Bucky Fuller, Behavior Analysis in Education, and Things We Think We Know Which Aren't So

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Session Purpose: Provoke behavior analysts into considering some of the faulty assumptions of the Cartesian Coordinate model of space, and the impact of such faulty thinking on our educational system.

Abstract

Many of us, as Behavior Analysts, have been involved in the delivery of superior educational technology. Whether the particular approach be Direct Instruction, Opportunity to Respond, Precision Teaching, combinations of the above, or a general Behavior Analysis model, we can produce measurably superior instruction compared to much of traditional education. What I suggest we need to consider but haven't -- doesn't really deal with the delivery system. Rather, we need to consider such basic concepts as our three-dimensional coordinate system. What seem to be some of the faulty assumptions underlying our models of reality? As behavioral scientists, we have likely acquired some of these trappings from mainstream science and mathematics -- things we think we know which aren't really so. Most of us realize how our language abounds in such imprecise mentalisms (e.g., "the sun rises and sets"). If our language and assumptions do not correspond with generalized principles, what does it matter how effective we can be as educational technologists if we're teaching the wrong stuff? I can show you some dimensional models to demonstrate my point in just a few minutes. Nothing original -- just ideas from the repertoire of Bucky Fuller with which each of us should have familiarity if Spaceship Earth and its humans on board are going to succeed. Again, why bother with such information? Because our educational achievements, however magnificent, will not overcome a faulty knowledge base.

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Brief Abstract: This presentation will not deal with delivery systems that produce measurably superior instruction. Rather, it will consider basic concepts such as our three-dimensional coordinate system and things we think we know which are not really so. Our educational achievements, however magnificent, will not overcome a faulty knowledge base.

Introduction

Here is our basic 'peat,' in other words, the theme, which will be peated first and then repeated at the end. Essentially, superior instructional technology is available in behavior analysis, whether it be through Precision Teaching, Direct Instruction, Opportunity to Respond or others that Heward (1992/1994) was just talking about. We have the techniques. What is not always so obvious is what to do, or what it is that needs to be taught. And so, one of the things that I thought would be sort of fun to look at, goes to this notion of "things we think we know which aren't so." So, we get to the notion of looking at some of the things that we are teaching kids, or not teaching kids, that they either should not be taught or ought to be taught. You can kind of figure that out.

So, essentially, then, what we are saying is, is that we have got the technology available for education, but the assumption is that what we are teaching is appropriate. Now, I am going to try today to challenge a couple of those assumptions. So, we are going to take a look at these different areas (Table reference?). And what we will see is that some of them sort of coalesce or run together. Also, I am going to suggest a few futures and talk about synergetics, or the "comprehensive anticipatory design science."

Buckminster Fuller Data

Now, that particular terminology was the wording of Buckminster Fuller. Last Spring (1992) in a college undergraduate class I found that only 1 in 30 of the students had ever even heard of Buckminster Fuller. To me that was scary and somewhat appalling. So, I hope that percentage would be higher if we took that count today. How many have heard of Buckminster Fuller before? How many have ever heard him talk?

Some of you would be interested to see these data. This was Bucky Fuller receiving awards (Figure 1; Standard Celeration Yearly Chart). This is year-by-year. He was born in 1895 and died in 1983. So, in 1988 (?) most of the awards had stopped coming. However, if we look at what sets up those rewards or awards it is usually something like keynote addresses and principal speeches. And the data are his count per year of keynote addresses and principal speeches (Figure 2; Standard Celeration Yearly Chart). And you can see that even at the age of 88, which was his age when he died, he was still on the speech-making tours. The honorary degrees which he received, which total 47 over the years, look like this on a year-to-year basis (Figure 3; Standard Celeration Yearly Chart). So, you can see that he was getting some recognition even during his lifetime for some of his accomplishments.

