Intervening on Cumulative Environmental Neurodevelopmental Risks:

Introducing a Complex Systems Approach

Devon Payne-Sturges, DrPH

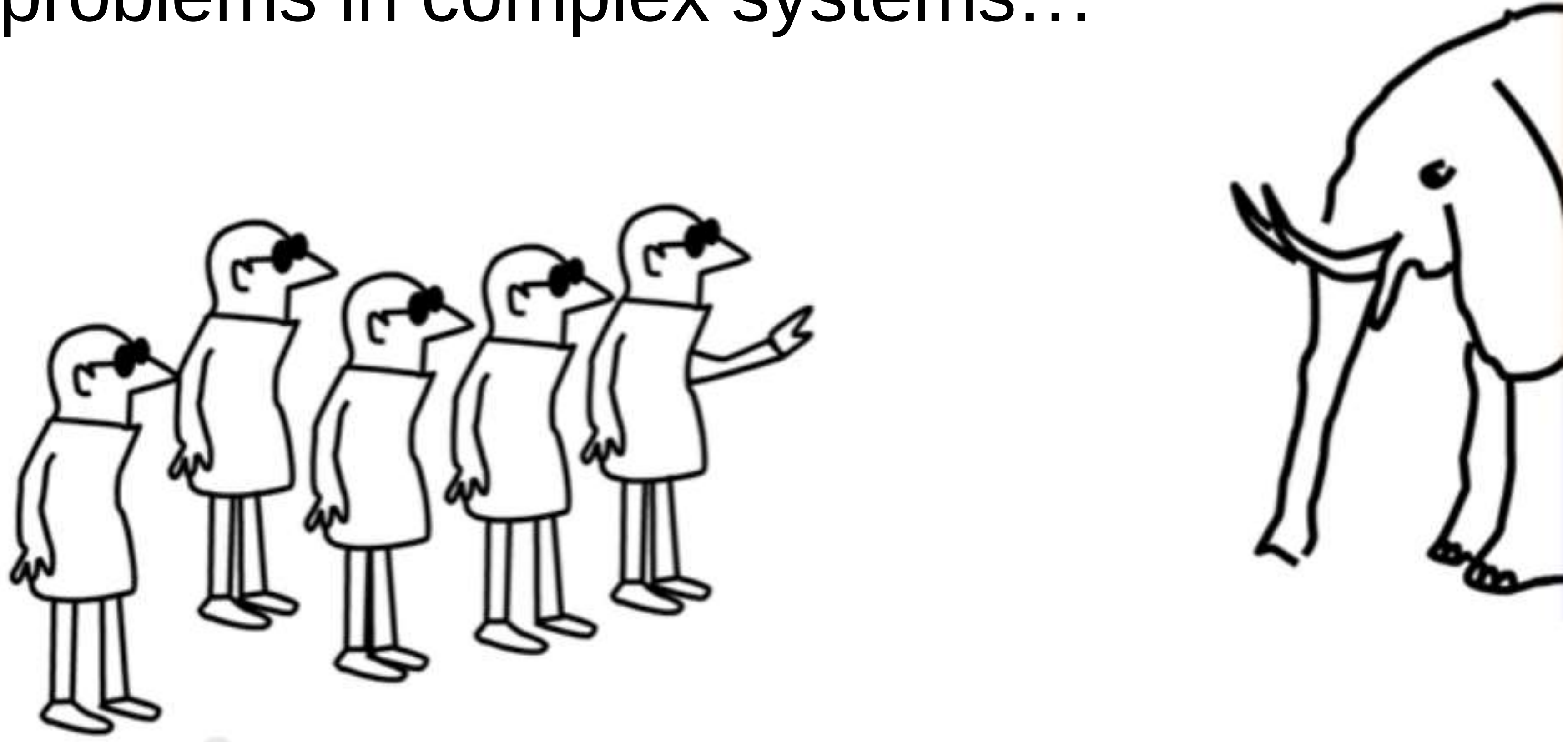
MAKING THE CONNECTION CONFERENCE 2020

Wisconsin Environmental Health Network

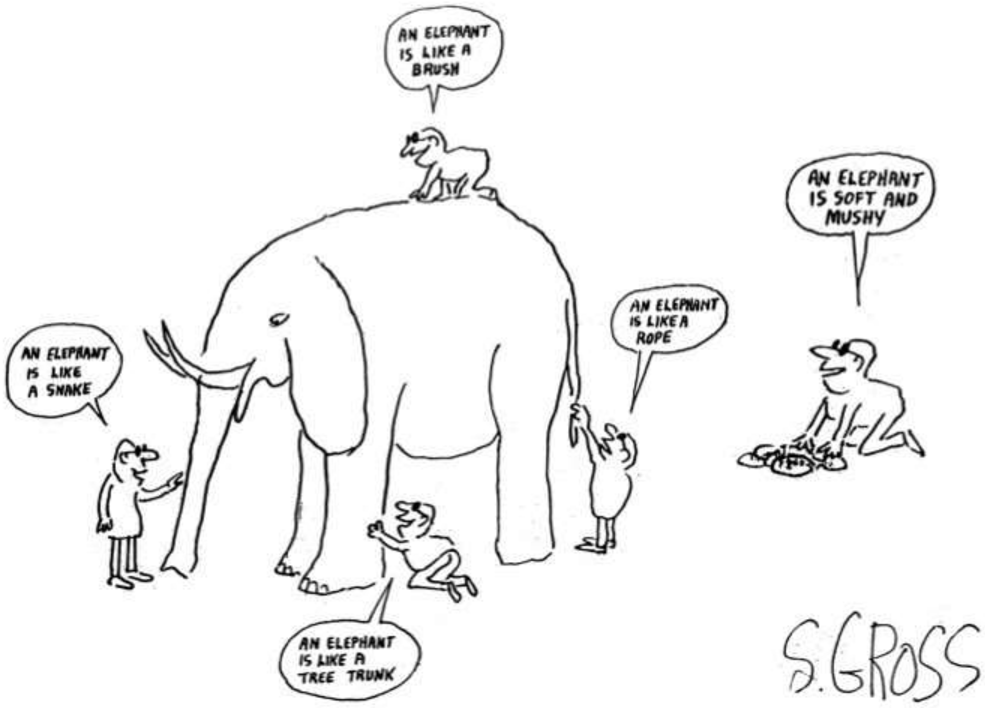
University of Wisconsin – Madison, WI

March 7, 2020

In public health we work to address problems in complex systems…



But how do we know what the problem is?



Hallmarks of Complex Problems

- Feedback loops linking factors
- Path dependence
- Heterogeneity
- Dynamics/Changes over time
- Nonlinear effects
- Time delays between action and response
- Counterintuitive
- Policy resistant

Sterman, J. (2006). Learning from evidence in a complex world. *American Journal of Public Health, 96(3), 505-514.*

Project TENDR: Targeting Environmental Neurodevelopment Risks

- Protect pregnant women and children from toxic chemicals and pollutants that harm brain development
- Eliminate disproportionate exposures of these harmful chemicals to children of color and low-income children.

http://projecttendr.com/

Perspectives | Brief Communication

Project TENDR: Targeting Environmental Neuro-Developmental Risks. The TENDR Consensus Statement

A Call to Action

Trends in Neurodevelopmental Disorders

Vulnerability of the Developing Brain to Chemicals

Prime Examples of Neurodevelopmentally Toxic Chemicals

PLOS | MEDICINE

POLICY FORUM

Organophosphate exposures during pregnancy and child neurodevelopment: Recommendations for essential policy reforms

Irva Hertz-Picciotto[1]*, Jennifer B. Sass[2,3], Stephanie Engel[4], Deborah H. Bennett[1], Asa Bradman[5], Brenda Eskenazi[5], Bruce Lanphear[6], Robin Whyatt[7]

Opinion

VIEWPOINT

Establishing and Achieving National Goals for Preventing Lead Toxicity and Exposure in Children

David C. Bellinger, PhD, MSc

Children are exposed to chemicals in consumer prod- ucts, household dust, food, air, water, and soil that at

cohort of children under 6 years of age), a cost-benefit ratio comparable to that of childhood vaccines.[6] An-

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COMMENTARY

Healthy Air, Healthy Brains: Advancing Air Pollution Policy to Protect Children's Health

Evidence is growing on the adverse neurodevelopmental effects of exposure to combustion-related air pollution.

