JAY W. FORRESTER ORAL HISTORY

COMPUTERWORLD HONORS PROGRAM
INTERNATIONAL ARCHIVES

Transcript of a Video History Interview with
Jay W Forrester
MIT, Sloan School of Management

Recipient of the 1998 PricewaterhouseCoopers
Leadership Award for Lifetime Achievement

Interviewer: Dr. David Allison (DA)
Curator,
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DA: Today is March 26, 1998. This is an interview with Dr. Jay Forrester, who will, on June 8th of this year, receive the PricewaterhouseCoopers Leadership Award for Lifetime Achievement. This interview is part of the permanent research collection held by the Smithsonian Institution's National Museum of American History and, unless otherwise noted in the interview, will be part of the public record and available for use by scholars and the public, subject to the normal Smithsonian Institution restrictions.

We can stop this interview at any point to indicate portions that you'd like to embargo. If there are any questions that you would like for either of us to ask, raise your hand. We'll stop the tape and we'll ask the questions, because that's real opportunity for us, sometimes, to learn things to ask that we probably might not have known about. Or, if you just need a break, we'll stop the tape and do it at that time.

I'd like to begin with your early life. Where did you grow up? Tell us about your parents and your hometown.

JF: I grew up not in a hometown - I grew up on a cattle ranch in Nebraska, which was twenty miles from a town of three hundred people. My birth certificate says I was born in Climax, Nebraska. If you go and try to find it now, you will find a windmill and a tank, and that's the extent of the city. But it was on a Nebraska cattle ranch, in the country.

DA: Tell me about your parents, siblings.

JF: My father had completed four years in Hastings College. My mother went to college for three years. I had one sister. And, in the community at the time, they would be the only people with any higher education. Probably a lot of the people - neighbors, hadn't even had high school education. The community was one of homesteaders. My father was the first private owner of the land where I grew up, so we're that close to the American frontier.

DA: When did your family arrive?

JF: This area was late in the U.S. homesteading wave - it was around 1910 that the homesteading in that area occurred. It was thought to be a very forbidding area. It's a very unusual geology, what's called the Sandhill region of Nebraska. It's an area about a hundred miles North and South, and it would be two hundred miles East and West. It is two hundred feet deep in beach sand, and completely wind-formed into dunes and then grassed over. I don't know of anything like it anywhere else in the world.

To people who were accustomed to farming it was a very forbidding territory. There was no surface water, and no chance of making a living on a quarter of a square mile, as people had homesteaded in Iowa and Illinois. But the so-called Kincaid Homestead Act opened this area up to one square mile claims and that caused people to come in and try it. They tried farming; it didn't work in the sandy soil. And then, gradually people would move out and a few – like my father and mother - stayed and began to consolidate this land into cattle-grazing country.

DA: Were there other Forresters? Do you have brothers, sisters?

JF: I had a sister, and there were other Forresters that were involved around the periphery. My father's sister homesteaded, a section also, and my father's brother. But my father's brother died very soon, and the sister moved to Jackson Hole, Wyoming, so there weren't really any close relatives in the immediate vicinity.

DA: How long did you stay on the farm?

JF: Well, until I went to college at the University of Nebraska. And then, of course, I still worked there through the summer.

DA: So you grew up as a hard-working farm boy in the middle of Nebraska?

JF: That's right.

DA: One of the questions I like to ask is if there were incidents early in one's life that might have given some indication of a future career. You told me a story once about a screen door and some flies. Would you tell me that again?

JF: Well, I was much more inclined toward mechanical and electrical things than I was toward taking care of cattle. I would read as many books on electricity that I could get my hands on – elementary kinds of things. The junkyards at that time had some wonderful devices for experimenting with. There were the twelve-volt Dodge starter generator units that were used to make the first electrical power system on the ranch, which I did when I was a senior in high school.

But the one you ask about comes from using the ignition coils from Model T Fords, which were vibrator-type units that you just connect them to a battery and they hum, and they put out twenty thousand volts or something. So, the one you're asking about was stretching wires across a screen door a quarter of an inch from the surface of the screen, connecting those wires to the Ford ignition coil. And then the flies that would land on the screen would go up between the wires and the screen and be electrocuted. (laughter)

DA: How old were you when you made that invention, Jay?

JF: Oh, I'm not sure. I suppose probably still in eighth grade or before.

DA: Sounds like you made one of the first "bug zappers."

JF: Well, it zapped 'em all right!

DA: Could have been an early career. Tell me about your teachers while you were in Nebraska, before you got to college. Were there any that were really special and meant a lot in your career?

JF: The chronology was that my mother and father both taught school to add marginally to their income, which they very much needed under those circumstances. My mother had stopped teaching as a career, but I studied what amounted to first and second grade at home under my mother.

Then I attended third and fourth grade at a one-room country schoolhouse, where my father taught. During fifth and sixth grade, I studied under a woman who had been one of my father's students; and seventh and eighth under that woman's sister, who'd also been one of my father's students. Then, I went to high school in the nearby town – eighteen miles away, in Anselmo. That was largely an agriculturally oriented high school. It had shop activities, or woodworking, and repairing automobile engines, and learning how to test cream for the amount of butterfat and things of that sort. And, of course they taught Latin, and mathematics, and such things.

DA: Tell me about applying for college. Was the University of Nebraska the only one that you applied to, or did you think about others?

JF: Unlike the turmoil that people go through now in picking a college, I don't think there was any question or any alternatives discussed. The University of Nebraska was required to accept any resident of Nebraska. They were not required to keep them, not required to graduate them, but you could enroll. The tuition was thirty-five dollars a term, and I had started with a scholarship from the Union Pacific Railroad to the agricultural college at the University. But a month or so before enrolling, I decided that really wasn't where I wanted to study, and shifted over to the engineering school.

DA: I was going to ask that question: If you went with the idea of being an agriculturist. So you made this decision to go into engineering. What, led you to do that?

JF: Well, I would say it was the entire background, of these various mechanical, electrical - more than experiments - a lot of them were very meaningful and important. The wind electric plant that I built when I was a senior in high school was the first electricity we had on the ranch. It ran motors for shop work. It ran a washing machine and even made a welder from one of those twelve-volt Dodge generators.

DA: Sounds like your father encouraged you in this area.

JF: Well, yes. He didn't especially like, and did not have much in the way of competence in the electrical area, so as part of putting the wind plant I wired the house and carried the electricity down to the barn and shop.

DA: What did you do for fun?

JF: I don't remember that we ever had that question. (laughter) Ah, well, a fair bit of reading. But it was a time of being busy from first thing in the morning through evening chores. And, in the summertime, a matter of having to inspect the fences riding horseback twelve or fifteen miles, to go around the fences to make sure they were in good repair, checking the wells to make sure they were all working.

