

Synthesizing Instructional Theories and Implications for Instructional Technology:

Joint Discussion

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**First Discussion: Relationship Between Content Models: Measuring the Behavior Associated with Models**

Joseph Scandura:

When people talk about knowledge they typically draw pictures/diagrams, consisting of one or more icons, each of which represents a concept. Then they draw arrows between them showing relationships. You can do that with essentially any domain of knowledge. One that comes immediately to mind is something we did some years ago involving basic trigonometric functions. In this case, concepts included everything from the Pythagorean theorem to various trigonometric identities. One can derive all kinds of relationships and represent them as arrows between concepts. One can look at it and know what is meant by the content. But is such a representation sufficient for designing instruction to teach content? For example, how would I observe, that is know, that a student does or doesn't know it? This requires a change in mindset. In the diagram, some of the arrows represent some sort of association. Some of them relate to operations by which one can go from one concept to another. The arrows can have all kinds of meanings. Like others, we tried to capture all of those meanings in this framework and ended up with all kinds of fancy labelings. The representation turned into something quite complex.

By the way, that same kind of thing is going on in software engineering -- in the object oriented paradigm, the objects and the methods that operate on those objects are packaged together. Software designers are effectively arguing about how to represent this or that construct but in many cases they are in my opinion getting lost in the details and missing some of the essentials. In object oriented design one of the things they talk about is 'use cases'. Use cases refer to system behavior, which in some sense is the essence of what software engineering is about. Object oriented designers tend to start with the objects and methods contained in those objects. But, when they get around to the behavior of the system, then they start talking about use cases. They know they have

to deal with behavior but the prevailing wisdom at this point in time is that use cases – behavior – are only represented in an informal way. I believe we have a similar situation in instruction when we try to convert content into representations that enable us to deal with identifying behavior, identifying it, teaching it and objectively testing for it.

Klaus Breuer:

I follow your comments. When we draw sketches of contact relations, we come up with something we can share. The problem is that we have no real syntax for that. Different relations have different meanings, as you say. So if we come up with individual sketches representing individual conceptions of the subject matter area we depict, we have no language to communicate. One of the advantages which makes an easy answer to the question of models and measurement of knowledge comes with system dynamics, because the stop and flow syntax which comes from there is a language representing a subject matter domain. You have a set of symbols which you apply to structure a subject matter domain. It's not valid for all areas, but it's valid for the field where you have a set of concepts with relations in respect to material flows and information flows. Different rules govern the material flows. So some people address or label these software tools as knowledge representation tools. You can elaborate on your understanding of a certain domain using that specific language. Everybody who has that language will understand you, because you have a mode of expression. In addition, you have the interactive tools, which now allow graphic based modeling on the computer screen. If you provide for feedback in your modeling process, the first level of feedback you get from the system is at the syntactic level. The software won't allow you arbitrary connections between the elements. So, you can't reasonably make an information connection into a stock considering to change something with that stock. This is not a tactical valid use of the language. It is a system of value. So at the syntactic level you already have an interactive environment, which tells you about the syntactical correctness of your modeling process. In addition, at the next level of semantics, you get feedback from systems when you elaborate your model to the level of a simulation. The behavior of the system within the simulation gives you feedback on the appropriateness of your model. Does it behave according to your knowledge about the behavior of the real system?

Joseph Scandura:

How do you tie the behavior to the knowledge representation, as you're describing it? I am not clear on the relationship between the underlying constructs. How do you tie those together?

Klaus Breuer:

The structure of the model defines the behavior.

Joseph Scandura:

But in what sense?

Klaus Breuer:

In the sense of the logic of stops and flows that you have presented and of the information flows. If you have worked with this in the Structural Learning Theory approach, I hope you will help me to elaborate. You can read by looking at the model; how it's basic behavior could be. You can't predict it on a numerical basis. But you can read from looking at the basic structure of a model whether you will have an exponential

growth process or whether you'll have a target searching process. And you can simply read it like that. So the knowledge representation part is one side of the coin, the second side of the coin is representing the subject area. It's tied together.

Joseph Scandura:

I think I'm hearing something very similar to data flow diagrams in software engineering. They are basically designed to capture data flow in a system. They have been used widely, but they also have a lot of limitations. Are there unique differences in what you're proposing relative to data flow and if so what would they be?

Klaus Breurer:

The basic difference is that these are sketches in a certain language, but they are non-operational. You have to convert.

Joseph Scandura:

Data flows are operational.

Klaus Breurer:

Are they?

Joseph Scandura:

Yes.

Klaus Breurer:

This is beyond my knowledge of that area.

Joseph Scandura:

The models which you develop with simulation-oriented modeling tools are operational. As you run a simulation, you get a feedback of the validity of your model with respect to certain validity criteria.

Franz Schott:

If you ask a very simple question, "what is content in the frame of instruction?" the answer is not easy. But every instruction intends the learner to perform some task and every task consists of content and behavior. So, how do we separate content and behavior? This is a matter of task analysis. I developed 20 years ago a method of task analysis that very clearly separated content and behavior. Every task you can describe in certain states, the beginning state of the task and the final state of the task and the states in between. These states are the content. The change of the state is a behavior. So with this method you can quantify the content and the behavior. From my experience what is underestimated is task analysis. Problems cannot be solved without a good task analysis.

First Person from the Audience:

I think that we are not trying to separate the content from the way it is expressed. I think that whatever the content we try to express it in some form of language. The language we use, whether it is structuring or American, is going to constrain what we can use. There is no content separate from the language in which it is expressed. You have the constraints of language.