Project TENDR (Targeting Environmental Neurodevelopmental Risks), a unique collaboration of leading scientists, health professionals, and children's and envi-

Devon C. Payne-Sturges, DrPH, Melanie A. Marty, PhD, Frederica Perera, DrPH, PhD, Mark D. Miller, MD, Maureen Swanson, MPA, Kristie Ellickson, PhD, Deborah A. Cory-Slechta, PhD, Beate Ritz, MD, PhD, John Balmes, MD, Laura Anderko, RN, PhD, Evelyn O. Talbott, DrPH, Robert Gould, MD, and Irva Hertz-Picciotto, PhD, MPH

Children are exposed prenatally and in early childhood to multiple environmental stressors that can adversely af-

pollutants—polycyclic aromatic hydrocarbons, nitrogen dioxide, fine particulate matter ($PM_{2.5}$), including ultrafine particulate

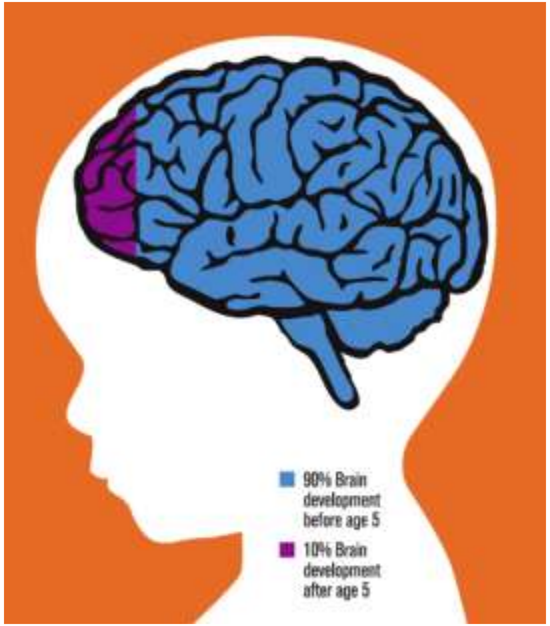
neurodevelopmental disorders in children.[1,2] A growing body of human studies associate exposure to combustion-related air pol-

Project TENDR: Education and Outreach

- **Congressional briefings**
- **Comment letters** on federal, state and international policies & proposed rules.
- **Grand rounds** and **professional presentations**
- **Op-eds**
- Providing **Expert Testimony** on the science
  - Federal agency rulings on PBDEs, lead
  - State bills on toxic chemicals in children's products, and on neurotoxic pesticides
  - Amicus brief in case on federal phthalates rule

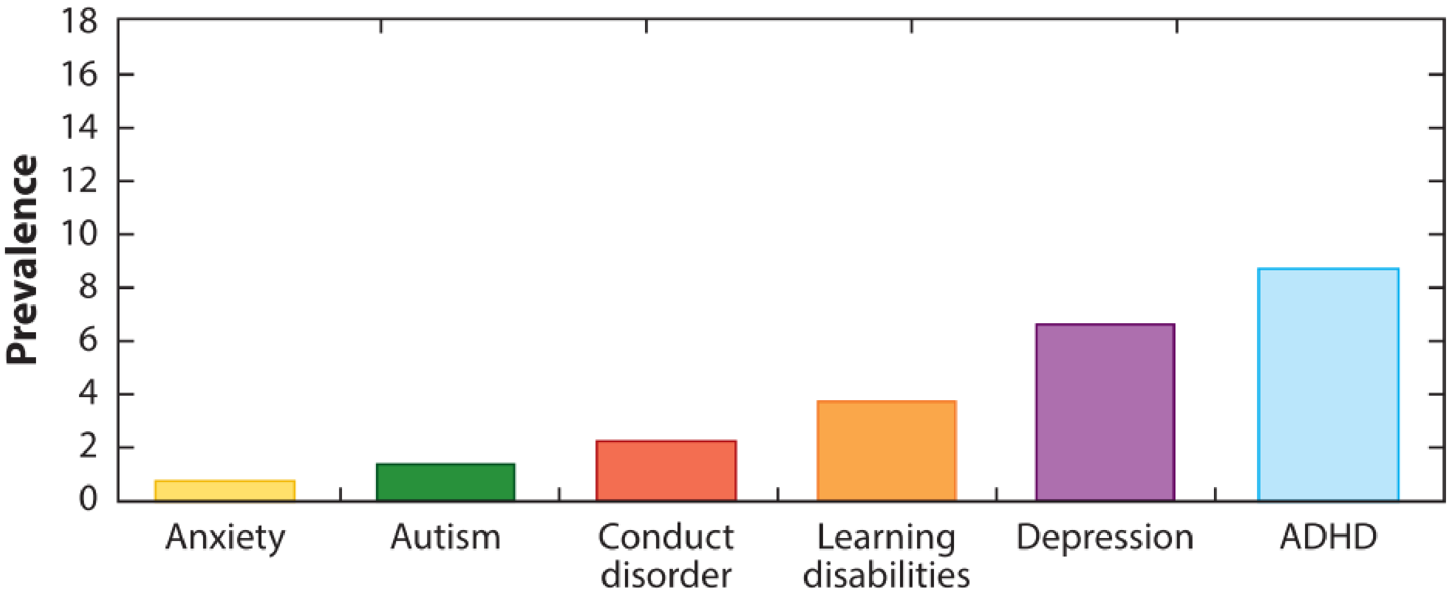
Multiple environmental neurodevelopmental stressors

A wide range of prenatal and early childhood environmental conditions, along with physical and psychosocial factors, can affect children's cognitive abilities and academic performance.

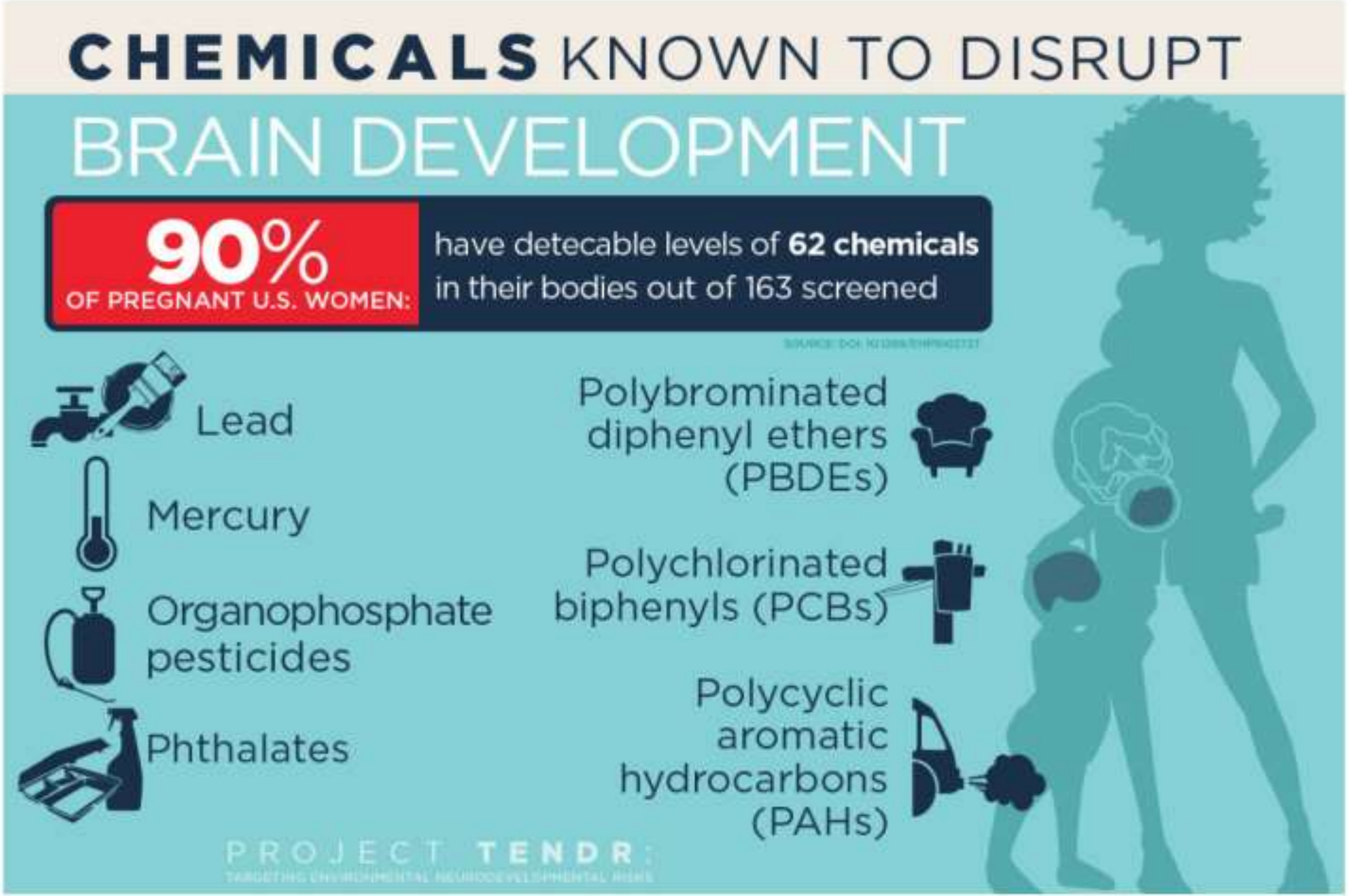


Graphic adapted from Harvard Center for the Developing Child

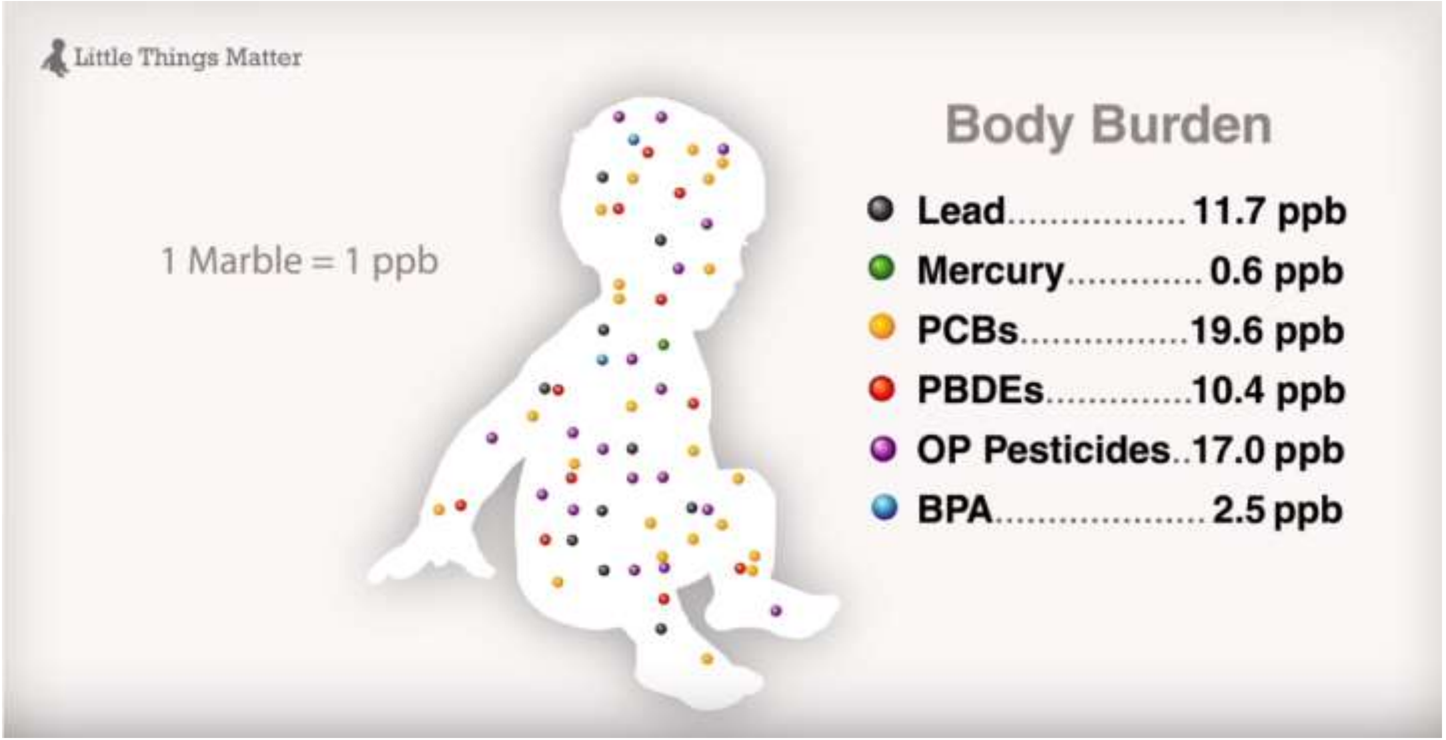
Prevalence of learning disabilities and mental disorders in US children