DA: Well, the rumor is that that work ethic has persisted through your career. What are the things that you do now for fun?

JF: Well, I have enough diversity in what I'm interested in that I don't really go looking for what you would call entertainment.

DA: The work itself.

JF: I'm busy looking after our place, giving my wife some help in her gardening, providing the electric fence for the garden to keep the deer and the raccoons out.

DA: Are you still zapping bugs with your own inventions?

JF: Ah, not zapping bugs, but we're zapping raccoons. (laughter)

DA: One of the themes for this program is a 'Search for New Heroes,' and one of the questions I wanted to be sure to ask you is, are there some people that were heroes for you, people that you really especially admired and looked up to?

JF: Well, I would occasionally find them in the Saturday Evening Post. There was a series of articles on Kettering of General Motors. I think I was inspired to the idea of doing inventions, like he was. I looked up to him and then, in retrospect, I find that I was added to the Inventors Hall of Fame before he was! (laughter)

DA: That was another question I was going to ask you: Did you ever think that you would be considered a hero?

JF: No, I don't think I did, or do now. (laughter)

DA: As you think about your career and your career achievements, a lot look at your invention of core memory as being, perhaps, the first thing that you're highly noted for. Can you briefly describe the context and how you came upon the idea for developing core memory?

JF: Well, the core memory came along as a strict necessity, that being the mother of invention. It came along because I had a group and an activity - a hundred or more engineers developing the first digital computer at MIT. It was intended for real-time control in military operations; that became its goal through several prior changes of focus.

And we were using cathode ray tube storage of our own invention, which were costing us about a thousand dollars to make. They would store about a thousand binary digits, and they would last about a month. We were paying one dollar per binary bit per month to sustain computer storage. At that rate, your desktop computer would be costing you fifty million dollars a month.

It was quite clear that those tubes were not sufficiently reliable, far too expensive, and we really had to have something else. Also, I had noted at that time, the design of computers was dominated by what kind of internal storage the designers chose to adopt. So there was work at the University of Pennsylvania on the EDVAC computer, which stored information in a one-meter-long tube of mercury. You would send shock waves down – shock waves would represent the binary digits - you pick them up at the other end, reshape them, and re-circulate them. But you couldn't get at the digits that were in the middle of the mercury line. You had to wait a millisecond for them to become available. A millisecond is a very long time in computing.

But there were various kinds of linear storage; there was the two-dimensional storage; there were several kinds of cathode ray tubes, and I began to wonder if there wasn't such a thing as a three-dimensional storage. In 1947, I had laid out the logic for a three-dimensional storage using glow-discharge tubes - like little neon tubes - as the non-linear active elements. You need some kind of non-linearity, and the glow tubes, you maybe have to raise them to seventy volts to start to glow, and you can go down as far as ten volts before it goes out, so you have a non-linear start-stop arrangement. We did a little experimenting with that, but it was clear from the beginning that it didn't meet the requirements for stability and reliability. The tubes generated heat, their characteristics would change with temperature. Besides which, they would be an expensive assembly to solder them all in place.

So the idea just sat there for two years, until I encountered, in one of the technical magazines, a material called "deltamax," which was a magnetic material with a very non-linear, rectangular historesis loop that had been developed for magnetic amplifiers. I immediately recognized it as a non-linear element, and I began to wonder if it could be put into the general logical structure that I'd been working on before.

DA: So you had very expensive memory, you had a prepared mind, and you found this article. What was the secret of this new material?

JF: The secret of the material is that it had a highly non-linear characteristic which potentially might seem to have a characteristic that could be worked into the kind of memory that I had begun to think about a couple of years before. So, after several evenings of walking the streets near where we lived and thinking about it, I came to a sketch which persisted, really, for the next twenty-five years as the logic of how that material would be used.

We started then to work with it, and began to develop the idea. I had a graduate student that was assigned to evaluating it, and, again, the first materials were magnetic materials, very thin magnetic tape wound into a coil. And this rectangular historesis loop characteristic was very sensitive to pressure or distortion of the metal, so it had to be put inside of a plastic case to protect it. All of this became expensive, besides which, the eddy currents, even in extremely thin material, meant that the magnetic material was slow.

So the next step was seeing an article about a ferrite magnetic material. It was an article by a ceramist working for General Ceramics, where he was trying to get a linear loss-less magnetic material for television amplifiers. He was having trouble because he couldn't get away from the rather fat, open historesis loop. So we went and said, "What we'd like to do is go in the opposite direction. Can you, in fact, sharpen this up, square it up?" At the same time, we wrote to Phillips in Eindhoven, Holland, where they'd done the early work on ferrites. We asked what they thought about the possibility of making a rectangular ferrite. And they wrote back and said that enough was known about the theory to know you could not do it.

On the other hand, the ceramist who was working for General Ceramics had already produced for us a few samples that came close to being what we wanted. And, gradually we began to have the situation where the art, as very often is true, ran ahead of the science. He was able to make, occasionally, some rectangular historesis loop magnetic materials. He really didn't know how he was doing it. Some of my people that would go down to see him work would say he would run his fingers through a bowl of black powder and say, "That feels square to me." Then he would fire it, and occasionally he would get a core that would do what we wanted. And you get one, and you know it's possible. From there on, we may have spent as much as a million dollars finding out what every one of the fifty variables in that process was doing to the shape of the historesis loop. And finally, when it was all adequately understood, you could get upwards of ninety-nine percent yield out of a production. But the really important thing was the first few that came really by trial, error, experiment and good luck.

DA: Did you ever doubt that this would work? I mean, this clearly was an expensive and difficult process to get to something that really did work according to this theory.

JF: Until it had really worked in a computer, there was always appropriate doubt. Nothing was known. Nobody knew anything about magnetic materials if you did not traverse the entire historesis loop with an alternating current. That's the way they'd all been tested. We did not know whether just going back and forth in one part of the historesis loop would perhaps gradually degrade, collapse the loop. We did not know that continuously beating on it with unbalanced kinds of pulsation would change the crystal structure, change the characteristics.

So we built a computer called the 'memory test computer,' which was a genuine digital computer separate from Whirlwind I, simply for the purpose of testing the memory. And that was the first time that we had a full magnetic memory really operating in the computer environment. And after it had been operating for two or three months, we saw that it really was going to work, and moved that memory and others over into Whirlwind.

DA: So that whole process of developing core memory, from the time you had that notion till the time it was really working, took about how long?

JF: The starting notion, with the low-discharge tubes was in 1947, the shift to using magnetic materials was in '49, and the first use of a magnetic core memory in the Whirlwind computer was in 1953.

DA: You really had to be persistent with this innovation, didn't you?

JF: We had to be persistent, but we also knew that we had to have some alternative to what we were using. And there was a great deal of commitment on the part of, initially, the Navy and later, the Air Force, to getting something that would work.

