioxide? When you stick a match in it. And tell me why you said before that the match lit when . . . that a match, that fire needs oxygen in order to burn?*

(Notice how his hesitations, corrections, and fresh leaps forward express and reveal the deeper structures underlying his question. The tone and timing—the whole *process*—of such questions is hard to convey on a printed page.)

This boy had heard about the smoldering match flaring up in oxygen, quite a way back in the tape he was listening to. The tape had gone on, and at one point the fact that a match does not burn in carbon dioxide was mentioned. The tape then went on *even further* to something not related to this matter. But then suddenly, later, the question came: its gestation was over, and it was born. We think this is a very exciting example (and there are others like it) because it shows, first, how fresh and acute a boy's questions can be (How many of us would think of it this way? And yet, if you changed the substances involved, he would be exactly right—oxidation does not require free oxygen); secondly, it shows how he has been listening and trying to integrate, which means make sense out of, what he hears; and finally, it suggests something about the *technique* of making the impedance match effective.

We cannot tell at this early point whether the train of thought which preceded the overt asking of this question was conscious or developed mainly on the fringes of consciousness. This is a matter we would like to explore. But it is clear, at whatever level the thought-line developed, that it was a *long* thought-line. Indeed, we find that the most exciting questions have the longest thought-lines. And this suggests, as a general principle, that a good impedance match is one in which the development of thought-lines—they are probably very delicate—is not perturbed. We shall return to this a bit later.

Now here is an example of a boy wrestling with an idea, an idea he almost grasps.

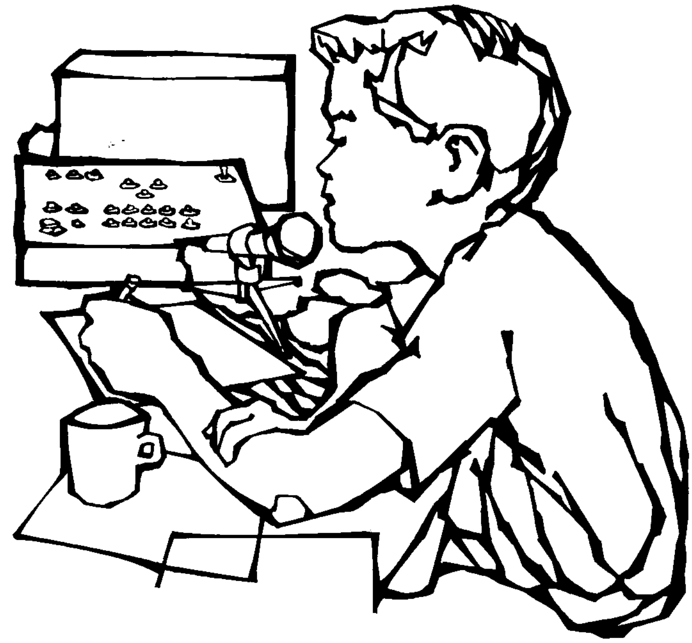
Q. *How could feathers be more denser than a pound of iron; a pound of iron and a pound of feathers, which weighs the most? How can they both weigh the same? It seems to me that a pound of iron would weigh, weigh more . . . but . . . feel heavier.*

This example shows how science has redefined words —iron *is* heavier than feathers—and how the concept of density is something that evolved very, very slowly. Here you can see it evolving in the child and you can be sympathetic with the idea that perhaps there is no kind of intellectual evolution, just as there is no kind of biological evolution, without going through the embryonic sequences; and so the embryonic sequences of ideas become something we must keep in mind.

The next question is an example of the formation of a hypothesis. Here is a boy who had just heard about gases and the fact that they are a swarm of moving molecules. The taped discussion then passed on to solids, and the fact that they, too, contain particles. The example used was diamond. He then asked this:

Q. *Do diamond crystals have molecules,* moving *molecules?*

We believe—we *guess*—that he said to himself, "A diamond crystal is so *different* from a gas. Yet he (the machine) says they both are made of particles. Maybe



the difference is that in a gas the particles are moving and in diamond they are not." We could be wrong about what he was thinking, but we think the lesson is that we must teach ourselves to listen.

Here is a question that is so beautiful that it eludes simple explanation. It is as though the atomic, particle nature of the universe is just starting to dawn on the boy. He is just beginning to feel it:

Q. *If an atom lost . . . Yeah, I mean if an atom lost its electrons, or lost an electron, where would the electron go? Or a neutron, or even a proton, if it lost any of its particles, where would they go?*

And here is the question that signaled a very important moment: his inner-felt urge to dive deeper into the atom. He had heard enough about the electrons around the outside and what they did. Now he was ready for the plunge:

Q. *Now! Show me a diagram on your Electrowriter of the electron system.*

Plunge it was, for he spent the rest of that session insisting, by pushing the "continue" button, that the answer (which was live) keep going.

