LEARNING ADVENTURES

Handout

Pre-and-Post Workshop Reading

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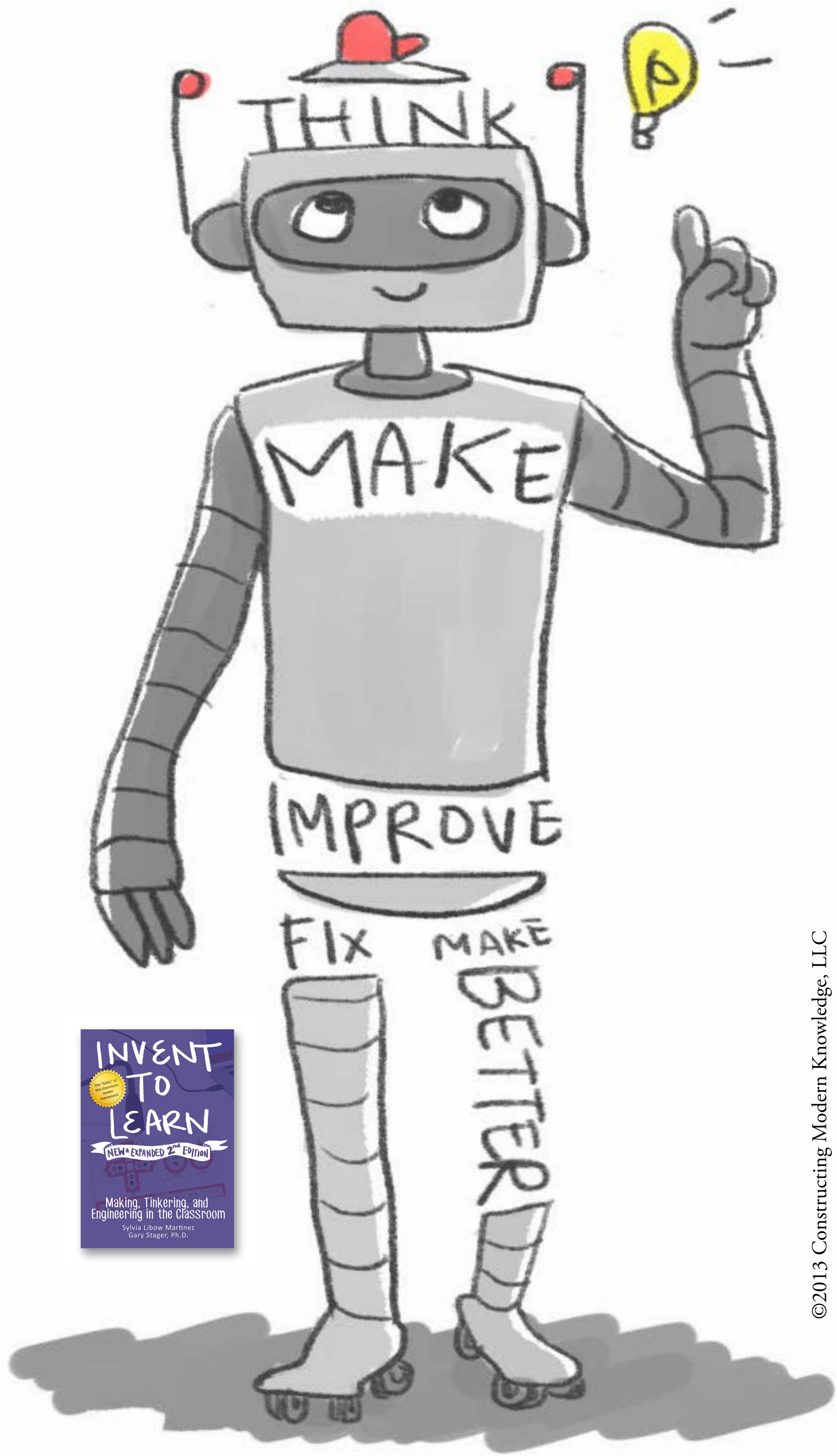


Process Learning

Eight Big Ideas Behind the Constructionist Learning Laboratory

By Dr. Seymour Papert (1999)

From the Ph.D. dissertation, "An Investigation of Constructionism in the Maine Youth Center," by Gary Stager, 2007.

The first big idea is **learning by doing**. We all learn better when learning is part of doing something we find really interesting. We learn best of all when we use what we learn to make something we really want.

The second big idea is **technology as building material.** If you can use technology to make things you can make a lot more interesting things. And you can learn a lot more by making them. This is especially true of digital technology: computers of all sorts including the computer- controlled Lego in our Lab.

The third big idea is **hard fun**. We learn best and we work best if we enjoy what we are doing. But fun and enjoying doesn't mean "easy." The best fun is hard fun. Our sports heroes work very hard at getting better at their sports. The most successful carpenter enjoys doing carpentry. The successful businessman enjoys working hard at making deals.

The fourth big idea is **learning to learn**. Many students get the idea that "the only way to learn is by being taught." This is what makes them fail in school and in life. Nobody can teach you everything you need to know. You have to take charge of your own learning.

The fifth big idea is **taking time – the proper time for the job**. Many students at school get used to being told every five minutes or every hour: do this, then do that, now do the next thing. If someone isn't telling them what to do they get bored. Life is not like that. To do anything important you have to learn to manage time for yourself. This is the hardest lesson for many of our students.

The sixth big idea is the biggest of all: **you can't get it right without getting it wrong**. Nothing important works the first time. The only way to get it right is to look carefully at what happened when it went wrong. To succeed you need the freedom to goof on the way.

The seventh big idea is **do unto ourselves what we do unto our students**. We are learning all the time. We have a lot of experience of other similar projects but each one is different. We do not have a pre-conceived idea of exactly how this will work out. We enjoy what we are doing but we expect it to be hard. We expect to take the time we need to get this right. Every difficulty we run into is an opportunity to learn. The best lesson we can give our students is to let them see us struggle to learn.

The eighth big idea is we are entering a **digital world** where knowing about digital technology is as important as reading and writing. So learning about computers is essential for our students' futures BUT the most important purpose is using them NOW to learn about everything else.

This document is translated into more than 15 languages at https://inventtolearn.com/around-the-world-with-the-8- big-ideas-of-the-constructionist-learning-lab/

Figure 1.2. Eight Studio Habits of Mind

We present the Habits of Mind in an oval because they are non-hierarchical, so none logically comes first or last. The habits do not operate and should not be taught in a set sequence that privileges one or another over the others. Instead, one can begin with any habit and follow its generative energy through dynamic, interacting habit clusters that animate studio experiences as they unfold.

Develop Craft

Technique: Learning to use tools (e.g., viewfinders, brushes), materials (e.g., charcoal, paint); learning artistic conventions (e.g., perspective, color mixing)
Studio Practice: Learning to care for tools, materials, and space

Understand Art Worlds

Domain: Learning about art history and current practice
Communities: Learning to interact as an artist with other artists (i.e., in classrooms, in local arts organizations, and across the art field) and within the broader society

Engage and Persist

Learning to embrace problems of relevance within the art world and/or of personal importance, to develop focus and other mental states conducive to working and persevering at art tasks

Stretch and Explore

Learning to reach beyond one's capacities, to explore playfully without a preconceived plan, and to embrace the opportunity to learn from mistakes and accidents

Envision

Learning to picture mentally what cannot be directly observed and imagine possible next steps in making a piece

Reflect

Question and Explain: Learning to think and talk with others about an aspect of one's work or working process
Evaluate: Learning to judge one's own work and working process, and the work of others in relation to standards of the field

Express

Learning to create works that convey an idea, a feeling, or a personal meaning

Observe

Learning to attend to visual contexts more closely than ordinary "looking" requires, and thereby to see things that otherwise might not be seen

Designed by Gunta Kaza, Graphic Designer, Professor, Massachusetts College of Art

Read: Winner, E. (2022). ***An Uneasy Guest in the Schoolhouse: Art Education from Colonial Times to a Promising Future.*** Oxford University Press.