DA: And it's, I guess, looking back now when everything's in solid state, it's hard to remember how critical this innovation was. From your perspective, what was the effect on the computer industry once it was perfected?

JF: Well, it took us about seven years to convince them that it was a good idea and they should use it. And it took us the next seven years in the patent courts to convince them they had all thought of it first. (laughter)

DA: But then pretty much every computer thereafter used it.

JF: Every, every computer used it up until the early eighties.

DA: Looking back, historically, it was the thing that made electronic processing meaningful - to have electronic storage to go along with it, wasn't it?

JF: The storage was absolutely crucial to any design of the digital computer. It was the weak link. It was what stood in the way of reliability. Some of the slow memories were reliable - the rotating mechanical wheels in the Harvard Mark I machine probably were reliable enough, but extremely slow. The mercury delay lines were reliable, but slow. So it was only the magnetic core memory that provided both speed, reliability and adequately low cost.

DA: You know, Dr. Forrester, one of the things that's surprising to people about your career is that you were a pioneer in computing. You made this major innovation. But by 1956 you've said – or maybe it was 1957, you've said you thought many of the fundamental problems of computing were solved and you would go on to other things. Can you describe that decision and why you made it?

JF: Well, I'd been in digital computers for ten years, which is enough for a career. I felt that the pioneering days in computers were over. Some people now would find that very strange.

DA: When did you feel that the pioneering days in computers were over?

JF: About 1956.

DA: And what did that mean to you?

JF: Well, it meant that there had been tremendous advances in the decade from '46 to '56. And if you take some composite of speed, reliability and other characteristics, I think you can argue that the ratio by which computers improved in the decade from '46 to '56 was probably bigger than in any decade since. But it has continued at a very high ratio ever since.

And so I would say that I felt I had been in that field long enough. The Lincoln Laboratory where I was working, by that time had changed its organizational structure and who was in charge, and it was becoming a less satisfactory place. And I had changed careers several times before. I had been in the servo-mechanisms laboratory work under Gordon Brown in the first half of the forties, then the digital computer work. And through a series of happenstances, had a chance to look into the new management school that MIT was getting organized and decided to give that a try.

DA: Jay, what were the problems and issues that attracted you about management and led you to begin to teach and work in the management school?

JF: When I first went to the management school, there was no definition of what I was going to do. The management school was very new. Officially, it had existed for four years. There had been an undergraduate management option at MIT for many years before that. And partly, I think, I adopted the view that I understood Alfred Sloan to have had, when he felt that management school in a technical environment would develop differently from one in a liberal arts environment. Maybe better, but in any case different, and it was worth ten million dollars to run the experiment. And up until the time I joined the school, there hadn't been really any overlap between the school and the scientific and engineering side of MIT. So I was the first transplant from that side over into the management school.

I had the first year there with basically nothing to do except to try to decide why I was there. I think others, and perhaps I, felt that would either be how to use computers in management data processing, or push forward the field of operations research, which was already defined and meant then about the same as it means now. And I looked at those two areas, and I felt that a small number of us weren't going to have any major impact on the business use of computers, because by that time the commercial companies, the banks and the insurance companies, were moving very rapidly down that road.

And as I looked at the field of operations research, it was interesting, it was probably worthwhile, but it was clear that it was not dealing with the big issues that made the difference between corporate success and corporate failure. So it didn't meet my requirements for being worthwhile in the outside real world.

The real development of the beginning of system dynamics came out of discussions with people in the industry. I think primarily, at that time, some people in General Electric, who were concerned about why their appliance factories in Kentucky were working seven-day-a-week three shifts one year, and have half the people laid off two or three years later.

While it was easy enough to sort-of blame this on business cycles, that wasn't entirely persuasive. I talked to them about the policies they were following on hiring and on production rates, and how they managed inventories. I remember that just on one notebook page I laid out columns for inventory, backlog, employees, production rate and a line, week by week, down the page. Then, in any given week, given the state of inventories and backlogs and production, would either hire people or reduce the workforce based on the kinds of policies they were following. What this showed was that you would internally, within the company, generate this kind of instability even if you had a constant demand from the market – that it was inherently a feedback system that was internally unstable. That was the beginning of what was then called industrial dynamics, which was the application of feedback concepts to how the policies of a corporation produces behavior.

DA: If I were to ask you, after the many years now that you've worked with system dynamics, what the real essence of that field is from your perspective, how would you characterize it?

JF: Well, in the broadest sense, system dynamics deals with anything that changes through time. That covers most of what most people are interested in. The reason it does that is that everything that changes through time changes because it is embedded in a feedback loop structure of some kind. A swinging pendulum represents a certain kind of feedback loop. The instability in the business cycle of the economy is a very similar structure. The kinds of psychological dynamics that you may see in a family that's in internal difficulty is a situation where the interactions between them are causing a certain scenario to unfold. And so, sweepingly, from physical systems through corporate systems into social systems, you find the same set of ideas apply. And now, if you go a little below that, I would say the main ideas grow out of the nature of feedback systems, and the kind of growth and oscillation and decay that they are capable of producing.

DA: And the whole notion of understanding things in terms of feedback systems… How did that allow you then to develop a way of thinking that was new?

JF: In engineering, people had dealt with feedback systems in engineering systems for a good many years. But I would say most of those engineers never considered the possibility that they themselves were within such a system, that they were part of a social or corporate feedback system around them. So it was a gradual expansion, an extension of the idea that feedback systems were sweepingly general in everything that evolves through time. There had been people who had nibbled at that. There had been people in different fields that had expressed such ideas within their field. But I would say that not many had both seen it as sweepingly general and then also began to identify what the underlying principles were that one would need to understand.

DA: So you developed this notion and began to see it as really a critical notion to a new field. And did that allow you start thinking about new business models? How did you begin to unpack this notion as a management theory?

JF: We got early on into a situation where we could go into a company that had serious and widely recognized problems - they might be falling market share, might be high instability of employment from year to year - we would go in and we would interview people about how and why they're making certain decisions. And this might require rather intensive interviewing - no prepared set of questions ahead of time, just talking to them about what they do. What had they done in various past crises? What would they do if something happened, even if it were highly unlikely? What would you do under certain circumstances? And you would get quite a clear picture of how they were responding to the information they had available in making their decisions. And essentially, always, those discussions would be in the form of, "This is what the person should do here in order to help solve the great problem." Well aware of the problems, well aware that they should be doing something about it, and believing that they were, in fact, doing something to solve the problem.

We would go through the organization, top to bottom, through various divisions of activity, and come away with what's a pretty good description of the policies they're following - in other words, the rules whereby they're making their decisions, based on what information they have to work with. One can then make a computer simulation model knitting together those policies and tying the information loops together. And what you would usually find is that taking the policies that people know they're following, which they believe they're following to solve the problem, and put those together, you will find in the computer simulation model that it creates the problems that they are experiencing. Absolutely implicit in what they know they're doing that they shall have the problems that they are in.