Boyle CA, Boulet S, Schieve LA, Cohen RA, Blumberg SJ, Yeargin-Allsopp M, Visser S, Kogan MD: **Trends in the prevalence of developmental disabilities in US children, 1997-2008.** *Pediatrics* 2011, **127:**1034-1042.
Lanphear BP: **The impact of toxins on the developing brain.** *Annu Rev Public Health* 2015, **36:**211-230.



TENDR graphic



Little Things Matter: The Impact of Toxins on the Developing Brain
https://youtu.be/E6KoMAbz1Bw

Multiple social and psychosocial factors have independent and substantial impacts on neurodevelopment, cognitive and behavioral functioning

- substandard housing, crowding and noise
- family turmoil, violence, poverty and household food insecurity

Social conditions make environmental exposures **worse**

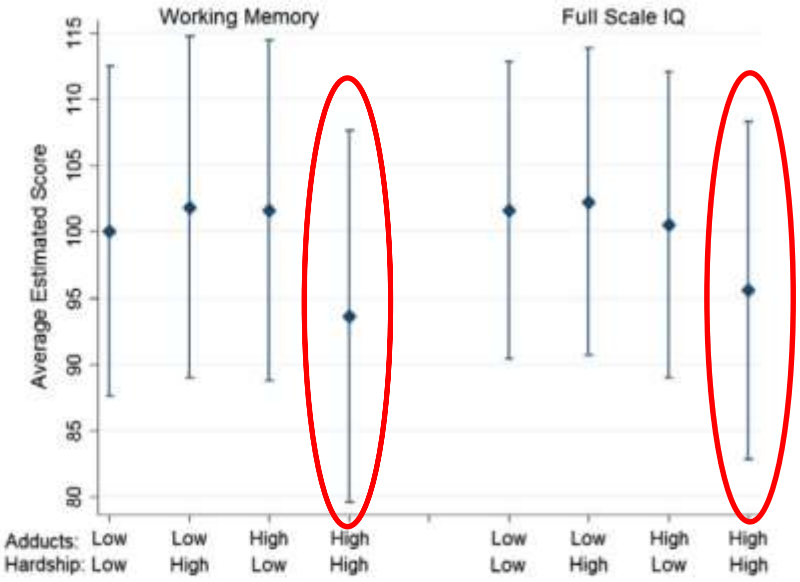
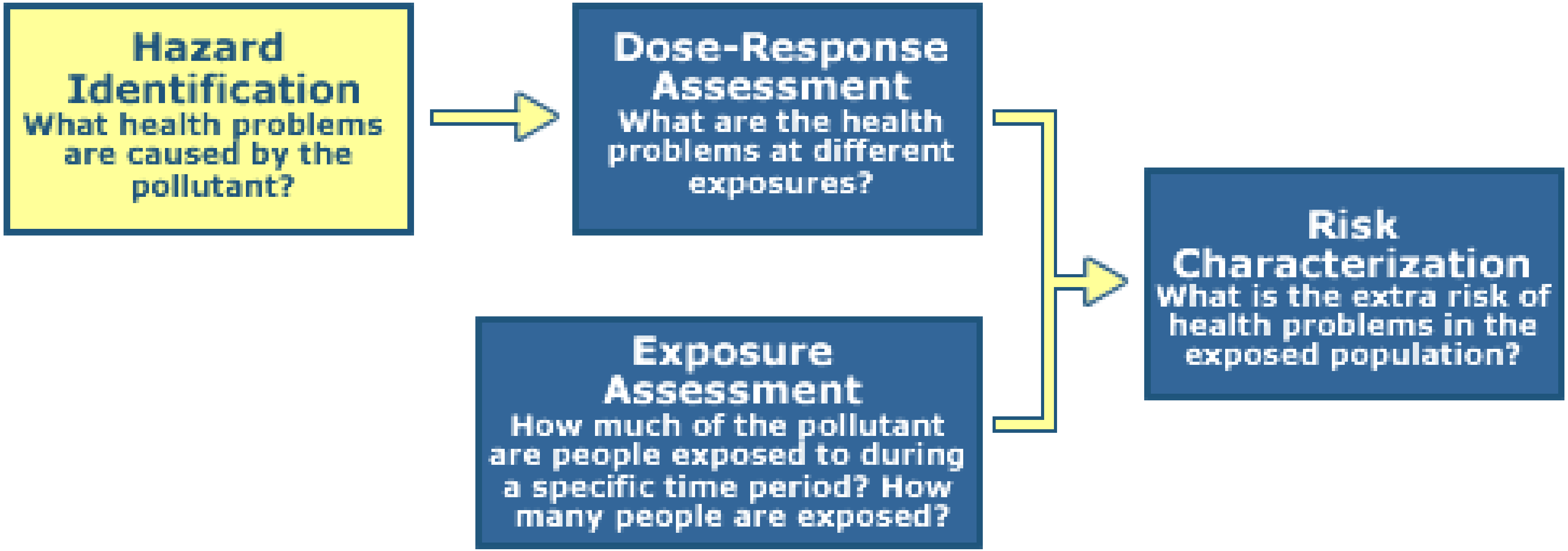


Fig. 2. Full Scale IQ and Working Memory Scores in the low and high cord PAH–DNA adduct groups stratified by recurrent hardship ($n = 276$).

Vishnevetsky, J. et al. *Neurotoxicol Teratol* **2015**, *49*, 74-80,

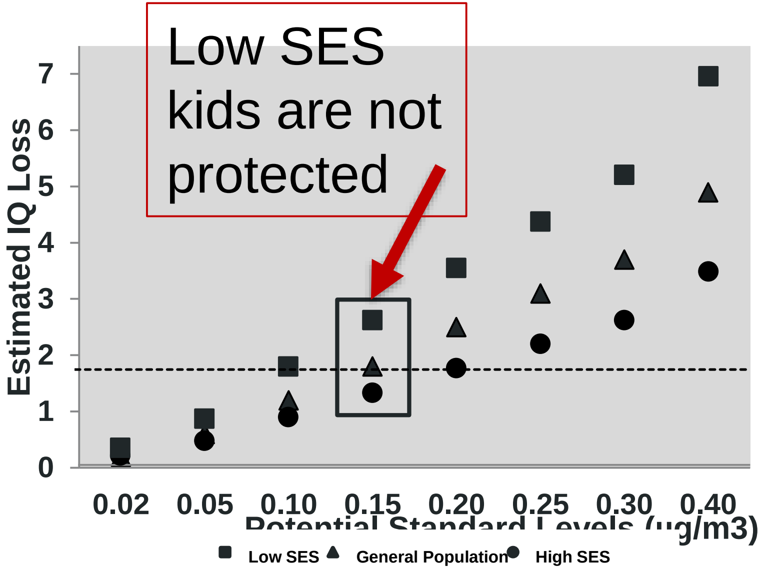
- Vishnevetsky et al. 2015 - Prenatal PAH exposures combined with poverty lowers IQ in kids
- Rauh et al. 2004 - combined ETS and material hardship (e.g poverty) resulted in lower cognitive functioning in kids
- Cory-Slechta et al. 2005– lab studies on lead and prenatal stress and neurological outcomes in offspring

The 4 Step Risk Assessment Process



Links, Johns Hopkins University

Expected mean IQ loss estimates for children exposed at the level of the NAAQS lead in air standard