Deborah Meier's Five Habits of Mind

as originally explored in the book, *The Power of Their Ideas: Lessons for America from a Small School in Harlem*

1. **Evidence** – asking, "How do you know?"
2. **Connections** – asking, "How is this connected to something else I already know or care about?"
3. **Perspective** or **Viewpoint** – asking, "From whose perspective is this story being told?"
4. **Conjecture** – asking, "How can I imagine a different outcome?"
5. **Relevance** – asking, "Why is this important?"

The Coalition of Essential Schools: **Common Principles**

Learning to use one's mind well

The school should focus on helping young people learn to use their minds well. Schools should not be "comprehensive" if such a claim is made at the expense of the school's central intellectual purpose.

Less is more: depth over coverage

The school's goals should be simple: that each student master a limited number of essential skills and areas of knowledge. While these skills and areas will, to varying degrees, reflect the traditional academic disciplines, the program's design should be shaped by the intellectual and imaginative powers and competencies that the students need, rather than by "subjects" as conventionally defined. The aphorism "less is more" should dominate: curricular decisions should be guided by the aim of thorough student mastery and achievement rather than by an effort to merely cover content.

Goals apply to all students

The school's goals should apply to all students, while the means to these goals will vary as those students themselves vary. School practice should be tailor-made to meet the needs of every group or class of students.

Personalization

Teaching and learning should be personalized to the maximum feasible extent. Efforts should be directed toward a goal that no teacher have direct responsibility for more than 80 students in the high school and middle school and no more than 20 in the elementary school. To capitalize on this personalization, decisions about the details of the course of study, the use of students' and teachers' time and the choice of teaching materials and specific pedagogies must be unreservedly placed in the hands of the principal and staff.

Student-as-worker, teacher-as-coach

The governing practical metaphor of the school should be "student-as-worker", rather than the more familiar metaphor of "teacher as deliverer of instructional services." Accordingly, a prominent pedagogy will be coaching students to learn how to learn and thus to teach themselves.

Demonstration of mastery

Teaching & learning should be documented & assessed with tools based on student performance of real tasks. Students not yet at appropriate levels of competence should be provided intensive support & resources to assist them quickly to meet those standards. Multiple forms of evidence, ranging from ongoing observation of the learner to completion of specific projects, should be used to better understand the learner's strengths & needs, & to plan for further assistance. Students should have opportunities to exhibit their expertise before family & community. The diploma should be awarded upon a successful final demonstration of mastery for graduation - an "Exhibition." As the diploma is awarded when earned, the school's program proceeds with no strict age grading & with no system of "credits earned" by "time spent" in class.

A tone of decency and trust

The tone of the school should explicitly and self-consciously stress values of unanxious expectation, of trust, and of decency (fairness, generosity, and tolerance). Incentives appropriate to the school's particular students and teachers should be emphasized. Families should be key collaborators and vital members of the school community.

Commitment to the entire school

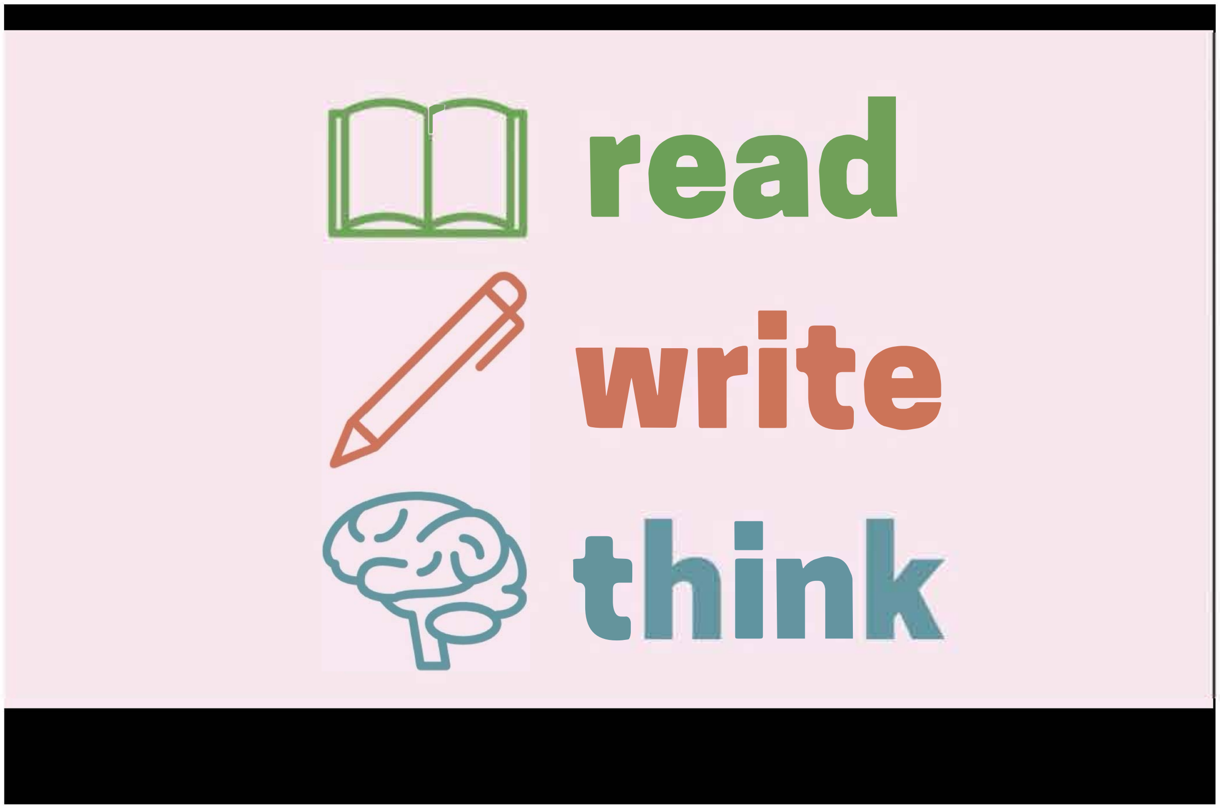
The principal and teachers should perceive themselves as generalists first (teachers and scholars in general education) and specialists second (experts in but one particular discipline). Staff should expect multiple obligations (teacher-counselor-manager) and demonstrate a sense of commitment to the entire school.

Resources dedicated to teaching and learning

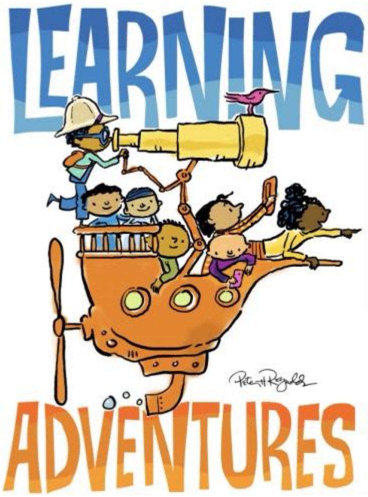
Ultimate administrative and budget targets should include student loads that promote personalization, substantial time for collective planning by teachers, competitive salaries for staff, and an ultimate per-pupil cost not to exceed that at traditional schools by more than 10 percent. To accomplish this, administrative plans may have to show the phased reduction or elimination of some services now provided to students in many schools.

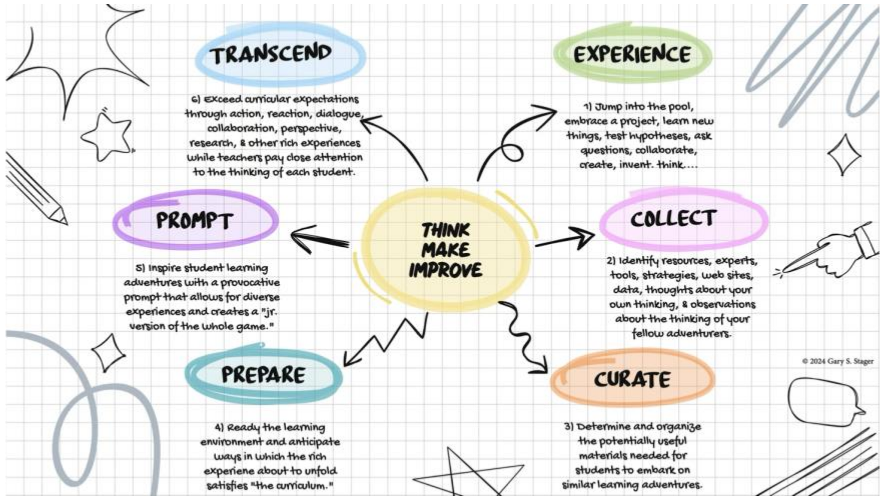
Democracy and equity

The school should demonstrate non-discriminatory and inclusive policies, practices, and pedagogies. It should model democratic practices that involve all who are directly affected by the school. The school should honor diversity and build on the strength of its communities, deliberately and explicitly challenging all forms of inequity.


read
write
think


The Writing Process
Prewriting
Drafting
Revision
Editing
Publication





Experience

What do you know? What can you do? What have you done?

