Jeremiah A. Ho
Assistant Professor of Law | University of Massachusetts School of Law
jho@umassd.edu | 508.985.1156
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Hybrid Within a Hybrid: Integrating Academic Success in Upper-Level Capstone Courses

- **Why Capstone Courses in General?**

Traditionally capstone courses have been used to take the knowledge that students have gained in earlier courses in law school and apply it on an advanced level within a combination of legal subjects. Many law schools employ capstone courses in the upper-level curricula to build on foundational knowledge and skills, and either sharpen previous learning or advance new learning on a previously-seen subject. These courses frequently tie together theory and doctrines from separate legal concepts, often illuminating the overlap amongst subject areas that law school courses tend to artificially compartmentalize. Across higher education, capstone courses are generally used as a culmination of the educational experience within a degree program.

Examples of capstone courses in law school curricula nationwide include:

Dispute Resolution
Commercial Real Estate Transactions
Domestic Relations
Small Business Planning
Remedies
Products Liability
Estate Tax
Environmental Law
Domestic Violence
Health Law
Family Law
Special Education
White Collar Crime
Mass Torts

Many of these courses enable skills development and experiential learning as well. Often such courses are infused with the reinforcement of either simulated or clinical professional experiences to add acquisition of practical legal skills by students. The potential of capstones, in this way, have engendered much discussion by legal educators and professionals on how capstones can be used to further the principles highlighted in Carnegie, MacCrate, and Best Practices. In addition, even more recently, capstones have been seen partly as solutions to the discussion regarding the state of legal education and the urge by the legal profession to expect "practice-ready" graduates.

- **Where Do They Best Fit for Academic Support?**

Based on the above, many law schools have built capstones in their late upper-division curricula. They are often meant to be a bridge between the study of law and the legal profession. This idea is consistent with how capstones are treated across higher education, in other graduate degree programs, as both a moment of culmination of learning and/or as a moment of reflexivity and assessment. Ideally, students should have some foundational coursework done on many of the areas of law taught in capstone courses so that both moments are captured and utilized to maximize the impact of the curricula.

The assessment piece places capstones well for upper-level academic support courses and bar support programs. In theory, as doctrines in a capstone courses are familiar ones that students might have encountered previously, capstones can serve as an in-depth review and advanced furtherance of prior knowledge. In addition, as "shorthand" might exist for the doctrine because of student familiarity, classes can spend more time engaged in course work dealing with legal analysis, communication skills, advocacy skills, bar testing, and other skills that embed academic support instruction. An instructor leading a capstone course can almost hinge the course on academic support instruction and allow the capstone doctrines to support the course work.

- **How Do Law Teachers Design Capstone Courses that Integrates ASP?**

This workshop combines both the practices underlined in *Teaching Law by Design* (co-authored by Michael Hunter Schwartz, Sophie Sparrow, and Gerald Hess) in course design and the principles within Jerome Bruner's spiral learning theory in order to plan an effective capstone course in the upper-level curriculum that incorporates academic support learning.

In essence, since a capstone course should also be "like any other good, effective course" in that the design and execution of the course should be one that maximizes and advances particular goals in student learning and is reflective of good teaching, some underlying principles regarding effective course design bleed into the realm of capstone course design.

Below is a checklist reproduced from *Teaching Law by Design*.

Course Design Checklist:

- ☐ Determine what you want students to know, value, and be able to do
- ☐ Figure out who your students are
- ☐ Decide how you will assess students and draft assessments
- ☐ Choose texts
- ☐ Design each part of the course
- ☐ Design the course as a whole
- ☐ Create a syllabus that
  - ☐ Provides the basic information students need and addresses all the issues that reasonably might arise in class;
  - ☐ Engages students;
  - ☐ Communicates high expectations;
  - ☐ Includes challenging and appropriate reading and problem-solving assignments
  - ☐ Paces the course carefully to make sure the course has an engaging opening and an effective closing and avoids the end-of-semester rush; and
  - ☐ Devotes instructional time to problem-solving instruction and experiences.
- ☐ Create a course webpage (if you have decided to have one)
- ☐ Implement your design
- ☐ Evaluate your design