Buckminster Fuller Accomplishments

Well, what were some of his accomplishments? One thing that might measure it is this cover of *Time* magazine (January 10, 1964). On this particular cover a number of his so-called artifacts were displayed. There is a tensegrity sphere here, the Dymaxion car is over here. His actual head is in the form of a (geodesic) dome. He's got the helicopter flying a dome. He's got some of his tensegrity masts here and some other domes, closest packing of spheres here. Some of these things may not be familiar to you. I just mention that this is a kind of nice showing for Fuller in the media on his contributions.

When Fuller started to look at the world his determination was that nature was very, very parsimonious. And I think that as behavior analysts we accept that sort of view. He was also extremely empirical, which was another scientific principle. One of the things he was looking for was the coordinate system used by nature. That is, he didn't believe and he said he could not believe that nature would work pi (π) out to some number of decimal points in order to form a little bubble. He said nature probably does not. He said nature could not know pi. So, it must use some other coordinating system. And thus, that was his great search.

Fuller came up with a number of terms. One was 'dymaxion,' which was a combination of 'dynamic' and 'maximum.' And he had a number of things to which he attached that particular term: Dymaxion House, Dymaxion Transfer. The only one which actually came into fruition was the Dymaxion Car. It was not really set up to be just a car, however. This was the land transport version. It also had wings and a propeller on the back. So it was touted eventually to be a boat, car, and plane. One of the features of this Dymaxion Car, which was conceptualized and built in the 1930s, was that it had two wheels in front, one wheel in back; very stable. If you were driving around you could pivot around that endpoint and turn around. So if there was a traffic cop in the middle of the street, go right up to him, go right around him, and park on a dime, and that was one of the features of the Dymaxion Car. It never quite caught on; a lot of interest, but bad publicity. But that was one of his artifacts.

Another was the Dymaxion Map. The Dymaxion Map (Buckminster Fuller Institute, n.d.) was his way of utilizing the fact that in a flat projection system you have difficulty keeping the land masses accurate. So, in the Mercator system, which is still one of the most widely used projection systems for looking at the world in two dimensions, you have a situation where Greenland looks about as big as South America. And, in fact, Greenland is very, very small compared to South America. On his Dymaxion Map he was able to slice it up into triangles in such a way that when you put it back together any of the distortions fell over the water areas so that it didn't make any difference anyway. And therefore the land masses appeared much more accurately, as you would see in front of a globe. So, you can unfold this (Dymaxion Map in globular form) and then fold it back up. So, a Dymaxion Map is much more accurate to look at and see those appropriate land masses.

Things We Know That Aren't So

Well, in some of the "things that we think are so that probably aren't," I am going to start off here sort of slow and easy, and list a few of these.

Handwriting. Handwriting is not something that Fuller talks about, but it's something that most of us have run into. The fact that we can teach children to write using a system that was set up for essentially goosefeathers, quill pens, where you could not go in certain directions, and yet that particular system is still in place in most of our schools across the country and across North America. This is sort of an easy, early example of the sorts of things that are still "we think are so," but does not really make a whole lot of sense.

Measurement. Another one is the measurement system. Now, I can go on and on about Standard Celeration Charting, how simple that is. But the difficulty that Ogden Lindsley has had in getting that adopted (in behavior analysis) is really a similar case to the sorts of problems we have run into with the Metric System. How many of you believe that the metric system is simpler than the other systems that we currently use? And yet, you look at the difficulty in even getting people to adopt that system. I think you can sort of see the types of problems that we run into.

Language. Another area is language. You would think, and there are a number of people who make a big point of this and one of them was A. Korzybsky in *General Semantics* (1933/1994), but you would think that we would talk when we are teaching children, we would talk in ways which accurately reflect the ways things are. Right? So, how many of us tell our kids that "the sun is rising," and "the sun is setting"? When in fact, that is not happening at all? And so this was one of Fuller's points; that we should really communicate at even an early level with our children in an appropriate way that actually reflects the way nature is. So, he said, better "sunsight" than "sunrise." Well, what is happening? You are seeing the sun with the Earth turning; nothing is really stationary. And also, "sunclipse," when the sun "goes down." It doesn't really.