This is very treacherous. Because if they believe that these policies will solve the problem - they do not know that these policies are making the problem, then as matters get worse, it becomes more and more of an incentive to do the very things that are making matters worse.

DA: It seems to me it must have been critical that instead of going into corporations and setting up a model based on corporate policy, you built your model on interviewing people about what they actually did. Was that a new technique that you used?

JF: Well, there's been lots of interviewing going on in the social sciences. But usually the emphasis is on reproducibility – every interviewer will get the same results. The emphasis then is on questionnaires that are sent ahead of time to which you get answers. And I believe you cannot expect to get into the real subtleties and structure of what people are doing because you don't know what it is until after you have carried on the interviews. So it's a very different approach to interviewing.

DA: I would guess, if you went into a corporation and did this massive interviewing and took to management a model that showed the inherent instability of the organization, it wouldn't necessarily be welcomed by management as a good result. How did people respond?

JF: I would say probably one of the most serious hurdles in the field of system dynamics is exactly that. That when you go in to solve a problem, you will probably discover that the people involved are creating that problem - that they will have to reverse things that they have been doing, reverse things that perhaps they have been proud of doing and outspoken about doing. So there's a great deal of emotional commitment to the steps that have to be reversed. And I would say that it's one of the greatest stumbling blocks, whether you're dealing with corporations, or countries.

DA: Jay, can you give a couple of examples of how, when people get in crises, they tend to do things that tend to make the situation worse rather than better?

JF: You see that in a number of different ways. If you take our work in urban dynamics, dealing with the growth and stagnation of cities - we found that the most powerful leverage point in the urban system with respect to stagnation and poverty in the city - the most powerful leverage point was the building of low-cost housing. And, in fact, you should take it out, not put it in. Because low-cost housing uses up land that could have been used for job-creating opportunities while it pulls in people that need jobs. It's a double-edged sword for creating poverty, because it concentrates people who need jobs in locations where there are not jobs. And then as the poverty gets worse, there's more pressure to provide housing. So it's a cycle that can carry the city into a very depressed state.

You see this in other areas. In aviation, there is something called the 'dead man's spiral.' This is what happens to a pilot who does not have blind-flying equipment, who is not competent in blind flying, who ends up in a fog bank, or a cloud. And the person is very apt to sense that the plane is diving, and so he lifts the nose. And he still feels that he's diving, and he continues to lift the nose. In fact it's not diving, it is in a turn. And the more you pull up, the tighter the turn, until the wings come off - until the centrifugal force is big enough to wreck the plane - a situation where the evidence leads you to do the things that are causing the problem.

We've seen it in a number of corporate situations, where perhaps the real problem is not having enough manufacturing capacity, or enough capacity to answer the phone, or enough capacity of good salesmen, but let's say just straight manufacturing capacity. The company may not realize that that's the problem. And so as sales miss their hopes and expectations, they tend to lower the price hoping to bring in more business. But of course you get very little effect there because more business leads to longer backlogs. Customers are put off by the long wait, and you find a situation where, by lowering price, you lower the margins, which lowers your ability to do anything about the real problem, which is adding to capacity. That's a syndrome that one can find probably in ninety to ninety-five percent of corporations. Either the corporation as a whole, or at least in some division or product line. I've almost never failed to find this situation where the lack of capacity is the thing that is limiting sales. And you would be absolutely amazed at how frequently people are not operationally aware that you cannot sell what you do not make.

DA: And I guess, as you're tighter and tighter on inventories, that may even become worse of a problem.

JF: Yes, they're very apt to then become vulnerable to any little discontinuities in the flow of materials, and then they try to make up for this by tighter and tighter management and more information processing systems, which themselves can become very, very expensive.

DA: I know that one of the ways you've tried to illustrate this is through different kinds of games or other things - one of them is the 'beer game.' Can you describe what that is and how it works?

JF: The so-called 'beer game,' which started out actually as the 'refrigerator game,' came directly out of that early work. I mentioned that we had worked with some General Electric people on their household appliances. And early on, probably around 1958, we began to conduct two-week summer session programs outlining the basis of our thinking with respect to industrial dynamics, which now is called system dynamics. In one of the first of those summer sessions, we developed a role-playing exercise illustrating the instability in a production and distribution chain. The structure of this was that there would be a person representing the retailers, a person representing the distributors, a person representing the factory warehouse, a person representing the production. And then each stage would pass chips or notes to the one-up stage – upstream - as to how much he'd like to order. And if that person could supply it - if he had the inventory - he would send the counters down with maybe a week or two to process the order, a week or two to make the deliveries. They would move along on the top of the table, and this would go on up toward the factory. And the retailer, down at the bottom end, would have a deck of cards; and each week he would turn over a card to see what he was selling out to the actual public.

The typical behavior would be that the factory, at the far end, would go through huge variations in production with many weeks between peaks. In the debriefing afterwards, people were absolutely convinced that this deck of cards had a very strong cyclically that was driving the instability in the chain. The only person that knew otherwise was the retailer, who had turned them over - and every card was the same. The system would start in equilibrium, and the first card might be a little bit more than what the system had been set up for; that's just enough to provide a little shock. And after that, the whole sequence of instabilities would build and persist within the chain, as the people would interact with each other.

DA: So the real secret in solving this becomes information flow and understanding the inherent dynamics, doesn't it?

JF: Information flow and how it is used. And we have a whole field of information technology that I believe is, for the most part, without any basis for what information they ought to be providing. Because unless you embed information in the structure of policies - that's using the information to create actions to see how the corporate system evolves- you don't have any good basis for knowing whether people are using the information they should use, and whether they are using information they have in the most effective way.

Very often they're perhaps taking information and making the opposite kind of decision than what they should. But more often than not, they are using the information given to them to make their decisions. They cannot decide on information they don't have; they can only decide on information that's available. And it's very unclear who decides what they should have available. A person's intuitive request for information is unreliable. The information technology people deciding to provide something is unreliable and can divert managers from their proper actions. So it's only, I would say, through building a system dynamics simulation model of the information streams and how the information is used in making decisions, that you can come to any appropriate decision about what information technology should be doing.

DA: Sounds like you're saying that information technology, although it has the possibility of being the solution, often becomes part of the problem because it starts to flood people with the wrong kind of information. Did I understand that right?

JF: Well, I would say our worst pollution is information pollution – entirely too much information. And one can't process more than a very small number of information streams, and you happen to be working on the wrong ones, you end up making the wrong kinds of decisions.