Because relevancy and context are important aspect of effective learning, this workshop on capstone course design with integrated academic support also draws on the learning theories developed by Jerome Bruner. I have included an article by Bruner that delineates the steps in which relevancy is established and then furthered for learning that takes place on a larger, more profound level for students. Although much of Bruner's work has been on the education of children, the underlying theme of his work deal with cognitive growth that engages basic human capabilities within a context where the aim of education is to create autonomous learners. Specifically, the goal of his spiral learning curriculum is to inspire learning of complex ideas by first teaching on a simplified level initially, and then re-visiting at more complex levels later on. Therefore, subjects would be taught at levels of gradually-increased difficultly (hence the spiral analogy). Ideally teaching this way should lead to learners being able to solve problems by themselves. This idea has significant application to law school learning—particularly as much of the legal profession and legal education demands autonomous learning.

Below, I have outlined the four stages of Bruner's learning theory here:

Relevance
- Where dissemination of new information is through a learning situation that is within an already-existing context of familiarity.

Discovery
- The dissemination of this new information creates a moment of discovery.

Narrative
- The moment of discovery builds on the already-existing narrative.

Questioning
- This discovery building upon an already-existing narrative leads to questions that push the enquiry into problem-solving.

A course for virtually any salient combination of legal doctrine for a capstone that highlights academic support skills can be built effectively using this spiral curriculum structure.

Works Used & Cited:

- Michael Hunter Schwartz, Sophie Sparrow & Gerald Hess, TEACHING LAW BY DESIGN: ENGAGING STUDENTS FROM THE SYLLABUS TO THE FINAL EXAM (Carolina Academic Press 2009).
- Jerome Bruner, SCIENCE EDUCATION AND TEACHERS: A KARPLUS LECTURE 5-12, 1 J. of Sci. & Tech. 1 (1992).

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Science Education and Teachers: A Karplus Lecture[1]

Jerome Bruner[2,3]

This speech is devoted to science education reform and the pivotal role of the science teacher in the process.

KEY WORDS: Science education; science education reform; spiral curriculum.

I am greatly honored to give the Karplus Lecture this year. Bob Karplus was a key figure in the curriculum reform movement of the late 1960s and 1970s, and the two of us fought in the trenches side by side in those distant days. I was greatly saddened by his death earlier this year, which occurred while I was teaching in his home state at UCLA. He was a lovely man altogether — full of lively curiosity and deep modesty. And his ideas about how to teach science were not only elegant but also from the heart. He knew what it felt like "not to know," what it was like to be a "beginner." As a matter of temperament and principle, *he* knew that not knowing was the chronic condition not only of a student but also of a real scientist. That is what made him a true teacher, a truly courteous teacher.

What he knew was that science is not something that exists out there in nature, but that it is a tool in the mind of the knower — teacher and student alike. Getting to know something is an adventure in how to account for a great many things that you encounter in as simple and elegant a way as possible. And there are lots of ways of getting to that point, lots of different ways. And you don't really ever get there unless you do it, as a learner, on your own terms. You get there on your own terms. All you can do for a learner enroute to their forming a view of their own view is to aid and abet them on their own voyage. The means for aiding and abetting a learner is sometimes called a "curriculum," and what we have learned is that there is no such thing as *the* curriculum. For in effect, a curriculum is like an animated conversation on a topic that can never be fully defined, although one can set limits upon it. I call it an "animated" conversation not only because it is always lively if it is honest, but also because one uses animation in the broader sense — props, pictures, texts, films, and even "demonstrations." Conversation plus show-and-tell plus brooding on it all on one's own.

Bob Karplus' film on the "reversibility" of physical phenomena was a lovely example of a prop. Rather than answering a question, it opens one — the great meta-question of whether you can describe something in nature without specifying the frame of reference or position from which you view it. "Obvious" distinctions like up-down, right-left, moving-stationary suddenly become nonobvious — as they are in physics. Never mind that the film makes everybody think (which in itself is a glorious pedagogical outcome, as we all well know), but it also livens the conversation. Well, the two are not so very different: thinking comes very close to being an internal conversation, and conversation can't be much good unless in some degree you are thinking aloud in the midst of it. That is what these days has come to be called, after the great Bakhtin, the "dialogic imagination." And we shall have more to say about it presently.