Andrew Gibbons:

Can I respond to that? Language is a perfect way of expressing thought. That is one of the reasons why there are so many languages, because there are so many different ways to express different thoughts. I've read a book, Cultures and Learning. One chapter deals with the idea that very often we will have a concept without being aware that we

have the concept. And as we're solving a problem we will invent little categories that will help us solve a problem momentarily. We are not even aware that we are inventing these categories. But what we are doing when we invent categories is that we are inventing something in our knowledge. Frequently these little things we invent inside our mind cannot be expressed. We don't have a language to express our feelings and that is why we have so many people fighting with one another. If we could just express ourselves to one another, maybe it would help. So I think when we use the word content, we start a cycle. We give them existence, but perhaps independent of the individual they don't exist. Perhaps your knowledge is yours and my knowledge is mine. And all we can do is invent some symbols to talk about it. Perhaps this idea of knowledge is really experiential and a residue of experience and language is a secondary expression of knowledge, rather than being knowledge itself.

Joseph Scandura:

Are you ready to give up on the idea of being able to externalize and talk about it? Constructivists would have you think that everything goes on in peoples' minds. They construct knowledge (representations) -- and this is all well and good. But, you can take any one class of behavior and develop not only one but an indefinitely large number of alternative accounts of that behavior. Alternatively, if there is one explanation there is an indefinitely large number of explanations for the same thing. The question is whether we're in an instructional situation (where observable behavior is critical). Or, we're interested in just abstract knowledge constructs, relationships between them and the behavior they produce? (Rather than the reverse, inferring knowledge from behavior.)

Jose Gonzalez:

I wanted to see what your reaction was. Now that you have answered this question of behavior maybe it's an opportune time to comment. System Analysis is a set of simple rules and some numbers that is supposed to represent a system, simple or complex. I agree in principle that if you are able to understand completely the symbols, you should be able to predict some behavior. This is only in the case that you want to make more than qualitative predictions. The second thing, which I think is very important, is to conceive that the very moment you start modeling, you might get interested in the perception of very complex problems in the world that are so rich that it's totally impossible to visualize their atomic particles. That's where behavior comes in, because, humans are able to detect patterns in a way we are not able to express.

For instance some people are able to recognize music of composers in compositions they have not heard before very rapidly and they are not able to tell you why. They simply hear it. You see similar things in other domains. One way of dealing with very complex systems is what neurologists call memory of the future. People explore the behavior of existence and then create a kind of scene of how it could behave and they create a representation of the future in a way that we still don't understand. Maybe individuals are able to anticipate patterns of behavior when it comes to taking positions in order to behave sensibly in a complex world. I don't know if I have contributed to the discussion with these ideas, because it's a very complex matter. But I believe there are real challenges as how to describe not only the model but also our way of discovering the patterns of behavior in the world.

Joseph Scandura:

Let's see if we can make a bit more precise what the problem is, and then challenge that. Irrespective of what you teach, the domain can be characterized by the problems presented to the learner and the learner's responses to them. The problems and solutions might be very simple. Or, they can be much more complex -- arbitrarily complex. They would include the things that Jose Gonzalez was talking about (complex simulation behavior). It would include how the chess master seems to recognize patterns immediately and react to them. Irrespective of the domain, we must specify the problems that characterize the domain and suitable answers to those problems. Are we willing to accept that much, or not?

Second person from the audience:

One question: Are we really addressing the discussion topic, the point of measurement? Or are we still surfing around on several different questions here?

Joseph Scandura:

I think we were. That's why I proposed a very specific definition for discussion. Do we agree? Or not? It's very easy in these discussions to talk past one another. If we can agree on something then at least we have a starting point. If we can't agree, then ....

Second person from audience:

We used the issue that it's hard to express emotions and that brings forth the music metaphor that Jose pointed out. Maybe we haven't really found that. There is some kind of universality out there and this world of being domain specific or individual specific, we're really missing some of the point.

Joseph Scandura:

Are you saying that you cannot take what Jose talked about and place it within the general framework?

Second person from the audience:

I'm agreeing. But what I heard you saying was something a little different.

Joseph Scandura:

I would certainly incorporate what Jose was talking about with what I was talking about. Are we talking about the same thing?

Third person from audience:

I'm a musician, and when I had classes in which we learned to recognize pieces of music by the sounds, we had to tell why. Why did we think this was early Haydn? Why is someone from the Mannheim school as esoteric and vague as they are? I just wanted to say that in case there were no musicians.

Joseph Scandura:

Behavior can be as specific or as vague as you want to make it.

Third person from the audience:

But you will not pass the test if you cannot tell why you answered the way you did.

Andrew Gibbons:

I would like to explain why I said what I said. Back in the Middle Ages at least to 1700, physicians and scientists of the day believed that the health of the body was regulated by four humors, black bile, yellow bile, blood and phlegm. If you had too much phlegm in your body you were said to be phlegmatic. If you had too much blood, you were

sanguine. If you had too much yellow bile, you were bilious. If you had too much black bile you were said to be melancholy. If you had too much blood, what would they do? They would open a hole in your vein and bleed you. That was the knowledge of the day. That's what they reified in those days. That was the knowledge. I think we have to be very careful of what we call knowledge. And we have to be kind of humble when we say that we can just write knowledge down and teach it to other people. That was the knowledge of the day. And we don't do that any more. We treat people differently, when they go to hospitals. Because we've allowed ourselves to change the knowledge. And its because we didn't try to pin down the knowledge. Suppose we limit ourselves to written transmission of knowledge, verbalized transmission of knowledge and not experiential knowledge, we'd still be bleeding people today. That's my problem with becoming too definite about the externalization of knowledge.

Joseph Scandura:

Andy, how does that conflict with or support what I was saying.

Andrew Gibbons:

I'm not sure because I didn't catch the gist of what you were saying. But it sounded to me like you were saying that we should be able to agree that we should externalize knowledge.

Joseph Scandura:

What I was saying is that we should be able to determine what a person knows about any kind of knowledge. The knowledge itself may be good, bad or indifferent. The important thing is to identify what kinds of situations and what kinds of answers to those situations characterize one's knowledge (e.g., of medicine).

Andrew Gibbons:

You're saying you have to be able to observe it.

Joseph Scandura:

Yes, you have to be able to observe it. If you can't observe it, you can theorize about it, but you can't do anything about it.