And if you go back to this matter of a capital plant and the very well-known model - the market growth and capital investment model, that I did a number of years - you find that one of the crucial inputs that people should be paying attention to is the delivery delay for the product: how long people are having to wait, how long they have to wait to get a telephone connection. You go through these three layers of telephone menus these days before you can find anybody that you can even talk to. These kinds of delays are repelling customers, and yet very often those delays aren't even reported and people aren't sensitive to them, aren't doing anything about it.

I was in the office of one president of a high technology company once, where behind sliding panels he had probably at least fifty time series of different things going on in the company. Not one of them dealing with delivery delay, and that was the primary one leading to their loss of market share.

DA: So, in some ways the growth of information technology can make the problem even harder to find, can't it?

JF: Information technology can make matters worse. I would say very often one of the worst parts of information technology is the sale forecasting activity. Many managers think that they cannot do anything until they get the sales forecast. Then, when you begin to look into where the forecast comes from, it becomes a very subjective, nebulous process and, generally, is self-fulfilling. A sales forecast for a certain amount - the company responds to that, they build capacity for it. Every time they build capacity for the forecast, they sell according to the forecast. They develop a very high confidence in the forecast, and what they don't know is that they could have been selling twice as much if they had built the capacity up.

So you have a forecast, in a situation like that, which is actually pushing sales down. In many ways, one of the best things one can do in the corporate environment is to put the sales forecasting out of business. You don't really need it.

DA: It's one thing to develop a theory of a new way of looking at business, and yet another one to try to take it out and make it work in the real-world environment. You've done some of that. I know you've been a consultant at places like Digital Equipment Corporation. What happens when you take system dynamics and try to apply it in the real world?

JF: Well, you can apply system dynamics in two rather extremely opposite ways. One of those extremes, I would say, was how I used it when I was on the board for the first ten years of the Digital Equipment Corporation. We were just beginning this process of developing system dynamics. I felt that if there really was as much to it as I thought, that it should be a useful process to guide my own position of the board of a high-tech growth company. And I did not really know what that would mean.

Over a period of a couple of years, I worked on a model of corporate growth. Coming to a model of about two hundred and fifty variables… some people would be challenged just to write down two hundred and fifty variables in a company. It was about a fiftieth-order system - fifty integrations, highly non-linear, and went far beyond the physical things, far beyond production and inventories. Because it went to the character of the founders, it included how the traditions of the organization were formed as the company evolved; it had goals and how those goals are created within the company.

It was a very interesting model, and it showed rather immediately, the differences in the patterns of various high-tech companies. Those that grow and go out of business, those that grow for a while and then just hang on in a fluctuating kind of instability, those that grow with great repeated crises, but keep growing, and then the rare company that has essentially a steady, relatively untroubled growth pattern. And you could see in this model why different companies were generating these different kinds of behavior.

On the other hand, in the board of directors there was no acceptance of the idea that this could be done, and they were actively disinterested in the model. On the other hand, I had a very strong position for an outside director, because the financial backers had all the legal authority. The founders had all the technical knowledge, and so when they would disagree, my position very often would swing in one direction or the other. I would say there was little use of the model to justify what I would suggest. But rather, I could discuss what I suggested in the context of everything else, because I could see in the model how these things were linked together. And so from a model, you can discuss an issue at length without contradicting yourself. You know what the assumptions are at the foundation of the model. You know the behavior the model will produce. You know how a change in policy will change the behavior, and you have an area there where you can be completely internally consistent in what you say.

Now, that doesn't make it right. You can be internally consistent, and wrong with respect to the real world. But if everything you say at every level, from the basic assumptions, to the behavior, to the effect of policies – if that matches with people's past experiences - then it tends to become persuasive. And out of that model came, really, a couple of rules of thumb. In spite of its complexity, there were really two things that came out of it that I think, had major impact. One was to keep juices about twice as high as they would otherwise have been set.

At that time in the market, there were computers with essentially the same technical specifications that ranged over a ten-to-one price range. And who had the most expensive computers? IBM. And who had the biggest market share? IBM. So much for Economics 101. The highest priced product had the largest market share, because they were providing a great deal more than computers. They were providing security to the most insecure level in a corporation, namely, the vice presidents. And if they bought from IBM, they were absolutely sure that if there were problems, the company would bail them out some way. And so, basically, they were paying for security. At the other end were people who were trying to get business by cutting their prices down practically to their manufacturing cost, leaving them no ability to provide the proper marketing and help and consultation and things that were necessary.

So part of the outcome of modeling was to push prices up, and then use that money for other things you should do. The other part was to expand, whether or not you had the business, on the assumption that it was for all practical purposes an infinite market if you did it right. And your challenge was to build the capacity to supply that market.

So Digital really became a real estate company, buying all kinds of abandoned shopping centers and buildings from other companies, and putting pieces of their business all over New England and even off into other countries.

DA: And that worked during that time period.

JF: That worked for thirty years, or forty. They then ran into a very different set of difficulties.

DA: But, what I understand in terms of applying the model, is that you became in a situation where you could make applications but you couldn't talk about them successfully, in terms of having come from the model, because the environment was not accepting…

JF: Well, I was not hiding this. I was not hiding the fact that they came from a model, but they did not believe that it came from a model. And I kept trying to get them to go into this kind of modeling and really understand. At one stage, the president said, "Look, we know you can't deal with the real management issues in a model. We do agree we've been doing what you suggested, and the reason for that is that you're just a better manager than we are." (laughter) Now, you see, that relieved them of having to pay attention to the methodology.

DA: Ah, is that the same kind of issue of having what to outsiders must seem like a relatively complex tool. It's something that's hard for them to accept in its original form. I mean, is that still something that's facing people that are trying to use system dynamics today, or do you think that was unusual for your time period?

JF: There's a wide spectrum, probably still a large fraction of people that are in that situation. On the other hand, more and more, the big consulting companies are trying to develop competence in the field of dynamics in the corporate world. It's being accepted in many places. There are companies that are making active use of it, and there are a lot who do not yet see any point. So there is a strong, steady infiltration, with a long way yet to go.

DA: You talked about Digital. Are there other examples where you had practical experience that might be illuminating about the history of the use of system dynamics? Are there specific places where you applied your models?

JF: I worked for many years with the Cummins Engine Company building diesel engines. And I and my graduate students - mostly David Peterson at that stage - built one of the most comprehensive models that dealt with everything from production through very interesting psychological interactions between finance and production, into marketing, competitors, customers and even their ability to borrow in the financial markets. And Cummins had faced two major problems. Again, this high instability of production and employment, working seven days, three shifts one year, and having the factory half shut down at other times. And they had been steadily losing market share. They had been more or less the pioneers in the early days of diesel engines, and by the time we entered the scene they were down to perhaps thirty percent of the market. So we were looking at those two issues. And it was in the model of the company that we saw for the first time that - according to the model - market share had not been falling steadily; market share had been going down in steps. In the models, market share was going down in steps. And it was going down in recessions.