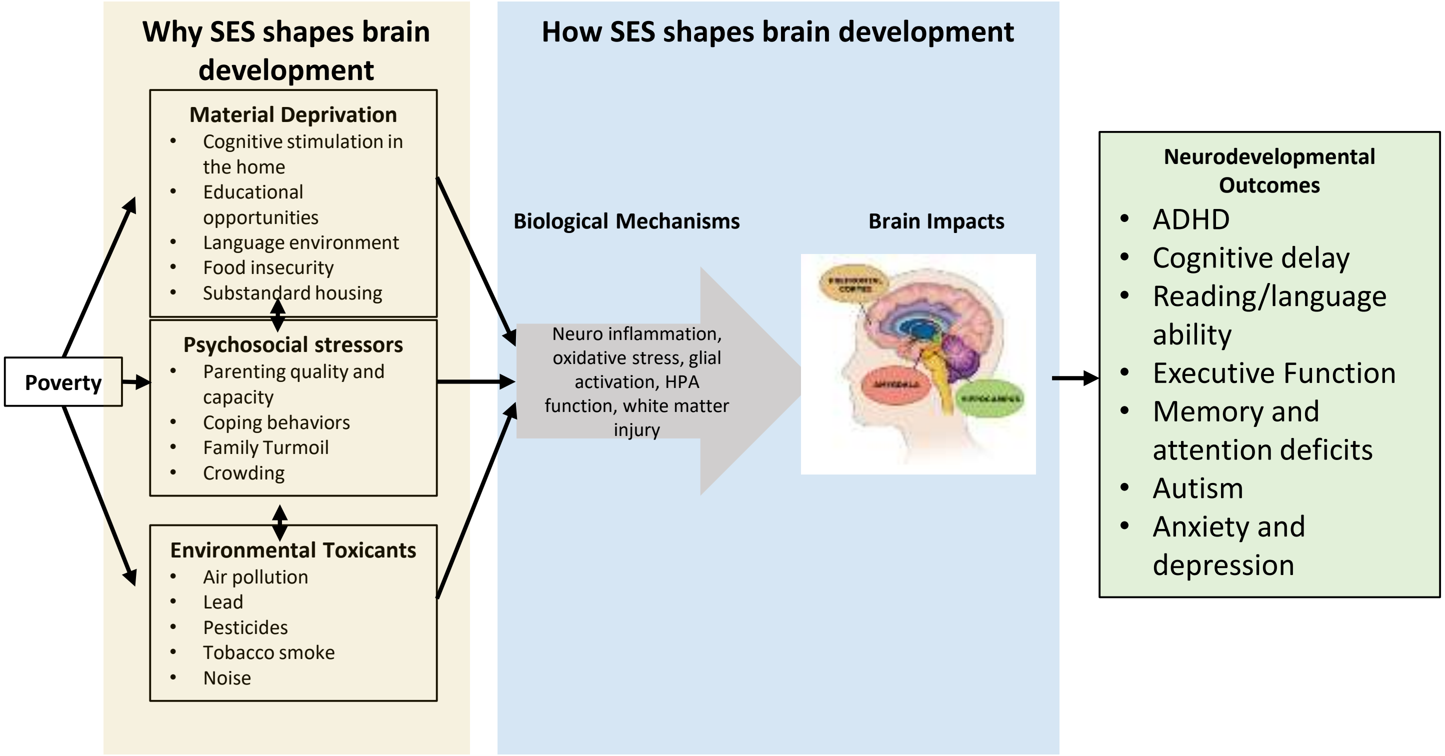
Comparison of population mean IQ loss estimates derived from general population and susceptible groups. Dotted line at 2 IQ points represents the acceptable risk level defined by EPA. A box surrounds estimates associated with the final chosen air lead standard

Chari R, Burke TA, White R, Fox MA. 2012. Integrating Susceptibility into Environmental Policy: An Analysis of the National Ambient Air Quality Standard for Lead. *Int. J. Environ. Res. Public Health* 2012, *9*, 1077-1096.

Longer-term cognitive consequences of childhood lead exposure

- Impairment in brain development in one domain could alter the trajectory of development in other domains.
- Set in motion a process that results in a child who is
    - poorly equipped to make good, future-oriented decisions and
    - has poor academic success, faces restricted employment opportunities, material hardship, and other socio-economic stresses

Environments of poverty and combined effects



Adapted by DC Payne-Sturges from Johnson, S.B.; Riis, J.L.; Noble, K.G. State of the Art Review: Poverty and the Developing Brain. *Pediatrics* **2016**, *137*, doi:10.1542/peds.2015-3075.

Hallmarks of Complex Problems : Lead Exposures

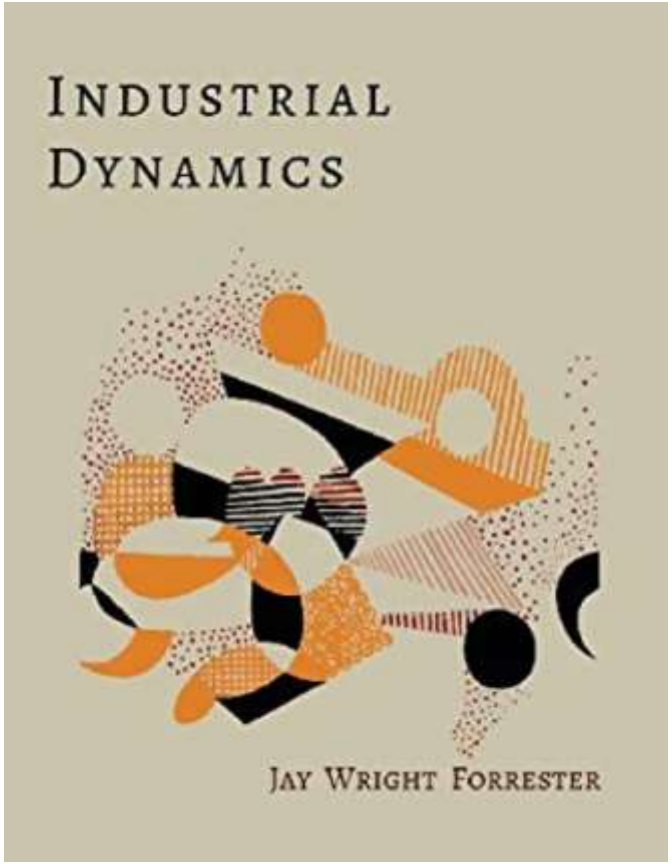
- Intergenerational effects /vicious cycles (Feedbacks)
- Trends in prevalence of neurodevelopmental disorders (Dynamics/temporal effects)
- Intervening early can lead to greater reduction in negative effects (Path dependence)
- Inequities by race/ethnicity/class (Heterogeneity)
- Despite knowing it’s bad we have not removed lead from housing (Time delays)

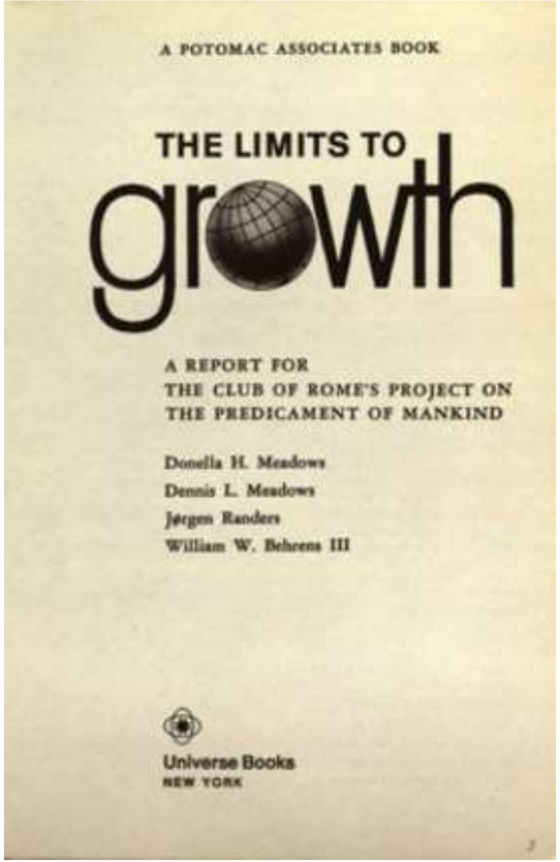
System Dynamics

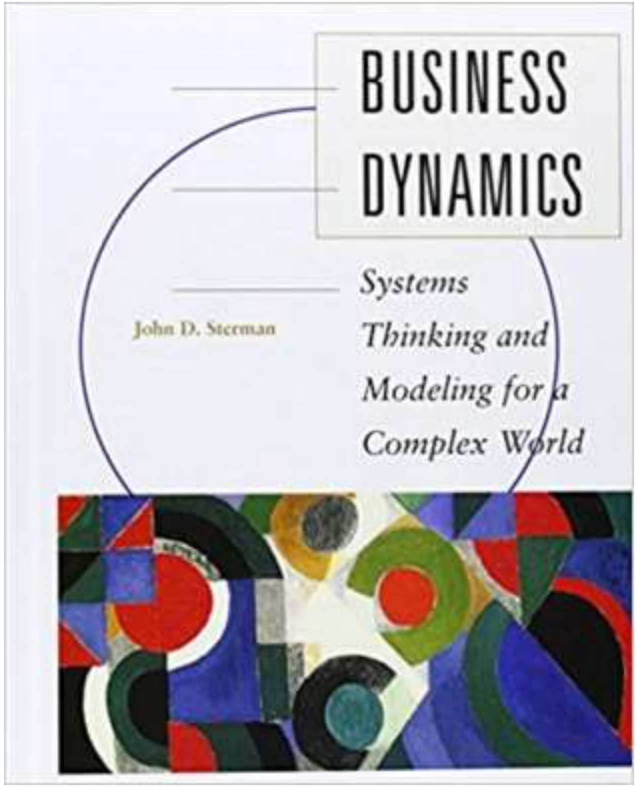
System dynamics (SD) is the use of informal maps and formal models with computer simulation to uncover and understand endogenous sources of system behavior.