Sanne Dijkstra:

Yes, well, first some comments on this last example, in case we are describing an educational goal. Suppose that we wish students to require some knowledge that we believe is valuable. Then, we have to look and see the criteria. The first criterion is the explanatory power of the knowledge, the explanation of how something came about. The second criterion is the predictive power. If you do something, what will happen later, and what will be the scope of it? Is it comprehensive or is it a very small scale? You have to realize in advance all those features of knowledge.

Now I choose to go back to Klaus and make a short comment. During your presentation I was thinking what do your students really have to learn? And what are the skills you hope your students will practice? What is the problem you will address? I heard your presentation in a somewhat different way in Germany. The issue may not be supply and demand, but maybe the things you are selling and buying. Suppose I have a terrible problem. Do I say to myself go to Klaus and to Jose and they will help me with system dynamics, whatever this may be, and my instructional problem will be solved? I believe it's not that simple; so first of all I challenge you to be a little more specific about

the conditions, based on the system you have made and have shown. But is this the instructional approach or do I have to construct a kind of modern situation, a shop in which you can bring in necessary objects and transport them to other shops, all over the world, maybe? Can you place your students in such a situation, and start with simple problems, instead of starting with this beautiful simulation? You can comment!

Joseph Scandura:

Can we stick with what Sanne just said?

Franz Schott:

Another comment about what the students should learn. I think in pragmatic problems it is easy to solve. For example, the time I cooperated with engineers who organized a course for students to learn how to automatize big process plans, it was not easy for me to learn the real goals for that course. We needed a crystallization point to negotiate our different understandings. The crystallization point is a good task analysis. We went to the course. We tried to write down the task that we thought learners had to learn. We went to the engineers and asked is this the right task or not? What should we change? And so in an iterated process we defined the task and we both learned to communicate. So I think it is possible for a good task analysis to solve problems pragmatically.

William Winn:

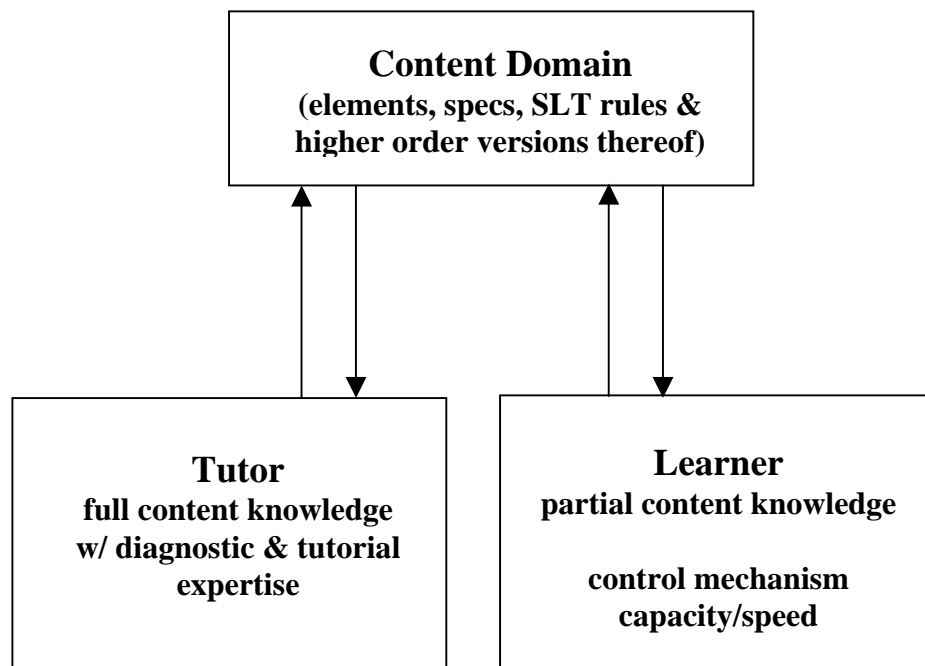
Well my comment finally follows on the next bead of the string, because a question I wanted to raise can now be phrased as a question to Franz. When you did your task analysis why did you go to the experts? That may seem like a very bizarre question to ask, but it seems that when you are finding ways to represent knowledge it seems that the traditional formulation is to do what Franz did. You assume that the experts have a way of understanding what they do and what they know. And that your goal is to make your student models as close to the expert models as you possibly can. That seems a logical thing to do and that's where you have task analysis defining your goals and all. Then you create whole series of instructional strategies to get you from A to B.

One of the things I have been listening to, if not following with particular closeness is the literature coming out of teacher training and the study of teachers and how they go about understanding knowledge domains that Lee Shulman and his students have been doing at Stanford. That introduces a different kind of understanding, that he calls the pedagogical content knowledge. And that is the way in which teachers understand the domain. In a way that doesn't make them experts in the domain, but makes them experts in teaching the domain to novices. So there is a third area. What is very interesting about his research is that effective teachers, even if they are specialists in a domain, have a very different way of organizing the knowledge, which may seem antithetical to an expert's organization of knowledge. That is where we should be looking for instructional strategies. Given that, if you take a novice and want to make an expert you can't do it in one step, you've got to do it in little steps. There is another question peripheral to that. I'm not yet convinced it matters which language or formalism you use to express those types of knowledge, that all in one way or another they are capable of getting the novice to the expert level. They may do it in different ways. System dynamics has obvious differences from structural analysis or structural learning theory, from general system theory from instructional systems design. Somebody said yesterday

“Well we had system theory and that gave us instructional systems, and that served us O.K. for a while. Why chuck it out?” Anyway that’s subsidiary now, I think we’re losing something when we ignore that third kind of knowledge representation.

Joseph Scandura:

You’re quite right. I am trying to define a starting point because I see my role as helping to keep us from speaking past each other. Essentially, the original topic relates to the representation of knowledge and associated observables. What Bill has done, essentially is to say, “There is knowledge that a teacher can have that is necessary and critical in presenting that content to a learner, in a way that the learner will learn.” Obviously, whether the teacher knows the subject matter or not is (critically) important.