Here are some questions by a mind which explores by comparing:

Q. *Is there any difference between the atoms in water and the atoms in earth, or dirt?*

Q. *How large is a sulphur molecule, and how large is an iron molecule? Show me the difference on the Electrowriter.*

Q. *Can you show me on the Electrowriter how a molecular bond breaks, and how an ionic bond breaks?*

Here is the same mind, and another, asking "why."

Q. *Why do oxygen atoms travel . . . (cancel). Why are oxygen atoms found in pairs?*

Q. *Why is it that when an astronaut goes out into space, and he's connected by a long umbilical line, a nylon line, why does he have a tendency to rise? Why?*

Now we have a sequence of questions by a boy for whom visualizations are very important to thinking.

Q. *Could extreme heat split an atom, and how would*

"How could feathers be more denser than a pound of iron; a pound of iron and a pound of feathers, which weigh most?"

it look if it could be split by extreme heat?

Q. *If I could split an atom at home, how would I go about doing it? Show me an example of how.*

Q. *How would the inside of an atom look after it has been split? Please show an example of how it would look.*

Q. *Could you show how a proton would look if it is split in half and what are the particles inside of it?*

And, finally, we see how this boy's visualization leads him to a conceptual paradox. He had heard how the positions of the electrons, since they are on the outside, define, roughly, the size of an atom. Then he asked:

Q. *You said the size of a molecule or an atom depends on where the electron is. What happens if the electron is one-millionth of a centimeter in large, and is over in the right-hand corner or over on the edge of the atom?*

We hope you will understand sympathetically that these are our very first experiments, our first probings of how a boy would explore and, in his own way, relive the structures of his culture, and our first attempts to make a part of that culture available in a way that means something to his mind.

The experiments were imperfect in several ways. We were not able to have the boys come oftener than once a week, and in many instances we could not follow every path their minds wished to take (we had to say "No answer available" or "No *more* answer available").

But we *did* the experiments. We learned from them, and we felt the color, life, and—we think—great adventure of this new science.

Unfolding the Structure in the Mind

But here is what we learned. We learned that the willingness of a student to reach out from the structure unfolding in his mind, to keep on unfolding it, is highly dependent on the attitude, the willingness, the very *tone* of the teacher at the other end of the line.

If, for instance, an answer by the teacher is too nearly perfect, too textbook-like—that is, if the teacher is more an information transducer than an originator—then the possibility that the next question will follow along the same track is low. And this seems to hold even when the teacher is very clear. On the other hand, if the teacher's answer is relaxed, exploratory, and does not imply a desire to impose a pattern, if the teacher uses his mind the same way he expects the student to use his, then the chances of a next question are high.

We find, in addition, that the more a teacher expresses his own feeling for the subject, his own unique point of view, without implying that he expects the student to adopt it, the more successful he will be in eliciting a subsequent question.

(One of the great values of our experimental arrangement was that it let us see these things more clearly, perhaps, than ever before. Because of their interpersonal separation, and because of the student's control, the student and teacher were, temporarily, peers.)

When we come to larger patterns of ideas, like whole subjects, we find that a teacher's habitual desire to direct the discussion in preconceived channels is inevitably frustrated, frustrated because the student *demands* changes of course, or, in the case of students more easily led, because the student's questions become less interesting or die out altogether.

It has become clear to us, in these experiments, that students want to structure knowledge in their own unique way. They want to follow an idea for awhile, until they are surfeited, so to speak, and then pick up another idea. (They return to the first idea perhaps the next day.) They do not honor the logic with which centuries of work has structured a subject, because they do not feel that peculiar and singular logic in themselves.

But it would be an error, we think, to suppose that what the students *are* constructing, as they leap from question to question, is not solid or ultimately fruitful. Isn't it clear that a path put together of things you really want to know, connected at *exactly* the moments you want to know them, will be more meaningful, more vital, and ultimately more fruitful than a path obtained from someone else?

This does not mean, though, that the teacher should be completely passive, should just wait for a question, answer it, and then wait for another. We have tried that and it does not work; although the questions come, they are old, stored-up questions. They are not likely to be intimately related to what the teacher has been saying. We think the trouble is that in *merely answering* a question, and then stopping, the teacher fails to evoke very many new "thought-lines" in the student's mind and brings those that *are* there to an end. What the student wants, and shows by signaling, is that the answer continue, blossom, and make contact with other things. Then the thought-lines continue and blossom, too, and an interesting question comes.

A Revealing and Expressive Guide

The student wants the teacher to guide him, but he wants his guide to be someone who *reveals* and *expresses*, without ever attempting, either actively or through inaction, to control.

Guides like this are hard to find. The role requires broad competence and the ability to adjust quickly to a student's frame of reference, and it also requires an untiring willingness to do so.

Being a good guide, being this new kind of teacher, means relinquishing the traditional concept of interaction between student and teacher. The interaction is there, but it is between the student and, in a broad sense, the culture around him. The guide is there because he may see more, or see further, or see in a special way. But he is not there to impress a set of ideas on the student, or even to facilitate and individualize a student's adaptation to a given set of ideas.