Jump into the pool, embrace a project, learn new things, test hypotheses, ask questions, collaborate, create, invent. think....

Collect

Identify resources, experts, tools, strategies, web sites, data, thoughts about your own thinking, & observations about the thinking of your fellow adventurers.

Curate

Determine and organize the potentially useful materials needed for students to embark on similar learning adventures.

Prepare

Ready the learning environment and anticipate ways in which the rich experiene about to unfold satisfies "the curriculum."

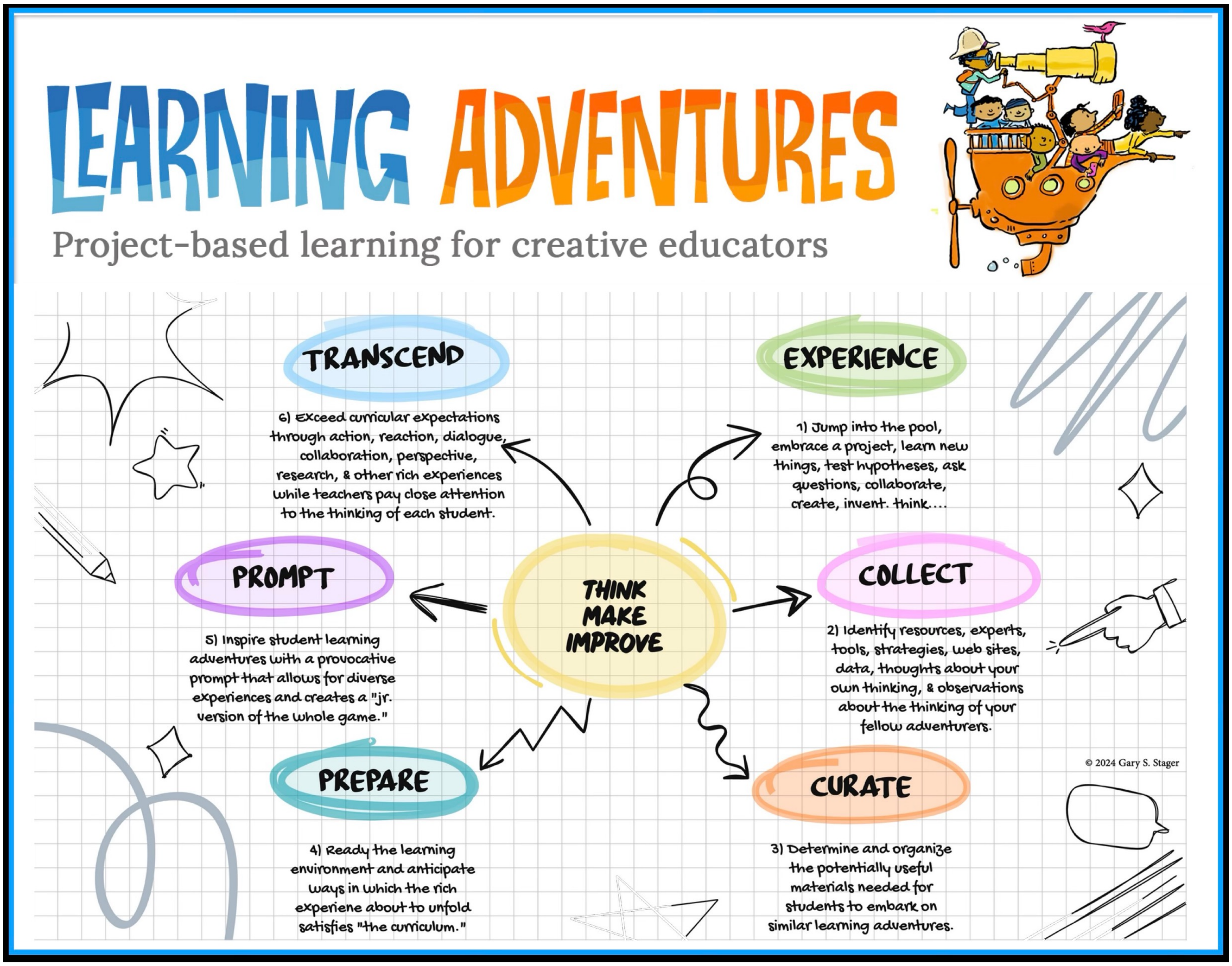
Prompt

Inspire student learning adventures with a provocative prompt that allows for diverse experiences and creates a "jr. version of the whole game."

Transcend

Exceed curricular expectations through action, reaction, dialogue, collaboration, perspective, research, & other rich experiences while teachers pay close attention to the thinking of each student.

Process Diagram



Education at Bat: Seven Principles for Educators

Professor David Perkins utilizes his childhood baseball experiences to develop a set of core principles and concepts for teachers

BY: Ruth Walker
POSTED: January 1, 2009

When Harvard Graduate School of Education Professor David Perkins looked back at his childhood little league and "backyard baseball" experiences, he found the perfect metaphor for the set of teaching concepts presented in his 2008 book, *Making Learning Whole: How Seven Principles of Teaching Can Transform Education*.

Asked in an interview with *Usable Knowledge* to describe how he would like educators to work with his ideas, Perkins says, “They should get a rough sense of the ideas and start using them.... They needn't read the whole book — they can just start with the first chapter.” *Making Learning Whole*, he says, “is a spiral process that front-loads action and then loops back to reflection and more learning — which is what the core principles recommend for learning anywhere.”

Seven Principles of Teaching

Why think about little league? Perkins says that in baseball, as in playing an instrument, one learns what it is to play the *whole* game first, and then to fine tune aspects of it over time. To elaborate on this concept of “learning by wholes,” Perkins details practical principles.

1. Play the whole game

Perkins identifies two unfortunate tendencies in education: One is what he calls “elementitis” — learning the components of a subject without ever putting them together. The other is the tendency to foster “learning about” something at the expense of actually learning it. “You don't learn to play baseball by a year of batting practice,” he says, but in learning math, for instance, students are all too often presented with prescribed problems with only one right solution and no clear indication how they connect with the real world.

The way to let young learners play the whole game is to find or construct a junior version of it. A junior version of baseball may involve fewer innings, a diamond that is smaller than standard, or teams consisting of whatever neighborhood kids show up in the park on a given day. Yet the junior version conveys the essence of baseball — swinging at and hitting a ball and then making your way around bases while the opposing team scrambles to put you out.

In teaching math, drilling children in multiplication or long division or even giving them “word problems” is likely to lapse into “elementitis.” But giving a child some money and asking her to calculate whether it's enough to buy the items in her shopping basket is a “junior version” of the way math skills are used in the real world.

2. Make the game worth playing

Perkins cites research showing that intrinsic motivation for learning academic subjects falls steadily from third to eighth grade. Students will want to learn, however, about things that they think have value and relevance in their lives. Perkins advises teachers to use “generative topics” — rich, engaging topics that encompass a wide scope — to make learning worthwhile for students. For example, a generative topic that could interest students might include a series of questions — “What is a living thing? Are viruses alive? What about computer viruses?” — and would help foster a discussion that creates conceptual knowledge.

3. Work on the hard parts

Again Perkins draws on personal experience for a metaphor: He observed that despite all their years of playing bridge, his parents really weren't getting better at it over time. He realized that they played for reasons of sociability, not competition. But if they had been trying to improve, they would have needed “deliberate practice” — a term Perkins borrowed from K. Anders Ericsson, a cognitive psychologist who focuses on the study of elite skill. Ericsson found that elite golfers, for instance, will go through the drudgery of endless “bunker” drills to improve their sand shots, and such practice matters more in the end than raw talent.