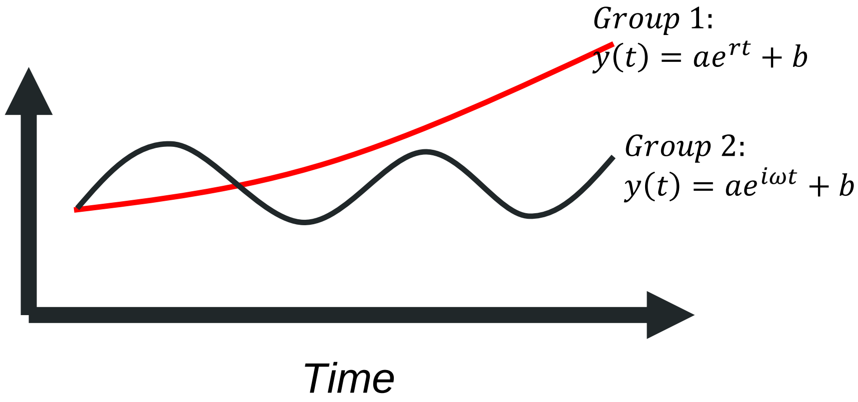
Richardson, G.P. (2011). Reflections on the foundations of system dynamics. *System Dynamics Review*, *27*(3), 219-243.

Canonical System Dynamics Texts

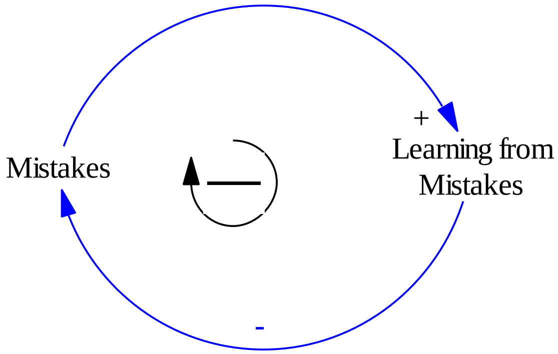




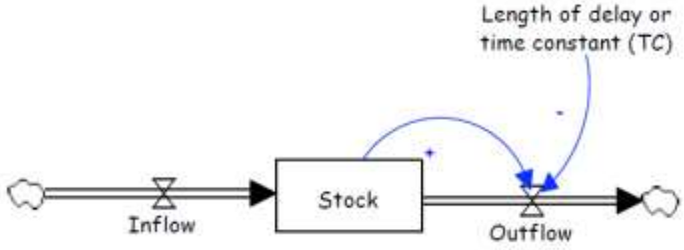




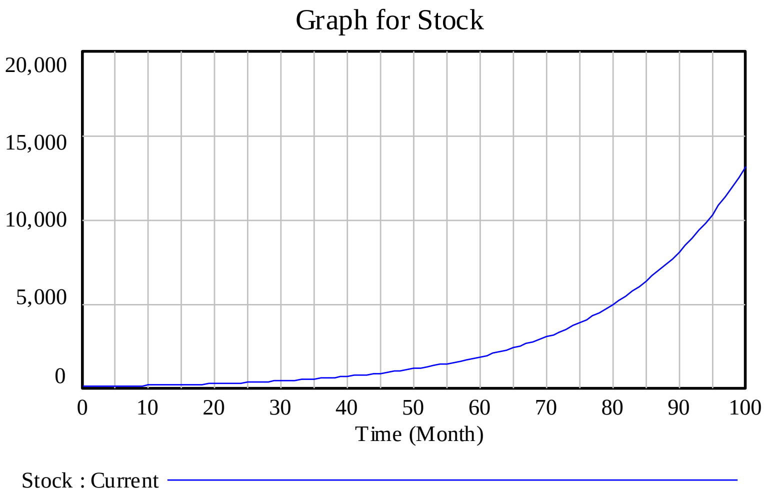
Group 1:
$y(t) = ae^{rt} + b$
Group 2:
$y(t) = ae^{i\omega t} + b$
Time



Mistakes
+
Learning from Mistakes
-



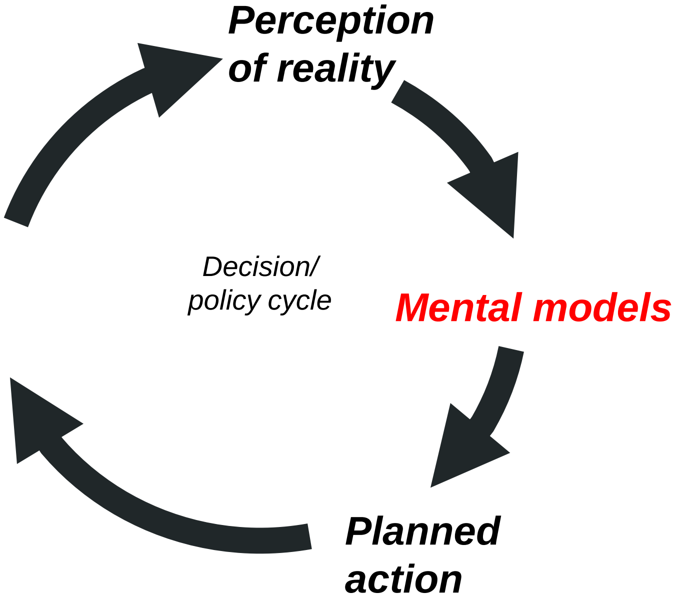
Length of delay or time constant (TC)
-
+
Inflow
Stock
Outflow



Graph for Stock
20,000
15,000
10,000
5,000
0
0
10
20
30
40
50
60
70
80
90
100
Time (Month)
Stock : Current

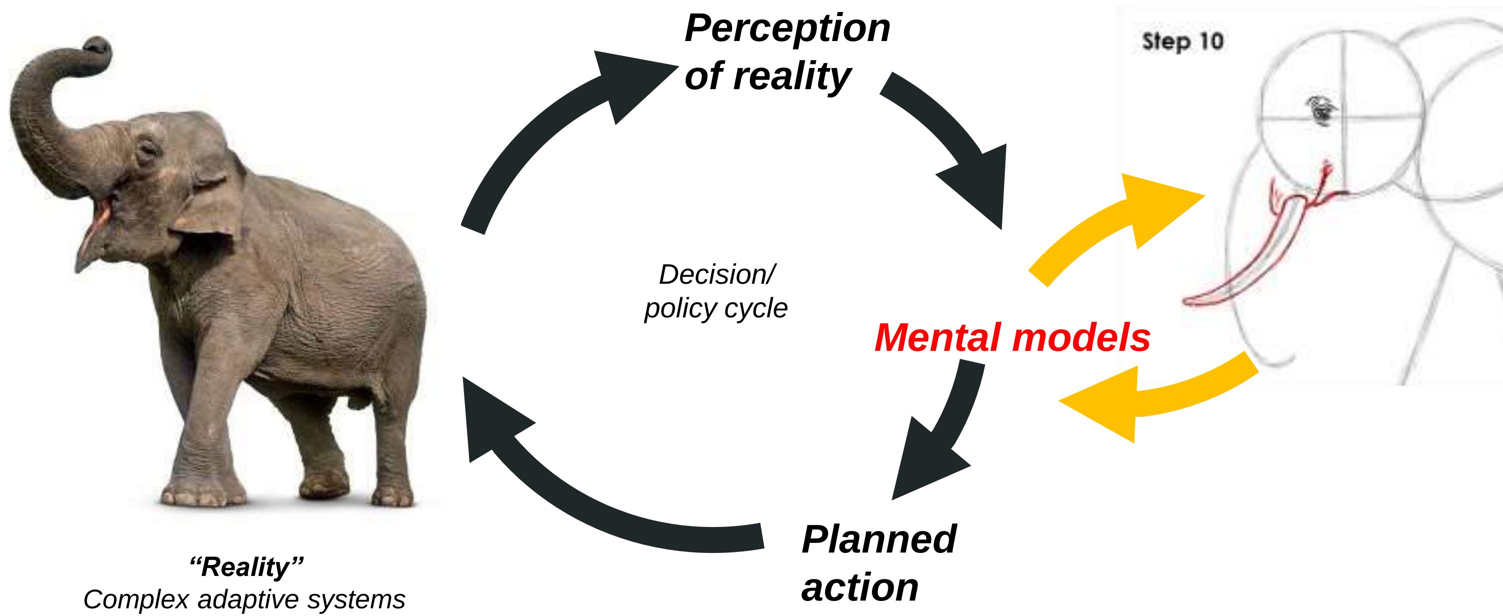
Mental models help us understand complex problems & systems

"Reality"
Complex adaptive systems



Johnson-Laird, P. (1983). Mental models: Towards a cognitive science of language, inference and consciousness. Cambridge, MA: Harvard University Press.

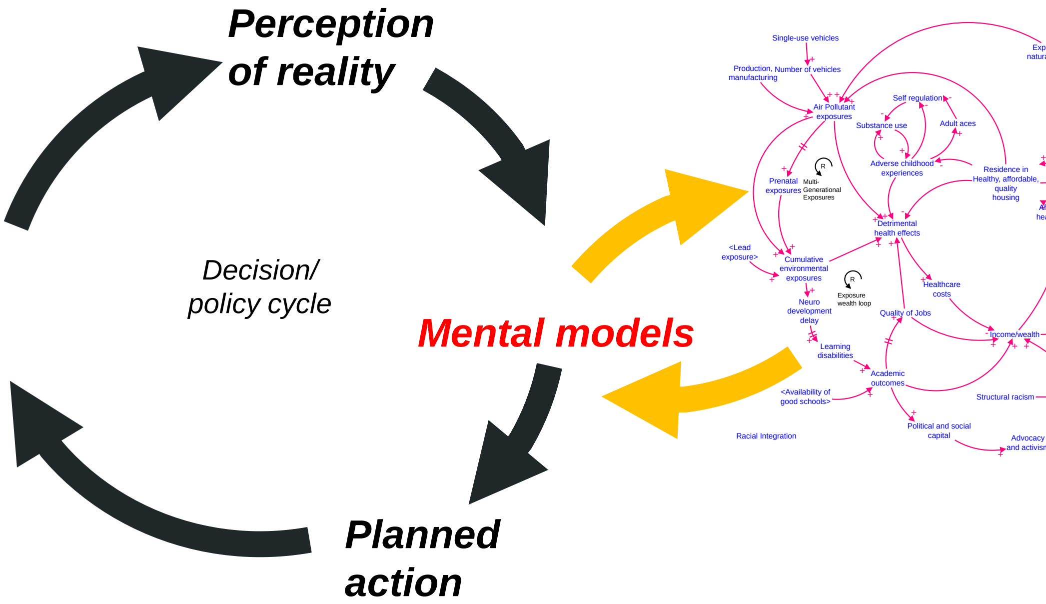
Use of SD models to improve mental models



Johnson-Laird, P. (1983). Mental models: Towards a cognitive science of language, inference and consciousness. Cambridge, MA: Harvard University Press.