Up-Down. Also, Fuller said our notion of up-down is probably inappropriate, because there is no "up" or "down" in Universe. When you say, "Well, the Skylab is up there right now," and you look up, where might it be? Well, it could be on the other side of the Earth and underneath your feet. So, the "up-down" is really inappropriate, said Fuller. It's probably better "in towards" something and "out away" from something or "around" -- are better words to use.

Mathematics. Now, when we turn to the area of mathematics, we run into something which I find extremely interesting. What do we say when we "raise something to the second power?" Squared. Ok. When we look at something which is squaring, we have a unit edge here, then 1 X 1 = 1. If we divide our edge into 2, if we have 2 on each side, then 2 X 2 = 4. So, 2 squared is 4. And likewise, 3 squared is 9, and 4 squared is 16. What Fuller points out, however, is that triangles are simpler than squares, because they've got 3 sides and not 4. And so actually, when you raise a triangle to the first power you've got 1. When you raise it to the second power -- that is, divide each of its equal sides in half by two portions here -- when you do that to each side and count up the number of sides, you've got 4. If you divide each side into 3 -- count up all the pieces -- and you've got 9. So, in terms of this triangling versus squaring, he says the triangle is much simpler than the square. Therefore, if you are going to use some sort of short version instead of 'power,' then it should be triangling versus squaring.

Now, that is for area. That's in planes. Planes are really only conceptual, and not so much experiential. You start looking at the world where you've got cubing and volumes, he says the same thing applies. You've got a cube versus a tetrahedron, or tetra. With a unit side of 1, 1 to the third power is 1. Two to the third power is 8. You do the same thing by crossing each of these sides and counting up the number of little chunks that you have. With the tetrahedron you get 8 just as you do with the cube. The same applies right along. So, in mathematics this is one example where what we are teaching is sort of the way to go is probably not the most simple thing to start with.

Physics. When we move into physics, here's a Fuller (1992) quote (I'll let you look at that and mull over it for a moment):

> The mathematician's purely imaginative points, lines, and planes are non experienceable. They cannot be modified, having no thickness, no breadth, and ergo neither insideness nor outsideness. All imaging derives from experience. Conceptually imaginable point, line, and plane experiences are systems; that is, they have insideness, outsideness, and angular constancy independent of size." (Fuller, 1992, p. 119, *Cosmography*).

It really says quite a bit in the sense that what is experiential is necessarily something which is a dimension that we have actually contacted in the world. He is saying that a lot of the things that we conceptualize both in mathematics and in physics are really nonentities. That is, there is no such thing as a solid, because no matter what you look at as "solid," if you look at it very closely, there are electrons, the nucleus, and there is mostly space in there. So, there is nothing really "solid." Also, there are no straight lines that go on forever. So, in physics a lot of the notions that we have are counter to what appears to be so.

Axioms

Another type of problem that you run into is that you have a lot of axioms that are assumed to be so. And we sort of take off and build a system or some sort of way of manipulating other things from that particular starting point. And Fuller's belief was that that is probably inappropriate. That is, he is really empirical here, because he is saying these axioms do not mean a whole lot, because we don't know that they are right or not. The way we can do it is go out into the world, find it, and then go from there. And that essentially is what he did. So, no "axioms," or "this is obvious" stuff. You've got to see it:

> "What cannot be experimentally proven is called axiomatic by geometricians and by mathematicians in general. Axiomatic means to them "obvious" or "it has always been taken for granted to be thus and so."
> "Synergetics, on the other hand, deals only with experimentally demonstratable phenomena." (Fuller, 1992, p. 119, *Cosmography*).

Question from Hank Pennypacker: Steve, quick comment: Would you see that as sort of his statement of the difference between deduction and induction?

Graf: I think that is a good point. He didn't use those terms, but I think that is a very good point.

Pennypacker: Which ties closely to Skinner.

Graf: Yes it does.