*Figure 1. Key elements and constructs in the instructional process (from Scandura, this volume).*

William Winn:

May I make one clarification when I talk about teacher’s knowledge, I’m not talking about knowledge of how to teach. I am talking about a qualitative special knowledge of the domain.

Fourth person from the audience:

It seems to me everybody is talking in a singular, teacher, knowledge, learner knowledge.

We’re in this kind of inferential statistic that there’s this general mean out there. Maybe that whole paradigm is wrong and that really throws a lot of things out. We learn from the introspective literature on psychology that all experts are going to report differently on what they do. All of them are going to have different mental models.

Joseph Scandura:

There are many ways of representing competence in any given domain.

Fourth person from the audience:

Right, but you're always using that singular.

Joseph Scandura:

No, there are a lot of alternatives. You can have as many alternatives as you want. In principle, there could be as many alternatives as there are individuals.

William Winn:

I'm not ready to follow up on Joe's question. I'm not ready to throw up my hands. I'm sort of a repenting constructivist. I've done that, and frankly, it didn't get me very far; so I'm coming back to the fold. I think to be effective, we still need to look for those prescriptions. But based on some general assumptions we can make about learning. That is what should be driving us. There should be a confluence, a commonality.

Joseph Scandura:

You seem to be implying that you can have knowledge of the diagnostic and remedial methods -- finding out what a person does and doesn't know.

This refers to knowledge that is associated to performance in some given domain.

William Winn:

But performance of experts.

Joseph Scandura:

No, it could be represented at any level. In fact, one of the key things, is to be able to represent competence in a way that allows you to characterize the knowledge associated with every individual in a given population.

William Winn:

I was putting that in your learner box not in the idealized competence box.

Joseph Scandura:

The learner is a black box, and initially you don't know anything about him.

William Winn:

I don't go with that, Joe.

Joseph Scandura:

You think you can know what the learner knows? Do you really think you know what I know?

William Winn:

I can know enough to carry out an instructional intervention that has a reasonable probability as a success.

Joseph Scandura:

That's different.

William Winn:

Why?

Joseph Scandura:

What you're saying is - You can know *enough* about what is known about something - so that, you can intervene for purposes which you have defined.

William Winn:

Not necessarily what I have defined.

Joseph Scandura:

Sure, you and your subject matter. You define it by selecting and representing the subject matter. Any one of us could start talking about some things that probably nobody

else in this room knows about, but then we have one-way communication.

William Winn:

Maybe I don't understand your model. But I'm not determining what the content is. The idealized competence is determining what the content is. Which we derive through task analysis, structural analysis, and that is subjective. I can't say –  $e=mc^3$ , right?

Joseph Scandura:

The point I'm trying to make here, and I think it is an important one, is that you are taking a cognitive psychologist's perspective. Here is a model, here is how people think in this domain. In this context, the only way you can really find out what's in somebody's head is if you have a microscope and a license to look at the neurons. That's not likely to happen in our lifetime. On the other hand, what we can do is say that I'm interested in this or that kind of behavior. You have defined some behavior and what it takes to master that behavior. Your job as a teacher, then, is to find out what the student knows about what it is you're interested in teaching -- what the student doesn't know, and what to do about it. Do we agree on that?

William Winn:

I will agree with that. I'll make one more comment and then I'm going to shut up. I would agree that we can't go into people's heads and observe what's happening at that level. But I do believe that we can build theories, that we can simulate, maybe using a computer, which may allow us to predict what would happen if we could do that. The best example of that I know is the work being done with vision. The computer is used as a research tool and a theory is built of what happens to information in the visual pathway.

A simulation model makes predictions that are able to be verified by putting probes in various places in the visual pathway.

Joseph Scandura:

How does that fit?

William Winn:

We can't do it for cognitive processes, yet. But it is being done for the central nervous system.

Joseph Scandura:

You think that we can't? Why?

William Winn:

Nobody had done it as far as I know. It's too complicated.

Joseph Scandura:

I don't agree with that. We can do it at a behavioral level.

William Winn:

O.K. fine.

Joseph Scandura:

Does anybody have anything further specifically related to this particular issue? I'd really like for us to pin things down not just pass around a lot of ideas.

Fifth person from the audience:

I'd like to use a clumsy metaphor and get some reaction. The name of the metaphor is "the best players don't make the best coaches." I can't imagine that one can coach

without really understanding the discipline. What I can't understand is how somebody can be an expert player in a sport and not have the perspective to understand the books that it would take for somebody to learn the sport? I may be way off target, but is there any relevance to what Bill is talking about?

Joseph Scandura:

I don't think we're differing with what you're saying.

William Winn:

I said I would shut up, but can I pick it up? I'm coming back to music. One thing has always struck me about concert soloists. The pianists and violinists are the ones in the lime light. When they talk about their teachers, they rave about them, people you've never heard of, who aren't concert performers. So it seems to me that there are some very very fine teachers with pedagogical content knowledge who can prepare people, put them in to the lime light, put them into world prominence in their domains, which completely surpasses their own ability in the domains.

The other case apprenticeship is totally opposite. The very famous person teaching by example and having the student make inferences. For example, I saw on PBS a cellist say to the student, "No, No, listen!" and played a little phrase from a cello suite. Then, the student would play the suite until eventually he played to the satisfaction of the master cellist. It seems to me you've got people sort of in the background and then you've got the experts that Franz is talking too, who exhibit idealized competencies.

Joseph Scandura:

I think I know what you're after. You're assuming that this is just what some expert knows about some subject matter - and you are in effect introducing other kinds of knowledge about a domain which has nothing to do with the content, per say. Here's an example from dancing lessons Alice and I took recently: The dance instructor taught us three little steps. (Three Waltz steps demonstrated.) That's what was taught. I also know a little bit about learning, and I know a little bit about teaching. And I said, ooh, I can put all these things together, if I think about it this way. And I could have taught that particular sequence better than the teacher taught it - but nothing else of course. The point that I'm making is that higher order knowledge allows one to go beyond what is taught. Higher order knowledge is independent of content, but from a structural analysis point of view derivable from the behavior. From the instruction one might infer that the expert dance teacher didn't have that higher knowledge, at least not verbally.