I can't resist the opportunity, before getting into my subject, to contrast the spirit of the "curric-

[1]This paper comprises a speech, the Karplus Lecture, given at the National Science Teachers Association annual meeting, Atlanta, Georgia, April 7, 1990.

[2]Professor of Psychology, New York University, New York, New York.

[3]Correspondence should be directed to Jerome Bruner, New York University, New York, New York.

ulum reform" movement in which Bob Karplus was so deeply involved with the present wave of school reform — what for lack of a better expression I shall call "assessment reform," or perhaps I should call it "Governors' reform."

I have no objection in principle to creating better measuring instruments in order to find out how well our students are doing in science, in mathematics, in literature, in reading, in whatever. Or, for that matter, I don't even object in principle to assessments of how our teachers are doing their jobs. If you think that the poor performance of our educational establishment is due principally to a failure in teacher evaluation or in student assessment, then such a reform movement would be appropriate enough. Our State Governors in solemn conclave proclaim that by the turn of the century, or whenever, we will "turn things around and be tops in the world in science and mathematics. And just what is it that is to be turned around? Assessment procedures and "standards"? If only that, then we will succeed only in fueling our internal indignation about how little geography our students know, how badly they read, how sorely lacking they are in mathematical skills, how deficient they are in understanding what science is about. Surely, that is a curiously indirect route to improving matters, indirect in the sense that indignation just *might* conceivably lead us to do something further about how we conduct our schools and the process of education generally. It might even, conceivably, lead to a different message on public lips about financial support for schools and schooling. Schools are surely as important as the savings and load industry that we propose to "bail out" with a three hundred billion dollar handout. It might even lead us to question why, for example, we have made such an exclusive fetish about improving our record in science and mathematics rather than, say, concentrating our effort as well on teaching our students about the politics and economics of the revolutionary world changes through which we are living, or about why human nature risks its neck in the interest of freedom in Tianenman Square in Peking, or in East Berlin, in Prague, in Bucharest, in Vilnius. I am not against providing the nation with scientifically and mathematically literate workers so that we can outcompete the Japanese or the new Europe in world markets — as if that aim alone could ever inspire either teachers or students. We forget at our peril that the great leap forward in Eastern Europe and soon, hopefully, in South Africa and in the Republic of China was led so much by mathematicians and scientists (although they were there too) but by playwrights, poets, philosophers, and even music teachers. What marks a Nelson Mandela or a Vaclav Havel is human wisdom and philosophical depth. And so too was it with Thomas Jefferson; nor could he have had the vision but for standing on the philosophical shoulders of John Locke and the learned men of the French Enlightenment.

Surely we need standards and resources to make our schools work well in solving the myriad tasks they face. But resources and standards alone will not work. We need a surer sense of what to teach to whom and how to go about teaching it in such a way that it will make those taught more effective, less alienated, and better human beings. The nation's teachers have been struggling to carry out this daunting task and, under the circumstances, have been doing it with courage and skill against enormous odds. And we in the universities and in scientific and cultural institutions have been giving them precious little help. I am not proud to admit that much of the most strident recent criticism has come from such self-appointed guardians of the culture as Alan Bloom, who longs bitterly for an imaginary past while immured in his ivory tower. Teachers and schools, let it be said, did not create the conditions that have made American education so difficult. They did not create an underclass. Nor could they have undermined the research and development mission of competitive American industry anywhere as effectively the greedy takeover tycoons of the 1980s, fueled by junk bonds. Nor did they, like the money-churners and real-estate speculators, create the disgraceful condition of homelessness on one side and of consumerism on the other, both now afflicting our economy and our sense of purpose. Nor the drug problem which Washington now proposes to solve not by capping the flow of drugs into the country or by destroying our home-grown drug cartels but, ironically enough, by giving over the prevention task to the schools.