Repercussions of Axioms

Now, what are the repercussions of some of these axioms and the use of these axioms? Well, we are going through this pretty quickly and I am not going to read this, but essentially here is one of his criticisms of measuring systems. You can see he is fairly strong in his language, while talking of volume:

> "The vector-edged cube's volume is the irrational number 3.5339+. This 3.5339+ cube is the vector-edged cube that physics illogically, encumberingly, and slavishly uses and has

> always used as the unit volume in the centimeter-gram-second and XYZ-coordinate system of academia's energetic mensuration. Using its volume as the standard unit volume for the entire hierarchy of primitive symmetric polyhedra makes them all awkward, irrational values. The measuring system used by business and industry and taught in every university science department is thus a mishmash of awkward, cumbersome values. Aesthetically inclined students are repelled by the irregularity and disorder." (Fuller, 1992, p. 60, *Cosmography*).

And, what essentially is his answer to that? Well, in looking for a system which will somehow handle things the way nature did, or a coordinate system which is sort of similar to nature, he thought that synergetics was in fact that sort of system. And he felt that one of the signs that we should see if we find that sort of a system, that is, close to nature, is that there shouldn't be any of these irrational numbers when you are calculating volumes and so forth, and imaginary numbers and so forth. All of that is unnecessary because he doesn't think we see that in nature"

> "Synergetics uses whole numbers, completely eliminating all irrational, imaginary, and irresolvable numbers and complex formulae. It is amazing that technology has been able to produce what it has, considering the obstacle presented by current scientific conventions in the field of geometry and measurement. The scientific and academic establishment still cowers in the Dark Ages imposed by human power structures many centuries ago. The dawn of scientific civilization is yet at hand." (Fuller, 1992, p. 63, *Cosmography*).

Now, here's a quick look at the cube where you have the unit edge and the unit diagonal, and then figuring the volume of some of the polyhedrons versus the tetrahedron which he used as the basic building block in looking at these various volumes if you use that tetrahedron. So, here in effect is the notion in actuality that you have available a much simpler system than the one we seem to be locked into, because with the tetrahedron rather than the cube then you've got a way of expressing volumes in very simple terms. So, our entire scientific base of measurement with the centimeter-gram-second in a cube, somewhere in France in the Department of Standards, as the central building block, is what we think is so, but really may not be as far as simplicity, parsimony, and actual empirical evidence.

Well, in synergetics then, Fuller was saying here's the way to go. So, Fuller built an entire synergetic geometry – two volumes. Unfortunately, I think his terminology sort of ran away with him. Melinda was saying that she had heard Fuller as an undergraduate, and loved to hear him talk, but it was very difficult because two sentences into his talk, why he would kind of run away and even though he was still interesting it was hard to figure out what the heck he was talking about sometimes.

Reading Fuller, *Synergetics* (1975) in particular, is even more difficult. And some of his other volumes are more readable, but still one of his difficulties was in communication; getting these principles across in a way which was simple; and in a way in which other people could learn. So, why have a lot of advocates of Fuller's ideas? There are very few of those individuals who have actually turned around and tried to teach this using the sorts of technological tools that we have available.

Models

One of the things that Fuller was a great believer in was the notion of modeling. And his idea was that since he had been born in 1895 at that point virtually everything was visible. Very quickly, as technology multiplied in the 20th Century, things became more and more invisible. So, virtually all of our technology today involves components of invisibility. He called this "ephemeralization." That is, sort of becoming less and less visible. He believed, however, that in order to get children to understand the principles of nature and principles of Universe, what you had to do was make things visible. And he felt the way to do that was use models.

> "I have always found models quite useful in illustrating apparently complex phenomena in nature. For instance, I have found the models of synergetics, my system of geometry, quite capable of illustrating such basic principles as quantum mechanics, forth-dimensional forms, and complex motions and phase transformations." (Fuller, 1992, p. 19 *Cosmography*).