Franz Schott:

Bill misunderstood me. In my example where we have cooperation with engineers. It was not the case, that we were trying to find out the expert knowledge of engineers. We wanted to find out the goals of a course where students learn to automatize plans. Our experience was that the engineers have wrong meanings of the course. They say, for example, we want students to be able to do this and that. When we made an analysis, what the engineers wanted students to learn and what the students', in fact, learned was different. So our results said that we have something to learn about the goals of the students, and the engineers had something to learn. They had some misunderstandings, and we had some misunderstandings. The crystallization point was the task analysis, because we had to have something to rely on. We wrote down what we thought the tasks were. We went to the engineers and asked can

you agree? They said, no, at this point not. And through an iterative process we found out what were the goals of this course.

Joseph Scandura:

In other words, there may be people who understand an awful lot about a subject matter. But, they cannot articulate it in a reasonable way and certainly not in behavioral terms.

Sixth person from the audience:

Wasn't this indeed the genesis of ISD? That you have an independent instructional designer. You're saying this in the form of having a teacher. But the idea of developing ISD principles was that you have someone who wasn't a subject matter expert, but was someone who could understand the domain from a different subject matter perspective. That person could work in conjunction with the subject matter expert, to come up with instruction that would be more useful, more beneficial, than someone who is merely an expert in the domain. You're just taking someone, an individual teacher. ISD would enable one to give those principles to many, many people, how one could perform in that situation, not just the teacher. You could develop lessons, independent of having a teacher in the room, if you have that instructional designer. So I don't see any difference between what you're discussing and using the subject matter expert with a good ISD person, who has a good understanding.

Joseph Scandura:

In essence is your question whether traditional ISD is a viable approach?

Sixth person from the audience:

In certain situations, the constructivists say, "There is no right or wrong answer." In my business there are definitely right and wrong answers.

Seventh person from the audience:

I would like to give an example. I developed an optimizing construction that teaches hypothesis testing in inferential statistics. I analyzed mental models for experts, intermediates, and novices. And the best thing that we could teach was the intermediate mental model, not the expert model.

Joseph Scandura:

The intermediate model was the easiest to teach? Is that your point?

Seventh person from the audience:

The instruction that I provided was the content that came from the intermediate mental model, not the expert mental model. The expert mental model makes intuitive jumps. The procedure was compiled using only intermediate mental models.

Joseph Scandura:

Here is an example that may be relevant. Take Piagetian conservation. For many years people thought - I can teach this kid to act like a conserver -- When you do certain manipulations things stay the same. When you do others they do not. You can teach kids how to do this within a very narrow framework. On the other hand, the behavior breaks down very easily when you change the situation. Conservation amounts to automatization -- a final stage in learning. We found that you can't teach what a master knows directly. What you can teach is the information that makes it possible for automatization to happen. But you have to identify what's required to bring it about and that's where systematic analyses go beyond what ISD and similar methods do.

Eighth person from the audience:

I want to go back to what you said. My problem is coming from observable outcomes over here and this black box in the middle. I don't see why you're saying we can't get at the black box and we should just know we're looking at observable outcomes. But we haven't really tried to get at what is in that black box. I think there is a failure to try to really see what student's mental models might be. I think there are ways to try and play with that. Don't rely on, "Oh here's my definition of a behavior I want a the student to have." When we start looking at behaviors, we tend to talk about what an expert would do. That's how we define our behavior, but we don't always want our students to become experts. So those types of behaviors aren't even the right types of behaviors to begin with and we fail to even play with the idea of getting at the underlying mental model. It's just as simple to ask a student to give you a concept map of the main themes. In this way you introduce them to educational technology. You can ask them at the end of a course to sketch out the main themes, and you can see how some students grasp some basic themes and others don't. It's not a mental model, but it's certainly a better approximation of what is going on in the student's mind than just looking at the behavior.

Joseph Scandura:

I didn't mean to give the impression that all I was talking about was behavior. Anybody who knows my work knows that my interests do not stop with behavior. Behavior must be tied to theoretical constructs, which explain that behavior.

Eighth person in the audience:

No, it's just that your comments to Bill when you were saying "You can't ever get at what I understand," and it sounded like "so give it up."

Joseph Scandura:

It was a deeper question. It was not a question of you can't get at what I understand. You can't drill inside a person's head, because you don't have a license to do so, even if you knew what you were doing.

Eighth person from the audience:

But there are some ways we can find out what they're thinking.

Joseph Scandura:

Let me finish. What you can do is infer information about what a person does and doesn't know and you can do that based on the representation of knowledge which is to be acquired. Those representations can be viewed as measuring devices (with respect to observable behavior) to get at what you don't know. Anyway I didn't want to leave you with that misunderstanding.

Sanne Dijkstra:

I have a short comment. First of all, teachers have content knowledge, that's a given condition, but it does not mean that content knowledge is a guarantee of being a good teacher. The concept of pedagogical content knowledge has to be made explicit. What is pedagogical content knowledge, in the sense that it can be used in such a way that people can learn? I have a small department of teachers of mathematics, chemistry and physics. First of all, the teachers know what their students should do in order to develop some knowledge and skills. More over, they have to accept what the students do with patience and give feedback on what the students do and how they make progress, again, always with patience. Now in

instructional design we try to find rules which make it possible to read such a situation. If we are successful then such rules can be used by teachers. Those rules can be used in making text books and in making those nice simulations that Klaus showed us this morning. What we have to do is make an integration between subject matter and pedagogical knowledge.

Joseph Scandura:

Are there any further questions on this issue?