And then you can go to the files of the shipping room and you can look at the orders, and when they were placed and when they were shipped, and you could see how long the delivery delays were. In fact, looking at all of the data, the market share was falling during recessions. And it was falling because when the factories were half shut down, they were less able to fill orders than they were when they were working seven days a week. In other words, as business fell off, they cut back production faster than the market would have cut back orders. So the delivery delays went up at the time when they could have, in fact, brought them down. So they were losing market share to competitors that were not quite so frightened about a downturn. And once the customers move, they tend to stay with their new supplier.

From this came a couple of policy recommendations. I don't think we ever encountered anybody in the company - from research to manufacturing to marketing to the top management - I don't think we ever encountered anyone who disbelieved the assumptions in the model. We did discuss the model with them. I don't think there was anybody that argued against the dynamics that were causing the problems of instability and falling market share, and I don't think there was anyone who intellectually argued with the recommended change in policies.

There was, however, a difficulty. And that is that the policies that were being suggested were diametrically opposite to two or three policies that three generations of top management had made public speeches about as the basis for their success. And the three generations of top management were all alive, all in town, all stockholders, and all on the board. Which meant it was very hard for a group of business school managers to really act in that environment. At one stage they did. Basically, the action was to keep up production in the face of a potential recession. At the next recession, maybe just as a gesture of good will to me, they said, "All right, we will allocate the large amount of money necessary to put these excess engines in inventory and hope we sell them at the next upturn."

Well, as the saying in the company went, every time they scheduled one of those engines for the warehouse, some damn fool went and sold it. (laughter) They never got any in inventory. And the president was quoted as saying this had meant ten million dollars net profit after taxes they otherwise would not have made. And in the next downturn they could not bring themselves to do it again.

DA: It's amazing how people decide what…

JF: There's a tremendous stability to the policy structure of a company or a city or a country.

DA: I know that this kind-of leads to another issue, and that is: In addition to thinking about system dynamics, you've talked about a whole general new design for corporations. Do you want to talk a little bit about your thinking along those lines?

JF: I wrote a paper in about 1965 called "A New Corporate Design," and an update to that only a few years ago. It was a search for a more effective kind of internal organization for the corporation that would release the initiative and the freedom to act on the part of people within the company.

The beginning point was to totally erase the concept of the superior, subordinate relationship, which most people in business find to be an unimaginable shock, and then begin to rebuild around the idea that each individual has a return on investment account. Each individual should personally benefit from how his account shows up in the accounting. And certain ground rules like "you must not get more than forty percent of your income from any one other person in the company," because that means you must have at least three clients. Which gives you mobility if you're not a captive of any one person in the company. And a whole set of issues that we probably shouldn't try to go into now.

When I talk to people in business, they say, "Well, you know, you can't do that in a big organization." And I say, "Well, can you think of any economic organizations that do operate this way?" And they will try to suggest maybe a law firm or some organization of that kind. And I point out to them the U.S. economy is exactly what I'm talking about - there's no superior-subordinate relationship between your dentist and General Motors, that every legal entity is separate in their accounting and their freedom to contract.

And, over a period of three or four years, I evolved this paper that became "The New Corporate Design" while I was on the board of Digital, with the idea of trying to implement it there. And I got them to run one experiment. They had a man who was an engineer. He'd been, I think, to the Harvard Business School. He was about to take on a new project, probably costing two-three hundred thousand dollars. And I was suggesting that we set it up according to this pattern, where he would not be charged overhead, he would be expected to return 6% compounded - 6% per month, compounded monthly, on any money that he used. He would be charged rent for his space. And 6% per month, compounded monthly, without any charge for overhead in a growing company is not unreasonable. But it places a very high premium on timing your expenditures correctly. If you buy something too soon, you're paying 6% a month on it while you don't use it. If it comes in too late, you're paying 6% a month on everything else while you wait for it. So it's a powerful incentive to get everything timed as nearly right as you can.

The negotiations for this went on through three different meetings where the engineer who was apparently wanting to do this was making presentations to the board and to subcommittees of the board. And it was fairly clear to me that his presentations were basically an engineer's snow job to try to get the money. They weren't in the spirit of what was being suggested. I would say to him, "Look, we are not here to decide if you get the money. We're only here to decide if you want it." Finally, in about the third meeting and the seventh hour, he stopped in the middle of a sentence and he said, "Oh, you mean you want me to run it like it my own company?" I think he must have been told that several times but it had not registered until that moment.

Well, he took the job. He carried through all the way into the marketing. He was very successful above his 6% per month compounded monthly. It was, I would say, a total success, and the company would not do it again. And the excuse was that it had made him uncooperative. What that really meant was that when was somebody else was in trouble and they came over, said, "Now you knock off from this and come and help." And he simply said, "I have my 6% per month to protect," and wouldn't do it. And of course that's exactly what he should have done. But the management discovered they had bargained away their right to interfere and that was the reason I think it was never done again.

DA: But, you feel that if you had that type of independence within a corporation, eventually the market structure would find out another way to solve that non-cooperation problem because it would be incentive-ized through funding or….

JF: Well, if the people that were having a problem had the same incentives, they probably would not have had the problem. Or you can have a group of troubleshooters who are available to help out, and when they become necessary they can charge a very high premium, just like you see in the real world. Or you have someone who is a true solver of big problems, he can afford to sit there for three months doing nothing and waiting for somebody to be in trouble, and then be compensated accordingly.

All of the kinds of things you see in the outside world, including the idea of investment bankers - there should be no internal monopolies. If somebody wants to go someplace for money, there is someone that controls the money stream. But there are other people who control money streams. And if you can't satisfy this person, you can try somebody else. There would be no function in the organization that has a monopoly.

DA: We were talking before going on tape, about the relation of this kind of thinking to system dynamics. It almost sounds like it makes a system dynamics automatic because it plays itself out in a free market type of enterprise. How would you describe that?

JF: I would say that system dynamics would become very important as an advisory to these people who have control of a project. Or there should be in this company people whose business is to be business advisors, who will bring new ideas in, who will coach people, who will carry on an educational function, in return for being paid. Yet in a lot of companies you see projects started before anybody decides whether or not they really want them. And the ratio can go as high, in some historical studies done by some of the consulting companies, only one project undertaken out of 200 becomes a commercial project.

Very often that is because nobody decided at the beginning that it did not fit the business or that they wouldn't be able to sell it. And if they had thought about it at the start, they wouldn't have undertaken a lot of those projects and yet they spend large amounts of money on research and development for which they have not looked through to the end of the process.

DA: I was thinking that we might transition from this now to the educational pursuits. It seems like this really laid out the theory, some examples, the new corporate design.