Demonstration of Models

And so his use of models and his building of models, and building of artifacts that incorporated the principles, was in fact not only the way he showed how the principles applied, but in his own terms the way he discovered these principles to begin with. So, I would like to take a look at some of these notions of models. We've passed around some of them that I've built or have purchased, and we are going to take a look at these again. I think you can see the difference between looking at something like this which is essentially a picture in a book (2 dimensional), and actually looking at a model and holding onto a model of that same thing.

Closest Packing of Spheres. Now, this is the closest packing of spheres. And what it essentially involves is the problem that if you've got one sphere, then how many other spheres does it take of the same size to completely encompass that particular sphere? Well, you can figure it out in this model. The way you do it is just pack them up like that.

And it turns out that it takes 12. Well, that is what this [model] is trying to show. But notice how much clearer it is when you can actually hold onto it, and see this type of relationship.

Jitterbug. The other thing which is interesting is, is this particular problem of what is called closest packing of spheres, also has some other features and repercussions. And that is that it turns out that this particular figure which Fuller called the "jitterbug" is a representation of that closest packing of spheres. Now, how does that work? Well, if you imagine a sphere in the center and you imagine a sphere whose center point is each one of these vertices, then that is this is the model for that closest packing of spheres. And it has universality, in that there are only 12 spheres that will fit around 1 regardless of the size of the spheres.

Vector Equilibrium. There is another principle with the model that can be seen from a little bit different version of it, and that's this with the same outer core here. But now we're running a diameter across from vertex to vertex through the center. Now, this is constructed with straws. All of these straws are approximately equal length. So you can see that each of these little units is equal; just as each of these units is equal. What I am saying is, is that these gold units going into the inside are also equal. So, this particular figure, which he called the vector equilibrium or VE for short, has the characteristic that from this one center point each of these vertices is an equal distance away. Which is demonstrated: We can see that because there is a gold straw coming out to each of those vertices. And what's the notion of usefulness of that particular notion? Well, it looks as if, according to Fuller, this is the type of way in which structure goes in Universe. That is, that if you look at very simple structures such as the tetrahedron -- very stable -- and you fit it in, then it will fit right into here. And you can fit a number of these right into here. In fact, with this figure and with this figure which is a square=based pyramid and this tetrahedron you can build the vector equilibrium. So, these simple structures make this complex structure. These parts, in other words, seem to be the way Universe is put together.

Bucky Balls. Now Fuller was talking about all of this using these models saying these things, and of course some people were paying attention and some people weren't. Well, interestingly, some of the things that he said were, after he said them, discovered with the electron microscope. So, a lot of what he conjectured, or what a lot of people took for conjecture, was actually later demonstrated in actuality. And even though Fuller died in 1983, since then they have discovered, and perhaps some of you have seen it in the news, things like, well, these are carbon compounds which heretofore had been undiscovered. And they called them buckminsterfullerenes. That is, they named this element in honor of Fuller because when you look at them with the microscope what you see sort of takes on the characteristics of a little geodesic dome. And Fuller had in fact described these in his models quite a few years before they were discovered. Those have also been called "Bucky Balls." And there appears to be a great deal of potential future in that realm of research. How many are familiar at all with "Bucky Balls"? Without going into it, there's a possibility that bad electric car batteries, for example, can be made as efficient as we need to make them to operate machinery by batteries. That is still down the road, but a lot of great possibilities. So, I guess, back tying that into what I am saying is if we want to understand that technology we had better get on the ball as far as better get on the VE as far as understanding what it is all about, and teaching that to the next generation so they can have a better chance of understanding that.

Tensegrity. There is also a number of other principles such as tensegrity. This is a model that hangs in a bank in Dayton that is approximated in a much simpler form. This is a tetrahedron in a tensegrity shape. Now, "tensegrity" was "tension" and "integrity" combined by Fuller, and really illustrates the other principles that essentially the two forces of tension on the one hand and compression on the other hand. He said that almost all architecture is built using principles of compression. So you get heavier and heavier stuff and then there are limits. If you use tension along with compression then you can widely expand what you can build. And that's the underlying principle behind the geodesic domes.