In Perkins' view, a learner needs both a sense of the whole game and a focus on specific trouble spots. “When I advocate playing the whole game, I don't mean doing nothing but that.”

4. Play out of town

Perkins refers to the challenge of taking one's game up a notch to play without the home-field advantage. In Red Sox Nation, it's a resonant sports metaphor, but it also refers to the transfer of knowledge from one context to another. Some information transfers are more easily made than others. For example, once you know how to drive a car you are easily able to transfer that knowledge to driving a truck, but it is much more of a stretch to relate the Civil War to the current tensions in Iraq. These examples illustrate the distinction between “near transfer” (car/truck) and “far transfer” (Civil War/Iraq). Educators can look for transfer to assess whether or not students thoroughly understand the topic they have been taught.

5. Play the hidden game

Again, a lesson from baseball: Perkins knew the concept of batting average, then he discovered the concept of “runs created,” a measure of how many runs a batter generates for each time at bat (on average) — an index more important than just getting hits. A stats view of baseball is one of baseball's “hidden games.” In baseball, algebra, or anything else we learn, there are richer, more layered aspects than what show up on the surface.

Perkins suggests two questions to help children learn to uncover the hidden game and do interpretative analysis: “What do you see going on? What do you see that makes you think so?” These questions can spark discussion about a work of art, but also about a scientific demonstration, a political speech, or any of a number of other kinds of presentations, and can draw “learners into the game of inquiry.”

6. Learn from the team

Perkins stands by this principle even with reference to activities that are not obviously team sports. He points out that the ethos of “Keep your eyes on your own paper!” is deeply ingrained in schools, even though they are natural centers of group learning. Perkins notes the importance of social learning, and he urges students to learn from teammates and from other “teams” — other students in different roles.

7. Learn the game of learning

Perkins suggests that teachers allow students to be in charge of their own learning by putting them in the driver's seat and letting them take control — rather than having them sit in the passenger seat and watch their education roll by.

In this era of high-stakes testing, Perkins cites a school that has emphasized diagnostic testing as a tool for individual students to understand their progress and to determine what to focus on next. “What particularly struck me,” Perkins writes, was that with a little help “the students, not the teachers, took stock of their own progress. The tests were framed emphatically as tools to provide information, not appraisals of worth.”

Putting it all together

To implement these ideas in the classroom, Perkins suggests that educators start with a junior version of the seven principles — picking and choosing what's most right for their own classrooms, while paying particular attention to “playing the whole game” and “making the game worth playing.” If educators use these principles, Perkins says, they will improve their students' understanding of the game and their ability to play it successfully.

From: The Informed Vision, Essays on Learning and Human Nature by David Hawkins Agathon Press 1974

Messing About in Science (1965)

> "Nice? It's the *only* thing," said the Water Rat solemnly, as he leant forward for his stroke. "Believe me, my young friend, there is *nothing*-absolutely nothing-half so much worth doing as simply messing about in boats. Simply messing," he went on dreamily, "messing-about-in-boats-messing-"
>
> Kenneth Grahame
> *The Wind in the Willows*

As a college teacher, I have long suspected that my students' difficulties with the intellectual process come not from the complexity of college work itself, but mainly from their home background and the first years of their formal education. A student who cannot seem to understand the workings of the Ptolemaic astronomy, for example, turns out to have no evident acquaintance with the simple and "obvious" relativity of motion, or the simple geometrical relations of light and shadow. Sometimes for these students a style of laboratory work which might be called "Kindergarten Revisited" has dramatically liberated their intellectual powers. Turn on your heel with your head back until you *see* the ceiling-turn the other way-and don't fall over!

In the past two years, working in the Elementary Science Study, I have had the experience, marvelous for a naive college teacher, of studying young children's learning in science. I am now convinced that my earlier suspicions were correct. In writing about these convictions, I must acknowledge the strong influence on me by other staff members in the Study. We came together from a variety of backgrounds-college, high school, and elementary school teachers-and with a variety of dispositions toward science and toward teaching. In the course of trial teaching and of inventing new curricular materials, our shop talks brought us toward some consensus but we still had disagreements. The outline of ideas I wish to present here is my own, therefore, and not that of the group which has so much influenced my thinking. The formulation I want to make is only a beginning. Even if it is right, it leaves many questions unanswered, and therefore much room for further disagreement. In so complex a matter as education, this is as it should be. What I am going to say applies, I believe, to all aspects of elementary education. However, let me stick to science teaching.

My outline is divided into three patterns or phases of school work in science. These phases are different from each other in the relations they induce between children, materials of study, and teachers. Another way of putting it is that they differ in the way they make a classroom look and sound. My claim is that good science teaching moves from one phase to the other in a pattern which, though it will not follow mechanical rules or ever be twice the same, will evolve according to simple principles. There is no necessary order among these phases, and for this reason, I avoid calling them I, II, and III, and use instead some mnemonic signs which have, perhaps, a certain suggestiveness: O, Δ, and [].

O Phase. There is a time, much greater in amount than commonly allowed, which should be devoted to free and unguided exploratory work (call it play if you wish; I call it work). Children are given materials and equipment-*things*-and are allowed to construct, test, probe, and experiment without superimposed questions or instructions. I call this O phase "Messing About," honoring the philosophy of the Water Rat, who absentmindedly ran his boat into the bank, picked himself up, and went on without interrupting the joyous train of thought:

> "-about in boats-or *with* boats. . . In or out of 'em, it doesn't matter. Nothing seems really to matter, that's the charm of it. Whether you get away, or whether you don't; whether you arrive at your destination or whether you reach somewhere else, or whether you never get anywhere at all, you're always busy, and you never do anything in particular: and when you've done it there's always something else to do, and you can do it if you like, but you'd much better not."

In some jargon, this kind of situation is called "unstructured," which is misleading; some doubters call it chaotic, which it need never be. "Unstructured" is misleading because there is always a kind of structure to *what* is presented in a class, as there was to the world of boats and the river, with its rushes and weeds and mud that smelled like plumcake. Structure in this sense is of the utmost importance, depending on the children, the teacher, and the backgrounds of all concerned.

Let me cite an example from my own recent experiences. Simple frames, each designed to support two or three weights on strings, were handed out one morning in a fifth-grade class. There was one such frame for each pair of children. In two earlier trial classes, we had introduced the same equipment with a much more "structured" beginning, demonstrating the striking phenomenon of coupled pendulums and raising questions about it before the laboratory work was allowed to begin. If there was guidance this time, however, it came only from the apparatus-a pendulum is to swing! In starting this way I, for one, naively assumed that a couple of hours of "Messing About" would suffice. After two hours, instead, we allowed two more and, in the end, a stretch of several weeks. In all this time, there was little or no evidence of boredom or confusion. Most of the questions we might have planned for came up unscheduled.

Why did we permit this length of time? First, because in our previous classes we had noticed that things went well when we veered toward "Messing About" and not as well when we held too tight a rein on what we wanted the children to do. It was clear that these children had had insufficient acquaintance with the sheer phenomena of pendulum motion and needed to build an apperceptive background, against which a more analytical sort of knowledge could take form and make sense. Second, we allowed things to develop this way because we decided we were getting a new kind of feedback from the children and were eager to see where and by what paths their interests would evolve and carry them. We were rewarded with a higher level of involvement and a much greater diversity of experiments. Our role was only to move from spot to spot, being helpful but never consciously prompting or directing. In spite of -because of!- this lack of direction, these fifth-graders became very familiar with pendulums. They varied the conditions of motion in many ways, exploring differences in length and amplitude, using different sorts of bobs, bobs in clusters, and strings, etc. And have *you* tried the underwater pendulum? They did! There were many sorts of discoveries made, but we let them slip by without much adult resonance, beyond our spontaneous and manifest enjoyment of the phenomena. So discoveries were made, noted, lost, and made again. I think this is why the slightly pontifical phrase "discovery method" bothers me. When learning is at the most fundamental level, as it is here, with all the abstractions of Newtonian mechanics just around the corner, don't rush! When the mind is evolving the abstractions which will lead to physical comprehension, all of us must cross the line between ignorance and insight many times before we truly understand. Little facts, "discoveries" without the growth of insight, are *not* what we should seek to harvest. Such facts are only seedlings and should sometimes be let alone to grow into...