What we need is a reform movement with a better sense of where we are going, with deeper convictions about what kind of people we want to be. Then, we can mount the kind of community effort that can truly address the future of our educational process — an effort in which all of the resources of intellect and compassion that we can muster, whatever the price, are placed at the disposal of the

schools. That is what Robert Karplus stood for in the domain of science — that human beings would be the richer for understanding the physical universe. He did his part by trying to help teachers do their task better. All the standards in the world will not, like a helping hand, achieve the goal of making our multicultural, our threatened society come alive again, not alive just as a competitor in the world's markets, but as a nation worth living in and living for. I can do no better than to cite the conclusion of Ernest Boyer's 87th Annual Report from the Carnegie Commission for the Advancement of Teaching. He says, speaking of current reforms:

> We are troubled that the nation's teachers remain so skeptical. Why is it that teachers, of all people, are demoralized and largely unimpressed by the reform actions taken [thus far]? . . .The reform movement has been driven largely by legislative and administrative intervention. The push has been concerned more with regulation than with renewal. Reforms typically have focussed on graduation requirements, student achievement, teacher preparation and testing, and monitoring activities. But in all these matters, important as they are, teachers have been largely uninvolved. . . .Indeed, the most disturbing finding in our study is this: Over half the teachers [surveyed] believe that, overall, morale within the profession has substantially declined since 1983. . . .What is urgently needed — in the next phase of school reform — is a deep commitment to make teachers partners in renewal at all levels. . . .The challenge now is to move beyond regulations, focus on renewal, and make teachers full participants in the process.

Now let me turn to the task at hand — narrative as a mode of thinking, as a structure for organizing our knowledge, and as a vehicle in the process of education, particularly in science education. In order to do so, I must take a step back to consider some fundamentals, and you will bear with me if I do so autobiographically.

A long time ago, I proposed the idea of a "spiral curriculum," the idea that in teaching a subject one begin with an "intuitive" account that was well within the reach of a student, and then circle back later to a more formal or highly structured account, until, with however many more recyclings were necessary, the learner had mastered the topic or subject in its full generative power. In fact, it was a notion that grew out of a more fundamental, more obvious view of epistemology. I had stated this more basic view in the form, almost, of a philosophical proverb, to the effect that "Any subject could be taught to any child at any age in some form that was honest." Another way of saying the same thing might be to say, "Readiness is not only born but made." The general proposition rests on the still deeper truth that any domain of knowledge can be constructed at varying levels of abstractness or complexity. That is to say, domains of knowledge are *made* not *found*: they can be constructed simply or complexly, abstractly or concretely. And it can easily be demonstrated within certain interesting limits that a so-called "higher level" way of characterizing a domain of knowledge encompasses, replaces, and renders more powerful and precise a "lower level" characterization. That is to say, the intuitive statement "the further out a weight is from the fulcrum of a lever, the more force it will exert," is contained, as it were, in the more powerful and precise Archimedean rules about how levers operate. And Archimedes, in turn, is replaced and contained by the rules of levers as described by quadratic equations. The kid who understands the intuitive rule of the lever and applies it to the playground seesaw is well on his or her way to becoming Archimedean, just as Archimedes was on his way toward that Renaissance algebraist who recognized that expressions in the form $(x^2 + 4x + 4)$ could be equated to multiplicative pairs in the form $(x + 2)(x + 2)$ which in turn could be reexpressed as $(x + 4)(x + 1)$, etc. All of which could tell you some canny ways of placing weights on a beam so that they would balance. A ten-year-old once said to me, having discovered how all of this mathematical abstraction can guide one to making a beam balance, "This gadget knows all about algebra." I tried to dissuade him, to convince him that it was *he* who knew the algebra, not the balance beam. But I doubt I succeeded. That might come later up the curriculum spiral, perhaps in graduate school or perhaps, with the luck of some good teaching, in the very next grade.

Let me say that the research of the last three decades on the growth of reasoning in children has, in the main, confirmed the rightness of the spiral curriculum, although it has also provided us with some cautions. There are stages of development that constrain how fast and how far a child can leap ahead into abstraction. Piaget's views are always to be taken seriously in this regard, but they too must be taken with caution. The child's mind does not move to the higher levels of abstraction like the tide coming in. Development depends also, as Margaret Donaldson, for example, has so beautifully demonstrated, upon the child's practical grasp of the con-

text or situation in which he or she has to reason. A good intuitive, practical grasp of a domain at one stage of development leads to better, earlier, and deeper thinking in the next stage when the child meets challenging new problems in that domain. As teachers, you do not wait for readiness to happen; you foster it by deepening the child's powers at the stage where you find him or her now.