With each of these models there are really a number of other demonstrations. I hope all of you have had a chance to go through the realm of some of the things I've been working with. I have found it much easier to understand Fuller when you are working with the models. One of his principal points is, is that this cube, which is the basis of our architecture, is not the most stable of structures. Not particularly when compared to the tetrahedron. So the tetrahedron, if you drop it, it still retains its shape; much more structurally rigid. The cube – how do you keep it? How do you even live in buildings? Well, they do get blown down by Andrew and blowing hurricanes as well. But what we try to do is shore them up with triangling -- triangulation -- beams in there. It's still not the best way to build architecture.

These are also interesting in that if you notice these are vector equilibriums as well, or vector equilibria, taken by making a circle or taking 4 circles and dividing them into 6, and then simply clipping it together with bobby pins. Now, I don't know if you noticed, but the are really quite ballistic, and even though these were done by a six-year-old they still demonstrate a lot of the tensional integrity when you clip those bobby pins together and actually put them in. These are little bow ties, in other words. If we take this apart (well, I'm not going to be able to do that since we painted over them). But taking these apart: You take 4 circles, fold them into 6, making a little bow tie out of it, and then clip them together. Then you have this particular model.

Carl Binder: Those colors make it pretty clear.

Graf: Yeah.

Dimensions. And the colors also make clear another point, which I'd like to sort of wrap up with. And that is that Fuller claims that what we have gotten out of our three dimensional cubical notion of the way to measure is all wrong. There's actually four dimensions in what we're claiming is just three. And those four dimensions are the four dimensions that would run through the face of each of the sides of the tetrahedron. So, that if you try to stabilize an object, it takes these four dimensions. That is, if you have a little ball and you have some string on that ball, well with just 1 string on the ball it's obviously not stabilized. With one on each side you can still twirl it around. You've got to take four different directions -- a vector going in each of these in opposite directions off of these four -- so eight vectors in all, to stabilize an object in space. And that's four dimensions, and that can be done. But those four dimensions can also be represented by following around the vector equilibrium with one of these colors around the circle. So this [gold] is one dimension; two dimensions is red; three dimensions is white; four dimensions is blue. That's four dimensions and that's what Fuller says is the way nature works with space.

Historical Note. To wrap things up, John Eshleman handed me just before we started today some of the studies he's been interested in. These are time lags between Chinese discoveries and the actual so-called invention or adoption of those discoveries in Europe. Here is when the Chinese invented it, the time lag, and when it hit Europe. So, that as you can see we have got a long history of these particular instances both in mathematics, physical sciences, and so forth of this whole notion of what we think is so or working on one assumption, and then seeing that at some later point that that's not in fact the way things were.

Summary

The title of this talk is really something that I picked up from a talk by Ogden Lindsley (1977) a number of years ago. He was quoting Ambrose Bierce, and the notion went originally something like, "It ain't what we don't know that gets us in trouble. It's what we think we know that ain't so." And with that particular quote there I think it is appropriate today to look at the sorts of things that we as technologists, with high technology at our disposal, what can we do in the future to teach some of these principles, and correct this problem of the sorts of things that we think we know that aren't really so. Obviously, Buckminster Fuller and this particular example is just one case in point. There are probably others out there as well. This is my particular interest. I hope today that what I've been able to do through this sharing is give you some ideas or at least a little bit of awareness of some of these others and this particular idea for your own edification.