I have illustrated the phase of "Messing About" with a constrained and inherently very elegant topic from physics. In other fields, the pattern will be different in detail, but the essential justification is the same. "Messing About" with what can be found in pond water looks much more like the Water Rat's own chosen field of study. Here, the implicit structure is that of nature in a very different mood from what is manifest in the austerities of things like pendular motion or planet orbits. And here, the need for sheer acquaintance with the variety of things and phenomena is more obvious, before one can embark on any of the roads toward the big generalizations or the big open questions of biology. Regardless of differences, there is a generic justification of "Messing About" that I would like, briefly, to touch upon.

This phase is important, above all, because it carries over into school that which is the source of most of what children have already learned, the roots of their moral, intellectual, and esthetic development. If education were defined, for the moment, to include everything that children have learned since birth, everything that has come to them from living in the natural and the human world, then by any sensible measure what has come before age five or six would outweigh all the rest. When we narrow the scope of education to what goes on in schools, we throw out the method of that early and spectacular progress at our peril. We know that five-year-olds are very unequal in their mastery of this or that. We also know that their histories are responsible for most of this inequality, utterly masking the congenital differences except in special cases. This is the immediate fact confronting us as educators in a society committed, morally and now by sheer economic necessity, to universal education.

To continue the cultivation of earlier ways of learning, therefore; to find *in school* the good beginnings, the liberating involvements that will make the kindergarten seem a garden to the child and not a dry and frightening desert, this is a need that requires much emphasis on the style of work I have called O, or "Messing About." Nor does the garden in this sense end with a child's first school year, or his tenth, as though one could then put away childish things. As time goes on, through a good mixture of this with other phases of work, "Messing About" evolves with the child and thus changes its quality. It becomes a way of working that is no longer childish though it remains always childlike, the kind of self-disciplined probing and exploring that is the essence of creativity.

The variety of the learning-and of inhibition against learning-that children bring from home when school begins is great, even within the limited range of a common culture with common economic background (or, for that matter, within a single family). Admitting this, then if you cast your mind over the whole range of abilities and backgrounds that children bring to kindergarten, you see the folly of standardized and formalized beginnings. We are profoundly ignorant about the subtleties of learning but one principle ought to be asserted dogmatically: That there must be provided some continuity in the content, direction, and style of learning. Good schools begin with what children have *in fact* mastered, probe next to see what *in fact* they are learning, continue with what *in fact* sustains their involvement.

Δ Phase. When children are led along a common path, there are always the advanced ones and always the stragglers. Generalized over the years of school routine, this lends apparent support to the still widespread belief in some fixed, inherent levels of "ability," and to the curious notions of "under-" and "over-achievement." Now, if you introduce a topic with a good deal of "Messing About," the variance does not decrease, it increases. From a conventional point of view, this means the situation gets worse, not better. But I say it gets better, not worse. If after such a beginning you pull in the reins and "get down to business," some children have happened to go your way already, and you will believe that you are leading these successfully. Others will have begun, however, to travel along quite different paths, and you have to tug hard to get them back on to yours. Through the eyes of these children you will see yourself as a dragger, not a leader. We saw this clearly in the pendulum class I referred to; the pendulum being a thing which seems deceptively simple but which raises many questions in no particular order. So the path which each child chooses is his best path.

The result is obvious, but it took me time to see it. If you once let children evolve their own learning along paths of their choosing, you then must see it through and *maintain* the individuality of their work. You cannot begin that way and then say, in effect, "That was only a teaser," thus using your adult authority to devalue what the children themselves, in the meantime, have found most valuable. So if "Messing About" is to be followed by, or evolve into, a stage where work is more externally guided and disciplined, there must be at hand what I call "Multiply Programmed" material; material that contains written and pictorial guidance of some sort for the student, but which is designed for the greatest possible variety of topics, ordering of topics, etc., so that for almost any given way into a subject that a child may evolve on his own, there is material available which he will recognize as helping him farther along that very way. Heroic teachers have sometimes done this on their own, but it is obviously one of the places where designers of curriculum materials can be of enormous help, designing those materials with a rich variety of choices for teacher and child, and freeing the teacher from the role of "leader-dragger" along a single preconceived path, giving the teacher encouragement and real logistical help in diversifying the activities of a group. Such material includes good equipment, but above all, it suggests many beginnings, paths from the familiar into the unknown. We did not have this kind of material ready for the pendulum class I spoke about earlier and still do not have it. I intend to work at it and hope others will.

It was a special day in the history of that pendulum class that brought home to me what was needed. My teaching partner was away (I had been the observer, she the teacher). To shift gears for what I saw as a more organized phase of our work, I announced that for a change we were all going to do the same experiment. I said it firmly and the children were, of course, obliging. Yet, I saw the immediate loss of interest in part of the class as soon as my experiment was proposed. It was designed to raise questions about the *length* of a pendulum, when the bob is multiple or odd-shaped. Some had come upon the germ of that question; others had had no reason to. As a college teacher I have tricks, and they worked here as well, so the class went well, in spite of the unequal readiness to look at "length." We hit common ground with rough blackboard pictures, many pendulums shown hanging from a common support, differing in length and the shape and size of bobs. Which ones will "swing together"? Because their eyes were full of real pendulums, I think, they could *see* those blackboard pictures swinging! A colloquium evolved which harvested the crop of insights that had been sowed and cultivated in previous weeks. I was left with a hollow feeling, nevertheless. It went well where, and only where, the class found common ground. Whereas in "Messing About" all things had gone uniformly well. In staff discussion afterward, it became clear that we had skipped an essential phase of our work, the one I am now calling Δ phase, or Multiply Programmed.

There is a common opinion, floating about, that a rich diversity of classroom work is possible only when a teacher has small classes. "Maybe *you* can do that; but you ought to try it in my class of 43!" I want to be the last person to belittle the importance of small classes. But in this particular case, the statement ought to be made that in a large class one cannot afford *not* to diversify children's work-or rather *not* to allow children to diversify, as they inevitably will, if given the chance. So-called "ability grouping" is a popular answer today, but it is no answer at all to the real questions of motivation. Groups which are lumped as equivalent with respect to the usual measures are just as diverse in their tastes and spontaneous interests as unstratified groups! The complaint that in heterogeneous classes the bright ones are likely to be bored because things go too slow for them ought to be met with another question: Does that mean that the slower students are *not* bored? When children have no autonomy in learning everyone is likely to be bored. In such situations the overworked teachers have to be "leader-draggers" always, playing the role of Fate in the old Roman proverb: "The Fates lead the willing; the unwilling they drag."

"Messing About" produces the early and indispensible autonomy and diversity. It is good-indispensible-for the opening game but not for the long middle game, where guidance is needed; needed to lead the willing! To illustrate once more from my example of the pendulum, I want to produce a thick set of cards-illustrated cards in a central file, or single sheets in plastic envelopes-to cover the following topics among others:

1. Relations of amplitude and period.
2. Relations of period and weight of bob.
3. How long is a pendulum (odd-shaped bobs)?
4. Coupled pendulums, compound pendulums.
5. The decay of the motion (and the idea of half-life).
6. String pendulums and stick pendulums-comparisons.
7. Underwater pendulums.
8. Arms and legs as pendulums (dogs, people, and elephants).
9. Pendulums of other kinds-springs, etc.
10. Bobs that drop sand for patterns and graphs.
11. Pendulum clocks.
12. Historical materials, with bibliography.
13. Cards relating to filmloops available, in class or library.
14. Cross-index cards to other topics, such as falling bodies, inclined planes, etc.

15 -75. Blank cards to be filled in by classes and teachers for others.

This is only an illustration; each area of elementary science will have its own style of Multiply Programmed materials. Of course, the ways of organizing these materials will depend on the subject. There should always be those blank cards, outnumbering the rest.

There is one final warning. Such a file is properly a kind of programming-but it is not the base of rote or merely verbal learning, taking a child little step by little step through the adult maze. Each item is simple, pictorial, and it guides by suggesting further explorations, not by replacing them. The cards are only there to relieve the teacher from a heroic task. And they are only there because there are apparatus, film, library, and raw materials from which to improvise.