The guide is there because he is the vital intermediary, the impedance matcher, between the structures unfolding in the student's mind, whatever they may be, and the structures of the culture. This is often a very self-effacing task, but it can also be an exceedingly exhilarating one.

We intend to go on with this study, with this new science of the free and inner-directed interaction between a student and his culture. We intend to understand clearly and deeply just what goes on in a student's mind when he reaches out, and what must be there to reach out *for* if the unique, highly personal, and, therefore, highly authentic, structures developing in his mind are to thrive.

We feel that the study of how a boy does this, how we can help him *do it his own way,* is the next domain that must be mastered. Now that the techniques for working within the schools with large and organized groups has been brought so far by the Physical Science Study Committee and Educational Services, Incorporated, all of that work, in addition to being invaluable in the new classroom program, has provided a set of clear, felt statements of the way our best minds see nature. Making these statements available in the new system is our next full step. But we must then learn what availability *means to the human mind.*

Here is how we are going to do it. We are going to go on with experiments of the kind described, to find out exactly what makes for a good, lasting impedance match; and we are also going to begin developing the technological tools which will make our vision practical.

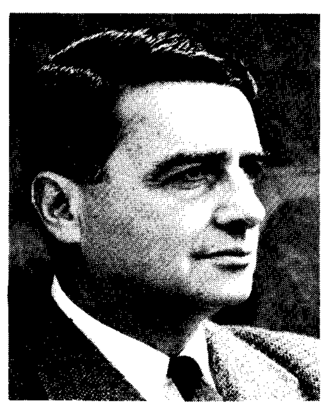
We have built a rather unique educational laboratory. In it we have private rooms for students and studios where teachers can make recordings and from which they can answer students' questions "live." We have a system which allows us to record, on the second track of a stereo tape, the diagrams which accompany a teacher's voice. When the tape is played back you hear his voice from one track and watch the recorded diagrams evolve from the second.

We are experimenting with indexing systems which will allow a nonexpert, but reasonably literate, operator to find answers to questions in previously recorded tapes. We are well aware of the vast and difficult problems of rapid and effective information retrieval, and we hope to draw fully on the results available internationally in this area. But we feel we should not stop and wait for the advent of completely automatic retrieval systems, because we feel that something short of full automation may be practical, that human operators, assisting computers, can serve the purpose of translating the voice to the machine during the next five, ten, or twenty years.

Human operators may be an important research tool in developing a more automatic system because we can observe the operators as they use indexes to retrieve tapes, and we can pick out gradually those parts of their activity which become regular, routinized, and strictly definable. And then, knowing what those activities are, we can define them to a machine.

The retrieval problem, attacked in this way, will form an important area of our research in the new laboratory, but there is a second technological area in which we are going to depend wholly on the work of others. I mean the problem of automatically recognizing the spoken word. Estimates of when this will become possible range from five to 20 years. But we believe it very important that a student be able to *speak* his questions; in fact, for younger students whose skills in written expression are undeveloped, that is the only satisfactory way. We will, therefore, continue to allow students to speak their questions directly; and, pending development of an automatic technique, we will continue to rely on operators for speech recognition. As a matter of fact, human operators may ultimately be as fast and as practical as an automatic device, since you have to wait for the words to be spoken, anyhow.

Thus we have begun to do two kinds of research in our laboratory—research on the way a student draws the culture's structures to himself, and research on how we can make the drawing, the interaction, the impedance match possible and practical for all students. Our work has convinced us that people enjoy and can grow through the question-answer-question approach to learning. We have satisfied ourselves that this may indeed be the best route from the naive and primitive, to the expert and sophisticated, mind. We have discovered that when people are sincerely permitted to learn in this way, they expect and demand a great deal from us. The initial answers must be given by men of enormous competence and considerable humanity, and we know that such men can be called upon only a few times for such a painstaking contribution. Americans go from mighty dreams to powerful realities through the intermediary of technology. Yet we often distrust, or lack confidence in, technology's relevance to man's deepest intellectual needs. We hope that this curious humanistic distrust will not block the evolution into reality of this particular, highly humanistic, dream.



Edwin H. Land's most recent honor has been the 1966 Albert A. Michelson Award; he holds seven honorary degrees and is a member of both the National Academy of Sciences and the National Academy of Engineering. Dr. Land founded Polaroid Corporation in 1937, and he is now its president and director of research. As Visiting Institute Professor at M.I.T., he has had an important role in stimulating development of the "project laboratory" programs.

Stewart W. Wilson, '60, who is working with Dr. Land on this unique educational experiment, is a graduate student in the M.I.T. Department of Electrical Engineering. His thesis will be an experimental study of the question-and-answer process, and he is also interested in pattern perception and the ability to interpret words.