Klaus Breurer:

Perhaps I better respond to Sanne's question. What Jose and I presented is not a general approach. You asked for the conditions. I would widen that to the question of the purpose of the representations. We didn't refer to the purposes of the representations. There may be very different purposes. The conditions or restrictions go with the approach which I, Jose and Mike presented. I just used the field of business processes as the example, because we are working in that field. The topic of supply and demand is just a subexample of the domain. The condition is that we want to foster the ability of the students to understand complex business processes and to be able to act within complex business processes with a certain understanding of the complexity. For that objective the approach is to have them represent subject matter areas using system analysis notations. They are to depict relations between concepts and the embedded dynamics, because there are problems in dynamic processes, problems which are based on interactions of sets of variables. These are conditions I did not refer to in my paper.

## **Second Discussion Topic: The Glass Box Approach and Student Modeling Guidance**

Michael Spector:

The glass box concept came up with regard to system dynamics based learning environments in yesterday's discussions. The very early kinds of learning environments built based on system dynamics were the kind you might be familiar with in the form of SimCity and those kinds of simulations and what we were calling black box systems. In them the learner was presented with a behaviorally complex system and then had the opportunity to manipulate certain parameters of this system with a goal in mind. The goal might be for the city to prosper, for a population to stabilize, or a resource to be preserved - something like that. It turns out that these were not in general successful in the terms of specific learning effect. As the models or situations varied learners couldn't produce robust policies to achieve the prescribed or desired goals. The more recent approach in building system dynamic learning environments is to reveal some of the underlying model to students in various ways, so that they can get some sense for what causes the system to behave as it does - the delays in the system and the relevant feedback relationships students are then asked to develop a robust policy to stabilize a population or to achieve some particular goal on the basis of a casual model.

Joseph Scandura:

Mike, can you frame the question in a general way, in terms of fundamental issues rather than peculiarities of a particular system?

Michael Spector:

Maybe somebody can do that better than I.

William Winn:

Let's assume that students are given absolute freedom without guidance to tinker with the model or to actually build their own models. At what point do you intervene upon that induction process or knowledge construction process and say, "Wait a minute if you go that way you'll get in trouble?" We've been having high school children build their own virtual worlds, virtual environments. They take the lead as instructional designers. For example, we're working on atmospheric problems, global warming. The classic misconception, documented in the science education literature, is the confusion of the ozone hole with global warming. In our simulation at some point the global warming problem corrects itself and you say, "why does it go down?" A sixth grade student put up his hand, and said, "maybe the ozone hole got so big it let all the hot air out." How far do you let them go, in wrestling with these misconceptions before you say "wait a minute, that's wrong." Or in my case, 40 years ago, "That's a stupid idea." That is my issue; that's why I raised the question.

Michael Spector:

The way I see it is this is just one of a range of issues. This morning, the question asked at the end of Klaus's presentation was "Why not?" Why not let students develop their own models from the very beginning. The purpose in that example was for students to become system dynamic modelers in order to promote understanding in a particular domain. That would be, probably, the very final step that might occur in some acquisition of deep insight and understanding. It would be very rare that very many people could model a complex domain. It would be unlikely, for example, for high school students to be able to – create a stock and flow model of an environmental problem from scratch without some support and preparation. So the concept I want to come back to, is this notion of graduated complexity, - a sequence of support you can build to help students get towards goals. Perhaps this is true. Let's take this hypothetical scenario. If you can produce a system dynamics model of a complex domain, then you have developed some deep understanding and have learned something about the system. Let's say this is the final goal to get that deep understanding. To get there you present someone with a model and they can get some information about the model, some background understanding. Then you give them an opportunity to manipulate the model. They get more direct understanding of the model's behavior. Then you fade or hide part of the model and ask them to complete the model, kind of like Van Merriënboer's exercise with his increasingly complex completion problems. So students start working with parts of the model. They get the opportunity to complete it, form a hypothesis about what the predicted outcome will be if completed in a certain way. And because these models are executable, they get feedback from the system. They can compare their hypotheses with the observed behaviors. So we're getting to Klaus' final goal in a step by step fashion. It's a very structured approach in that sense. Finally, maybe with very advanced learners, you let them build entire models themselves. So it's a very graduated approach.

I want to make one more comment and then I'll let him go, - it has to do with Andy's point. Andy Gibbons designed this flight tutor a long time ago - Flight Planning Tutor - and it addresses this question about when do you give feedback, which is part of your concern also. The contrast was with Anderson's Lisp tutor, which gave corrective feedback immediately. With Andy's Flight Planning Tutor, he withheld the feedback even though the system "knew" that "this guy's gonna run out of fuel over Kansas and crash and burn." He

didn't give them the feedback. He let them crash and burn and then figure out what went wrong and why. This was kind of a meaningful experience so them right?

Andrew Gibbons:

For the guys that crashed and burned it was.

Michael Spector:

This is the learning from failure – the failure must last long enough so that it becomes a significant event for the learner – that the learner recognizes that there was a failure. These are two unrelated things but I wanted to make comments about both.

Klaus Breurer:

May I add a little? We do not start from scratch with modeling. We try to define a frame of reference for both the teachers and the students. We present a problem to a student, a logistics problem, for example, a supply and demand problem, in a verbal mode. He has a verbal description of the problem to build a model as a solution, to depict the process underlying the solution of that problem. So this problem is a frame of reference for both the teacher and the students. I think this is an essential basis for interventions. If you find that the students can't elaborate or cannot define certain concepts, which are embedded in the problem, then there is reason for intervention. And, then at the next level, the interactivity of the device and the student's modeling process is another mode of intervention. It ends, as Mike says, with the simulation of the system giving feedback with respect to the validity of the model involved.

Michael Spector:

To add to that, the way most of these systems are built is so that they are running in time steps. There is iteration - run - stop - run - stop. And they typically run in small groups and there is collaboration and discussion. Often, the coach, who is observing this and the system, doesn't tell this group that they've made a good or bad decision. The group gets a question to analyze and reflect on the decision itself, and the "play" continues so the group is sort of building their own critique. After a round, the coach may again intervene with a comment or question.

Joseph Scandura:

What is the basic issues here? Rather than individual vignettes, can we identify basic issues? What are we trying to get at?