[] Phase. In the class discussion I referred to, about the meaning of *length* applied to a pendulum, I was reverting back to the college teacher habit of lecturing; I said it went very well in spite of the lack of Multiply Programmed background, one that would have taken more of the class through more of the basic pendulum topics. It was not, of course, a lecture in the formal sense. It was question-and answer, with discussion between children as well. But still, I was guiding it and fishing for the good ideas that were ready to be born, and I was telling a few stories, for example, about Galileo. Others could do it better. I was a visitor, and am still only an amateur. I was successful then only because of the long build-up of latent insight, the kind of insight that the Water Rat had stored up from long afternoons of "Messing About" in boats. It was more than he could ever have been told, but it gave him much to tell. This is not all there is to learning. of course; but it is the magical part, and the part most often killed in school. The language is not yet that of the textbook, but with it even a dull-looking textbook can come alive. One boy thinks the length of a pendulum should be measured from the top to what he calls the "center of gravity." If they have not done a lot of work with balance materials, this phase is for most children only the handle of an empty pitcher, or a handle without a pitcher at all. So I did not insist on the term. Incidentally, it is not quite correct physics anyway, as those will discover who work with the stick pendulum. Although different children had specialized differently in the way they worked with pendulums, there were common elements, increasing with time, which would sustain a serious and extended class discussion. It is this pattern of discussion I want to emphasize by calling it a separate, O phase. It includes lecturing, formal or informal. In the above situation, we were all quite ready for a short talk about Ga1ileo, and ready to ponder the question whether there was any relation between the way unequal weights fall together and the way they swing together when hanging on strings of the same length. Here we were approaching a question-a rather deep one, not to be disposed of in fifteen minutes-of theory, going from the concrete perceptual to the abstract conceptual. I do not believe that such questions will come alive either through the early "Messing About" or through the Multiply Programmed work with guiding questions and instructions. I think they come primarily with discussion, argument, the full colloquium of children and teacher. Theorizing in a creative sense needs the content of experience and the logic of experimentation to support it. But these do not automatically lead to conscious abstract thought. Theory is square! []

We of the Elementary Science Study are probably identified in the minds of those acquainted with our work (and sometimes perhaps in our own minds) with the advocacy of laboratory work and a free, fairly O style of laboratory work at that. This may he right and justified by the fact that prevailing styles of science teaching are [] most of the time, much too much of the time. But what we criticize for being too much and too early, we must work to re-admit in its proper place.

I have put O, Δ, and [] in that order, but I do not advocate any rigid order; such phases may be mixed in many ways and ordered in many ways. Out of the colloquium comes new "Messing About." Halfway along a programmed path, new phenomena are accidentally observed. In an earlier, more structured class, two girls were trying obediently to reproduce some phenomena of coupled pendulums I had demonstrated. I heard one say. "Ours isn't working right." Of course, pendulums never misbehave; it is not in their nature; they always do what comes naturally, and in this case, they were executing a curious dance of energy transference, promptly christened the "twist." It was a new phenomenon, which I had not seen before, nor had several physicists to whom, in my delight. I later showed it. Needless to say, this led to a good deal of "Messing About," right then and there.

What I have been concerned to say is only that there are, as I see it, three major phases of good science teaching; that no teaching is likely to be optimal which does not mix all three; and that the one most neglected is that which made the Water Rat go dreamy with joy when he talked about it. At a time when the pressures of prestige education are likely to push children to work like hungry laboratory rats in a maze, it is good to remember that their wild; watery cousin, reminiscing about the joys of his life, uttered a profound truth about education.

Computer as Material: Messing About with Time

By Seymour Papert

This article was published in the *Teachers College Record* in Spring 1988 (Volume 89, Number 3). The project reported in this article was carried out at The Computer School, New York City Board of Education, 100 West 77th Street, New York, NY 10024. The work presented here was aided by a grant from the Apple Education Foundation. Seymour Papert is affiliated with the Massachusetts Institute of Technology. George Franz is affiliated with The Computer School and the New York City Board of Education.

Computers began in education with a charismatic aura that cannot remain characteristic of their long-term presence. As they become part of the everyday toolbox that kids can dig into, will they have any special value?

Computers, with their power and technological sophistication, fascinate just about everyone. Teachers, parents, administrators, and students agree that computers have added an important presence and dimension to educational settings. However, within the history of education, computers represent a very recent arrival on the scene and their role has not yet begun to be explored.

An examination of computer use in schools today reveals that students' interactions with computers are largely teacher-directed, workbook-oriented, for limited periods of time, and confined to learning about the machines themselves or about programming languages. Further, computers are located in separate labs and are not integrated into the standard curriculum. "Doing computer" in school is thought of as an exciting activity in and of itself. This separation is reflected in the often asked question: "Does what children learn with the computer transfer to other work?" The present separation of computers from other curricular areas is reflected too in arguments about whether computers might even be bad for children.(1)

The project described in this article approaches the computer in quite a different sense. Instead of the familiar uses of the computer, which Robert Taylor has christened "Tutor, Tutee, Tool," (2) the computers in this project are employed in a new way, which we call "Computer as Material."

The setting for the project was a junior high school science classroom in the New York City public schools. The classroom was well supplied with various materials from test tubes, pulleys, and microscopes to scrap wood, broken electronic devices, marbles, and the like. Also present in the room were computers and LOGO. In this project, the students built devices for measuring time using any materials they wished. Some used string and a metal weight to make a pendulum, some used plastic containers to dribble sand -- and some used computers. Our central focus is this use of the computer as just another type of material.

We mention one other closely related point of interest. The phrase "messing about" in our title is, of course, taken from a well-known paper by David Hawkins.(3) Marvelously entitled "Messing About in Science," it describes how he and Eleanor Duckworth introduced children to the study of pendulums by encouraging the students to "mess about" with them. This would have horrified teachers or administrators who measure the efficiency of education by how quickly students get to "know" the "right" answers. Hawkins, however, was interested in more than right answers. He had realized that the pendulum is a brilliant choice of an "object to think with," to use the language of Papert's *Mindstorms* (4), one that can build a sense of science as inquiry, exploration, and investigation rather than as answers.

Just as pendulums, paints, clay, and so forth, can be "messed around with," so can computers. Many people associate computers with a rigid style of work, but this need not be the case. Just as a pencil drawing reflects each artist's individual intellectual style, so too does work on the computer.

THE PROJECT -- TIMERS AND CLOCKS

Step one of the project was to bring the students to understand the need for the measurement of time. The teacher began by putting an empty glass jar over a lit candle and having the class watch the flame go out.(5) This was repeated several times, then the students' wristwatches were collected and the classroom clocks were disconnected.

Repeatedly the candle was lit and the jar was placed over it, and the students were asked to predict when the candle would go out. They quickly realized the need to develop a timing procedure -- such as counting their heartbeats or breaths, or counting one-Mississippi two-Mississippi, and so forth. It might take fifty-seven heartbeats or fourteen breaths from the time the jar was placed over the candle until the flame was extinguished.

After perfecting their own "body timers," the students covered their eyes and raised their hands to indicate when they thought the candle had gone out. There was much discussion concerning different methods of timing and the accuracy of each, prompting the students to defend, evaluate, compare, and evolve their individual timing systems.

The need for something more objective than body clocks was sharpened by introducing environmental influences. Without any explanation, phonograph records (first a fast rock 'n' roll, later a slow Brahms) were played as the students carried out their timing methods. Further, students reentering the room on successive days were asked to predict from memory when the candle would extinguish. While some students' predictions remained quite accurate, most were significantly off. Discussion led to the conclusion that the rate of their body timers varied from one day to the next and that they were also affected by what went on in the class, such as the type of music that was played. It thus became obvious that the next step was to create a timer that was much more accurate and consistent from day to day.

What to do? How to proceed? Different suggestions were offered, most of them fantastic and impossible, often ideas centering around the creation of complex timers such as the gear-driven type on the wall or on their wrists. After a period of discussion, the teacher suggested that this was enough talk. "Let's get to work and make some clocks," was the challenge.

BUILDING CLOCKS

The room was well stocked with materials -- in part because students were encouraged to bring in what a casual observer (and even the children) might call "junk," such as egg cartons, soda bottles, tin cans, and so forth. (The project would have been very different in a room full of only "sterile," store-bought equipment.)