We use SD models to refine & improve our mental models

“Reality”
Complex adaptive systems



Johnson-Laird, P. (1983). Mental models: Towards a cognitive science of language, inference and consciousness. Cambridge, MA: Harvard University Press.

Critical questions to consider

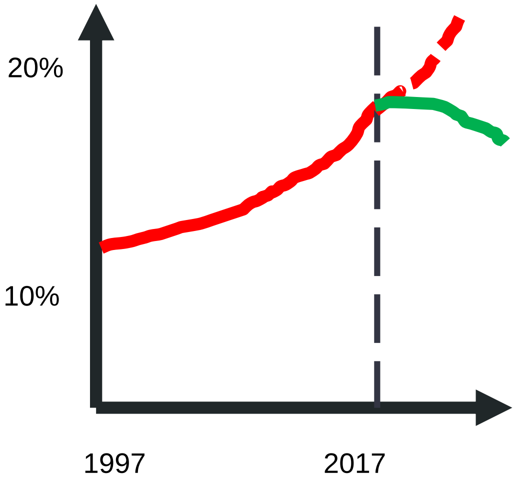
Question	How is this answered
What is the problem? Is the problem dynamic?	Drawing a BOT graph with the desired and feared behaviors over time over a defined period of time
What kind of problem is it?	Primary diagnosis as a learning, coordination analysis or restructuring problem or a combination
Does the system involve feedback mechanisms?	Drawing a diagram of the system that involved one or more feedback loops
What kind of insights would help solve the problem?	Identifying the types of model-based insights such as visualizing the system of identifying leverage points that will help solve the problem
What is the purpose of the model?	Writing a description of the problem, explaining why it is dynamic and involves feedback and clearly stating the purpose in terms of insights that will help solve the problem
What would be the added value of the model?	Identifying how the approach being considered would offer something above the existing tools

Hovmand PS: *Community Based System Dynamics.* New York: Springer; 2014

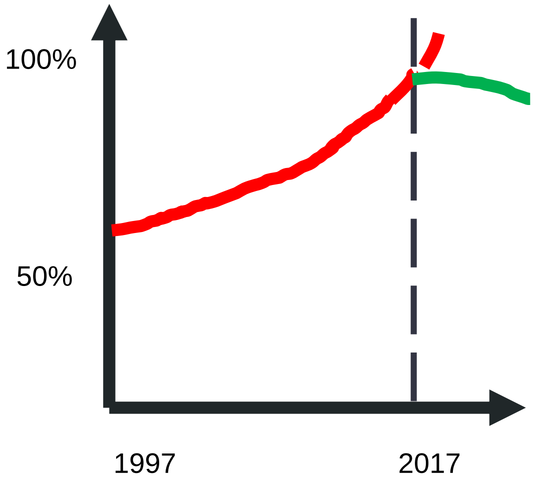
Is it dynamic?

- What is the reference mode?
  - What do you know about the behavior of the system over time?
  - Stagnant patterns of behavior are still dynamic
- What is/are the key variable(s) of interest or importance?
  - Not restricted to variables for which numeric data exists
- What is the time horizon of your model?
  - How long has it taken for dynamics to emerge?
  - How soon might you expect to see change?

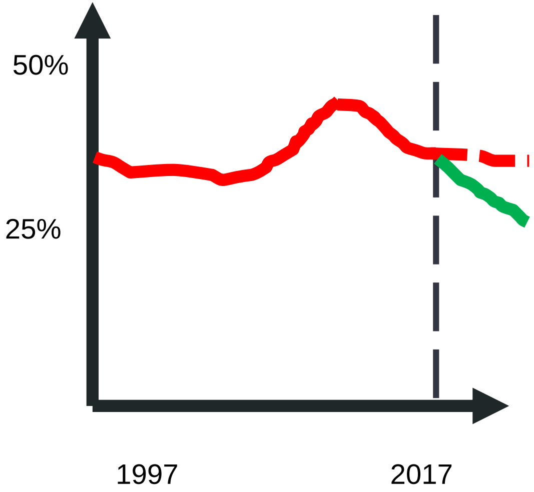
Example: Targeting Environmental Neurodevelopmental Risks Reference Modes



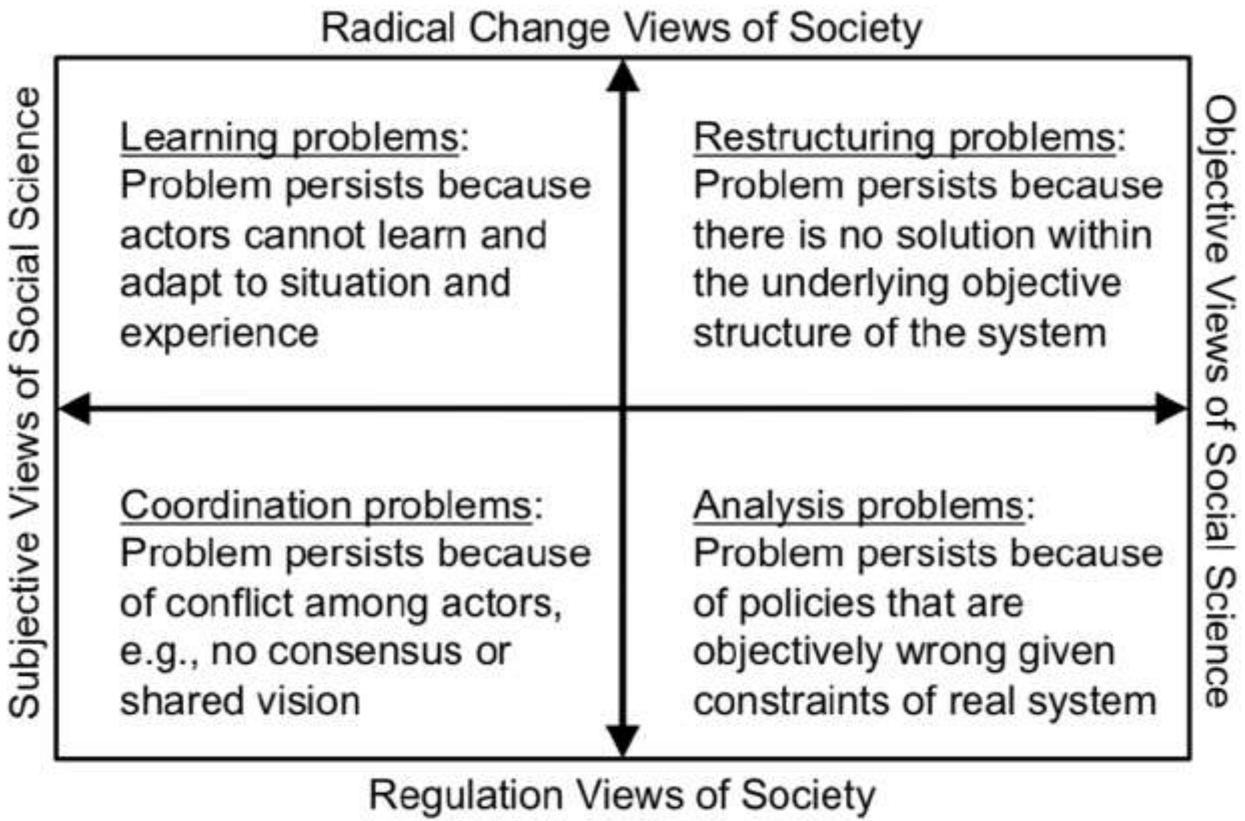
Prevalence of developmental disability among US children



Prevalence of pregnant women with detectable levels of 62 neurotoxic chemicals



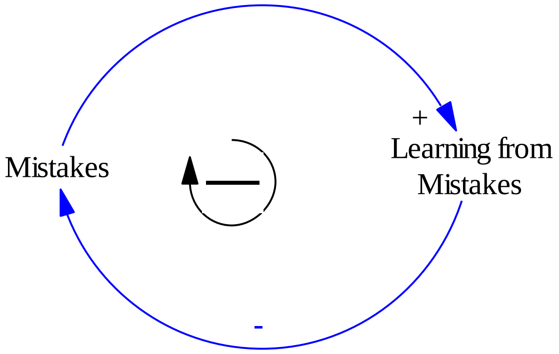
Prevalence of US children living below 200% poverty line

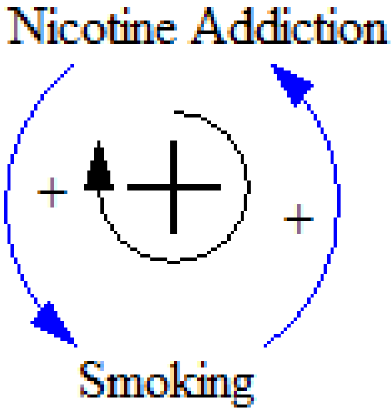


Adapted from Hovmand (2014)