Jay, you've talked about different ways of approaching management of businesses and yet you often encounter resistance to this. And I understand that that led you to think about the need to do a better job of educating people before they assume positions of power. How could you work to get the ideas of system dynamics involved in educating both in management and later in lower level education?

JF: I think the road is open for an entirely new kind of management school. Let me start by an analogy as to who the two most important people are in the successful operation of an airplane. I would say it is the designer, the person who made an airplane that can be flown successfully, and it is the pilot who does the flying.

Now if you turn around to the corporation, I would say that most managers are simply the pilots. They are piloting the corporate organization and there is no one who really can claim to be the designer. The design has occurred by happenstance, by intuition, by responses to crises, without anybody giving thought to what the structure of the organization is doing.

So you get organizations in which people in certain positions are pre-destined to fail. And under those circumstances some one comes in, he fails, he's taken out, somebody else is put in the position and he fails. And this goes on. It is like an engineer who has designed an electronic circuit and the resistor burns out. He puts another resistor in and it burns out. Now he doesn't keep doing that because he looks at why this circuit is burning out resistors. And he will change the structure and the design of the piece of electronic equipment so that ordinary resistors will work.

So you have the challenge of designing a corporation such that ordinary people can succeed within it. Which is to shift the role from the manager as a day-by-day person who does things to the idea of the key top person being the designer of an organization. Along with this then goes the idea of a new kind of management school, one that focuses on the design of corporations rather than the management of the various functional areas.

I don't think every management school should be that way. There are still going to be people, a need for people, that essentially run the day-by-day activities, but there is a need for a new hierarchy in education. A few schools at least that focus on the design of corporations. This is a change as big as the change pioneered by the Harvard Business School in case studies.

In fact it links fairly well with case studies. A case study describes a situation, describes a problem, describes what people are doing. The next step beyond that is to now build a system dynamics simulation model from what's described in the case study and show what those assumptions and insights lead to.

And I had the interesting experience once of being invited to a major anniversary at the Harvard Business School in which every classroom was discussing the same case that people were supposed to have read before. And one which we had in fact simulated.

And just watching the discussion you could see the whole room gravitating toward a recommendation that was completely contrary to what they were trying to accomplish. You can't blame them because in the very complex non-linear, multi-loop system, there is no possibility of intuition coming to a correct solution to the dynamics.

DA: So the structure of this new management school would focus on a whole new set of things that you'd teach the students?

JF: Well instead of having courses in finance and marketing and production those would be integrated into the idea of a computer simulation model that puts the pieces together because the big issues in management usually come from how those separate functions interact with each. And yet in most of academia, those functions are dealt with separately and not enough done with how they are interacting one with the other.

So it would be an integrating approach to pool together the various functions into a cohesive whole and when you do that you'll find that you want to teach the functions quite differently. So it would be a unifying influence whereas in academia there tends now to be a fragmentation according to people defending different turfs and no one who is really looking at how the entirety works in terms of its connections.

DA: Would you need a different academic structure to allow this teaching to take place?

JF: Well, yes. You cannot have separate fiefdoms for finance and production and marketing and go down the road that I am speaking of because they would have to become part of, maybe even subservient to, the idea of the entirety of the organization.

DA: Is this something that you've proposed in a very specific way to MIT or other people as an idea that you think really will take root or is it more of a dream at this point?

JF: Well I have written some papers on it. I have proposed it to the MIT Management School. There has been no evident response to that. I think it will occur. And it will occur probably in the second level schools. The first level schools have their reputation based on something they've done in the past. They want to perpetuate that. The second level schools are the ones that don't have that commitment to the past and are looking for something to leapfrog into the front lines. So I'm rather expecting that we will see this emerge out of what would ordinarily be called the second lower tier of schools.

DA: And again because?

JF: And there's some evidence that that's beginning to happen.

DA: Well part of your thinking in recent years has been that many of your ideas although first formulated at high levels of business, to fully take root actually have to be taught to very young people. Can you talk about how the whole notion of system dynamics now seems to you to be something that can be taught to very young children?

JF: A management school that a move focusing on design is not likely to happen until there are people coming up that see the possibilities, and begin to see the vision, and start to implement it at the graduate school level. So I came to the conclusion that we must start very early and a lot of my time now is devoted to pushing system dynamics in kindergarten through twelfth grade education. And this is going very well.

DA: Jay, let's go back and talk again about what led you to think about teaching system dynamics at very young ages.

JF: I think it started out of our experiences with working with corporations and people in management schools. Our experience in corporations had been that we would work three or four years with the management of a corporation. They would begin to understand the importance of dynamics. They would begin to grasp the ideas and by that time they would get promoted or retire or die and you had to start over with a new group. Which meant you never carried through the kind of intensive understanding that was necessary.

System dynamics is a profession like medicine or engineering and you don't teach those professions out of a few sessions over a period of a couple of years advising people. They must get into it fairly deeply. And dynamics in the management school is quite contrary to the backgrounds people have. A lot of them have come up through economics that has an emphasis more on statistics than it does on dynamic behavior.

So there's a whole paradigm that is contrary to understanding dynamic behavior. And it began to be fairly evident that what we need is a significant fraction of the public that has some understanding of the nature of these systems that we live in. And over the last twenty years, there has been experimentation going on in bringing system dynamics into kindergarten through twelfth grade education.

It was started initially by Nancy Roberts whose husband, Ed Roberts, is on the MIT Sloan School Faculty, and was one of the early people in system dynamics. She had some family background in system dynamics. And when her children were in college she went back for a doctorate in education, I think at Boston University. And her doctoral thesis was on introducing system dynamics in fifth and sixth grade schools. That was in the mid-70s.

The idea was kept alive but not very aggressively for a number of years. Then in the 80s, the latter part of the 80s, it began to take off. My mentor responsible for a great deal of my career at MIT, Gordon Brown, who had been head of electrical engineering at one stage, dean of engineering MIT, retired, was living in Tucson, Arizona, began to pick up some of the ideas that I had been developing in dynamics and introducing them into the local school system.

Nancy Roberts' work was one beginning point. Another was when I met John Bemis in Concord, Massachusetts who gave substantial funding to start the Creative Learning Exchange, a non-profit organization to act as an intermediary to exchange information among schools that were interested in system dynamics. And he also funded the beginning of my program at MIT on the development of dynamic material for K-12 education working with MIT undergraduate students.

So it began to gain momentum in the late 80s and all through the 90s and the progress is quite dramatic in a number of schools now. The Creative Learning Exchange has a mailing list of maybe 4,000 people. We at MIT are running a web site on which a large amount of material is available for K-12 education. The demand has been rising rapidly.

We're getting now about 7,000 accesses a week to that web site. And it appears that two-thirds of them are coming from corporations for internal education because you can literally use identically the same material from fifth grade to chief executive officers. Because it's accessible at every level and it's new at every level. So the, in a number of schools, there are teachers that have gone a significant distance down this road and have some very interesting things to say about it.