The students set to work constructing timers, which took many different forms. Plastic cups taped together after having been filled with just the right amount of sand (determined experimentally) became crude egg timers. Water dripped out of a small hole in the bottom of a tin can and loudly plopped on a tin plate; the number of drops was carefully counted to tell elapsed time. A metal marble rolled through grooves chiseled out of pieces of wood; its speed, and therefore the time involved, could be controlled by varying the angle of the wood. Water slowly flowed into a cup on the up-end of a seesaw, and when the proper amount of time had elapsed, enough water filled the cup to make the seesaw tilt, at which point a piece of metal was tripped to complete a circuit that rang a bell. For students who found it hard to imagine a timer, there were library books with drawings, descriptions, and model plans of many different timing devices.

The room was also well supplied with material of a very different kind -- computers and LOGO -- which some of the students chose to use in constructing their clocks. The first LOGO timers were not really very different from the. other clocks being built. Some examples included a regularly blinking screen, or a turtle alternately moving forward and then pausing, or the computer beeping at regular intervals.

While some students were speaking the language of LOGO in order to achieve their goal of making a timer, others were speaking the language of a chisel, or of a battery and electric motor, or of a ball rolling down an inclined plane. Most of these languages were new to the children. What was important was that the students were learning to speak the languages of many different materials in the classroom in an attempt to create their clocks from ideas in their minds. When the students let their imaginations go, they found a variety of odds and ends for different explorations and investigations. The emphasis was on inquiry and learning, not on the type of material used. The computer was just one more material, alongside candles, crayons, ammeters, and rulers. The computer did, however, add dimensions not present in other materials, allowing students to go beyond the capabilities of the clocks constructed with the more commonly found materials.

BEYOND "MESSING AROUND"

While computers were used like wood, string, and electricity as material to mess about with, they evolved into something else as the LOGO timers became more differentiated and sophisticated. The students began constructing LOGO clocks that were highly accurate and precise, a goal not easily attained with the other materials.

Many of the LOGO clocks became as accurate as the students' wristwatches. These clocks ranged from a second hand that moved clockwise around the face of a square clock each minute to a digital readout of hours, minutes, and seconds. Some students added a beep for each second; others printed out on the computer monitor the number of seconds as they ticked by.

CALIBRATION: A FIRST CONNECTION TO MATH

The original problem of predicting when the candle would go out could be solved without using standardized units of time, that is, seconds, in the handmade clocks. As long as a clock beat with a fixed rhythm, it could be used to find out that the candle burned for, say 47 units, while another "slower" clock might have used only 27 units. Now a new question was posed to the class: "How do the units of our clocks compare with the standard unit of seconds?" This is the problem of calibration, and it gave rise to a new phase of the project. The goal this time was to relate the unit of their clocks to the standard time unit of seconds.

The precision of the LOGO clocks did not come automatically from the precision of the computers themselves. Like the other clocks, these also needed to be calibrated. It is easy to write a LOGO program that will repeat an action with a fixed period. However, calibration was still needed to make the period precisely match normal time units. The computer clocks were just like the non-computer clocks in this respect, so calibration is discussed in its general form.

Suppose you have a process that repeats about once a second and you want to adjust it to repeat exactly once a second. How would you proceed? Some of the students began by trying to adjust each individual unit to once per second. Discrepancies were easy to see when the intervals between their clocks and actual seconds were very far apart (say once per two seconds or twice per second), but when the intervals came close together, judgment could not be made by eye. Students tried using intermediate processes -- for example, clicking their fingers in time with a watch to signal one beat per second and then comparing this with the period of their own clocks. Such tricks improved their estimation but were still rather limited.

A suggestion that spurred more fruitful directions of inquiry was the idea of thinking in terms of series of cycles rather than individual cycles. Instead of trying to time a single event that took one second, students could make a test run by timing twenty of these events-which should take twenty seconds. This was quite an improvement.

Students also incorporated the concept of averaging numbers to their data. They realized that in order to ensure the accuracy of their clocks, they had to make several test runs and then average the results of the runs. Obtaining an average had never been quite so effortless in math class! This was the first time any of the students had come across the concept of statistical averaging -- using more than one trial run since it was possible that they had made a gross error on just one test try.

The connection with statistics was only one of many ways in which the work on clocks led into analytic reasoning. We saw another example in the LOGO clocks. If the clocks used WAIT 20, the program counted out the seconds too slowly. (The LOGO manual states that the command WAIT 20 pauses for one second.) Interestingly, when they analyzed the problem, the students often thought that their clocks ran too slowly because "twenty was too small," so they changed it to twenty-five. This made their timers pause for a longer period of time and therefore go even more slowly. Trial and error mingled with ample quantities of thought and discussion led them to realize that the smaller the number following WAIT, the shorter the wait. Then it was simply a matter of finding the right number by further trial and error. In the case of the non-computer clocks, too, it was not always obvious to the students which direction of change would increase the period. Should one lengthen or shorten the pendulum's string or maybe increase the weight of the pendulum bob?

In the work on calibration, careful measurement revealed that a large graduated cylinder with a small funnel in its mouth became an accurate timer as it filled up with one milliliter of water every two seconds; a battery-driven LEGO car moved precisely one centimeter in three seconds, so the distance it traveled also represented the elapsed time; a pendulum was carefully constructed with a swing time of precisely one second and was ingeniously electrically wired to blink a light bulb on each swing. Regardless of the material selected to construct their timers and clocks, the students were dealing with many of the same types of issues, such as accuracy and calibration.

BEYOND THE CLOCK PROJECT

A significant difference of the computer clocks became apparent in the area of extensibility. While many of the sand or water clocks were excellent timers, their use could not be extended beyond that. The computer clocks, however, were put to a variety of uses.

EXTENSIONS: A COMPLEX TIMER

In one instance, the students obtained a photoelectric eye, similar to the type used by stores to signal entrance and exit. Using an electronic interface box, they plugged it into the game port of a computer, and used a LOGO command to measure the amount of light the eye was sensing. In another project, students were messing about with motion by using LEGO blocks to build cars to go down an eight-foot ramp. Wanting the cars to be fast, the students experimented with design variables, such as the size and weight of the car, the diameter of the tires, whether more weight should be in the front of the car ("front wheel drive") or the rear ("rear wheel drive").

At some point, the students who were building LOGO clocks realized that they could use their clocks in conjunction with the electric eye as timers for these LEGOmobile races. Now, different groups of students were working together, combining and expanding upon each others' projects. They placed the electric eye opposite a light bulb at the bottom of the ramp, and wrote LOGO programs to measure the amount of time it took the cars to travel down the ramp. They placed a LEGOmobile at the top of the ramp, and let it go simultaneously as they began their timer programs. When the car reached the bottom of the ramp, it passed between the electric eye and its light source. The amount of light hitting the eye momentarily decreased, causing the timer program to stop. The last number printed was the time the car took to run down the ramp.

Realizing the inadequacy of whole seconds, the students expanded the computer clocks by improving their timer programs so that tenths of a second were printed out on their monitors (by changing the number following the WAIT command). This was probably the first time in their lives they had used decimals in a real and useful way. One boy, inspired by the Olympics, even tried to print out hundredths of a second. Some of the students were encouraged to calculate the speed of the cars in miles per hour. They did this by knowing the length of the ramp and the amount of time it took the LEGOmobile to move that distance, and then converting to miles per hour. After many calculations (off the computer!) and spurred on by their own excitement and curiosity, they determined that their little cars were traveling at a rate of six to eight miles per hour.

The point of these explorations is that different groups of students had come together to solve problems in which they were interested. Some students had created a highly sophisticated timing device. Some had built the ramp, others the cars, two were experts on the electric eye, while others had written the functional LOGO programs. Some had perfected the clocks to an accuracy of tenths of a second while others had calculated the speed of the cars in miles per hour. They had all joined in a rather informal way and had worked toward a common goal. To say that the computer was the central focus of the project is to miss the point, but it is clear that the extensibility of the computer to other objects was fundamental to the project's success.