I am fully aware of the fact that what I am telling you is old hat to working teachers. They have grasped all of this intuitively ever since Socrates in the *Meno* set forth the first version of the idea by illustrating how that slave boy could, starting from innocence, quickly grasp the main ideas of plane geometry. But it helps (as with our example) to push our understanding to another level. I still get a lot of mail from teachers; years back it used to average ten a week. Most of it was to cheer me on for going public with what every teacher already knew. But there was also a steady trickle of doubting Thomases who dared me to try to teach the calculus or Mendeleev's periodic table in nursery school. Well, five-year-olds are delighted with the story of the tortoise and the hare. And you can go easily on from there to the joke-story that is embodied in Zeno's paradox — there's still halfway to go, wherever you are, so how do you ever get there. Invariably, given the superiority of intuition, young kids think Zeno's paradox is "silly." But it bothers them. Have you ever heard a six-year-old tell a friend about Zeno's paradox? They do it like a shaggy dog story (which it is, of course). And that now brings me to the heart of the matter — narrative.

Let me say a little about stories and narratives generally. For it is very likely the case that the most natural and earliest way in which we organize our experience and our knowledge is in terms of the narrative form. And it may very well be that the beginnings, the transitions, and the full grasp of ideas in a spiral curriculum depend upon embodying those ideas into a story or narrative form. So what is a narrative? Fortunately, we are aided by a decade of lively research on this problem, and form a variety of sources — linguistics, literary theory, psychology, philosophy, even mathematics.

Begin with some terribly obvious points. A narrative is a sequence of events. The sequence carries the meaning: contrast "The king died, the Queen cried" with its reversed mate, "The Queen cried, the King died." But not every sequence of events is worth recounting. Narrative is discourse, and the prime rule of discourse is that there be a reason for it that distinguishes it from silence. Narrative is justified or warranted by virtue of the sequence of events it recounts being a violation of canonicality: it recounts something unexpected, or something that one's auditor has reason to be in doubt about, or whatever. The "point" of the narrative is to resolve the unexpected, to settle the auditor's doubt, or in some manner to restore or explicate the "imbalance" that prompted the telling of the story in the first place. A story, then, has two sides to it: a sequence of events, and an implied evaluation of the events recounted.

What is particularly interesting about a story as a structure is the two-way street that it travels between its parts and the whole. The events recounted in a story take their meaning from the story as a whole. But the story as a whole is something that is constructed from its parts. This part-whole tail-chasing bears the formidable name, "hermeneutic circle" and it is what causes stories to be subject to interpretation, not to explanation. You cannot explain a story, all you can do is give it variant interpretations. You can *explain* falling bodies by reference to a theory of gravity. But you can only *interpret* what might have happened to Sir Isaac Newton when the legendary apple fell on his head in the orchard. So we say that scientific theories or logical proofs are judged by means of verification or test, or more accurately, by their verifiability or testability, but stories are judged, rather, on the basis of their verisimilitude or "lifelikeness." Indeed, one of the reasons why it is so difficult to establish whether a story is "true" or not is precisely because there is a sense in which a story can be true to life without being true of life. For those who have concerned themselves with such arcane matters as the theory of meaning, this means that stories can make sense but have no reference. It is much harder to construct "fictional science," not to be confused with science fiction, simply because it is immediately caught up in issues of verifiability with respect to a specifiable possible world. And that, after all, is what *real* science is about.

Science uses as its apparatus of exposition such means as logic, mathematics, or whatever helps it achieve consistency, explicitness, and testability. One of its favored weapons is the hypothesis which, if well formed, will be "frangible" — easily found to be false. However derivationally deep any scientific theory may be, its use should lead to the formulation

of falsifiable hypotheses, as Karl Popper would say. But you can falsify an awful lot of hypotheses, historians of science make clear, without bringing down the theory from which they have been derived. Which has suggested to many in recent years that grand theories in science are perhaps more storylike than we had expected, a matter we shall have to revisit presently.