Andrew Gibbons:

I remember reading a book about the power law, as associated with practice. The author was showing the logarithmic power law of practice and he was showing it in all kinds of studies, in memory studies, in animal studies, in problem solving studies. The one constant that keeps coming back to my mind is this parallel of practice and if our instruction is not producing this parallel of practice, it is because we do not have the student practicing what we really intend for him to learn. So I think one of the things we have to do is hone in on specifying in detail what it is that you want the person to be able to do. I think it's an important essential starting point. So if someone is going to solve a complex problem, he is going to have to find out what is going on inside a variety of experts minds. I give experts a chance to solve a problem but not the whole problem. See in every problem that you solve there is this much benefit and this much problem solving. Like you were saying Mike, somehow you have to figure out how to give them the core, the best part of the problem, the

biggest sling shot, so to speak, that is going to move them up that power curve. So I think density of practice, critical practice is a core concept.

Joseph Scandura:

Anybody else have a core idea?

Ninth person from the audience:

How far is learning controlled and how far is teaching controlled? In some ways I feel that we are going back to discovery learning and guided discovery learning. In some ways we are just repeating the same thing. I have always said that if the student knew at all that the student should be teaching. We need to accept that there is a problem. But in terms of the learning there isn't much you can do unless you want to allow the students to keep on trying and trying and trying. Then something else is going to get in, which is the time element, the resource element.

Joseph Scandura:

In that context I'd like to raise the issue of how people learn. You can throw a person into a problem situation and they basically have to discover a solution. Bill's question basically is when do you intervene, when do you have to get them back on track? A general answer (to that question) has been known ever since a guy named Scandura did a dissertation many years ago before many of you were born. Essentially, what came out of that study very clearly was that if you present people with a true discovery situation and you don't give them "sufficient" hints then what happens is they get lost and lose interest. They get bogged down. Eventually, they give up. But, some do succeed and that's wonderful. But why? Have they gotten something that goes beyond what you could possibly get by direct expository instruction? What's the answer to that? Anybody? If they discover something on their own – if they really master it, have they learned something that can only be learned by discovery?

Andrew Gibbons:

It depends on what you're going to measure. If you're looking for increased motivation toward future learning, then the answer is "yes". They've got something they couldn't get any other way. Or possibly, also, resistance to decay. If you're talking about the ability to generate future knowledge from the knowledge they just learned then the answer is also "yes".

Joseph Scandura:

If you said maybe in each of these cases, I would agree with you (audience laughter). The reason I say that, Andy, is that one thing that is pretty well-documented, is that if you understand what it is that a person learns that "motivates them", or that makes it possible for them to learn new things, etc -- and you identify that higher order knowledge via structural analysis. Then, you identify and you teach that knowledge, in fact, you can't tell the difference as to how it was learned. The only detectable differences seem to involve the efficiency of learning.

Andrew Gibbons:

Actually, I think there are studies that say differently. It's the whole problem of inner knowledge. That is that some people have the knowledge to solve a particular problem, and they can transfer for instance, and I think we agree here, that one of the things that we've looked at to instill in people is not just what we would teach them but the ability to transfer to new situations. People will have knowledge that would allow them to transfer, but

somehow they can't make a conversion of the knowledge from the very form in which it was learned into a performance form; so they miss the gap.

Joseph Scandura:

That's what I'm saying. You can in fact teach higher order knowledge that does allow people to transfer.

Andrew Gibbons:

Ok and one of the things I'm saying is that that's extremely difficult to teach by direct experience.

Joseph Scandura:

A study by Roughead and myself back in 1966 proved that you can.

Andrew Gibbons:

Basically, the findings of other research are that you cannot very well teach by direct instruction those kind of cognitive processes. They are learned through the exercise of the higher cognitive processes.

Joseph Scandura:

My point is that I have never found anything that you can't teach, if you understand what it is. If you know what it is, I don't care if it's higher order knowledge or it's knowledge that is gradually transferred to you overtime, or otherwise.

Andrew Gibbons:

No, I'm not saying you can't teach it, I'm saying you can't teach it by direct instruction, as well.

Joseph Scandura:

Well, I would even qualify that. There may be some things that are very hard to describe and very hard to convey in a direct mode, that certainly can be true. There may not be an adequate vocabulary, for example, that describes the ideas in a way that can be understood.

The point that I'm making is, how you learn it is not nearly as important as, in fact, that you do learn. That's the essence of it.

Andrew Gibbons:

How you learn knowledge has a great deal to do with how you use the knowledge later and it's usability to you.

Sanne Dijkstra:

It's an issue of more or less of all these variations of intelligence. We guess that an expository instruction will be enough for ordinary students. But for other students even if they discover a rule or regularity it is not enough to transfer that knowledge to other situations.

Joseph Scandura:

I think the difference Sanne, is that Andy is saying if you do it in this way, people are not likely to learn it or to learn it as well. That certainly may be true. The question is, if in fact they do learn this higher order knowledge, and you know that they know it -- because you've measured it and you've seen that it exists -- then it doesn't make a difference at that point how it was learned. In discovery, persons may learn some extra skills, which allow them to

utilize higher order knowledge in a variety of situations. Perhaps they wouldn't get that knowledge if you had told them directly. Similarly, expository learners also learn something

that the discovery learner does not learn. They are learning how to interpret descriptions of things. Both are valuable skills. The point is that if you identify exactly what's going on -- what's being learned -- then you can make predictions.

Andrew Gibbons:

Let me come back with a firm maybe on that.

Pascal Van Gerven:

Can I ask something? What do you mean by direct teaching? Does this also hold for higher order knowledge? Can you directly teach this "crystallized knowledge?"