I think I might convey that best by reading a few quotations from some of these teachers.

DA: That would be great, what are they telling you about their experiences?

JF: As a background to this - there are a number of fundamental ideas at the foundation of dynamics. And one of these is that there are two kinds of variables, and only two. What we call levels and rates, what some people call stocks and flows, there are no other variables. This is a powerful organizing statement when you come to believe it. You look into the real world and everything you see is one or the other.

Now people in business should not be surprised at this. In the annual reports of a corporation, the data exists on two pages. One is the balance sheet, and the other is the profit and loss statement. The balance sheet gives the stocks or accumulations. The profit and loss statement reports the flows, and there is no third sheet. The idea of stocks and flows is found in many other professions, but seldom is it proposed as a fundamental, sweeping concept underlying to all systems.

Now to Tim Lucas. He is an elementary school principal in Ridgewood, New Jersey, who wrote to me: "We are introducing kindergartners to the concepts of stocks and flows and the idea that behaviors can be graphed over time. Beginning in first grade students are mapping larger sets of information and working with causal loops to explain cycles in nature and everyday events. Students continue working across the curriculum strengthening their understanding of behaviors over time, casual loops, and simulations mediated through a systems approach. By fifth grade students are manipulating simple computer models that integrate into their curriculum." In academia the idea that you can't deal with dynamics until you have studied differential equations is one of the great misunderstandings. In my opinion the invention of differential equations has been one of the great disservices to understanding.

Mathematicians have had a considerable difficulty in even defining a derivative and the reason for that is that derivatives do not exist. In nature, nature only integrates. Nature only accumulates. You will not find in nature any process of differentiation. And yet mathematics is taught through differential equations and it has the effect of reversing the sense of causality for many people.

I have had MIT students argue that the water in filling a glass with water, the water that flows from the faucet because the water is rising in the glass. And if you look upon the flow as a derivative of the water level, then it focuses you on the water level as the independent variable.

So for any child, if you reverse this and talk about integration through accumulations as the source of dynamic behavior, then any child that can fill a water glass or take toys away from a playmate, knows what accumulation means, and knows what integration means. And they can begin to move into non-linear dynamic systems and never really encounter it as being difficult.

DA: What other kinds of feedback are you getting?

JF: Tim Joy in Oregon is an English teacher, and some of the most interesting dynamics in classrooms is being done by English teachers dealing with the psychological dynamics in pieces of literature. And so he says: "I honed two models for Golding's novel, *The Lord of the Flies*. One based on the boys declining civility, another describing the how the boys' loss of hope drives the increasing power of the beast. I was left with how to introduced system dynamics and the Stella software." The Stella software is especially for system dynamics and is used in many schools. "How to introduce this to 135 sophomores within the guise of an English class. Graphs in hand the students were arguing positions before I could take attendance, peering over books and tables, pointing out misjudgments and omissions.

"Students were not ready to accept their first attempt. Indeed quite a few wanted to re-do it. Some asked for more time to run another graph on a different boy. Others were just plain dissatisfied and came after school, on Friday no less, or the following Monday to finish their work. This was a new experience for me. System dynamics has a logic based grammar, a universal language that students can readily learn and manipulate to create meanings."

"What have I found? Creating meaning results in bolder questions. Whole new views which do not house traditional understandings. In some ways it's been terrifying. I have to give over some portion of the direction and instruction of the material to their own instincts and inquiry. It's slower at the start, but the curve steepens as we discuss and build models."

DA: Maybe one more example.

JF: Jan Mons, who is the system dynamics advisor to the schools in Glynn County, Georgia, in the southeast corner of Georgia writes: "My most fruitful experiences occur when I discuss classroom discipline systems. We have both students and teachers build a discipline system together so that all parties will know what the system is capable of producing. When we do this many students have an 'ah ha' experience and state that they now understand how a teacher's frustration can accumulate over time. Teachers have their own insights as well. They begin to understand how they have often built discipline systems that were pre-programmed to result in unpleasant situations."

DA: That's fascinating. So there's something that they have a personal stake in that gives them a real understanding of how system dynamics works. Jay, if you look forward ten, twenty years from now and could project how you would like education to be running. What would it look like?

JF: I think we'll see a gradual infiltration of dynamics into the entire sweep of the educational system. Looking back there's been very little, almost nothing in dynamics except in electrical engineering in colleges and to some extent other engineering disciplines. In electrical engineering, dynamics has been taught because relatively simple dynamic structures have practical use.

Electrical engineering has had the most advanced use of mathematics because it has some of the simplest of problems. A lot of pioneering in dynamics over the last 100 years has been in mechanical and electrical engineering systems. Now today with the availability of low cost, high capacity, digital computers for simulation, it is possible to deal with meaningful social systems.

There is no chance of getting mathematical solutions to the kinds of dynamic structures that one must deal with. So it's only through simulation, which means it's only through trial and error, the computer simulation approach is essentially the real life approach of trying something and seeing what happens. Except in real life, it may take several years to see the result, and by that time lots of other things have happened and you're not sure whether your own intervention accounts for the behavior or not.

Computer simulation is a vicarious experience in which you try different ideas and immediately find out which ones are high leverage policies with some chance of changing behavior, which ones are low leverage policies that no matter what you do will not effect the system. I would say that most of the policies debated in corporations and governments are debates around low leverage policies that don't matter one way or the other.

And very often they're totally ignoring the very small number of high leverage policies. And even when you find someone that is working with a high leverage policy, the odds are very high that that person is pushing that policy in the opposite direction from what that person wants to accomplish. And so it's to develop a public with some sense of the behavior, like knowing that a policy change that is good in the short run will be detrimental in the long run and vice versa.

If you want to get to a better future you have to pay a price in the short run. All of government is really geared to making things good in the short run and our big national crises come from having done that for years in the past. And now the day of reckoning is gradually closing in.

DA: So the new education would allow students to run simulations and not just guess, but really see what happens not tomorrow but years from now.

JF: Really see what happens and also see what happens if you change the structure or the policies in a system. Very often you need to change the structure in the sense of using a different source of information, for example. Or to reorganize the way the system is set up. Or change the emphasis on certain information inputs.

So that you get different modes of behavior from the system depending on the policies that are followed, and the word "policy" encompasses what information is available, and what information is used. Within the corporation we've already said that information technology has largely been conducted without adequate guidance as to what information ought to be available.

So with respect to practice in the real world, with respect to education at the more advanced levels of college and business schools, we need people who are much more alert than they are now to the nature of the systems and the wide diversity of behavior that you can create with modifications in the information structure and modifications in the policies.

DA: Anything else you think we should touch on before we close this?

JF: Well we may have pretty well covered things.