A few other preliminaries and we can get back to the main task. Stories, notably, are about human agents rather than about the world of nature — unless the world of nature is conceived "animistically" as human like. What marks human agents is that their acts are not produced by such physical "forces" as gravity, but by intentional states: desires, beliefs, knowledge, intentions, commitments. It is intrinsically difficult to "explain" why it is that human agents, impelled by intentional states, do as they do or react to each other as they do — particularly in the unexpected or noncanonical situations that constitute stories. This reinforces the requirement of interpretation in understanding stories. As does one other thing. Stories are the product of narrators, and narrators have points of view, even if a narrator claims to be an "eyewitness to the events." Now this is also the case where science is concerned, although the language of science, cloaked in the rhetoric of objectivity, makes every effort to conceal that view save when it is concerned with the "foundations" of its field. The famous "paradigm shifts" that occur during scientific revolutions reflect this cover-up situation, since they betray the fact that the so-called data of science are constructed observations that are designed with a point of view in mind. Light is neither corpuscular nor wavelike; waves and corpuscles are in the theory, in the mind of the theory makers and holders. The observations they devise are designed to determine how well nature fits these pieces of "fictional science."

Now, it has been a curious habit of Western thought since the Greeks to assume that the world is rational and that true knowledge about that world will always take the form of logical or scientific propositions that will be amenable to explanation. Theories, made up of such propositions, it was thought until quite recently, would be found to be true or false by virtue of whether they corresponded to that world. Nowadays we quite properly ask how it is that we can ever know what *the* world is actually like, save by the odd process of constructing theories and making observations once in a while to check how our theories are hanging together — not how the world is hanging together, but our theories. The more advanced a science becomes, the more dependent it becomes upon the speculative models it constructs, and the more "indirect" its measurements of the world become. My physicist friends are fond of the remark that physics is 95% speculation and 5% observation. And they are very attached to the expression "physical intuition" as something that "real" physicists have: they are not *just* tied to observation and measurement, but know how to get around in the theory even without them.

Constructing "speculative models" at the highest levels of science is, of course, highly constrained by the mathematical languages in which advanced theories are formulated. They are so formulated, of course, so that we may be as explicit as possible. Through explicitness, logical contradictions can be avoided. But the mathematics has another function: a well formed mathematics is also a carefully derived logical system, and it is the full derivational power of the mathematics that the scientist is out to exploit. After all, the object of a mathematized theory in physics is not just description, but generativeness. So, for example, if the algebra of quadratic functions describes what might be happening in the domain of levers and balance beams, then the application of such *general* algebraic rules as the associative, distributive, and commutative laws should (with luck) lead to previously unimagined predictions about levers, fulcra, balance beams, etc. When that happens, it is science heaven and a time for prizes.

But as every historian of science in the last hundred years has pointed out, scientists use all sorts of aids and intuitions and stories and metaphors to help them in the quest of getting their speculative model to fit "nature" (or getting "nature" to fit their model by redefining what counts as "nature"). They will use any metaphor or any suggestive figure or fable or foible that may luckily come to hand. Niels Bohr once confessed how he had arrived at the idea of complementarity in physics — illustrated, for example, by the principle that you cannot specify both the position and the velocity of a particle simultaneously and therefore you cannot include them in the same set of equations. The general idea had first struck him as a moral dilemma. His son had stolen a trinket from the local notions shop but, some days later, stricken with guilt, he had confessed the theft to his father. As Bohr put it, he was greatly touched by this moral

act of contrition, but was also mindful of his son's wrongdoing. "But I was struck by the fact that I could not think of my son at the same moment both in the light of love and in the light of justice." This led him to think that certain states of mind were like the two aspects of one of those trick figure-ground pictures where you can see either the duck or the rabbit, the vase or the profiles, but not both at the same time. And then some days later, as if the idea were blossoming, it occurred to him that you could not consider the position of a particle as stationary in a particular position and at the same time as moving with a velocity in no particular position at all. The mathematics was easy to fix. It was grasping the right narrative that took the hard work.