Sources

Here are some suggested sources:

Buckminster Fuller Institute
1743 S. La Ciegna Blvd.
Los Angeles, CA 90035
(310) 837-7710 FAX: (310) 837-7715

The Buckminster Fuller Institute carries a lot of his materials. There's a book that came out this year, even nine years after his death, which I have been sort of pulling together over this last year to put into as Dick Malott says, "plain English," some of the things that Fuller was trying to say (*Cosmography*, by R. Buckminster Fuller, 1992). There also are a number of toys -- educational toys -- which are on the market. This is called the "tensegritoy." I found it very well done. It has a number of struts and little rubber bands tied to them, and then models for making a number of these structures -- very, very fun to do, easy to do, but difficult to see what they are all about until you actually get working with them. Again, just looking at the picture of it doesn't do it justice. There are a number of things that you can do just on your own. This is one that we put together. The one that we're looking at here is a professionally done one. Thus what appears to be the difference is if you get surgical tubing then it's much better to punch holes through that this more inflexible tubing that we used. Also virtually all of those models that I did were constructed simply out of straws; taking straws and hairpins and putting them together gives you by yourself, or you and your spouse, or you and your children a lot of fun together in sort of putting together these models.

Thank you very much.

Question & Answer Session

Question: I was trying to put it in context of this particular strand, and also what Carl was talking about. You mentioned that Fuller had trouble communicating and the issue was promoting behavior analysis, it seems like you're almost moving in an opposite direction to what Carl was saying we need to communicated in what we {inaudible} think of as phenomenal language or language of appearances rather than the language of reality, which is where the difficulty of sitting down across the kitchen table to explain things. Would you like to comment on that or maybe Carl?

Graf: Yeah, let's get Carl's.

Binder: Well, my only thoughts are that it would be useful first to understand this stuff before we figure out how to communicate it. That's what I would think that Steve is doing. He's introducing something to us which perhaps some of us have had some contact with, but maybe never took time to really pay attention, and if we can figure it out then maybe we can figure out the Plain English versus what have you. I mean that's the only thought I have. This is a resource which maybe will be useful. Besides which they've done a nice job of marketing products here. They've packaged it well. I don't know, I'm not sure beyond that.

John Eshleman: So, basically what Fuller's saying then is that we don't really have or don't exist in a 3 dimensional world with 90 degrees up and 90 degrees this way and 90 degrees that way. Is that what he's kind of saying with the "4 dimensions" kind of thing?

Graf: Right. And interestingly, he said that the Euclideans seem to be the people who locked us into it. At that particular point it was thought to be a flat Earth. So, East and West went on forever. North and South went on forever. And you didn't know how far high it was to Heaven or how far down below you could go, but those were the three directions. They used those with their scribes, their measuring instruments, and we've sort of been stuck with that. Also, interestingly, the Phoenicians some thousand years before that had actually used a spherical geometry. But that didn't catch on for one reason or another.

John Eshleman: Isn't there some evidence that the Phoenicians and maybe even the Polynesians circumnavigated the Earth back around the time of Eratosthenes, and those kinds of people we don't really know too much about in our history?

Graf: Yes, in *Critical Path* (1981), another one of Fuller's works, he speculates based on using the notion of one world in one world ocean how mankind probably started in Polynesia rather than the Euphrates basin. So, he's got his own speculative prehistory which he seems to think is maybe empirically understandable than some of the other cases that have been made for history.

Dick Malott: How was that book by Amy Edmondson (1987) for explanation?

Graf: Difficult. So, she worked with Fuller very closely, but again.

Dick Malott: What about *Bucky for Beginners*?

Graf: This is the *Cosmography* (Fuller, 1992). And this is the *Fuller Explanation* by Edmondson (1987). As you say now, Dick, it's still difficult reading. *Synergetics* (Fuller, 1975) and *Synergetics 2* (Fuller & Applewhite, 1983) are very, very difficult. But the real starting point I think is *Bucky for Beginners* (Laycock, 1984). A lot of these models were based on that particular book.

Dick Malott: What was the name?

Graf: *Bucky for Beginners* -- Mary Laycock (1984). Still in all, it's really only a shell of what would be possible given some of our technology for setting up instructional materials. And so that's probably the best available but by no means is it anywhere where it should be if we've really serious about communicating these concepts ultimately to children.

References

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1992: Quotations from *Cosmography* – presented on transparency slides during the talk – were added to this paper in the appropriate locations.

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