1. **Cognitive and Instructional Issues in System Modeling**
   - Sylvia A. Shafto, Ph.D., CJ Kalin, and Michael G. Shafto, Ph.D.
   - MS in System Management Program, College of Notre Dame, Belmont, CA mssm@cn.edu 415-508-3724

2. **MS in System Management**, College of Notre Dame, Belmont CA
   - Exploit similarities among systems
   - Transfer analysis and problem-solving from one management context to another
   - Managers apply systems thinking in technologically oriented industries
   - Students come from aerospace, biotechnology, materials science, telecommunications, computer hardware, and software industries

3. **Metaphors and Analogies**
   - Concrete, memorable, and resonant with students' prior knowledge
   - More complexity, more difficult to understand and predict
   - Need refinement to mathematical models
   - Example of early 20th Century physics: Rhodes, *Making of the Atomic Bomb*

4. **Modeling Tools for Organizations**
   - Bridge from metaphor (jungle, machine, team, family, community, rational individual, learner) to data
   - Represent systems accurately without representing them completely
   - Organize & interpret data
   - Visualize, communicate with a group

5. **Cognitive research on problem solving and reasoning**
   - Rule-based expertise
   - Solving puzzles, algebra, geometry, and computer programming
   - Metaphor or mental models
   - Misconceptions in physics, computer systems, medicine, probability
   - Explanation of error patterns

6. **Rule-based Expertise**
   - Knowledge from past problem-solving experiences
   - Rules to define legal moves through problem-space
   - Low memory load
   - Well-defined problems
Metaphor & Analogy in Problem Solving

- Structure problem-space, control search
- Progress within memory capacity
- Plans remembered long enough to be implemented
- Insufficient for real system

From Metaphor to Mental Models

- More variables, more interactions
- From logic to troubleshooting
- Heuristic rules supplemented by models
- Progression from novice to expert
- Physics, economics, human-automation
- Instructional software using carefully designed sequences of models

Mental Models in Problem Solving

- Useful but insufficient
- Mental models operationalized different ways
- Can’t analyze real systems mentally
- System complexity limits data collection
- Not extensible

Management Students

- Need to develop problem-solving skills
- Analyzing novel situations, creating new solutions, transfer of learning
- Work in business settings constrained by
- Rapid decision making
- No experimentation

System Modeling in Problem Solving

- Establish correct mental models
- Supplement limited human memory
- Organize and interpret data
- Encourage testing and refining business processes
- Support thinking about new possibilities
- Flexible, extensible, refinal

Rule-based Analysis

- Linear programming, forecasting, inventory, queuing analysis
- Recognition of types, matching of structures
- Limited in scope
- Artificially simplified problems
13 □ Modeling with *iThink*
   - Simple, graphical, affordable tool
   - Solves problems in ordinary differential equations
   - Draw relationships among components
   - Output numeric, graphical, and animation

14 □ Goals for Model-Based Instruction - 1
   - Identify components of the system
   - Partially describe functions
   - Verbalize relations and interactions among system components
   - Describe qualitative causation, expectations, and interpretations of the performance of the system

15 □ Goals for Model-Based Instruction - 2
   - Predict and explain step-by-step system performance
   - “Think-aloud” during problem-solving
   - Develop plan for problem approach
   - Groups discuss conclusions from results

16 □ Goals for Model-Based Instruction - 3
   - Show how model solves different problems
   - Identify metaphorical or analogical explanations
   - Integrate several model versions

17 □ Students’ Initial Modeling Efforts
   - System, model, and tool are overwhelming to the student
   - “As-is” defined, not “what must be”
   - Process vs. system: trace path of individual person or object, rather than showing system
   - Extensible: How to add elements/relations?
   - Sensitivity analyses: do not lead to questioning structure of model

18 □ Problem of Resources
   - How many resources should be used?
   - Pick just one, or too many
   - "Mix up units"
   - "What is perceived quality?"
   - "Where do I plug in the data?"

19 □ Problem of Feedback
   - Linear flows with no feedback
   - Do not anticipate time-lag
   - Feedback in process control
"Everything I expected came out different"
"Why didn't a change have immediate impact?"

20  □ Problem of Levels
  - Fundamental to controlling complexity (nested subroutines in computer programming)
  - Students: flat models with no hierarchy
  - Need at least three modeling levels, with easy movement

21  □ Summary of Student Problems
  - Student problems mirror properties of mental models
  - Small models, due to working memory limits
  - Diagrammatic, not dynamic, models
  - Concrete situations represented

22  □ Instructional Solution
  - Analogy/Metaphor
  - Rules What is the policy? But what if?
  - Mental Models some degree of coherence
  - Multiple Mental Models coverage
  - Integrated Models require iThink

23  □ Communication
  - iThink as a mechanism for modeling and communicating
  - Students capture features of real life
  - Brain-storming and problem-solving tool

24  □ Selected Research on Mental Models
  - Gentner & Gentner’83: metaphors
  - Johnson-Laird & Byrne’91: logic
  - White & Frederiksen’85: physics
  - Gott, Bennett, Gillet’86: troubleshooting
  - Salter (n.d.): macro-economics
  - Feltovich, Spiro, Coulson’89: medicine
  - Jonassen’96: methodology