To come directly to the point, let me propose that we characteristically convert our efforts at scientific understanding into the form of narratives or, say, "narrative heuristics." "We" includes both scientists and the pupils who inhabit the classrooms in which we teach. This consists of turning the events we are exploring into narrative form, better to highlight what is canonical and expected in our way of looking at them, so that we can more easily discern what is fishy and offbase and what, therefore, needs to be explicated. Here are some examples, some from the frontier, some from the classroom. A physics colleague lamented to me some years ago on a squash court that what was wrong with contemporary physical theory was that it conceived of most events as entirely in the extremely short-term nanosecond range, which made no sense since the physical world went on forever. So, he asked, what kind of "story" could you tell about an enduring universe? I jokingly suggested to him that he should invent a kind of hypothetical physical glue, a substance that went on and on in time — call it, say, glueterium. "Brilliant, brilliant," he said, for reasons still unclear to me. Several years later he told me that it had been a turning point in his thinking, glueterium. Or let me take one from a classroom. The topic was "atomicity," the smallest thing of which other things might be made, which is as old a topic as you can get. The discussion grew lively when it reached the point where it got on to "cutting up" matter into smaller and smaller pieces until, as one of them put it, "they've got to be invisible." Why invisible? somebody asked. "Because the air is made of atoms," which produced a general pause. A kid took advantage of the pause to ask, "Does everything have to be made of the same atoms?" "Well, so how could the same atoms make stones and water both?" "Let's have different kinds of atoms then — hard ones and soft ones and wet ones." "No, that's crazy: let's have them all the same, and they can make up into different shapes like Leggo or something." "And what happens when you split an atom?" "Then the whole thing goes Boom!" Echoes of the early Greek philosophers: not Thales but Empedocles prevailed.

What happens when the discussion takes that turn? Well, to put it as bluntly as possible, the focus of attention shifts, as it were, from an exclusive concern with "nature-as-out-there" to a concern with the *search* for nature — how we *construct* our model of nature. It is that shift that turns the discussion from dead science to live science *making*. And once we do that, we are enabled to invoke criteria like conceivability, verisimilitude, and the other criteria of good stories. Gerald Holton, the distinguished historian of science and a keen observer of the scientific *process*, comments that scientists from earliest times have relied on just such narrativizing to help them, using the metaphors, myths, and fables along the way — snakes that swallow their own tails, how to lift the world, how to leave traces that can be followed back, and so on, and so on.

Let me put it in somewhat different language. The process of science making is narrative. It consists of spinning hypotheses about nature, testing them, correcting the hypotheses, and getting one's head straight. Enroute to producing testable hypotheses, we play with ideas, try to create anomalies, try to find neat puzzle forms that we can apply to intractable troubles so that they can be turned into soluble problems, figure out neat tricks for getting around morasses, and so on. The history of science, as James Bryant Conant tried to show us, can be dramatically recounted as a set of almost heroic narratives in problem solving. His critics liked to point out that the historical case histories that he and his colleagues had prepared, while very interesting, were not science but the history of science. And I am not proposing that we should now substitute the history of science for science itself. What I *am* proposing, rather, is that our instruction in science form the start to the finish be mindful of the lively processes of science making, rather than being an account only of "finished science" as represented in the textbook, in the handbook, and in the standard and often deadly "demonstration experiment."

I know perfectly well that good science teachers (and there are many, though there can never be enough of them) in fact do just what I have been proposing: place the emphasis on live science making rather than upon the achieved remains of, so to say, already accomplished science. But in the spirit of Bob Karplus, I want to make a few suggestions about how we in the scientific community can help each other — rather than merely laying down the law about standards and about the linking of salaries to teacher qualifications. For I believe that there is what you might call a "soft technology" of good teaching that would be an enormous help in the classroom, a soft technology that would place the emphasis back on the process of science problem solving rather than upon finished science and "the answers." Let me end this talk with a few examples and maybe even a principle or two.