EXTENSIONS: A TEMPERATURE SENSOR

Another area of computer extensibility was seen in some interesting work done with long-term LOGO clocks used to measure aspects of the environment over periods of time. Some students, and the teacher as well, had long been concerned about the well-being of the class animals (hamsters, mice, snakes, turtles, and fish) during the cold winter nights, weekends, and vacations. Rumor had it that the schools saved money by shutting down their boilers at night, and it was feared that the animals would die or become ill as a result of the cold temperatures. We obtained a temperature sensor able to interface with a computer. The students wrote LOGO programs that instructed their clocks to print out the reading of the temperature sensor every hour, and we set up the clock programs and left them running over the weekends. Students were relieved to find out that although the outdoor temperature measured in the teens Fahrenheit, the nighttime and weekend classroom temperature remained fairly warm.

Once again, the point is that while the computer was treated as another type of material in the classroom, it did possess the power to allow a link to be formed between the students' clocks and their very real concern for their animals.

ROLE OF THE CLOCK PROJECT IN THE COMPUTER CURRICULUM

It was not necessary for the students to be fluent with LOGO to set up their clock projects. Indeed, they learned a good deal about computer programming in the process of creating their clocks and timers. For example, students had been exposed several times to the idea of variables in a computer program. (A variable is a number that changes as the program proceeds.) However, only some of the students had assimilated this concept and used it in their programming. Others had not been so quick to grasp the idea of LOGO variables.

When the students were confronted with the problem of making a timer, many of those using computers needed to find a way to represent seconds by a number that increased by one as the seconds ticked by. For the first time, they needed variables to solve a problem they were interested in. When they realized that they could solve it by using "one of those words with the two dots in front of it" (i.e., "seconds"), they understood the previously learned but not fully comprehended idea.

For most of the students, creating LOGO timers was the first time they had used computers to make programs that made connections with the physical, tangible, non-computer world. The insight that LOGO could be used to solve real-world problems was further amplified when they used their LOGO timers to determine the speed of their homemade cars and when they interfaced their clocks with the temperature sensor.

THE ROLE OF THE COMPUTER

WHY IT IS SO SPECIAL

The computer clocks, as compared with those made from other materials, were unique in several aspects. First, these clocks could be extremely accurate. As we have noted, some students calibrated them to tenths of a second. This high degree of accuracy is clearly unparalleled when compared with the other types of clocks the students made, and the students appreciated this accuracy when they wanted to time their LEGOmobile's speed precisely.

Second, it was quite simple to adjust the speed of the LOGO clocks by changing the number following the WAIT command. Thus, it was relatively easy to match the handmade LOGO clock to the clock on the wall or the wrist. By contrast, calibrating the sand clocks meant ripping them apart and changing the size of the hole through which the sand flowed. Only painstaking trial and error showed exactly how much larger or smaller the hole had to be. This was true for the other non-computer clocks as well.

Further, the LOGO clocks were more adaptable and could be easily connected to other ongoing projects in the classroom. We have described the timer/ LEGOmobile connection and the clock/temperature-sensor experiment. The students took quite naturally to the integration of the LOGO clocks with these other projects.

WHAT IS NOT SO SPECIAL

None of this should be taken to mean that the computer and LOGO are the be-all and end-all of this type of exploration. Certainly the LOGO clocks were accurate, adaptable, and easily adjustable -- but the other clocks were wonderfully inventive, creative, and fun. They were also far more accurate than we would have predicted at the beginning of our study of time. While not as accurate as the LOGO clocks, almost all of them certainly did the job, within a few seconds, of telling their inventors when the candle would go out.

It is important to note that none of the clock media (computers, sand, wood, etc.) stood out for the students as more desirable or valuable than the others. Some of the students were attracted to wood and so made their clocks out of wood. Similarly for water, or electrical devices, or pendulums. There was no competition for who could make the "best" clock (whatever that would mean) or even the most accurate one. There was simply a classroom filled with various types of clocks being constructed, some on the computer, some out of wood, some with water, and so on. All of the students were involved with their own, individual clocks, trying to perfect them to the best of their ability and interest.

A NEW WAY TO USE THE COMPUTER

We have described what we consider to be an example of truly educational computing -- active, exploratory, student-directed learning involving the use of the computer. Through programming languages such as LOGO, computers allow our students, within certain limits, to perform tasks that are difficult or even impossible to achieve with other materials. We emphasize that it is possible to create activities that connect many different students' interests to various curricular areas, and to connect "separate" disciplines to each other. Our goal was, and continues to be, to create learning situations in which connections are allowed to develop freely and to move in any direction, albeit many or even most of them unpredicted. A certain degree of openness and flexibility on the part of both teachers and students is obviously necessary to keep the inquiry interesting, stimulating, and exciting.

Some important guidelines, then, for the placement and use of computers in schools include the following:

1. Seek out open-ended projects that foster students' involvement with a variety of materials, treating computers as just one more material, alongside rulers, wire, paper, sand, and so forth.
2. Encourage activities in which students use computers to solve real problems.
3. Connect the work done on the computer with what goes on during the rest of the school day, and also with the students' interests outside of school.
4. Recognize the unique qualities of computers, taking advantage of their precision, adaptability, extensibility, and ability to mirror individual students' ideas and constructions of reality.
5. Take advantage of such new, low-cost technological advances as temperature and light sensors, which promote integration of the computer with aspects of the students' physical environment.

While the theme of this article has been the role of the computer in the educational process, let us clearly state that the ideas underlying our teaching strategies were formulated by educators and philosophers whose lives long predated the invention of the computer, and whose ideas can be applied to any learning situation and to any material. Our emphasis, as was that of Piaget, Dewey, Susan and Nathan Isaacs, and others, is clearly on the inquiry and the learner, not on the specific curriculum or facts to be learned. In this undertaking, all materials are created equal, although admittedly the computer did add unique and powerful aspects to the learning process.

Notes

(1) "The Computer in Education in Critical Perspective." *Teachers College Record* 85, no. 4 (1984): 539-639.

(2) Robert Taylor, ed., *The Computer in the School. Tutor, Tool, Tutee* (New York: Teachers College Press, 1980).
(3) David Hawkins, "Messing About in Science," *Science and Children 2*, no. 5 (1965): 5-9.
(4) Seymour Papert, *Mindstorms: Children, Computers and Powerful Ideas* (New York: Basic Books, 1980).
(5) See Hubert Dyasi, African Primary Science Program, *Measuring Time: Part I-Making Many Simple Clocks* (New York: The Workshop Center, n.d., NAC 4/220 City College of New York).

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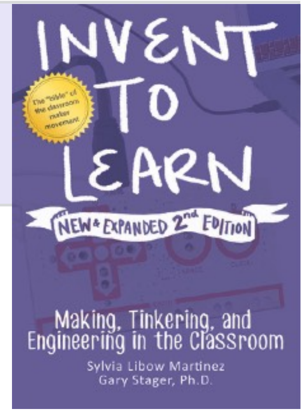

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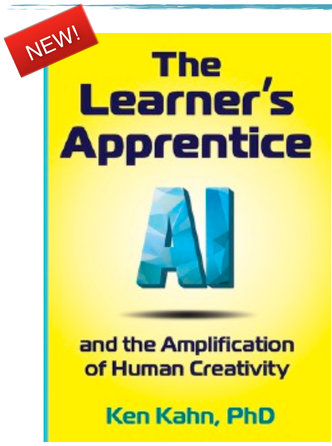

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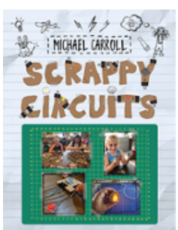

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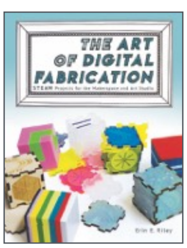

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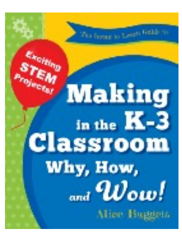

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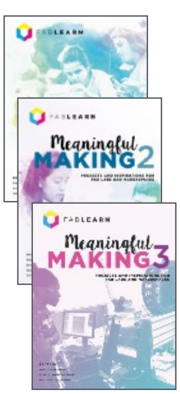

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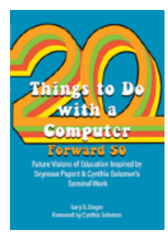

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