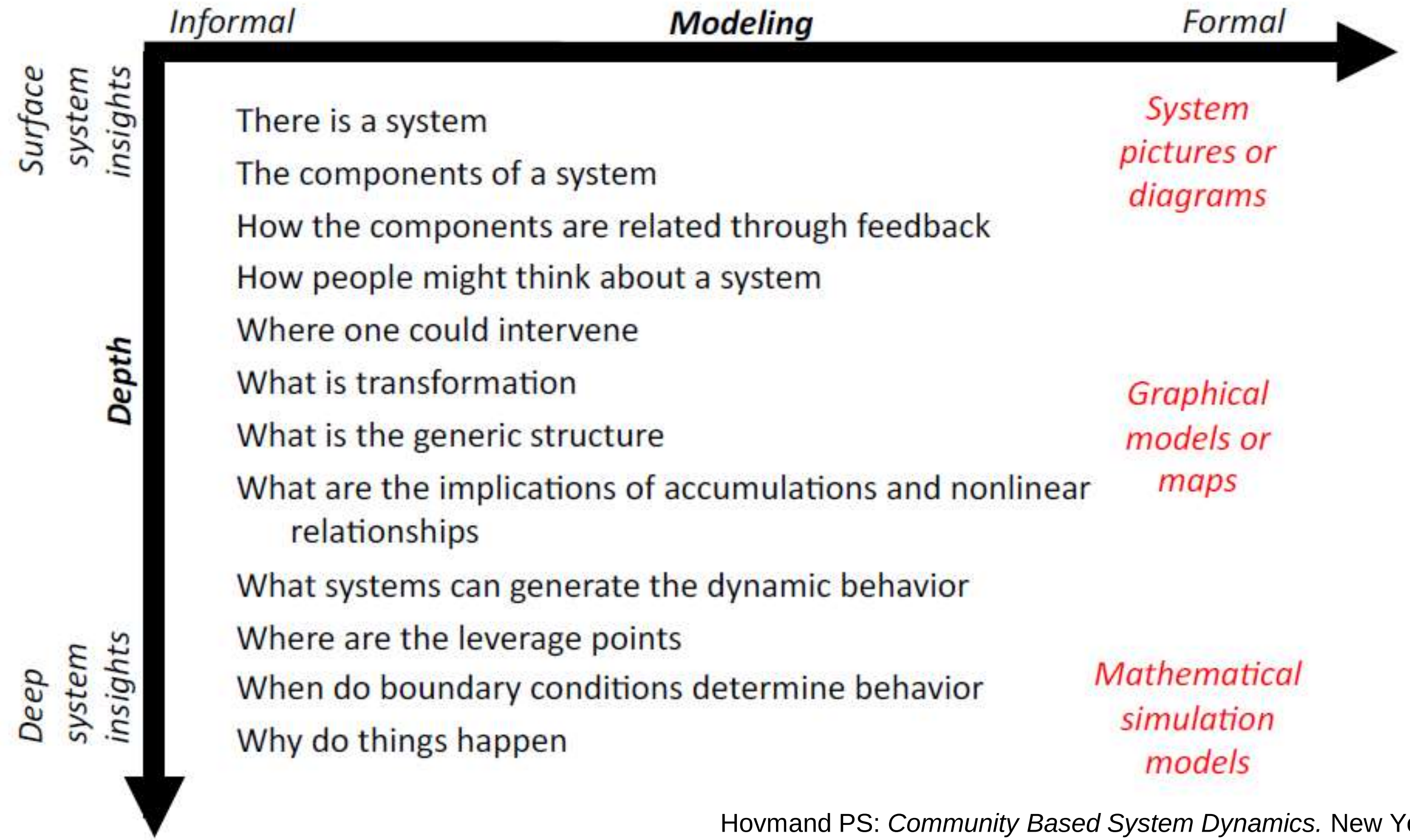
Does it involve feedbacks?

- Take time to sketch out some hypothesized loops
- Are there important delays?
- Nonlinear relationships?





What kinds of insights would solve the problem?



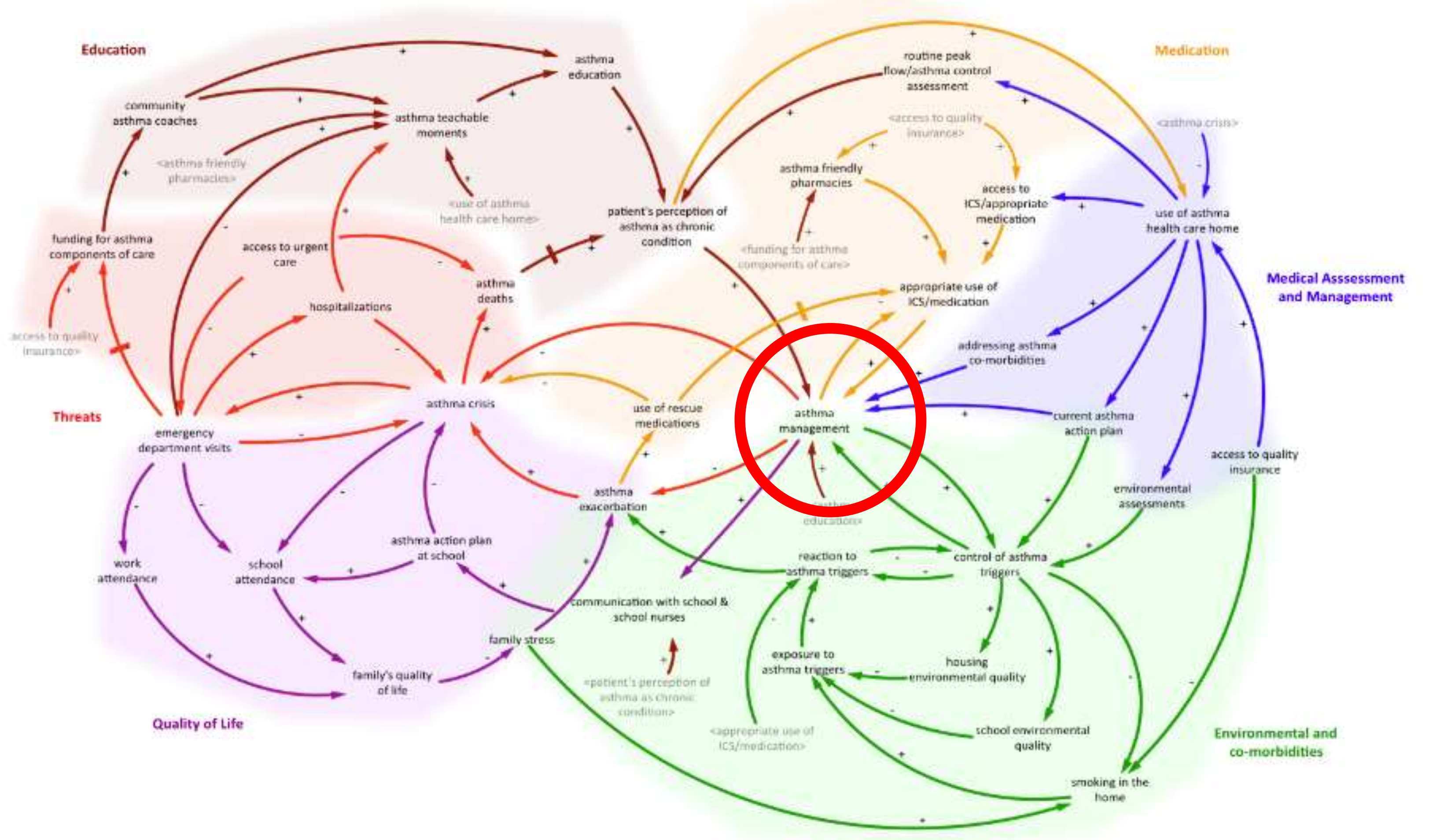
Hovmand PS: *Community Based System Dynamics.* New York: Springer; 2014

What is the value added?

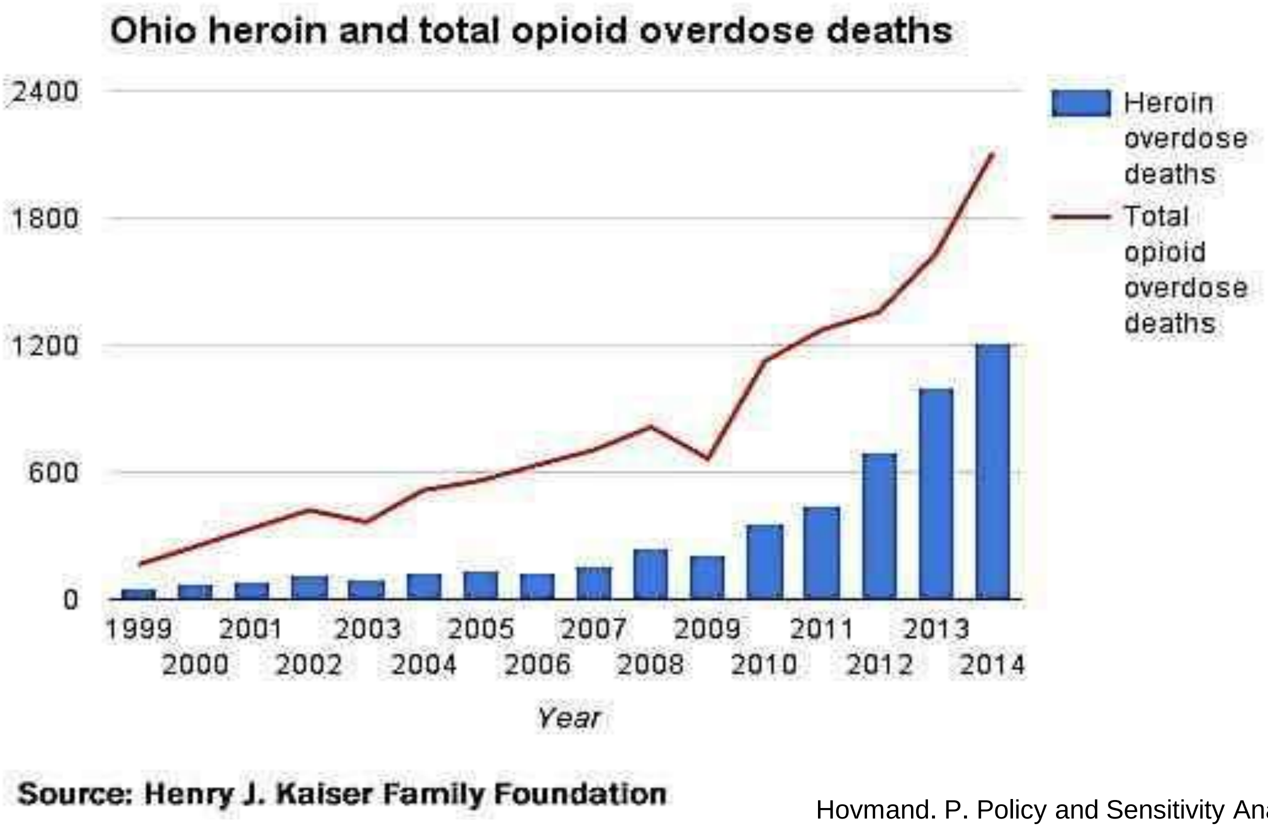
- Examples of value added: learning, shared understanding, dialogue, developing policies, policy evaluation, and more…
- What is the value added for your community partners?
- What is the value added for researchers/outsiders?
- How does this fit into a larger plan of work?