The first suggestion might even qualify as one of those principles. It says: "The art of raising challenging questions is easily as important as the art of giving clear answers." And I would have to add, "The art of cultivating such questions, of keeping good questions alive, is as important as either of those." Good questions are ones that pose dilemmas, subvert obvious or canonical "truths," force incongruities upon our attention that require attention. Curiously enough, much of the best support material produced by the science projects of the curriculum reform movement of the 1960s was of this order. Let me mention a couple of them, both of them produced by the Physical Science Study Committee. One was a "frictionless puck," a squat can of dried ice with a hole in its bottom, such that thawed CO_2 seeped through, causing the puck to float frictionlessly atop its cushion of gas on a pane of window glass. On that surface, under those conditions, bodies set in motion seemed virtually to stay in motion just as counterintuitively as required by Newtonian laws of motion. It's only a neat little hardware store trick, but it leads to endless questions about the "ideal conditions" required of general physical laws, how you figure out ideal conditions, what you might mean by such things as "perfect vacuums" and "frictionless planes," and so on. It gets a narrative conversation going in much the same way as Sir Alan Bullock got a conversation going a few years ago with the Queen of England on the occasion when she as Royal Patroness was to come to the annual dinner of the Museum. Sir Alan, as Chairman of the Board, was her host. He is a mighty historian and was then Vice Chancellor of the University of Oxford. Queen Elizabeth is notorious for her dislike of small talk, so Sir Alan decided he would find a question that would be deeply nontrivial while not being politically too controversial. He hit on the perfect one. "Ma'am," he asked, "when did the Royal Family decide to become respectable." "Well," she said, "it was during Victoria's reign when it was realized that the middle class had become central to Britain's prosperity and stability." And the conversation went on for the better part of an hour. The parallel? Well, able historian that he was, Sir Alan realized that the "Royal image" was a construction, a stipulation, an ideal condition for a theory of royalty. The moral of the story: always look an "ideal condition" in the mouth if you want to find out how the world works.

The other demonstration was a ceiling-hung pendulum with a large can of finely ground dirt at its terminus, with a tiny hole in the middle of the can's bottom and with wrapping paper spread on the floor beneath it. The only thing remarkable about this gadget is that it left a trail of its movements — trajectory length, damping effects, Lissajous figures for its eccentric excursions, the lot. There must be some kind of rule that says that the object of instrumentation is to make it possible to observe what before could not be observed because they were too small or weak, too big and ubiquitous, too fleeting or not fleeting enough, whatever. I think the idea had originally been hit upon by Frank Oppenheimer at the Exploratorium in San Francisco. It is perfect for exploring an unknown world of forces and symmetries: you can dream up and do experiments fifteen an hour. I have seen a group of twelve-year-olds at a summer session in Cambridge learn more fundamentals in an afternoon than I did with dear Mr. Doyle in an entire term.

The recording pendulum has a lesson that goes with it, which runs something like this. "If one picture is worth a thousand words, then one well-wrought guess is worth a thousand pictures." A well-wrought guess, of course, is usually and rather grandly called "an hypothesis." What is important about an hypothesis (or a well-wrought guess) is that it derives from something you already know, something generic that allows you to go beyond what you already know. That "something generic" is what I used to call the "structure" of a subject, the knowledge that permitted you to go beyond the particulars you had already encountered. The structure is, so to speak, in the head. Being able to "go beyond the in-

formation" given to "figure things out" is one of the few untarnishable joys of life. One of the great triumphs of learning (and of teaching) is to get things organized in your head in a way that permits you to know more than you "ought" to. And this takes reflection, brooding about what it is that you know. The enemy of reflection is the breakneck pace — the thousand pictures.

In some deep sense, just as Mise van der Rohe said of architecture, we can say of learning, and in particular science learning, that "less is more." And that again has a narrative tang to it. The story is how can you get the most out of the least. And the denouement is learning to think with what you've already got hold of. I believe that this truism lies at the heart of every good curriculum, every good lesson plan, every learning-and-teaching encounter. So when it comes time for the bureaucrats to set their standards and to make up their tests for monitoring how we are doing, they will adopt this one as their primary standard. They will have to construct better tests than the ones we have now. And when the time has come again for us to help each other in devising or constructing curricula in science curricula, I hope this ideal will shine over the effort.

One last word and I am done. I have said nothing about computers, which seems strange in this day and age. I really have nothing to say about them, aside from the fact that I love them and my life would be much more tedious without them. They can be a boon to scientific consciousness and, besides, they have reintroduced the servant in an era when the sages all said we would forevermore be servantless. Best of all, we can construct programs that can "simulate" what we might with great cost and effort do in our heads or on paper, and, in so doing, making us aware of what it is that we must still do ourselves in our own heads. My father used to tell a story about the Chinese delegate to the London Naval Disarmament talks in London in 1921. At the weekend, his British opposite number invited him to his country place, where he witnessed a ding-dong set of tennis between the British diplomat and his eldest son. At the end of the game, the British diplomat asked his Chinese colleague if there were any questions he'd like to ask about the game. "Yes," he replied, "it was very interesting, but I do not understand why you do not get your servants to play it for you." Well, remember that science is like that too.