Joseph Scandura:

I'm not sure exactly what you mean by crystallized knowledge. It is really a matter of identifying what it is that needs to be learned, or alternatively, what do you want to be learned. Whether it's higher order knowledge, or lower order knowledge is not important. All knowledge is potentially learnable. How something is best learned is going to be a function of the availability of some way to describe it efficiently, to illustrate it, and set up a problem solving situation some other way where a person will be led to utilize knowledge or extend knowledge he already has to deal with that situation. I don't think you can make a general statement as to which (alternative) is best for all things. It's a matter more of what it is that you are interested in a particular situation -- whether it's higher order or lower order knowledge. Or, if you're talking about crystallized (automated) knowledge then it is certainly true that, for example that you can't teach a child to become a true conserver, for example, unless they can already do things like match numbers of sticks one to one, understand what a one to one comparison is, and that sort of thing. Unless they have those capabilities as determined by assessing their behavior, you can't effectively teach conservation behavior. If you're interested in more details, I would recommend that you read Structural Learning and Concrete Operations.

Franz Schott:

I think the question, what's better, expository learning or discovery learning is the wrong question. It's a question on the surface level. What's interesting is what might be going on in the mind of the learner. If you make a task analysis, it can be said that good expository learning makes the learner think about a lot of things and have a deep understanding. And at the other end, discovery learning can be so bad that there is no learning. So, I think often the mistake which is made in discussion of expository vs. discovery learning is that it is discussed on the surface level and not on a level of what's going on and what's in the action between the learner and the learning environment.

Joseph Scandura:

There may be a difference here. Andy is taking a different perspective from that expressed by Franz and myself. The question is: Is there something truly intrinsic to discovery learning as discovery learning, for example? That is, apart from what is actually being learned. In my view it's not a matter of whether something is learned by discovery or by some other method. What, in fact, is being learned is what's important.

Andrew Gibbons:

That is exactly the question. As a matter of fact, the question is: "Can we describe knowledge so specifically that it not only fills the definition of what we intend to provide, but that it goes no further, that is, is there no residue, no after effect, no side effect of

knowledge and the way it was obtained? For instance, it's clear that a person who has a certain experience, in the presence of frightening stimuli, when they recall that knowledge later the emotional stimuli came back with it. So I'm not willing to say that we can talk about knowledge as a packaged little thing. This was my statement earlier about the four body humors. They used old packaged knowledge. We stand a chance today of reifying that knowledge.

Joseph Scandura:

Would you agree, that this "fear" situation you are describing is something that is describable in and of itself? Can you identify something that is being learned?

Andrew Gibbons:

It's unintentional, as a matter of fact a certain amount of our learning is inaccessible to us at the conscious level. For instance, the work of Rumelhart, the identical patterns that are learned, which people don't even know that they know until, the experimenter analyses the data. As a matter of fact, the accuracy of their responses went way up, because they've learned this pattern without even realizing it.

Joseph Scandura:

I'd certainly agree with you. But to press the point, I think what you're talking about is something that needs to be better understood, needs to lend itself to more complete analysis in exactly the same way that simple higher order knowledge, when I use simple higher order knowledge, I mean the ability to put a couple things together that didn't automatically go together and you had to learn how to do things like that. But, once you understand what, in fact, is involved, you can identify it, you can teach it, people can learn it, people can use it. And, in the same way, you're talking about some things which have not been, to date, fully analyzed. That doesn't mean they can't be. It means that they haven't been.

Sanne Dijkstra:

It's a category of problems I described yesterday, interpretation problems. You will find irregularities in the data. In the data you will observe and label this discovery. Of course the data can be shown and you can explain expositoryly what is the regularity and how math can be used and maybe the students will understand. But there is no guarantee that they actually will use it and will be able to do it. That's why I made some propaganda for problem-based learning.

Joseph Scandura:

I would agree Sanne that you could teach people how to discover those patterns, in effect, rather than teaching, instead of giving them the food, you teach them how to grow the food so that they can take care of themselves. In the same way, you could teach learners how to discover the patterns that you might teach. In that case, you're teaching them something different.

Sanne Dijkstra:

Education will provide the situation in which you can find the data and find irregularities. That's one of the purposes of education.

William Winn:

Again, I'm probably going to demonstrate that I'm misunderstood for the second time, but I think there is an implication here in (if we're going to talk about camps) this camp, that if we try to teach something and we don't succeed, the solution is to do more analysis and I don't

think that that always works. I think that the alternative of placing some of the responsibility back on the student through problem-based learning has proven to be successful. There are two things that have always bothered me about ISD, determinism and the other is reductionism. The assumption of determinism is if I were to know at any single point in time, the exact condition of every particle in the universe then I could predict everything that was going to happen in the future and describe everything that happened in the past. Now, there's a flavor of that in some of this. And the other one is that the only way you can get there is by making your analysis finer and finer and finer and finer which I call pulling the wings off the butterfly to try to understand how it can fly. Why don't you just watch it fly? So, I don't know, I think I must be going through my midlife crisis or something. I'm afraid I don't know which camp I belong in right now. I've had this excursion into post-modernism, which seems to me that there are dangers in both of the extremes. In a sense, you've got the deterministic reductionistic view of you don't subscribe to any absolute sense, but which I sense you lean towards. Then you've got the rabid social constructivist view where any viewpoint is perfectly valid and if you want to believe that  $e=mc^3$ , that's OK. And, I get confused. But I'm put off a little bit by both extremes.

Joseph Scandura:

I don't think we have to make an either/or choice.

William Winn:

I don't think so either. I don't like the idea of camps by the way.

Joseph Scandura:

What I think we're talking about is that by analysis you can understand things, in principle, as deeply as you wish. In practice, it's not always necessary and in a lot of cases, it's not even desirable. And, I think you're indicating that you definitely do not want to do some things for the learner. In fact, there is diversity in this universe. People do learn different things. Could we teach everybody exactly the same thing, in the same way so everybody knew the same things and so on. This would be utterly impossible because people come into any situation with so many variations (in knowledge). The point is simply that if you do want to intervene directly, then you can intervene directly only to the extent that you have specifically identified what's involved -- to put it differently, to the extent that you have analyzed that situation. To that extent, and only to that extent can you intervene directly. To the extent that you haven't done that, you cannot.

I guess we are about out of time. I thank you for coming and I hope you enjoyed the session.