Shifting the Burden of Asthma Management to Fundamental Issues

*EPR3 4 Components of Asthma Care

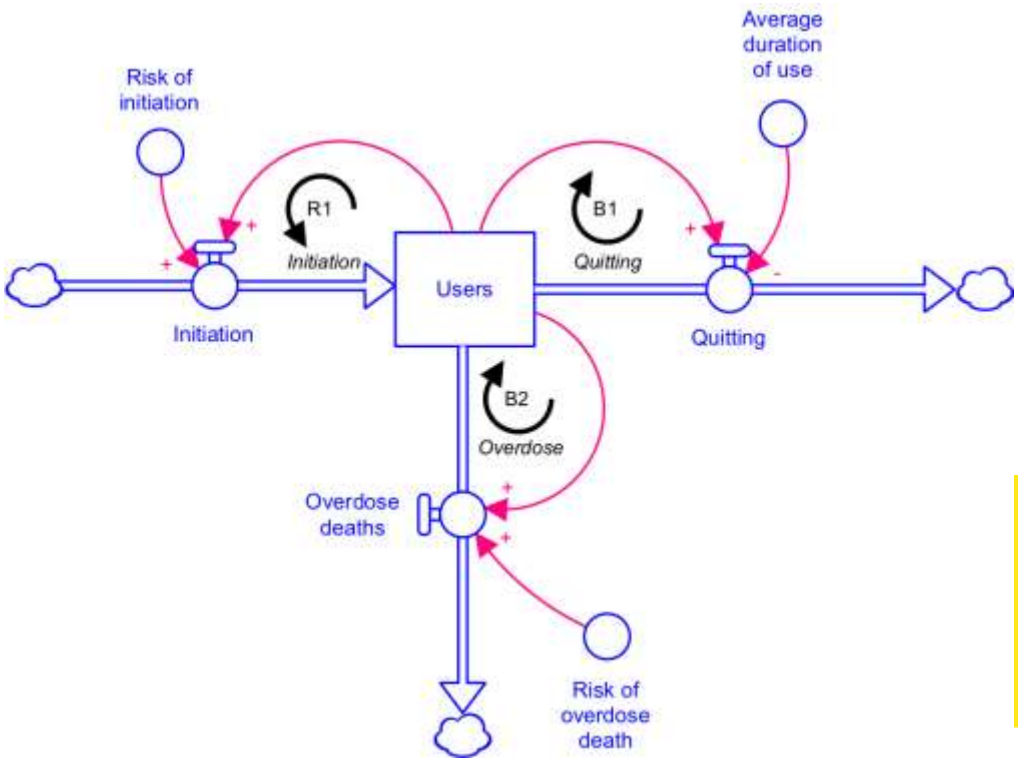


St. Louis Regional Asthma Consortium, Navigating Pathways to Asthma Health in St. Louis,2013



Hovmand. P. Policy and Sensitivity Analysis using the Opioid Model S65-5660

Opioid simulation model



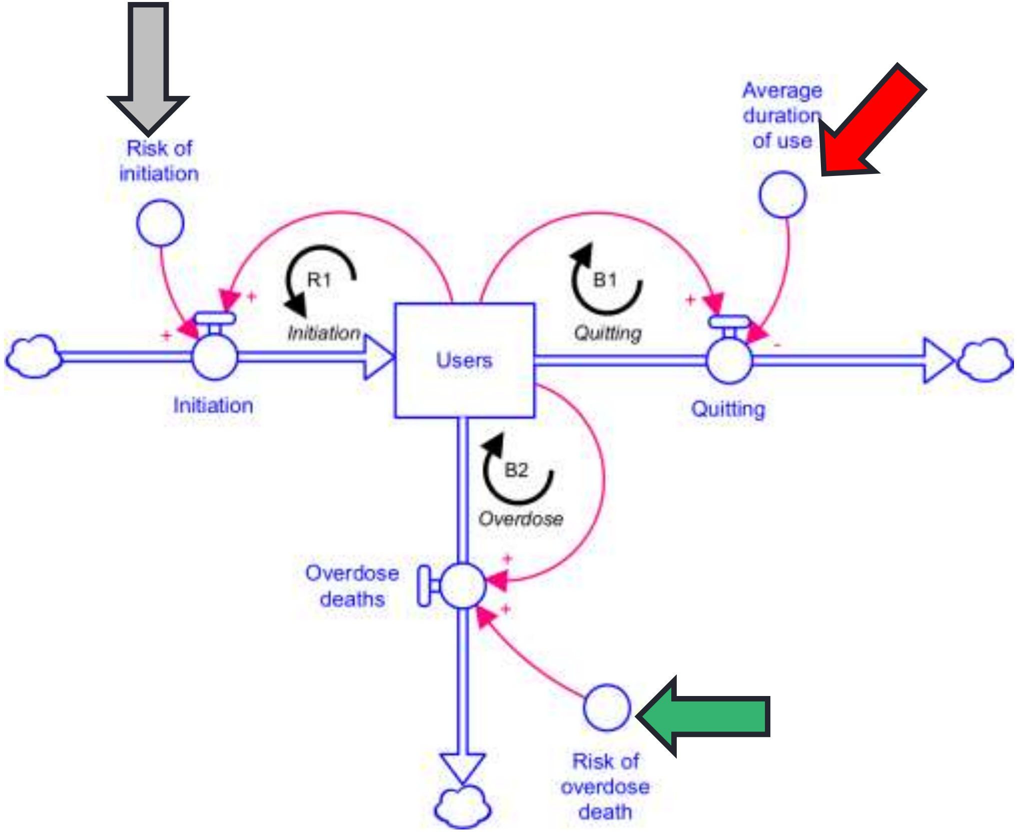
Feedback loops

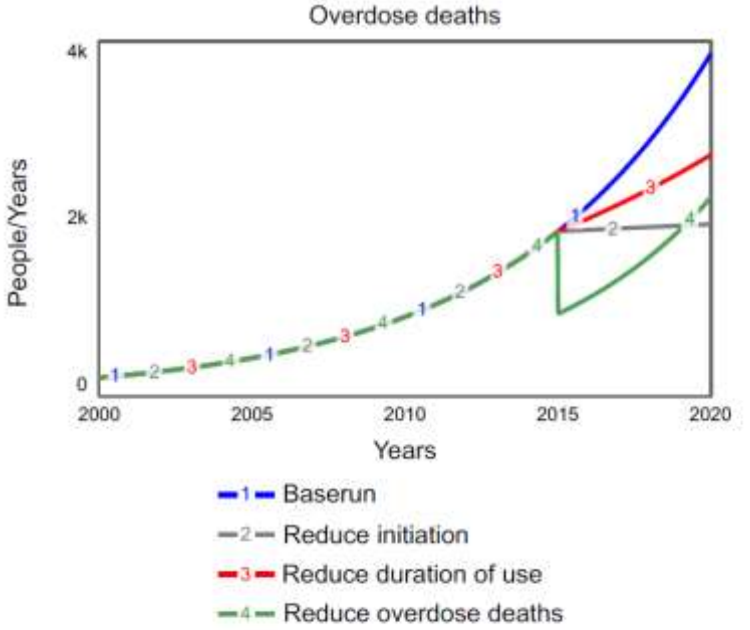
R1: Reinforcing loop of initiation where initiation spreads through social networks at a rate proportional to the number of current users
B1: Balancing loop of quitting where users have an average duration of use
B2: Balancing loop of overdose deaths associated with the risk of overdose

Equations and initial conditions

$Initiation(t) = Risk\_of\_Initiation \cdot Users(t),$
$Quiting(t) = Users(t)/Average\_duration\_of\_use,$
$Overdose\_deaths(t) = Risk\_of\_overdose\_deaths \cdot Users(t),$
$Users(t=) = Init\_users.$

Hovmand. P. Policy and Sensitivity Analysis using the Opioid Model S65-5660





Hovmand. P. Policy and Sensitivity Analysis using the Opioid Model S65-5660

Key Takeaways

- Systems models can help us to develop insights that change our mental models
- SD could be useful tool for research on health inequities – can see feedbacks that are relevant to diverse disciplines
- Systems simulation modeling can be used to help policy makers understand the impact of various policy decisions and how they play out over time before implementation.
- Iterative process; need stakeholder engagement

"All models are wrong, some are useful"

-George Box, 1976

Thank you!